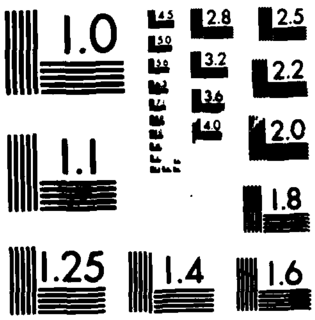
AD-A180 326 PROBLEMS AND SUGGESTED SOLUTIONS RELATED TO DISPERSION FORECASTING UNDER..(U) EASTERN SPACE AND MISSILE CENTER PATRICK AFB FL B F BOYD ET AL. 05 MAY 87 ESMC-TR-87-04 1/1

UNCLASSIFIED F/G 8/3 NL

END
DATE
FILMED
6-87


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

ESMC-TR-87-04

PROBLEMS AND SUGGESTED SOLUTIONS RELATED TO DISPERSION FORECASTING UNDER SEA BREEZE CONDITIONS

B. F. Boyd
T. L. Wilfong
ESMC/WE Staff Meteorologist
Patrick Air Force Base, Florida 32925

5 May 1987

Evaluation 1987
(Final)

Prepared for
EASTERN TEST RANGE
RANGE SUPPORT OFFICE
PATRICK AIR FORCE BASE, FLORIDA 32925

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS: None

2a. SECURITY CLASSIFICATION AUTHORITY: N/A

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S): ESMC-TR-87-04

6a. NAME OF PERFORMING ORGANIZATION: Office of Staff Meteorology Eastern Space and Missile Center

6b. OFFICE SYMBOL *(If applicable)*: ESMC/WER

7a. NAME OF MONITORING ORGANIZATION: Eastern Test Range ETR/RA

6c. ADDRESS *(City, State and ZIP Code)*: Patrick AFB FL 32925

7b. ADDRESS *(City, State and ZIP Code)*: Patrick AFB FL 32925

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Eastern Space and Missile Center

8b. OFFICE SYMBOL *(If applicable)*: ESMC

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State and ZIP Code)*: Patrick AFB FL 32925

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.

11. TITLE *(Include Security Classification)*: Problems and Suggested Solutions Related to Dispersion Forecasting Under Sea Breeze Conditions

12. PERSONAL AUTHOR(S): T.L. Wilfong and B.F. Boyd

13a. TYPE OF REPORT: Evaluation

13b. TIME COVERED: FROM 1987 TO 1987

14. DATE OF REPORT *(Yr., Mo., Day)*: 87-5-5

15. PAGE COUNT: 9

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*: Sea Breeze, Dispersion, Range Operation, Meteorology

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Problems in forecasting toxic effluent dispersion under sea breeze conditions at Cape Canaveral are examined. Land and sea breezes are fairly well understood in a general sense; however, in order to forecast dispersion and transport of toxic effluents or to assess the impact of a major accident in a coastal region, smaller scale features of the sea or land breeze must be considered. A case study is presented to demonstrate the problem. Important small scale features associated with a land or sea breeze must be observed and measured before they can be effectively modeled. Such measurmements must employ techniques that yield observations with high spatial and temporal resolution. Techniques using Sound Detection And Ranging (SODAR) And Light Detection And Ranging (LIDAR) are proposed as possible methods to provide high resolution measurements of the Cape Canaveral sea and land breeze. Keywords: Eastern Test Range Operation, Meteorology.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: B. F. BOYD

22b. TELEPHONE NUMBER *(Include Area Code)*: 305/494-5915

22c. OFFICE SYMBOL: ESMC/WER

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

PROBLEMS AND SUGGESTED SOLUTIONS RELATED TO DISPERSION FORECASTING UNDER SEA BREEZE CONDITIONS

T. L. Wilfong and B. F. Boyd
Office of the Staff Meteorologist
Eastern Space and Missile Center
Patrick Air Force Base, Florida 32925

ABSTRACT

Problems in forecasting toxic effluent dispersion under sea breeze conditions at Cape Canaveral are examined. Land and sea breezes are fairly well understood in a general sense; however, in order to forecast dispersion and transport of toxic effluents or to assess the impact of a major accident in a coastal region, smaller scale features of the sea or land breeze must be considered. A case study is presented to demonstrate the problem. Important small scale features associated with a land or sea breeze must be observed and measured before they can be effectively modeled. Such measurements must employ techniques that yield observations with high spatial and temporal resolution. Techniques using Sound Detection And Ranging (SODAR) and Light Detection And Ranging (LIDAR) are proposed as possible methods to provide high resolution measurements of the Cape Canaveral sea and land breeze.

INTRODUCTION

The Commander, Detachment 11, 2nd Weather Squadron, is the Staff Meteorologist to the Commander of the United States' Eastern Space and Missile Center (ESMC). One operational unit of ESMC is the Eastern Test Range (ETR). As a national range, the ETR supports the National Aeronautics and Space Administration (NASA), Army, Navy, Air Force, and foreign government space and missile programs. This support begins at Cape Canaveral and continues through the Caribbean and into the South Atlantic Ocean.

Detachment 11 personnel provide forecasts, observations, climatological studies, and consultant services to a wide variety of range users, as illustrated by current programs supported (Table I) and number of launches (Table II). This unique mission, coupled with geographical location, has lead to the development of one of the best meteorologically instrumented operational areas in the world. An illustration of instrumentation at the ETR is the Weather Information Network Display System (WINDS). The WINDS consists of 16 permanent towers, 9 temporary locations, and other special sites located within the Cape Canaveral Air Force Station (CCAFS) and the Kennedy Space Center (KSC). That network has been temporarily expanded to include another 20 sites, some of which are off Federal property. Figure 1 shows the location of the towers with sensors mounted from 2 to 165 meters (6 to 500 feet).

