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# OCD: THE OFFSHORE AND COASTAL DISPERSION MODEL

## VOLUME I: USER'S GUIDE

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# ABSTRACT

The Offshore and Coastal Dispersion (OCD) model has been developed to simulate the effect of offshore emissions from point, area, or line sources on the air quality of coastal regions. The OCD model was adapted from the EPA guideline model MPTER (EPA, 19801. Modifications were made to incorporate overwater plume transport and dispersion as well as changes that occur as the plume crosses the shoreline.

Hourly meteorological data are needed from both overwater and overland locations. The overwater measurements include wind direction and speed, mixing height, overwater air temperature and relative humidity, and the sea surface temperature. Overland data include the standard EPA UNAMAP model requirements. Overwater and overland turbulence intensities are used by the model but are not mandatory. For overwater dispersion, the turbulence intensities are parameterized from boundary layer similarity relationships if they are not measured.

Specifications of emission characteristics and receptor locations are similar to the standard EPA UNAMAP models. Hourly emission rate, exit velocity, and stack gas temperature may also be specified. Up to 250 point sources, 5 area sources, or one line source and 180 receptors may be used.

Plume reflection off elevated terrain is calculated following the method proposed in the EPA TUPOS model (Turner et al., 1986). Plume inpaction on elevated terrain is calculated following procedures in the EPA RTDM (Rough Terrain Diffusion Model) (ERT, :1982). That is, if the plume is below the critical dividing streamline height ($H_c$), the plume impacts the terrain, and if the plume is above $H_c$, the plume flows up over the terrain. A revised platform downwash algorithm based on laboratory experiments is incorporated in OCD. Partial plume penetration into elevated inversions is treated using Briggs' model.

A virtual source technique is used to change the rate of plume growth as the overwater plume intercepts the thermal internal boundary layer (TIBL) at the shoreline. The TIBL is assumed to be terrain following.

The revised DCD model (Version 4) and the previous version of OCD (Version 3) are tested with measurements from four offshore tracer experiments. Considering the overall performance of the models, the OCD (Version 4) model is shown to be an improvement over the OCD (Version 3) model.

## EXECUTIVE SUMMARY

The Offshore and Coastal Dispersion (OCD) model was developed to simulate plume dispersion and transport from offshore point, area, or line sources to receptors on land or water. The OCD model is an hour-by-hour steady state Gaussian model with enhancements that consider the differences between overwater and overland dispersion characteristics, the sea-land interface, and platform aerodynamic effects.

Categories of overland turbulence levels have been successfully parameterized as a function of solar radiation and wind speed only. This approach can be used over land without considering surface temperature or humidity because the surface temperature responds rapidly to changes in solar radiation, and sensible heat fluxes dominate latent heat fluxes in the boundary layer. This is not the case for the boundary layer over water surfaces where diurnal temperature changes are quite small, response times long, and latent heat fluxes important. Therefore, the traditional methods of determining stability category and thus atmospheric turbulence characteristics are not applicable for overwater sources. Overwater turbulence levels are largely governed by the air-water temperature difference, overwater wind speed, and the specific humidity. If overwater turbulence levels are not measured directly, they must be estimated from boundary layer theory using bulk aerodynamics.

The OCD model requires both overwater and overland meteorological data. The overwater data include the following parameters:

- overwater wind direction,
- overwater wind speed,
- overwater mixing height,
- overwater air temperature,
- water surface temperature,
- overwater relative humidity,
- overwater wind direction shear in the vertical,
- overwater vertical potential temperature gradient,
- overwater turbulence intensities (y and z components), and

- overland turbulence intensities (y and z components).

The overland meteorological data required by the OCD model are identical to those required by the standard EPA UNAMAP model. Missing overwater turbulence intensities are parameterized using bulk aerodynamic wind and temperature profile relationships as well as the overwater stability category (defined in terms of the Monin-Obukhov length). Missing overland turbulence intensity measurements are replaced by the rural Briggs (19731 defaults.

Several options available in the standard EPA UNAMAP models are included in the model:

- terrain adjustments,
- stack-tip downwash,
- gradual plume rise,
- buoyancy-induced dispersion, and
- pollutant decay (monthly daytime transformation rates are user-specified).

The OCD model has incorporated several other features:

- Complex terrain is treated as in COMPLEX I/II (EPA, 19861, except for the consideration of partial reflection and an improved method to calculate deflection around or over terrain.
- Plume reflection off elevated terrain is treated using a method proposed in the EPA TUPOS model (Turner et al., 1986).
- Building downwash due to platform influence on the plume is treated using a revised platform downwash algorithm based on laboratory experiments, dispersion coefficients are enhanced and final plume rise is reduced as a result of downwash effects.
- The effective mixing depth at the shoreline includes mixing that is effectively unlimited if the plume is in a stable layer.
- The default turbulence intensity is inversely proportional to the wind speed for all stabilities.
- The Thermal Internal Boundary Layer (TIBL) is terrain following.
- Point, area, or line sources may be modeled.
- Partial penetration of elevated inversions is accounted for.
- Stacks can be oriented at any angle relative to the vertical to

-accommodate a variety of oil platform sources.

- The land/sea interface need not be a straight line; a rectangular grid system is used to accommodate any complex coastline.
- A virtual source technique is used to change the rate of plume growth as the overwater plume intercepts the overland internal boundary layer.
- Continuous shoreline fumigation (stable overwater and unstable overland conditions1 is **parameterized** using the Turner method where complete vertical mixing through the TIBL occurs as soon as the plume intercepts the TIBL.
- Hourly source emission rate, exit velocity, and stack gas temperature can be specified.

The OCD model can provide estimates of pollutant concentrations at a maximum of 180 receptors from a maximum of 250 point sources, 5 area sources, or one line source. Summary tables generated by OCD may be used to determine the peak modeled concentrations. Alternatively, modeled concentrations can be written to an output tape or disk file for subsequent postprocessing by the ANALYSIS program. The postprocessor can provide several statistical summaries:

- the top N concentrations for each receptor for averaging periods up to 24 hours in length;
- cumulative frequency distributions of concentrations for each receptor; and
- identification of periods for which threshold concentrations are exceeded at any receptor.

In addition, the ANALYSIS **postprocessor** can create new concentration files which can be used as input to the processes described above:

- a file of running averages (up to 24 hours in length), and
- a file that is the sum of concentrations from up to five separate files. (Concentrations from each file summed are first multiplied by a user-specified scale factor.)

A performance evaluation of the OCD (Version **4)** model along with the OCD (Version **3)** model was conducted with measurements from four different offshore tracer experiments. The four experiments included 17 hours of data from the MMS sponsored experiment at Ventura, CA, 31 hours from the MMS experiment at Pismo Beach, CA, 26 hours of data collected at Cameron, LA in an experiment sponsored by the American Petroleum Institute (API), and 36 hours from the API experiment at Carpinteria, CA.

The uncertainties associated with the OCD model (Versions 3 and 4) are examined using a blocked bootstrap or jackknife resampling method to estimate whether there are significant differences in the fractional bias (FB), normalized mean square error (NMSE), and correlation (R). 95% confidence limits are calculated using bootstrap resampling for FB and R for each model, and the difference in FB, NMSE, and R between models. An arbitrary scoring scheme is used to combine all the results into a final "score." Considering the overall performance of the models, the OCD (Version 4) model is shown to be an improvement over the OCD (Version 3) model.

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## LIST OF SYMBOLS

Symbols used in the OCD user manual and all appendices are listed here. Symbols with more than one meaning are multiply listed. The units (dimensions1 for each parameter are listed, except for dimensionless quantities.