TABLE I: Current ESMC Major Programs as of 30 Sep 86

Space	Ballistic
- Atlas Centaur	- U. K. Polaris
- Delta	- Pershing I
- Titan IV	- Pershing II
- Titan 34D	- Poseidon
- Ariane	- Trident I
- Space Shuttle	- Advanced Trident
Guided Missile	
- SRAM	

TABLE II: Annual ESMC Launch Support Summary

	AF	NASA	NAVY	ARMY	TOTAL
FY 80	6	4	45	9	64
FY 81	3	8	21	6	38
FY 82	3	13	28	8	52
FY 83	1	12	25	13	51
FY 84	2	7	17	7	33
FY 85	1	11	21	1	34
FY 86	0	7	18	8	33
TOTAL	16	62	175	52	305

With the materials used in support of the unique mission of the ETR, dispersion is of some concern. Current models used as forecasting aids at the ETR have been discussed recently by Boyd and Bowman,[7,8] Boyd and Overbeck,[9] Taylor and Schuman,[31] and Englehart et al.[12] Earlier reports dealing with the problem at the ETR include Haugen and Taylor[13] and Siler.[29] Diffusion modeling under the best conditions presents a challenge. A complete review of basic diffusion modeling, as currently practiced, was recently (1985) completed by Briggs and Binkowski.[10] In their 200 plus page report, supported by over 240 references, they limited their discussion to ". . . 'basic' atmospheric boundary-layer diffusion, leaving out the complications introduced by source buoyancy, plume deposition, chemical reactivity, and complex flows due to structures, large terrain features, and land-water boundaries". The purpose of this paper is to look at one of those specific items — the land-water boundaries.

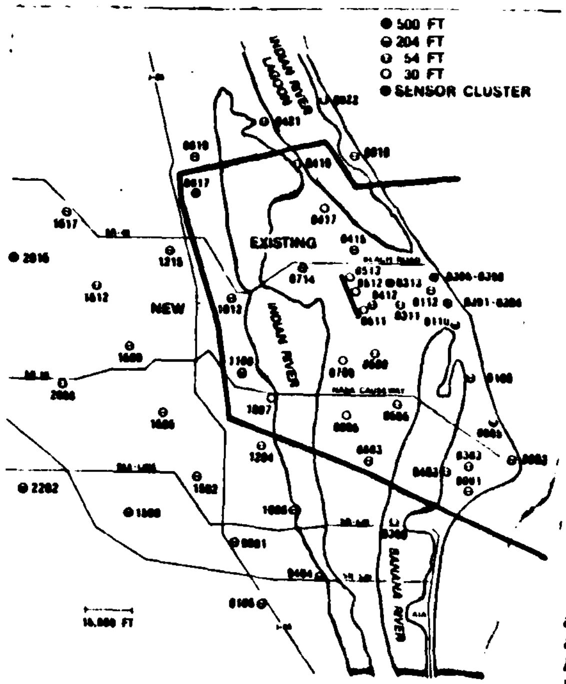


Fig 1: WINDS Tower Locations

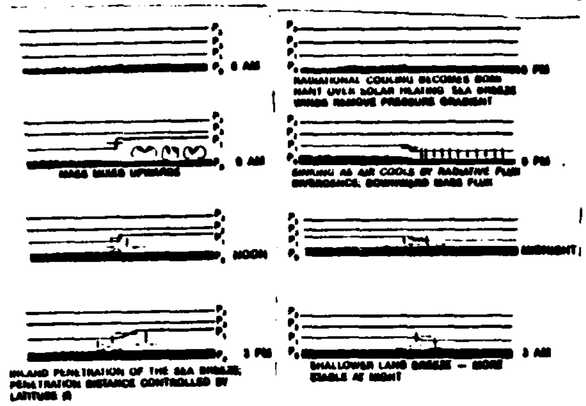


Fig. 2: Schematic of the diurnal evolution of the sea and land breezes in the absence of synoptic flow. P_0 ... P_3 refer to arbitrary pressure levels. From Pielke (24).

SEA BREEZE DEFINITION

The basic features of land and sea breezes in a coastal environment have long been known, and according to Lyons et al[18] are documented in the American scientific literature as early as 1797. Land and sea breezes develop in response to differential heating in a coastal region. The land heats and cools much more rapidly than the water. Figure 2 shows how the sea and land breezes develop during the course of a day. The effect of strong solar heating of the land results in a net upward motion of the air over the land. This rising air is replaced at the surface with cooler, moist air from over the water. At night, the pattern is reversed; however, the temperature contrasts are not as large, and thus, the resulting circulation is weaker and not as deep. In areas where sea temperature is low enough, the land breeze does not develop at all.[32]

When the prevailing large-scale wind is light, the sea breeze develops as a small circulation in the immediate vicinity of the shore. The circulation gradually increases in depth and horizontal

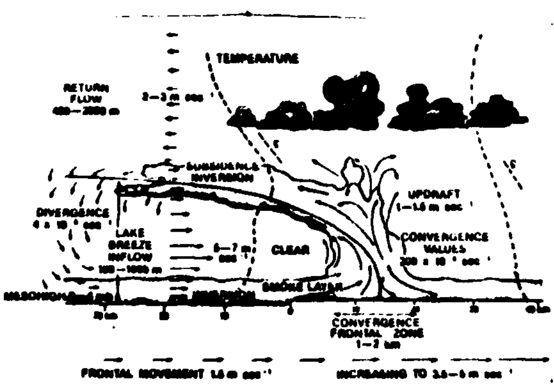


Fig 3. Characteristics of a Lake Breeze
From Lyons et al (18)

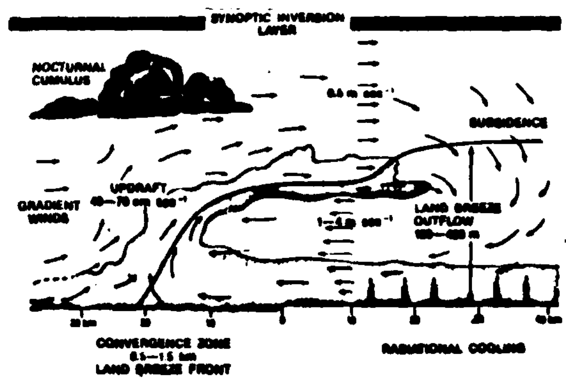


Fig 4. Characteristics of a Land Breeze
From Lyons et al (18)

extent, both landward and seaward. If there is a large-scale wind blowing from land to sea, the sea breeze initially develops out at sea, advancing more slowly landward and reaching the coast much later in the afternoon like a cold front with its characteristic wind shift. A pictorial description of the known structural and dynamical parameters defining sea (or lake) and land breezes (Fig. 3 and 4) was taken from Lyons et al.[18]

The sea breeze circulation system consists of a landward current close to the earth's surface and a much weaker but deeper return flow above. The sea breeze (and associated land breeze) will vary with geographical location, season, time of day, and the synoptic scale weather pattern. The top of the landward current ranges from a few hundred meters near large lakes and middle latitude sea coasts to approximately two kilometers in the tropics. The landward penetration of the sea breeze varies with the land-sea temperature contrasts and the prevailing synoptic situation. Under ideal conditions the sea breeze is frequently observed as far inland as 30 to 70 km from the seashore in middle latitudes. In tropical regions, the sea breeze sometimes reaches 100 to 200 km inland.[30] Maximum wind speeds are as high as a few tens of meters per second, while the vertical velocities are about two orders of magnitude smaller. The daily maximum winds generally occur shortly after the temperature maximum.

LOCAL PROBLEMS

The general structure of the sea breeze is well understood. Early studies by Hill[14] and Reed[26] investigated some features of the sea breeze in the Cape Canaveral area. Sea breeze models have successfully reproduced broad effects of the sea breeze over southern Flordia;[19,25] however, there is a distinct lack of observational data to validate and reinforce modeling efforts.[11,18] Lack of high resolution observations of sea breeze frontal slope, height, intensity, onset time, and speed of movement under various synoptic conditions seriously limits the modeling of toxic effluent transport in a coastal environment. In fact, it remains to be demonstrated that current diffusion models can assess the complete impact of a major accident in a coastal environment in either a post event or a prognostic manner.[18] This is especially true in view of the recent reassessment of exposure limits by the Surgeon General which resulted in lowering the acceptable limits.

There are a number of different parameters that must be forecast during a launch sequence that may depend on sea breeze conditions. These include damage due to acoustic overpressures and dispersion of possible toxic spills and rocket exhaust. With the advent of payloads containing radio isotopes, dispersion of the isotope debris in the event of vehicle destruction may also be necessary. As an example of an operational problem, consider the Space Shuttle launch scheduled for 1630 EDT on 12 July 1985. As part of the launch sequence, a forecast of the rocket exhaust effluent dispersion is required by four hours before launch time. The Rocket Exhaust Effluent Diffusion Model (REEDM)[6] is used to forecast the dispersion of rocket effluent for Shuttle launches. Practically speaking, the REEDM provides reasonable estimates of concentration, dose and deposition, provided the input meteorological parameters -- primarily temperature and wind profiles -- are valid.[8] There is no wind forecast capability in REEDM itself, and the model assumes there is no horizontal variation in the wind and temperature profiles.

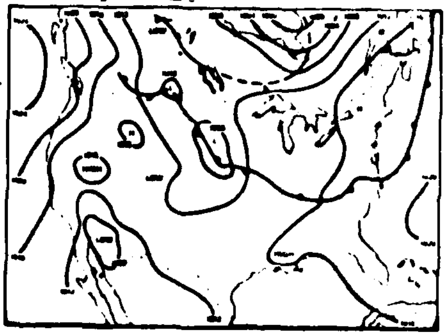


Fig. 5: Surface Weather Map at 0800 EDT 12 Jul 85 (From 22)

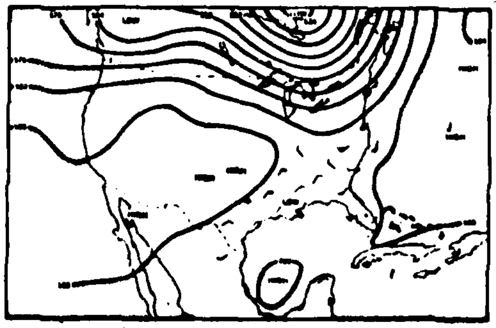


Fig. 6: 500-Millibar Height Contours 0800 EDT 12 Jul 85 (From 22)

Figures 5 and 6 show the surface and 500 millibar maps at 0800 EDT. A high pressure ridge dominated the region. Winds were southwesterly at less than 3.5 meters per second below 5000 meters. With no synoptic changes expected, the forecast problem was the sea breeze. Figure 7 shows the REEDM deposition forecast made using winds actually observed at 1130 EDT using a rawinsonde and tower 0313 sensors. To provide a forecast for launch time, the input wind profile was subjectively modified to account for the sea breeze effect. Persistence was assumed above 975 meters. The REEDM output based on this forecast profile is shown in Fig. 8. By 1530 EDT a strong sea breeze had set

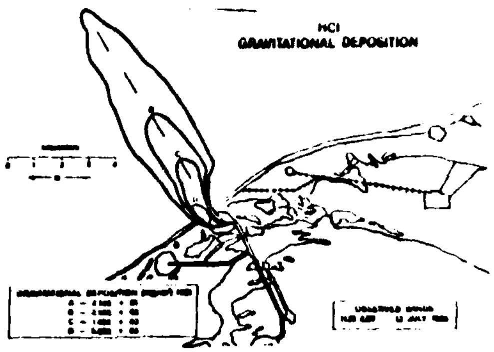


Fig. 7: REEDM HCL Gravitational Deposition Analysis Using Winds Observed at 1130 EDT 12 Jul 85. From Boyd and Bowman (7)

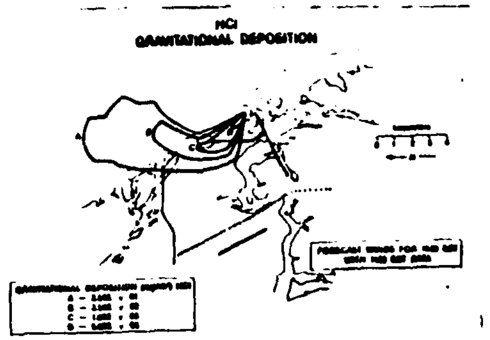


Fig. 8: REEDM HCL Gravitational Deposition Analysis Using Forecast Winds Valid at 1630 EDT 12 Jul 85. From Boyd and Bowman (7)

in to about a kilometer in height at the launch site and winds aloft had become southeasterly. Using winds actually observed at 1530 EDT, REEDM was run again to produce the output shown in Fig. 9. This is only one example, but demonstrates the importance of an accurate sea breeze forecast.