$a$: deviation of the stack angle from the vertical, deg

$\beta$: entrainment coefficient used in plume rise calculations

$C_d$: momentum transfer drag coefficient

$C_H$: heat transfer drag coefficient

$C_o$: observed concentration

$C_p$: predicted concentration

$c_p$: specific heat of dry air, cal/gm-deg

$C_{pv}$: specific heat of water vapor, cal/gm-deg

$C_q$: moisture transfer drag coefficient

$C_T$: bulk transfer coefficient

$C_{TN}$: bulk transfer coefficient for heat for temperature profile calculations, assuming neutral conditions

$C_{uN}$: drag coefficient used in bulk aerodynamic wind profile calculations, assuming neutral conditions

$d$: stack-top inside diameter or diameter of the effective source representing an area source, m

$d\theta/dz$: vertical potential temperature gradient, °K/m

$e$: water vapor pressure, mb

$e_s$: saturation water vapor pressure, mb

$\varepsilon$: eddy dissipation rate, $m^2/s^3$

AE: difference in elevations (m) of the ground or water surface at the receptor location and at the source location

. f: Coriolis parameter (1/s), equal to 2 $\Omega$ sin $\phi$ where $\Omega$ is the angular speed of the earth and $\phi$ is the latitude

$F$: plume buoyancy flux, $m^4/s^3$

FB: fractional bias

FT: terrain correction factor, specified as a function of the overland stability class

$F_Y$: empirical scaling parameter used in the calculation of the horizontal turbulence intensity if no measurement is available

$F_z$: empirical scaling parameter used in the calculation of the vertical turbulence intensity if no measurement is available

$g$: acceleration due to gravity, $m/s^2$

$h$, $h_T$: average elevation of the well-mixed overland surface layer, or turbulent internal boundary layer (TIBL), in which fumigation can occur, m

$h_B$: building height, m

$h_m$: marine mixing depth, m

$h_{ter}$: terrain elevation toward which the source to receptor is aligned, m

$H$: plume height above stack base in the absence of terrain effects, m

$H$: vertical heat flux, $cal/s\text{-}m^2$

$H'$: effective stack height taking into account downwash, m

$\Delta H$: plume rise due to buoyancy or momentum, m

$H_c$: critical dividing streamline height, m

$H_e$: effective stack height, m

$H_i$: mixing depth, m

$H_m$: plume rise due to momentum, m

$H_s$: height of the stack top above stack base elevation, m

$H_1$: effective height of the plume above terrain, alternative #1, m

$H_2$: effective height of the plume above terrain, alternative #2, m

$i_Y$: turbulence intensity, horizontal component

$i_z$: turbulence intensity, vertical component

$k$: pollutant chemical transformation rate, **%/hour**

$L$: Monin-Obukhov length, m

$L_h$: latent heat of vaporization, **cal/g**

$L_v$: Monin-Obukhov length for moist air, often used interchangeably with L, m

$N$: Brunt-Vaisala frequency, $s^{-1}$

NMSE: normalized mean square error

NPER: time it takes a ship to travel from start to finish, hrs

NSEGS: number of line source segments

$P$: fraction of plume material penetrating mixed layer

$P$: atmospheric pressure, mb

PPC: plume path coefficient

$\psi$: pollutant decay coefficient, $s^{-1}$

$\psi_u$: empirical scaling parameter used in the calculation of bulk aerodynamic wind speed profiles

$\psi_\theta$: empirical scaling parameter used in the calculation of bulk aerodynamic temperature profiles

$\phi_u$: empirical scaling parameter used in the computation of $\psi_u$

$\phi_\theta$: empirical scaling parameter used in the computation of $\psi_\theta$

$Q$: emission rate, g/s

$Q_{seg}$: line source segment emission rate, g/s

$\rho$: density of air, $g/m^3$

R: correlation

RH: relative humidity, or the fraction $w/w_s$, in%

$R_{yo}$: initial plume dilution radius in the horizontal due to building downwash, m

$R_{zo}$: initial plume dilution radius in the vertical due to building downwash, m

$\sigma_\theta$: wind direction standard deviation, deg

$\sigma_\phi$: wind elevation angle standard deviation, deg

$\sigma_v$: standard deviation of the wind speed, horizontal component, m/s

$\sigma_w$: standard deviation of the wind speed, vertical component, m/s

$\sigma_y$: standard deviation of the plume concentration distribution in the horizontal, m

$\sigma_{yB}$: value of $\sigma_y$ at the land/sea interface, m

$\sigma_{yb}$: component of $\sigma_y$ due to buoyant plume enhancement, m

$\sigma_{yo}$: component of $\sigma_y$ due to structure downwash, m

$\sigma_{ys}$: component of $\sigma_y$ due to wind direction shear, m

$\sigma_{yt}$: component of $\sigma_y$ due to atmospheric turbulence, m

$\sigma_z$: standard deviation of the plume concentration distribution in the vertical, m

$\sigma_{zB}$, $\sigma_{zi}$: value of $\sigma_z$ at the land/sea interface, m

$\sigma_{zb}$: component of $\sigma_z$ due to buoyant plume enhancement, m

$\sigma_{zo}$: component of $\sigma_z$ due to structure downwash, m

$\sigma_{zt}$: component of $\sigma_z$ due to atmospheric turbulence, m

s: stability parameter equal to $g/\theta \cdot d\theta/dz$, it is the square of the Brunt-Vaisala frequency, $1/s^2$

S: terrain slope

SC: Pasquill stability class

$S_y$: empirical factor used in computation of $\sigma_y$ as a function of downwind distance

$S_z$: empirical factor used in computation of $\sigma_z$ as a function of downwind distance

$\tau$: OCD averaging time, s

$\Delta T$: difference between stack gas and ambient temperature, °K

$\Delta T_c$: critical temperature difference, °K

$\Delta T/\Delta z$: rate of change of air temperature with height, deg/m

$t'$: dimensionless time (used in fumigation model) at which fumigation begins

$t^*, T^*$: dimensionless time (used in fumigation model) usually used in reference to t' to give elapsed time of fumigation

$t^*_f$: dimensionless time of final (complete) entrainment, used in fumigation model

T: travel time, s

T, Ta: temperature of ambient air, °K (overland or water).

Ts: stack gas temperature, °K

Ts: water surface temperature, °K

$T_{Ly}$: Lagrangian time scale of eddy dissipation, crosswind component, s

$T_{Lz}$: Lagrangian time scale of eddy dissipation, vertical component, s

$T_v$: virtual temperature, °K

$T_{vs}$: virtual temperature of saturated air, °K

Tw: wet-bulb temperature, °K

$\theta$: potential temperature, °K

$\theta$: wind direction, deg

$\theta'$: direction from source to receptor, deg

$d\theta/dz$: vertical potential temperature gradient, deg/m

$\Delta\theta$: wind direction shear over the plume depth, deg

$\theta_v$: virtual potential temperature, °K

$\theta_{VS}$: virtual potential temperature of saturated air, °K

$\theta_{v*}$: proportional to the upward heat and moisture flux in the surface layer; it is the scaling value of $\theta_v$ used in bulk aerodynamic temperature profile calculations, °K

u: horizontal wind speed component, m/s

u*: friction velocity, proportional to the upward momentum flux in the surface layer; it is used as a scaling value of u in bulk aerodynamic wind profile calculations, m/s

$v_s$: stack gas exit velocity, m/s

$w$: vertical wind speed component, m/s

$w$: ratio of water vapor to dry air by mass, referred to as the mixing ratio, g/kg

$w_e$: entrainment or growth rate in the vertical of fumigant, m/s

$w_s$: mixing ratio of saturated air, g/kg

$w^*$: convective velocity (vertical component) scaling value used in bulk aerodynamic profile calculations, m/s

$W_b$: building width, m

$\Delta WD/\Delta z$: vertical wind direction shear, deg/m

$x$: downwind distance along the plume axis, m

$x_f$: distance to final plume rise, m

$x_o$: in the fumigation model $x_o$ is the distance from the shoreline where the plume first enters the well-mixed surface layer, m

$x_1$: inland distance measured from $z_o$, m

$x_B$: distance from the source to the shoreline, m

$x_v$: virtual distance, m

$X_{end}$: line source x-coordinate endpoint, user units

$y$: distance perpendicular to the plume axis, m

$Y_{end}$: line source y-coordinate endpoint, user units

$z$: height (of a plume or receptor) relative to stack base or ground level, m

$z_i$: height of the mixed layer, m

$z_o$: surface roughness length, or height at which the wind speed drops to zero, m

$Z_{elp}$: elevation of ground, water, or platform base at stack location relative to the water surface, user height units

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# 1. MODEL OVERVIEW

## 1.1 Introduction

The revised Offshore and Coastal Dispersion (OCD) model (Version 4) was developed by the Minerals Management Service (MMS) for applications in which the onshore impact of plumes released from offshore sources (e.g., oil platforms, tankers1 must be calculated. The background and purpose of the model are presented in Section 1.2 and a general description of the model is presented in Section 1.3. A more detailed technical description of the model is presented in Section 2. The user's instructions for applying the OCD model are presented in Section 3. The revised OCD model has been evaluated with field tracer data from four coastal experiments, three on the California coast, and one in the Gulf of Mexico. The model evaluation and results are presented in Section 4.

An overview of the OCD code and the source listing of the model code are presented in Appendix A. Instructions for the use of the postprocessing program ANALYSIS along with the source code are presented in Appendix B. Finally, Appendix C discusses offshore meteorological data collection instrumentation.

This revised edition of the the OCD User's Guide has been prepared to provide the user with a full set of updated documentation describing the mathematical formulations, model evaluation results, and procedures for computer applications. The new User's Guide (an edited version of the first edition1 is comprehensive and self-contained so that users of the new OCD model will not need to refer back 'to the original User's Guide. Portions of this new User's Guide are based on the original OCD Version 3 User's Guide (Hanna et al., 19841 and the OCD API (American Petroleum Institute1 User's Guide (Hanna and DiCristofaro, 19881. Many changes have been made to this new version of the User's Guide, although some sections have been left verbatim from the previous versions.

## 1.2 Background and Purpose

In September 19'78, the U.S. Congress passed the Cuter Continental Shelf (OCS) Lands Act Amendments, directing the U.S. Secretary of the Interior to implement a program to inventory and develop the mineral resources, including oil and gas, on the OCS areas of the United States. These areas lie in the ocean between 3 miles (10 miles off Texas and parts of Florida) and 200 miles from the coastline. The responsibility for the development and implementation of this program was delegated to the Minerals Management Service (MMS).

Section 5(a) (8) of the Cuter Continental Shelf Land Act (OCSLA) amendments directed the Secretary to promulgate regulations for air quality emissions "for compliance with the national ambient air quality standards (NAAQS)..., to the extent that activities authorized under this [Act] significantly affect the air quality of any State." Under this authority, on March 7, 1980, the MMS published a final rule establishing a regulatory program concerning the control of air emissions from oil and gas operations on the OCS (45 FR 15128, March 7, 1980). The final rule recognized that no air quality model was available for regulatory use for overwater applications. To remedy this situation, the agency outlined a process which would lead to the development of an acceptable overwater model and encourage further scientific work (45 FR 37816, June 5, 1980). First the U.S. Environmental Protection Agency's (EPA) CRSTER and PTMTP models were identified for temporary use, but with the modification that stability class A and B conditions determined from overland data would be modeled as stability class C. Second, a model more appropriate for overwater applications would be developed by the agency and validated with actual offshore field data. The MMS sponsored two field studies to gather data at Ventura 'and Pismo Beach, California and supported the field study by the American Petroleum Institute (API) at Cameron, Louisiana.

Following the completion of the field studies in 1982, the new model, called the Offshore and Coastal Dispersion Model (OCD), was developed. Following extensive peer review and comment, the MMS officially approved the model's use for the evaluation of onshore impacts from OCS facilities in March 1985 (50 FR 12248, March 28, 19851. The U.S. SPA formally approved the use of the OCD model, with minor restrictions, in January 1988 (53 FR 392, January 6, 1988) as part of its Guidelines on Air Quality Models (EPA, 1987).

The OCD model was originally developed and evaluated by Hanna et al. (1984, 1985) using tracer data from three flat coastal areas (Ventura and Pismo Beach, CA, and Cameron, LA). However, the vast majority of applications of the OCD model in the 1985 to 1987 period have been in the Santa Barbara Channel area, where terrain is often very steep near the coast. The original OCD model (Version 3) contains a highly simplified and untested complex terrain algorithm. Interactions with various agencies with jurisdiction in the Santa Barbara Channel area (EPA Region IX, MMS, Santa Barbara County Air Pollution Control District, California Air Resources Board) led to the conclusion that several portions of the OCD code should be revised.

At the same time as these regulatory agency activities were taking place, research on overwater and coastal turbulence and dispersion modeling has continued. For example, Stunder and Sethuraman (19861 compared the predictions of several coastal fumigation models. Petersen (19861 conducted laboratory experiments on dispersion around oil platforms. The final report on the EPA's Complex Terrain Model Development program (Strimaitis et al., 19881 indicates the importance of the dividing streamline height, $H_c$, concept in stable conditions, where a plume located below $H_c$ will be forced around the sides of an obstacle and a plume located above $H_c$ will pass up and over the obstacle. Tracer experiments sponsored by the American Petroleum Institute (API) were conducted at a coastal/complex terrain site at Carpinteria, CA (Johnson and Spangler, 1986). Based on new research, agency use, comments from model users, and the additional field data from Carpinteria, work was begun in May 1988 to revise the model and streamline its operating code.

## 1.3 General Description of OCD

The OCD model is an hourly, steady-state Gaussian model built on the framework of the U.S. EPA-approved MPTER model (EPA, 19801, with appropriate modifications to accommodate the unique dispersion regime and source characteristics of overwater pollutant releases. The model consists of three major components: the overwater subroutines which are new algorithms based on overwater boundary layer dynamics, the overland subroutines borrowed from the MPTER model to describe dispersion over flat to rolling terrain, and the subroutines borrowed from existing models to describe dispersion in complex terrain.

Differences in mixing depth and stability between the overwater and overland boundary layers are of importance to dispersion processes. The overwater mixing depth is relatively shallow due to the lack of strong sensible heat flux from the surface. LeMone (19781 shows that the average mixing depth is about 500 m over low-latitude oceans. In over half of the hours from the tracer studies used to test and develop the OCD model, the mixing depth was observed to be 100 m or less. These limited mixing depths can cause trapping of plumes near the surface.

The other major difference between the overwater and overland boundary layers is in the diurnal and annual variation of stability, which is completely unrelated to typical overland behavior. For example, air and water temperature observations from the North Sea (Nieuwstadt, 19771 show that temperature inversions typically persist most of the day in June and unstable conditions persist all day in January. The data also show that in March or April, conditions are stable in the afternoon and unstable at night. Other seasonal and diurnal stability patterns would be evident in other geographic areas, and these effects can be modeled accurately only if air and water temperatures and turbulence intensities are directly observed.

To develop the initial version of the OCD model (Hanna, 1984), the MPTER model was modified to include overwater boundary layer dynamics, land-sea mapping required by the differing overland and overwater dynamics, and the inclusion of complex terrain subroutines. The modifications are summarized in Table 1-1 and are more fully described in the User's Guide to the OCD Model (Hanna et al., 19841 or in Hanna et al. (1985). These two references also fully explain and document the theoretical and physical bases for the initial OCD model including the assumptions regarding the overwater boundary layer and provide an extensive discussion of the performance evaluation for the original model and the data needs of the model.