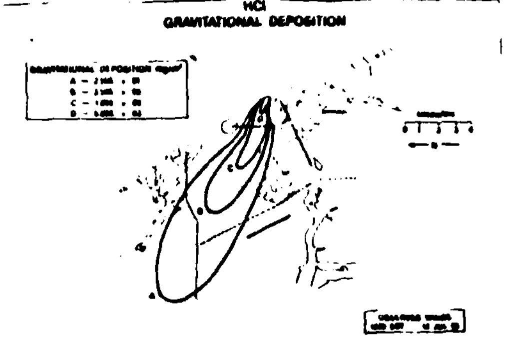


Fig. 9: REEDM HCL Gravitational Deposition Analysis Using Winds Observed at 1530 EDT 12 Jul 85. From Boyd and Bowman (7)

Evolution of the sea breeze at Cape Canaveral is complicated by the fact that the coastline is irregular. Further, the presence of the Indian and Banana Rivers and the Indian River Lagoon present an alternating land/water terrain; thus, one would expect to see the effects of smaller scale land/sea breezes superimposed on the large scale feature. Figures 10 through 13 show the evolution of the land/sea breeze at four towers -- all three miles north of the Port Canaveral Barge Canal. Tower 0003 is nearest the coast. Tower 0303 is three miles inland; tower 0403 is four miles inland; and, 0803 is eight miles inland. The WINDS network provides data in five minute averages. To produce these figures, data were gathered from the sensors at 16 meters (54 feet) and resolved into the east-west (U component) and north-south (V component). Note that a north wind is then represented by a positive V, and a west wind is represented by a positive U. A seven point running mean (35 minute) was used to smooth the data.

With very light synoptic wind conditions, the transition from the nighttime land breeze to the daytime sea breeze can be taken as the point where the U component of the wind switches from offshore (+U) to onshore (-U). Times are displayed in Eastern Standard Time (EST) rather than Daylight Savings Time in order to better represent true local (sun) time. By 1015 EST, the sea

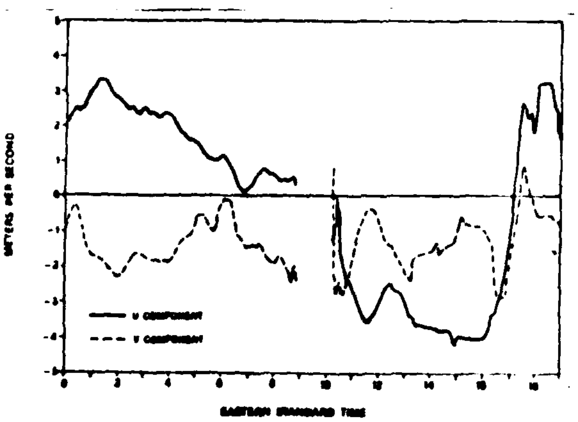


Fig. 10: Tower 0003 Winds at 16 Meters 12 Jul 86

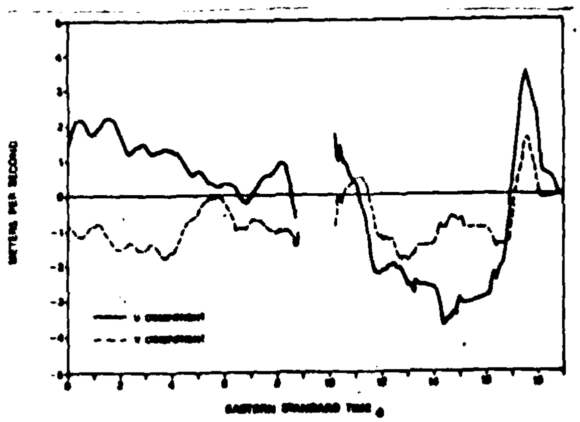


Fig. 11: Tower 0303 Winds at 16 Meters 12 Jul 85

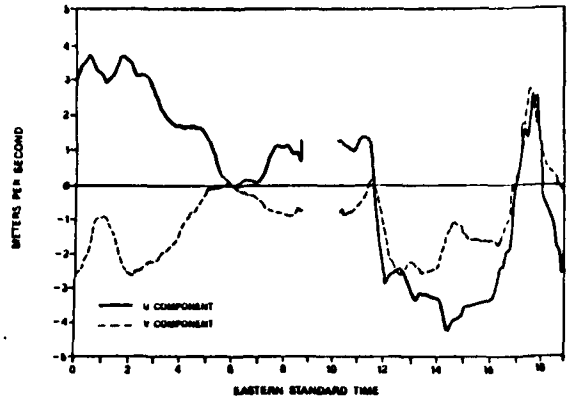


Fig. 12: Tower 0403 Winds at 16 Meters
12 Jul 85

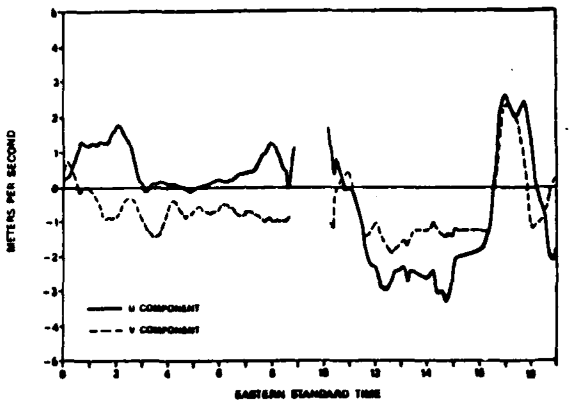


Fig. 13: Tower 0803 Winds at 16 Meters
12 Jul 85

breeze has established near the coast at tower 0003. At approximately 1110 it appears to have moved three miles inland to tower 0303. At approximately 1120 it appears at tower 0803, but does not appear at tower 0403 until 1145. Looking even further inland at tower 1108 which is 11 nautical miles from the coastline, a sea breeze circulation appears at about 1055 (Fig. 14). Thus in these cases, as one would expect, smaller scale circulations developed that affect the development of the large scale sea breeze. This effect can be more dramatically seen by looking at snapshots in the horizontal plane.