TABLE 1-1

SUMMARY OF DIFFERENCES BETWEEN MPTER, OCD/3, AND OCD/4 MODELS

| Component | MPTER | OCD/3 | OCD/4 |
|---|---|---|---|
| Platform Downwash | Not Considered | BLP or ISC/API Formulas | Petersen (1986) Wind Tunnel Results, with Modifications |
| TIBL | Not Considered | Hanna (1987) Linear Growth | Hanna (1987) Linear Growth |
| Fumigation | Not Considered | Deardorff-Willis (1982) Convective Scaling | Turner (1969) Virtual Source |
| $\sigma_y$ | Standard EPA | Observed $i_y$, Briggs $f_Y$ | Observed $\sigma_\theta$, Draxler $f_Y$ |
| $\sigma_z$ | Standard EPA | Observed $i_z$ | Parameterized $i_z$ |
| Critical Streamline | Not Considered | Not Considered | RTDM approach |
| Plume Reflection | Standard EPA | RTDM (ERT, 1982) complex method | Simple TUPOS (Turner et al., 1986) formula |
| Line and Area Sources | Not Considered | Not Considered | Virtual Source Approach |

Definitions:

| | |
|---|---|
| TIBL: | Thermal Internal Boundary Layer |
| $i_y$, $i_z$: | Lateral and vertical turbulence intensities |
| $f_Y$ | Dimensionless function applied to $\sigma_Y$ |
| $\sigma_\theta$ | Standard deviation of wind direction fluctuations (in radians) |

Since its regulatory approval, Version 3 of the OCD model has been used by the Department of the Interior (DOI), by local agencies, and by the oil and gas industry to determine onshore impacts from OCS activities. Most of the emissions from these facilities are from point sources, such as exhaust vents and stacks for power generation equipment. Estimations of source emission and stack parameters are readily available for the model's input run stream. Meteorological data for these sources are more difficult to acquire, offshore data are sparse, and turbulence intensity data are not routinely measured. The model has been most often applied using offshore sea surface and air temperature data, along with wind data taken from buoys maintained jointly by the DO1 and the National Oceanic and Atmospheric Administration (NOAA).

The OCD model has been modified based on comments from agency and private users of the model. The focus of these modifications has been the streamlining of the model code, the expansion of the capabilities of the model to assess line, area, and intermittent sources, and the incorporation of recent field and theoretical work into the relevant algorithms of the model. Also, among the modifications incorporated were the restructuring of the algorithm to more realistically represent the impact of the plume on shoreline terrain and a standardization of the size of the grid cells used in the shoreline mapping routine. Many of the modifications are based on the work of Hanna and DiCristofaro (1988) and are summarized in Table l-l along with a comparison of OCD (Version 3) and MPTER.

# 2. TECHNICAL DESCRIPTION

The Offshore and Coastal Diffusion (OCD) model is an hourly, steady-state Gaussian model built on the framework of the EPA MPTER model (EPA, 1980). The MMS required that the new model adhere as closely as possible to the structure of existing regulatory models. Because of fundamental differences in the factors determining atmospheric turbulence characteristics over water and over land, modified schemes were developed to calculate plume dispersion. Specific model components are discussed in detail in this chapter.

## 2.1 Model Input Data

### 2.1.1 Source Input Data

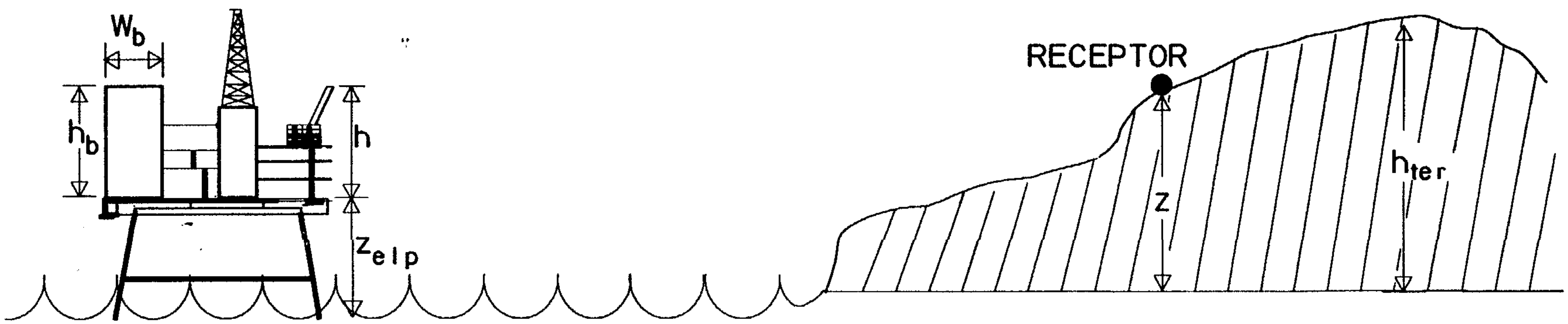
The OCD model will accept point, line, or area source information as input. The source input data requirements of the OCD model are summarized in Table 2-l. The relationships of the various source and receptor heights used in the model are presented in Figure 2-1. It is seen that the OCD model requires the same source variables as most EPA air quality dispersion models except for the following variables: the stack angle from the vertical and the height of the building at or near the stack location. On some offshore platforms, stacks may protrude from a building at an angle that is not vertical. In such a case, the vertical component of the plume rise due to initial jet momentum will be a function of the stack angle, but the vertical component of the plume rise due to initial plume buoyancy will not be affected. The height of the top of a tilted stack is specified in terms of height above the reference base height. For example, for a horizontal stack protruding from a building from an opening 15 m above a platform level, the stack top height would be set equal to 15 m. The height of the building itself is used in building downwash calculations.

The Universal Transverse Mercator (UTM) coordinate system can be used to define source locations if a Cartesian receptor array is used and it employs the UTM system. If a polar receptor array is specified, then the origin is specified as input to the model. The x and y coordinates of other sources, if modeled, are then obtained from a map drawn to scale. The x axis is positive

TABLE 2-1

SOURCE INPUTS REQUIRED BY THE OCD MODEL

| Parameter | Definition |
| --- | --- |
| $Q$ | Pollutant emission rate for concentration calculations (mass per unit time) |
| $\psi$ | Pollutant decay coefficient ($s^{-1}$) |
| X, Y | Point Source: x and y coordinates of stack (user units)<br>Area Source: x and y coordinates of circle center (user units)<br>Line Source: x and y coordinates of starting point (user units) |
| $X_{end}$, $Y_{end}$ | Line Source: x and y coordinates of ending point (user units) |
| $Z_{elp}$ | Elevation of ground, water, or platform base at stack location relative to the water surface (user height units) |
| h | Stack height (m) above $Z_{elp}$ |
| $V_s$ | Stack gas exit velocity (m/s) |
| d | Stack-top inside diameter (m) for point or line sources.<br>Diameter (m) of the effective circle representing area source. |
| $T_s$ | Stack gas temperature (°K) |
| $h_b$ | Height of building or obstacle at or near stack location (m) |
| $W_b$ | Building width used to compute platform downwash (m) |
| $\alpha$ | Deviation of stack angle from the vertical (degrees1 |




$h_b$ : Height of building or obstacle near stack location

$W_b$ : Building width used to compute platform downwash

$h$ : Stack height above $Z_{elp}$

$Z_{elp}$: Elevation of platform base at stack location relative to the water surface

$Z$ : Receptor terrain elevation

$h_{ter}$: Terrain elevation toward which the source to receptor is aligned

Figure 2-l. Relationships of various source and receptor heights used as inputs to the OCD model.

to the east and the y axis is positive to the north. When using a polar coordinate system-, only one origin of the receptor array can be specified.

The pollutant emission rate is required for each source. If a line source is being modeled, the emission rate is for the total distance traveled by the line source. For area sources, the emission rate represents the total emissions from each of the represented circular depictions (see Section 2. for more details). Hourly emission information, if available or necessary, consists of pollutant emission rate, stack gas exit velocity, and stack gas temperature. Hourly emission data may only be used with point or area sources. Results of stack test measurements should be used to determine how these parameters vary as a percentage of full capacity if significant (10 to 20%) load variations are common. If a source has a constant emission parameter value, hourly information is not necessary. Hourly emission data should only be used if stack testing has been performed.

Additional information concerning the emissions data input requirements of the OCD model is found in Chapter 3, User's Instructions.

### 2.1.2 Receptor Data

The OCD model allows the user to select either a Cartesian (x,y) or a polar $(r,\theta)$ receptor grid system. In the Cartesian system, the x-axis is positive to the east of a user-specified origin and the y-axis is positive to the north. In the polar system, r is the radial distance measured from the origin (x=y=O) and the angle $\theta$ (azimuth bearing1 is measured clockwise from north. If concentrations are to be calculated for impacts on elevated terrain, receptor terrain elevations (z) must be input for each receptor. The OCD model permits receptorground-level elevations to be above the elevations of stack tops.

In the polar coordinate system, receptor points are usually spaced at $10^\circ$ intervals on concentric rings. Therefore, there are 36 receptors for each ring. The radial distances from the origin to the receptor rings are user selected and are generally set equal to the distances to the expected maximum concentrations for the major pollutant sources under the most frequent stability and wind-speed combination. The maximum number of radial distances is five; therefore, the maximum number of receptors that can be modeled at any one time is 180.

In the Cartesian coordinate system, the x and y coordinates of the receptors are specified by the user. The spacing of the grid points is not required to be uniform so that the density of grid points can be greatest in the area of the expected maximum concentrations.

### 2.1.3 Meteorological Input Data

The hourly overland and overwater meteorological inputs which may be input to the OCD model are listed in Table 2-2. Unless specified, the recommended measurement height is at stack top. Those parameters which are mandatory for the model to run are specified. The overland meteorological data include the stability class, wind speed, ambient air temperature, wind direction (from which the wind blows), and the mixing height. In general, these inputs are developed from concurrent surface and upper-air meteorological data by the RAMMET preprocessor program as used by the Single Source (CRSTER) Model (EPA, 1977 and Catalano, 19861. The overland data may also include the horizontal and vertical turbulence intensity data. The overwater meteorological input data include wind direction, wind speed, mixing height, relative humidity, air temperature, surface temperature, wind direction shear, turbulence intensity, and vertical potential temperature gradient data. Only four overwater data parameters are mandatory (mixing height, humidity, air temperature, and surface water temperature). Sensitivity tests have shown that the humidity variable is of lesser importance than the other required overwater input data. The local MMS agency should be contacted concerning what values should be substituted for missing data. Climatological data or long-term averages of meteorological data (as recommended in OCD/3) should NOT be used anyway, since they can lead to spurious estimates.

Although the OCD model can be run with only limited meteorological data, the user is urged to obtain as much representative overwater data as possible to improve the accuracy of the model results. In regards to onsite versus airport data for land measurements, the MMS may require an onsite meteorological tower. It is up to the local MMS agency to make the appropriate decision.

TABLE 2-2

HOURLY METEOROLOGICAL INPUTS TO THE OCD MODEL

| Parameter | Definition | Mandatory Input? |
|---|---|---|
| **Over Land** | | |
| SC | Pasqulll Stability Class (1 = A, 2 = B, etc. ) | Yes |
| u | Wind Speed (m/s) | Yes |
| $T_a$ | Ambient Air Temperature (°K) | Yes |
| $\theta$ | Wind Direction (degrees) | Yes |
| $z_i$ | Mixing Height (m) | No |
| $i_y$ | Horizontal Turbulence Intensity[1] | No |
| $i_z$ | Vertical Turbulence Intensity[1] | No |
| **Over Water** | | |
| $\theta$ | Wind Direction (degrees) | |
| u | Wind Speed (m/s) | No |
| $z_i$ | Mixing height (m) | Yes |
| RH | Relative Humidity (%), Wet Bulb Temperature (°K), or Dew Point Temperature (°K) | Yes |
| $T_a$ | Ambient Air Temperature (°K) | Yes |
| T | Water Surface Temperature (°K) or Air Temperature Minus Water Temperature (°K) | Yes |
| AWD | Vertical Wind Direction Shear (degrees/m) (Recommended layer of surface to stack top) | No |
| $i_y$ | Horizontal Turbulence Intensity[1] | No |
| $i_z$ | Vertical Turbulence Intensity[2] | No |
| $\frac{d\theta}{dz}$ | Vertical Potential Temperature Gradient (°K/m) (Recommended layer of surface to stacktop) | No |

1: $i_y = \sigma_v/u = \tan \sigma_\theta$, where $\sigma_\theta$ is standard deviation of wind direction fluctuations.

2. $i_z = \sigma_w/u = \tan \sigma_\phi$, where $\sigma_\phi$ is standard deviation of wind elevation angle fluctuations.

In general, the hierarchy of meteorological data measurements are as follows:

1) **Onsite** overwater meteorological data
2) Representative overwater meteorological data
3) Representative overland meteorological data

Details concerning the availability of offshore meteorological data and the available offshore meteorological instrumentation and collection systems are presented in Appendix C, Volume II of this User's Guide. Specifications for the format of the overland and overwater meteorological data are given in Section 3.

## 2.2 Platform Downwash

The oil platform or ship presents an obstacle to the flow over the water and creates a turbulent wake that can "downwash" the pollutant plumes. This downwash leads to two effects: (1) increased initial plume diffusion in the turbulent wake, and (2) reduced plume rise. Oil or gas platforms sit on stilts at a height of about 20 m above the water surface. The API sponsored a series of wind tunnel tests of the flow and dispersion around model oil platforms, from which empirical formulas for dispersion enhancement were derived by Petersen (19861. These formulas were used as a basis for developing the OCD/4 model platform downwash algorithm. Some additional work was required so that the formulas covered the following conditions:

- All stabilities.
- All values of $H_e/H_b$, where $H_e$ is effective plume height and $H_b$ is building height.
- Inclusion of initial $\sigma_y$ and $\sigma_z$ by quadratic summation.

The new formulas for the initial dispersion parameters $\sigma_{yo}'$ and $\sigma_{zo}'$, which as stated above are modifications by Hanna and DiCristofaro (19881 to formulas suggested by Petersen (19861, are given as:

$$\sigma_{yo}' = 0.071\, x\, (A_y + B_y\, (x/L_y)^{C_y} - 1)^{1/2} \qquad (2\text{-}1)$$

$$\sigma_{zo}' = 0.11\, x^{0.81}\, (A_z + B_z\, (x/L_z)^{C_z} - 1)^{1/2} \qquad (2\text{-}2)$$

where

$A_Y = 1.9 \quad B_Y = 48.2 \quad L_Y = W/2 \quad C_Y = -1.4$

$A_z = 3.0 \quad B_z = 40.2 \quad L_z = H_b \quad C_z = -1.4$

The parameter W is the platform width in meters, $H_b$ is the total platform height above water surface in meters, and x is the downwind distance in meters. Equations (2-1) and (2-2) are valid for $2.2 < x/H_b < 12.6$. For $x/H_b$ less than 2.2, use the solutions at 2.2, and for $x/H_b$ greater than 12.6, use the solutions at 12.6.