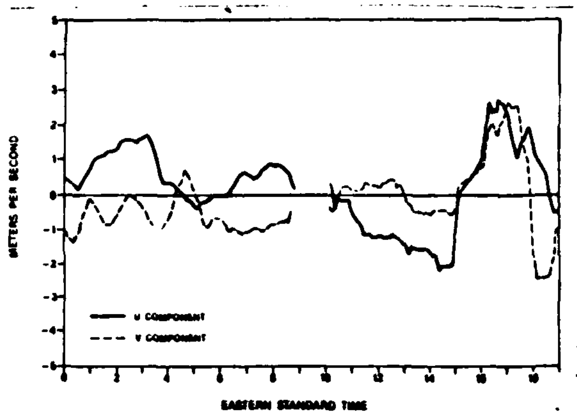


Fig.14: Tower 1108 Winds at 16 Meters
12 Jul 85

Using a Barnes analysis technique,[3,4] irregularly spaced data like that from the WINDS towers can be transferred to a regular grid system. This technique was applied to the winds at 16 meters from all available towers at 1030, 1100, and 1130 EST (Fig. 15-17). Wind patterns at 16 meters changed dramatically during that hour. At 1030 EST one can see the sea breeze transition beginning along the coast and also along the banks of the Banana and Indian Rivers. By 1130 EST, the primary sea breeze circulation appears well established, and the effects of the secondary circulations can be prominently seen in the broader regions of the rivers. Several regions can be seen where convergence or divergence is occurring. These are, of course, also regions of strong upward and downward motion respectively.

We have only looked at the near surface aspects of the land/sea breeze circulation in this analysis, but it does demonstrate the complexity of the toxic effluent transport problem in the Cape Canaveral area. Effluents are caught up in a complex circulation pattern that can carry them aloft and back down again. Effluents released near the coast before the onset of the sea breeze may be carried out to sea, only to return again as the circulation develops. The complete sea breeze circulation patterns — and thus, the outcome of a toxic release — cannot be completely described with near surface data. Attempts to model such circulations have met with good success in the general sense; however, such circulations are highly dependent on local terrain conditions. Site specific characteristics must be modeled. Finally, modeling efforts suffer from a lack of detailed observations of the vertical and horizontal structure and time evolution of the land/sea breeze.

POTENTIAL SOLUTIONS

The sea breeze is a complex phenomenon that presents a difficult three dimensional transport problem under ideal circumstances. The problem is further complicated in the Cape Canaveral area by an irregular coastline and the presence of the Banana and Indian rivers and the Indian River Lagoon. In order to develop an adequate model that will forecast the sea breeze, detailed observations are required of the sea breeze depth, structure, and behavior under varying synoptic conditions. In order to observe the evolution of the sea breeze, measurement methods with high temporal and spatial resolution must be employed. Modern sounding techniques employing light and sound provide two

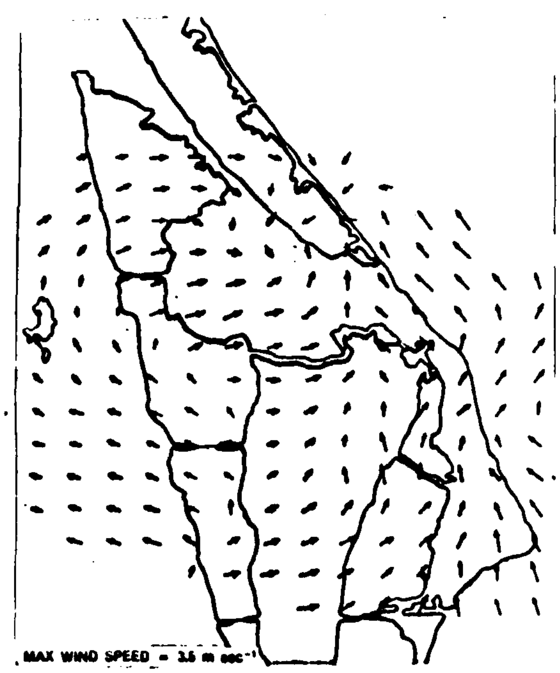


Fig. 15: 16 Meter Winds at 1030 EST 12 Jul 85 Obtained by Barnes[3,4] Analysis of tower data.

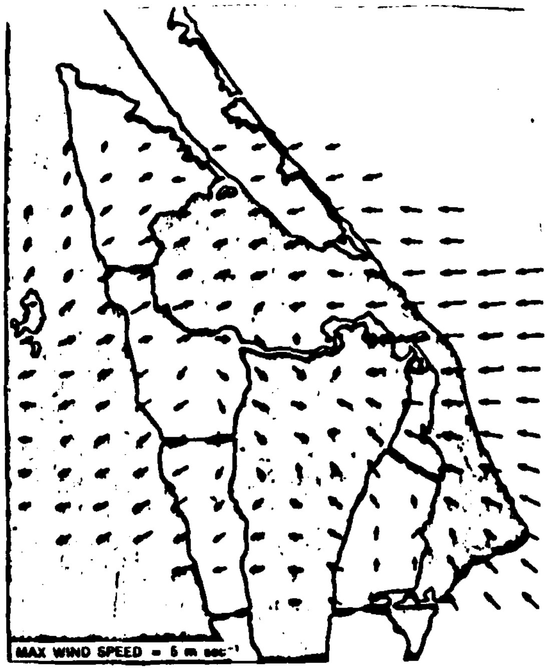


Fig. 16: Same as Fig. 15 at 1100 EST

possible observing systems. Such systems are analogous to the familiar RADAR -- RAdio Detection And Ranging -- but employ sound (SODAR) and light (LIDAR) and have been shown to be effective tools in probing the atmosphere.[21,28]