If $H_e$ is the effective height of the plume (stack height plus plume rise), then the effective "initial plume size' used by the OCD model at various heights above the oil platform can be calculated as follows:

$$H_e/H_b \le 1 \qquad \sigma_{yo} = \sigma_{yo}' \qquad (2\text{-}3)$$

$$\sigma_{zo} = \sigma_{zo}' \qquad (2\text{-}4)$$

$$1.0 < H_e/H_b \le 1.2 \qquad \sigma_{yo} = 0.5\, (6-5\, H_e/H_b)\, \sigma_{yo}' \qquad (2\text{-}5)$$

$$\sigma_{zo} = 0.5\, (3-H_e/H_b)\, \sigma_{zo}' \qquad (2\text{-}6)$$

$$1.2 < H_e/H_b \le 3.0 \qquad \sigma_{yo} = 0 \qquad (2\text{-}7)$$

$$\sigma_{zo} = 0.5\, (3-H_e/H_b)\, \sigma_{zo}' \qquad (2\text{-}8)$$

$$H_e/H_b > 3.0 \qquad \sigma_{yo} = \sigma_{zo} = 0 \qquad (2\text{-}9)$$

Field evaluation of these new platform **downwash** formulas with the tracer data from OCS field experiments is not possible, since many of the field experiments used boats or tethersondes for tracer releases. In the case of the few experiments that used a platform for tracer releases, the concentration sampling instruments were several kilometers from the platform, where the component of dispersion due to platform **downwash** is a minor perturbation to the total plume spread. The sampling instrument should be located within about 200 m of the tower to permit satisfactory testing of the formulas in the OCD code.

## 2.3 Plume Rise

### 2.3.1 Neutral and Unstable Conditions

Final buoyancy rise in neutral or unstable conditions is computed in the OCD model as

$$\Delta H = 21.425\ F^{0.75}/u \ , \quad F < 55\ m^4/s^3 \ , \tag{2-10}$$

$$\Delta H = 38.71\ F^{0.6}/u \ , \quad F \geq 55\ m^4/s^3 \tag{2-11}$$

where $\Delta H$ is the plume rise (m),
$F$ is buoyancy flux $(m^4/s^3) = (g v_s d^2\ \Delta T)/(4T_s)$,
$u$ is stack-top wind speed (m/s),
$\Delta T$ is the difference between stack gas and ambient temperatures,
$T_s$ is the stack gas temperature (°K).

These formulas are based on Briggs' (1969) recommendations. The effects of the initial size of the source are not accounted for in this section.

Momentum rise in neutral/unstable conditions is computed, with the additional consideration of the stack angle from the vertical, $\alpha$:

$$\Delta H = (3 d v_s/u) \cdot \text{cosine}\ (\alpha) \ , \tag{2-12}$$

where $d$ is the stack diameter (m),

$v_s$ is. the stack gas exit velocity (m/s),

$\alpha$ is the stack angle (0° for upward pointing stacks, 90° for horizontal stacks, and 180° for downward pointing stacks).

A critical temperature difference, $\Delta T_c$, between the stack gas and ambient air can be defined such that if the actual temperature difference exceeds $\Delta T_c$, then buoyancy rise dominates; otherwise, momentum rise is used. The value of $\Delta T_c$ for neutral and unstable conditions can be derived from Equations (2-10), (2-11), and (2-12) for $\alpha \leq 90°$ from the definition of the buoyancy flux, F:

$$\Delta T_c = (0.0297\ T_s v_s^{0.333} d^{-0.667}) \cdot (\text{cosine}(\alpha))^{1.333},\ F < 55\ m^4/s^3 , \qquad (2\text{-}13)$$

$$\Delta T_c = (0.00575\ T_s v_s^{0.667} d^{-0.333}) \cdot (\text{cosine}(\alpha))^{1.667},\ F \geq 55\ m^4/s^3 . \qquad (2\text{-}14)$$

If $\alpha$ is less than 90° and the value of $\Delta T$ for a given hour is greater than $\Delta T_c$, buoyancy rise is computed using Equation (2-10) or (2-11); otherwise Equation (2-12) is used. If $\alpha$ is greater than 90° (downward pointing stack), the total plume rise is assumed to be equal to the sum of the (negative) momentum rise and the buoyancy rise.

### 2.3.2 Stable conditions

Final buoyancy rise for a bent-over plume in stable conditions is computed in the OCD model as:

$$\Delta H = 2.6\ (F/us)^{1/3} \qquad (2\text{-}15)$$

where s is a stability parameter equal to (g/T) $d\theta/dz$, and $\theta$ is the potential temperature (Briggs, 1969). Final buoyancy rise for calm stable conditions is computed using the formula:

$$\Delta H = 4\ F^{1/4}\ s^{-3/8} \qquad (2\text{-}16)$$

where Equation (2-16) is used only if the stack-top wind speed is less than $0.2746\ F^{1/4}\ s^{1/8}$.

Momentum rise in stable conditions is computed as

$$AH = 1.5[(v_s{}^2 d^2 T)/(4T_s u)]^{1/3}\ s^{-1/6} \cdot \text{cosine}\ (\alpha)\ . \tag{2-17}$$

The value of the critical temperature difference $\Delta T_c$ that separate the use of Equations (2-15) and (2-17) in stable conditions is given below:

$$\Delta T_c = (0.01958\ v_s\ T\ s^{0.5})\ .(\text{cosine}(\alpha))^3\ . \tag{2-18}$$

If a is less than $90^\circ$ and the value of AT for a given hour is greater than $\Delta T_c$, buoyancy rise is computed; otherwise momentum rise is used. If $\alpha$ is greater than $90^\circ$, the sum of momentum and buoyancy rise is used.

### 2.3.3 Plume Penetration

If the top of the plume (located at 1.6 $\Delta H$) after final rise approaches or exceeds the height of the mixed layer, $z_i$, then plume penetration of elevated stable layers is considered using the model proposed by Briggs (1975) and implemented by Weil and Brower (1984). The following equation describes this scenario:

$$AH \geq 0.62\ (z_i - H'), \tag{2-19}$$

where H' is the effective initial stack height taking into account downwash. If the criterion in Equation (2-19) is satisfied, final plume rise is recomputed using the stable plume rise Equations (2-15) and (2-16) assuming an isothermal atmosphere ($\partial\theta/\partial z$ = 0.01 °C/m). This is a conservative assumption since the atmosphere in the mixed layer is usually less stable and would lead to a higher plume rise. Briggs (1975, 1984) recommends this approach rather than integrating through layers of different stabilities for the sake of complicated approach constantly overpredicted.

The fraction of plume material penetrating into the stable layer aloft (P) is estimated as:

$$P = 0 \quad \text{if } z_i'/\Delta H_i \geq 1.5 ,$$

$$P = 1 \quad \text{if } z_i'/\Delta H_i \leq 0.5 , \tag{2-20}$$

$$P = 1.5 - z_i'/\Delta H_i \quad \text{if } 0.5 < z_i'/\Delta H_i < 1.5 ,$$

where

$$z_i' = z_i - H' \tag{2-21}$$

and $\Delta H_i$ is the plume rise computed assuming an isothermal lapse rate. If partial penetration occurs ($0 < P < 1$, where P is a weighting factor), the plume is split into parts below and above the mixing height. The plume above the mixing height must be considered because it may become entrained into the rising mixing height over land as the plume moves inland.

The source strength of each plume is given by:

$$Q = P\,Q_s \quad \text{above } z_i, \tag{2-22}$$

$$Q = (1 - P)\,Q_s \quad \text{below } z_i. \tag{2-23}$$

The plume height below $z_i$ is determined by linear interpolation between the limits, $P = 0$ and $P = 1$. The lower limit ($P = 0$) is when the height of the top of the plume equals $z_i$. Assuming the radius of the plume is given by:

$$R = \beta\,\Delta H \tag{2-24}$$

where $\beta$ is the entrainment coefficient (equal to 0.6 for bent-over plumes), where $\beta$ is the entrainment coefficient (equal to 0.6 for bent-over plumes), then as P approaches zero the limit to AH is

$$AH = (1 + \beta)^{-1} z_i' = 0.62 z_i' . \tag{2-25}$$

As P approaches unity, the limit to AH is $z_i'$. Thus for $0 < P < 1$,

$$\Delta H_B = (0.62 + 0.38 P) z_i' . \tag{2-26}$$

The height of the plume above $z_i$ is given by

$$\Delta H_A = (1 + P) z_i' . \tag{2-27}$$

For plumes that only partially penetrate the inversion, initial dispersion due to buoyant plume rise (see Equation (2-34)) is weighted by the fraction of mass penetrating the inversion. The weighting factor P applies to the part of the plume above the mixed layer and the weighting factor 1-P applies to the part of the plume within the mixed layer. Subsequent dispersion is controlled by the stability and turbulence intensities of each layer. Note that plumes above the marine mixed layer are modeled as stability class E.