Sound traveling in the atmosphere is scattered by small scale density discontinuities -- essentially thermal turbulence. Operating in a monostatic mode, SODARs can project sound vertically and use the returned signal to monitor the growth of the planetary boundary layer. Thermal turbulence generally exists throughout the atmosphere. At the top of the planetary boundary layer, strong temperature gradients exist that result in particularly strong thermal turbulence. Similarly, at the boundaries of a sea breeze front, strong temperature gradients produce thermal turbulence that can be monitored by a SODAR.[1,5,21,27] SODARs thus employed can detect the time evolution of the height of a land/sea breeze. By tilting beams to the north (or south) and to the east (or west) and examining the doppler shift of the backscattered signals, profiles of the north-south and east-west wind components (V and U respectively) can be derived. These, of course, can be resolved into horizontal wind speed and direction. Similarly, the vertical wind component profiles (W) can be derived from a vertically looking beam. Power and signal-to-noise ratio limit the SODAR to altitudes generally less than a kilometer.

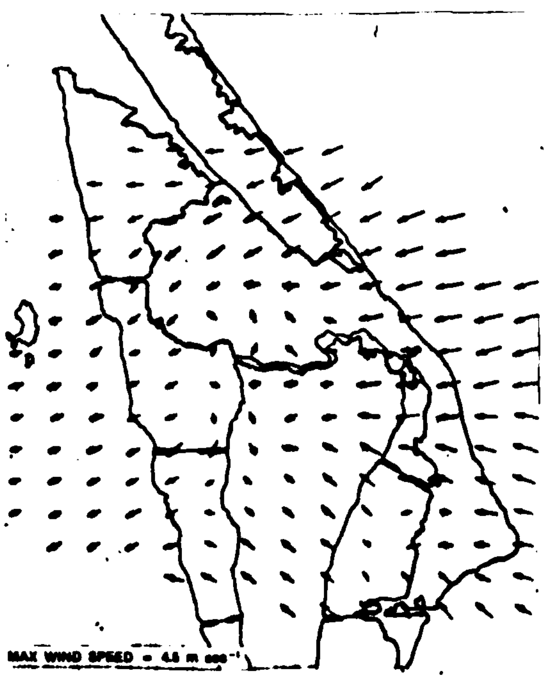


Fig. 17: Same as Fig. 15 at 1130 EST

SODARs with wind profiling capabilities have been operated successfully in various locations and conditions. Three have been deployed at Vandenberg AFB for over a year. Derived profiles indicate very well the evolution of the sea breeze there. In the southern part of the Great Salt Lake Desert, SODARs were deployed to investigate detailed flow structure in the boundary layer.

Data were obtained on a sufficiently small space and time scale to describe diurnal circulation patterns in addition to more well defined discontinuities. For example, Fig. 18 depicts a time height wind profile that shows a cold frontal passage on 16 December 1984. The near surface frontal boundary appears as a distinct narrow transition zone, whereas aloft the zone is more broad and diffuse.

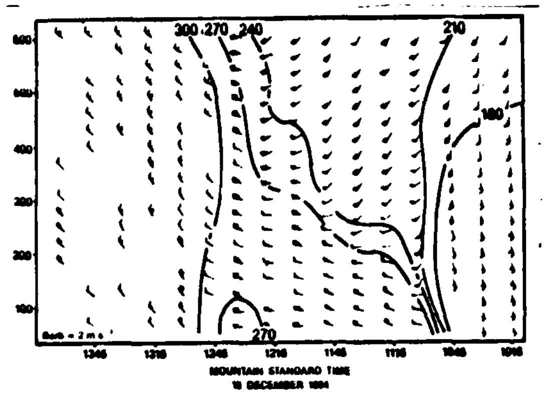


Fig. 18: SODAR Time Height Wind Profile 16 Dec 1984. From Astling (2)

By contrast with SODAR, a LIDAR system depends upon ambient aerosols to observe the structure of the boundary layer and determine winds. A LIDAR uses a laser to transmit monochromatic light. Discontinuities in aerosols produce differential backscattering of the incident laser light. Backscattered light is sensed by the LIDAR detector and processed into a visual image. Whereas a SODAR is inherently limited to a point measurement, a LIDAR can scan much like a RADAR. By scanning both in the horizontal and vertical (PPI and RHI scans), a complete three dimensional picture of the boundary layer structure can be derived.[16] Figures 19 and 20 show RHI scans in both a convective boundary layer and a stable nocturnal layer. Wind profiles can be derived from LIDARs by tracking inhomogeneities[15] or using the Doppler shift of the backscattered light to measure the radial component of the wind.[17]

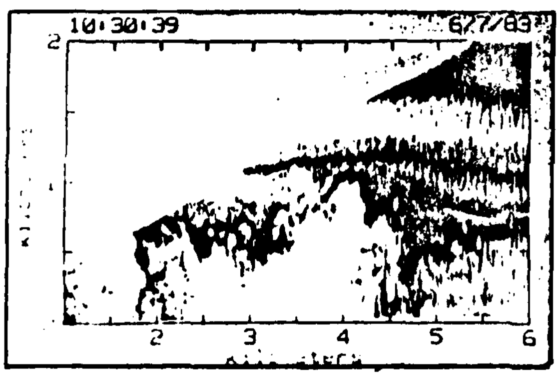


Fig. 19: LIDAR Depiction of Clear Air Convective Plumes. From E. Eloranta, University of Wisconsin.