### 2.3.4 Gradual Plume Rise

Unless specified in the OCD model, gradual rise is not considered, and final rise is assumed to occur very close to the source. This assumption is usually valid for determining the impact of offshore sources on onshore receptors, since the sources are often located several kilometers offshore. However, if buoyancy rise dominates, gradual rise can be computed if the user selects this option. For unstable and neutral conditions, the distance to final rise, $x_f$, is given by

$$x_f = 0.049 F^{0.625} , F < 55 m^4/s^3 \tag{2-28}$$

$$x_f = 0.119\ F^{0.4}\ ,\ F > 55\ m^4/s^3 \tag{2-29}$$

where $x_f$ is in kilometers (Briggs, 1969).

In stable conditions, the distance to final rise is

$$x_f = 0.00207\ u\ s^{-0.5} \tag{2-30}$$

For all conditions, the gradual buoyancy rise formula is

$$AH = 160\ F^{1/3}\ x^{2/3}/u \tag{2-31}$$

where x is in kilometers and AH is in meters. Following the recommendations of the EPA, users are advised not to select the gradual plume rise option since it has been found to occasionally produce large overpredictions close to the stack.

## 2.4 Chemical Transformation

The OCD model can account for the removal of pollutant mass by chemical transformation or decay. In the calculation of pollutant concentrations, the chemical transformation term is assumed to be linear. . The concentration predicted by the Gaussian equation is multiplied by the following term:

$$\begin{matrix}\text{Chemical}\\ \text{Transformation}\\ \text{term}\end{matrix} = \exp\left(-\left(\frac{kx}{360{,}000\ u}\right)\right) \tag{2-32}$$

where x is the downwind distance from source to receptor (m), k is the transformation rate (%/hr), and u is the stack-top wind speed (m/s).

Examples of pollutants among the criteria pollutants commonly involved in offshore emissions include $SO_2$ and $NO_x$. Emissions of oxides of nitrogen ($NO_x$)

are commonly in the form of NO, which is gradually converted to NO2 (Cole and Summerhays, 1979). Subsequent photochemical reactions can lead to transformation of $NO_2$ to nitrate compounds. For applications of the OCD model, all $NO_x$ emitted is conservatively assumed to be $NO_2$.

Several investigators have analyzed data concerning chemical transformation rates of SO2 (Table 2-3) and $NO_x$ (Table 2-4). In general, it is found that the transformation rate is highly correlated with incoming solar radiation. At night, the decay rate is negligible compared to the daytime rate. Use of a uniform transformation rate for day and night or for all seasons can be significantly in error. Therefore, the OCD model uses monthly transformation rates of reactive pollutants, and assumes that the nighttime decay rate is zero. The period of daylight is computed from the latitude, longitude, and time zone of the source location. The references cited above can be consulted to estimate typical decay rates for $SO_2$ and $NO_2$. For example, typical $SO_2$ decay rates can range from 1% per hour in winter to 4% per hour in summer for a typical continental U.S. location. The effect of transformation is small for transport distances of the order of 10 km or less.

The OCD model does not consider dry deposition of suspended particulates. Model results using particulates may be conservative (overestimates) if long transport distances are involved.

## 2.5 Dispersion Parameters $\sigma_Y$ and $\sigma_z$ Over Water

Standard Pasquill-Gifford-Turner stability classification schemes, as used in EPA models are not valid over water because the surface boundary layer structure does not depend much on diurnal changes in solar intensity and cloudiness. In coastal areas where inhomogeneities in sea surface temperature exist, the boundary layer structure may be determined by advection (e.g., the Gulf of Mexico coast in winter). The sea surface temperature has a small diurnal range, and over homogeneous surfaces much of the buoyancy in the boundary layer is due to vertical moisture fluxes rather than sensible heat fluxes. Positive buoyancy fluxes can occur during light wind nighttime conditions. It is shown in Section 2.6 that the dominant stability parameter is the Monin-Obukhov length $L_v$ (including effects of moisture). Dispersion coefficients $\sigma_Y$ and $\sigma_z$ can be estimated from this stability parameter.

TABLE 2-3

TRANSFORMATION RATES* OF $SO_2$ FOUND IN RURAL POWERPLANT AND SMELTERPLUMES

| Source | SO2 Oxidation Rate ($\% \ h^{-1}$) | Comments |
|---|---|---|
| Forrest and Newman (1977) | <1.5 | - four coal-tired power plants (30° to 40° N)<br>- no correlation could be found between conversion and temperature (10 to 25°C), humidity or time of day |
| Husar et al. (1978) | 1 to 4 (noontime)<br><0.5 (night) | - St. Louis (38°N)<br>- power plant<br>- photochemistry may be the dominant mechanism |
| Lusis et al. (1978) | 1 to 3 (June, noon and p.m. )<br><0.5 (winter, or summer early a.m.1 | - Fort McMurray (57°N)<br>- power plant<br>- evidence of photochemical activity during relatively high conversion rates<br>- temperature varied from -13 to 23°C |
| Dittenhoefer and de Pena (1979) | 0 (<65% RH)<br>-1 (65 to 90% RH)<br>2 to 6 (90% RH) | - Pennsylvania (41°N)<br>- power plant<br>- evidence that both gas phase and aqueous phase oxidation are important |
| Forrest et al. (1979) | <2 | - Tarpon Springs, Florida (28°N)<br>- oil-fired power plant<br>- no correlation was found between individual meteorological parameters and extent of oxidation, although higher conversions were observed in August than in February |
| Forrest et al. (1981) | 0.1 to 0.8 (night, early a.m.1<br>1 to 4 (late a.m. and afternoon) | - Cumberland coal-fired power plant (35°N)<br>- reactions are correlated with solar radiation |

TABLE 2-3 (CONCLUDED)

TRANSFORMATION RATES* OF $SO_2$ FOUND IN RURAL POWER PLANT AND SMELTER PLUMES

| Source | $SO_2$ Oxidation Rate (% $h^{-1}$) | Comments |
| --- | --- | --- |
| Garber et al. (1980) | <1 | - Northport oil-fired power plant (41°N)<br>- a wide range of meteorological conditions were examined. The data suggest a weak positive correlation of conversion rate with temperature, water vapor partial pressure and insolation |
| Hegg and Hobbs (1980) | 0 to 5.7 | - five coal-fired power plants, West and Midwest U.S.A.<br>- various times of year<br>- evidence of photochemical reactions; conversion depended on u.v. light intensity |
| Gillani et al. (1981) | rate = 0.3 $R \cdot H \cdot O_3$<br>R = solar radiation<br>H = mixing height<br>$O_3$ = background ozone | - plumes from Labadie, Cumberland and Johnsonville power plants<br>- for dry conditions only |
| Chan et al. (1980) | <0.5 | - Sudbury smelter plume (47°N)<br>- no correlation of rate with temperature, relative humidity |
| Eatough et al. (1981) | <0.5 to 6 | - Western U.S. smelter and power plant plumes<br>- positive temperature dependence of oxidation rate; data are consistent with a homogeneous mechanism |

References and comments compiled by M.A. Lusis and L. Shenfeld, 1982.