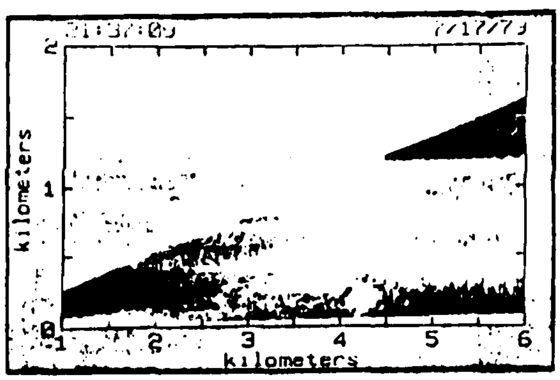


Fig. 20: LIDAR Depiction of Night Time Convective Plume Over Local Heat Source (Pond). From E. Eloranta, University of Wisconsin.

The contrasting aerosol content of air masses in a coastal area make LIDAR a natural tool for observing a sea breeze. For example, Nakane and Sasano[20] tracked the inland penetration of a sea breeze front and observed its structure in detail. The observations were carried out over a region of the Kanto Plain about 60 km northeast of Tokyo, Japan. Figure 21 shows the position of the LIDAR and the inland penetration of the sea breeze. Figure 22 shows a vertical cross section of the sea breeze front itself. The original figure showed measured aerosol concentration in terms of the volume extinction coefficient crossection displayed by ten color slice levels. The figure is reproduced here to show the structure and slope of the front and the billows present.

SUMMARY

The general structure of a land/sea breeze is fairly well understood; however, numerical sea breeze models, and certainly diffusion modeling in coastal regions are still in an exploratory stage.[18] Several numerical models have been developed that simulate a sea breeze; however, verification and application of these models have been hampered by a lack of detailed two and three dimensional measurements of the sea breeze wind structure, slope, speed of movement, etc. under varying synoptic conditions. The Cape Canaveral area presents unique challenges and opportunities. The coastline is irregular. Alternating land/sea interfaces may give rise to secondary circulations that retard or enhance the primary land/sea breeze circulations. On the other hand, the area is well instrumented. The new tower network upgrade, when complete, will provide one of the largest meso-scale networks in the world and could provide measurements to study the near surface features of the sea breeze. These measurements combined with those made with a network of SODARs and a LIDAR could provide the data sets needed for further model development and refinement.

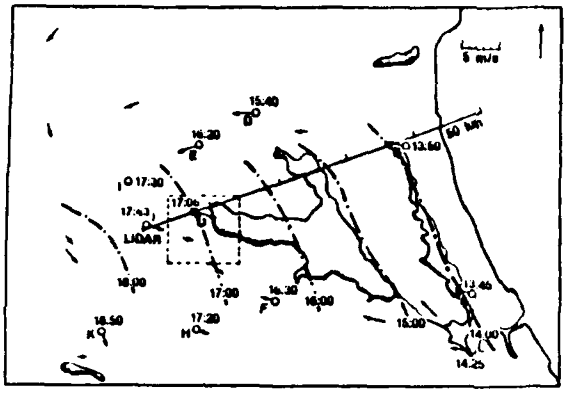


Fig. 21: Penetration of the Sea Breeze in the Kanto Plain on 15 Feb 84. Sites A-K supplied wind strip chart recordings. Arrows are wind vectors at 1700 Japan Standard Time. LIDAR measurements were done in the region bounded by the broken line. From NaKane and Sasano (20).

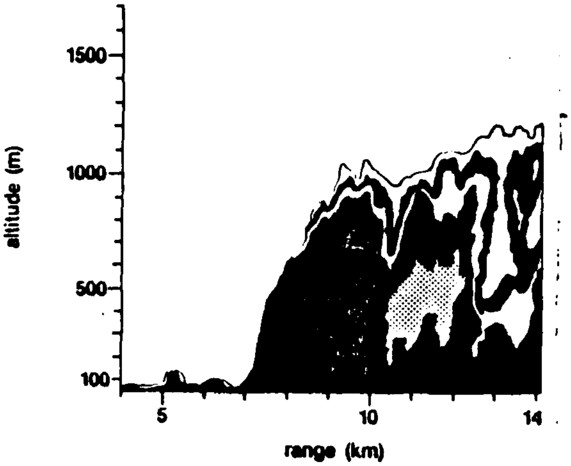


Fig. 22: Graphical depiction of a LIDAR scan showing the distribution of aerosol concentrations in the sea breeze front in the Kanto Plain on 15 Feb 84 at 1700 JST. Nakane and Sasano (20).

ACKNOWLEDGMENTS

The authors would like to thank Edwin Eloranta at the University of Wisconsin for providing LIDAR photographs; Walt Lyons of RSCAN Corp for his helpful discussions; Rick Schumann of ENSCO Corp for preparing analysis fields; and Greg Taylor of ENSCO Corp for providing the Barnes analysis technique references.

REFERENCES

1. Aggarwal, S. K. and S. Singal, (1980): A Study of Atmospheric Structures Using SODAR in Relation to Land and Sea Breezes, Boundary Layer Meteor., 18, 361-371.

2. Astling, E. G., (1987): Remote Sensing of Vertical Profilers of Mesoscale Wind Discontinuities in the Boundary Layer, Preprints Sixth Symposium Meteorological Observations and Instrumentation, New Orleans, Amer. Meteor. Soc., 31-34.

3. Barnes, S. L., (1964): A Technique for Maximizing Details in Numerical Weather Map Analysis, J. Appl. Meteor., 3, 396-409.

4. Barnes, S. L., (1973): Mesoscale Objective Map Analysis Using Weighted Time-Series Observations, NSSL Tech. Memo, NSSL-62, 60pp.

5. Bennet, R. C. and R. List, (1975): Lake Breeze Detection With Acoustic Radar, Preprints 16th Conference on Radar Meteorology, Houston, TX, Amer. Meteor. Soc., 260-262.

6. Bowman, C. R., J. R. Bjorklund, and J. E. Rafferty, (1985): "User's Manual for the Revised REEDM (Rocket Exhaust Effluent Diffusion Model) Computer Program for Launches at Kennedy Space Center." TR-85-157-03, H. E. Cramer Co., USAF Contract F08606-83-C-0014.

7. Boyd, B. F., and C. R. Bowman, (1985): "Diffusion Modeling in Support of the Space Shuttle", presented at the Joint Army-Navy-NASA-Air Force Safety and Environmental Protection Subcommittee Meeting, Monterey, CA, 4-8 Nov 85.

8. Boyd, B. F. and C. R. Bowman, (1986): Operational Use of Air Pollution Models at the Space and Missile Ranges, Preprints Fifth Joint Conference on Applications of Air Pollution Meteorology, Chapel Hill, N. C., Amer. Meteor. Soc., 315-318.

9. Boyd, B. F. and K. B. Overbeck, (1987): Forecasting Atmospheric Sonic Propagation at the Eastern Test Range (Paper AIAA-87-0012), AIAA 25th Aerospace Sciences Meeting, Reno, NV.

10. Briggs, G. A. and F. S. Binkowski, (1985): Research on Diffusion in Atmospheric Boundary Layers: A Position Paper on Status and Needs, EPA1600/53-85/072, 227pp.

11. Chang, L. P., E. S. Talke, and R. L. Soni, (1982): Development of a Two Dimensional Finite-Element PBL Model and Two Preliminary Model Applications, Mon. Wea. Rev., 110, 2027-2037.

12. Englehart, R. W., B. W. Bartram, H. Firstenberg, R. W. Jubach, and F. R. Vaughn, (1987): "Innovative Meteorology and Development in U. S. Space Radioisotope Power Safety Risk Assessments," the Fourth Symposium on Space Nuclear Power Systems, Albequerque N. M., 12-16 Jan-87.

13. Haugen, D. A. and J. H. Taylor, (1963): The Ocean Breeze and Dry Gulch Diffusion Programs, Volume II, AFCRL-63-791 (II), Air Force Cambridge Research Lab, Hanscom Field, MA, 100pp.

14. Hill, C. K., (1967): Study of the Land and Sea Breeze Regimes at Cape Kennedy, Florida, from May 23 through September 1966. NASA MSFC Branch Memo R-AERO-YE-29-67, 12pp.

15. Hooper, W. P. and E. W. Eloranta, (1986): Lidar Measurements of Wind in the Planetary Boundary Layer: The Method, Accuracy and Results from Joint Measurements with Radiosonde and Kytoon, J. Clim. Appl. Meteor., 25, 990-1001.

16. Kunkel, K. E., E. W. Eloranta, and S. T. Shipley, (1977): Lidar Observations of the Convective Boundary Layer, J. Appl. Meteor., 16, 1306-1311.

17. Lawrence, T. R., B. F. Weber, M. J. Post, R. M., Hardesty, and R. A. Richter, (1986): Comparison of Doppler Lidar, Rawinsonde, and 915-MHz UHF Wind Profiler Measurements of Tropospheric Winds, NOAA-TM-ERL-WPL-130, 89pp.

18. Lyons, W. A., C. S. Keen, and J. A. Schuh, (1983): Modeling Mesoscale Diffusion and Transport Processes for Releases within Coastal Zones During Land/Sea Breezes, NUREG/CR-3542, 184pp.

19. Lyons, W. A. and R. A. Pielke, (1985): Forecasting Sea Breeze Thunderstorms Using a Mesoscale Numerical Model, Final Report to NASA, Contract No. NAS10-11142.

20. Nakane, H. E. and Y. Sasano, (1986): Structure of a Sea-Breeze Front Revealed by Scanning Lidar Observations, J. Meteor. Soc. Japan, 64, 787-796.

21. Neff, W. D. and R. L. Coulter, (1986): Acoustic Remote Sounding, Probing the Atmospheric Boundary Layer, Amer. Meteor. Soc., Boston MA., 201-239.

22. NOAA: "Daily Weather Maps, Weekly Series", July 8-14, 1985, National Meteorological Center, National Weather Service.

23. Peterson, F. L., N. O. Jenson, and U. P. Jenson, (1976): A Mesoscale Phenomenon Revealed by an Acoustic Sounder, J. Appl. Meteor., 15, 662-664.

24. Pielke, R. A., (1978): Mesoscale Meteorological Modeling, Academic Press, 612pp.

25. Pielke, R. A., (1974): A Comparison of Three-Dimensional and Two-Dimensional Numerical Predictions of Sea Breezes, J. Atm. Sci., 31 1577-1585.

26. Reed, J. W., (1979): Cape Canaveral Sea Breezes, J. Appl. Meteor., 18, 231-235.

27. Rizzo, K. R., and W. A. Lyons, (1977): Acoustic Sounder Measurements of Summer Mixing Depths in Coastal Environments. Preprints Conference on Applications of Air Pollution Meteorology, AMS, Salt Lake City, 68-71.

28. Schwiesow, R. L. (1986): Lidar Measurement of Boundary-Layer Variables, Probing the Atmospheric Boundary Layer, Amer. Meteor. Soc., Boston, MA., 139-162.

29. Siler, R. K. (1980): A Diffusion Climatology for Cape Canaveral, Florida, NASA Technical Memorandum 58224, 43pp.

30. Simpson, J. E., D. A. Mansfield, J. R. Milford, (1977): Inland Penetration of Sea Breeze Fronts, Quart. J. R. Met. Soc., 103, 47-76.

31. Taylor, G. E. and R. A. Schuman, (1986): A Description of the Meteorological and Range Safety Support (MARSS) System, Preprints Fifth Joint Conference on Applications of Air Pollution Meteorology, Chapel Hill, N. C., Amer. Meteor. Soc., 133-136.

32. Wexler, R. (1946): Theory and Observations of Land and Sea Breezes, Bull. Amer. Meteor. Soc., 27, 272-287.

ATE

LMED

-8