TABLE 2-4

TRANSFORMATION RATES* OF $NO_x$ COMPOUNDS FOUND IN RURAL POWER PLANT PLUMES

| Compound | Parameter | Rate | Reference | Comments |
|---|---|---|---|---|
| $HNO_3$ | Conversion rate from $NO_x$ | 3 to 10 times $SO_2$ conversion rate | Richards et al. (1980) | Daytime measurements, Navajo generating station plume (Arizona); June-July and December |
| $HNO_3$ and particulates, nitrates | Conversion from $NO_x$ | 0.1 to 3% $h^{-1}$ (nighttime) 3 to 12% $h^{-1}$ (daytime) | Forrest et al. (1980) | Cumberland coal-fired generating station, August. $NO_x$ conversion rate was 2 to 4 times $SO_2$ rate. |

*Reference and comments compiled by M.A. Lusis and L. Shenfeld, 1982.

Total $\sigma_y$ -is made up of contributions from turbulence, $\sigma_{yt}$, buoyant plume enhancement, $\sigma_{yb}$, wind direction shear, $\sigma_{ys}$, and structure downwash, $\sigma_{yo}$:

$$\sigma_y^2 = \sigma_{yt}^2 + \sigma_{yb}^2 + \sigma_{ys}^2 + \sigma_{yo}^2 . \qquad (2\text{-}33a)$$

Similarly, total $\sigma_z$:

$$\sigma_z^2 = \sigma_{zt}^2 + \sigma_{zb}^2 + \sigma_{zo}^2 , \qquad (2\text{-}33b)$$

is made up of contributions from turbulence, $\sigma_{zt}$, buoyant plume enhancement, $\sigma_{zb}$, and downwash, $\sigma_{zo}$. The **downwash** values of $\sigma_{yo}$ and $\sigma_{zo}$ are given in Section 2.2.

The recommendations of Pasquill (1976) are used for the buoyant plume enhancements, $\sigma_{yb}$ and $\sigma_{zb}$:

$$\sigma_{yb} = \sigma_{zb} = \Delta H/3.5 \qquad (2\text{-}34)$$

where AH is local plume rise above stack top.

The shear contribution, $\sigma_{ys}$, is also based on a recommendation by Pasquill (1976):

$$\sigma_{ys} = 0.17\ (\Delta WD/\Delta z)\ x\ \sigma_z . \qquad (2\text{-}35)$$

where $\Delta WD/\Delta z$ is the wind direction shear (in radians per meter) over the depth of the plume, and x and $\sigma_z$ are in meters. The model requires $\Delta WD/\Delta z$ to be input in degrees/meter. Observations of wind direction shear are not usually available, but shear diffusion is an option in the OCD model because of its potential effect on $\sigma_y$ where plumes enter stable layers with strong wind shears (Pasquill, 19761. In some overwater research experiments, the wind shear can be estimated from the platform tower or radiosonde observations.

To estimate the turbulence contributions to $\sigma_Y$ and $\sigma_z$, the OCD model follows the recommendations of the AMS Workshop on Stability Classification Schemes and Sigma Curves (Hanna et al., 1977) and uses the approximations:

$$\sigma_{yt} = i_y \times f_y(x) \tag{2-36}$$

$$\sigma_{zt} = i_z \times f_z(x) \tag{2-37}$$

where $i_Y = \sigma_v/u$ and $i_z = \sigma_w/u$ are turbulence intensities and $f_Y$ and $f_z$ are dimensionless functions that equal unity at $x \simeq 0$, where x is the downwind distance in meters. The function $f_y$ decreases slowly to about $0.6 \pm 0.3$ at $x \simeq 10$ km, independent of stability. The standard averaging time for these parameters is one hour and input parameters also represent one-hour averages.

2.5.1 Lateral Dispersion Parameter $\sigma_Y$

As noted in Equation (2-36), lateral dispersion is parameterized by the downwind distance, the dimensionless function ($f_y$), and the horizontal turbulence intensity ($i_y$). Several studies of $f_y(x)$ have been published, including those by Irwin (19831, Briggs (19731, Cramer (19641 and Draxler (19761. Irwin (1983) of the U.S. EPA recommends the Draxler $f_y$ formulation of

$$f_y(x) = (1 + 0.9\ (x/1000\ u)^{1/2})^{-1} \tag{2-38}$$

where x is in meters and u is in m/s. In order to make the OCD model consistent with observations of $\sigma_y$ (Heffter, 19651 at mesoscale distances, $f_Y$ evaluated at 10 km is used in the model for x greater than 10 km. The original OCD model used the Briggs (1973) formulation for $f_Y$, but recent studies have shown that Equation (2-38) provides better agreement with overwater data (Hanna and DiCristofaro, 19881.

### 2.5.2 Vertical Dispersion Parameter $\sigma_z$

In the absence of vertical profiles of tracer concentration, formulas for $\sigma_z$ cannot be directly evaluated. Their evaluation is usually conducted implicitly through analysis of observed ground level concentration patterns. However, in this case, other parameters such as the plume rise and the mixing depth also strongly influence the ground level concentration but are not usually observed directly. The authors know of no offshore or coastal experiments in which all of these parameters have been observed.

For overland sources, the Briggs (1973) $f_z$ formulation as a function of overland stability has been adopted for the OCD model:

| Pasquill Stability Type | $f_z(x)$ |
|---|---|
| A and B | 1 |
| C | $(1 + 0.0002\ x)^{-1/2}$ |
| D | $(1 + 0.0015\ x)^{-1/2}$ |
| E and F | $(1 + 0.0003\ x)^{-1}$ |

For overwater sources, the Briggs (1973) $f_z$ formulation as a function of overwater stability class with the correction that Briggs' $f_z$ curve for class D is used for overwater classes A, B, C, and D are:

| Pasquill Stability Type | $f_z(x)$ |
|---|---|
| A, B, C, and D | $(1 + 0.0015\ x)^{-1/2}$ |
| E and F | $(1 + 0.0003\ x)^{-1}$ |

These formulas for $f_z$ are based upon observations from widely scattered data bases over land, and have not yet been thoroughly evaluated over water. These formulas will be retained in the OCD model until direct plume observations are available. The leading coefficient for $\sigma_z$ is $i_z$, as derived from site-specific measurements. Methods of estimating the stability category are discussed further in Section 2.6.

The OCD model uses a special formulation for $\sigma_{zt}$ for very stable conditions because of frequent observations of high concentrations near shorelines during periods when warm air is advected over cold water surfaces. The very stable formula is triggered in the OCD model when the observed $d\theta/dz$ in the lowest 100 m of the marine boundary layer is greater than or equal to $0.04°C/m$. This "trigger" for stability class G is changed from $0.05°C/m$ in OCD/3. This change provides better agreement with data from very stable conditions at the seven experiment sites analyzed by Hanna et al. (1984). It was found that several of the hourly observed $d\theta/dz$ values ranged from 0.04 to $0.05°C/m$, and if the trigger was shifted slightly, many more data would fall into class G. Vertical dispersion was observed to be very slight for those runs. This criterion is also used by the Nuclear Regulatory Commission to define their stability class G. The following formula is used for $f_z$ in these conditions (Strimaitis et al., 19831:

$$f_z = (1 + s^{1/2} x/0.32u)^{-1/2}. \tag{2-39}$$

where the constant, 0.32, has been shown to provide a best fit to a set of EPA observations during stable conditions at Cinder Cone Butte, Idaho. In addition, it is necessary to set the vertical turbulence intensity, $i_z$, equal to its theoretical value as computed within the model (Section 2.6.6), 0.02, during these extreme stabilities, since observations of $i_z$ are highly uncertain.

On the basis of analyses of ground level concentrations, the following OCD vertical dispersion procedures are used:

- The use of overland or overwater observed vertical turbulence intensity, $i_z$, is not recommended, since experience by a wide variety of users (e.g., Dugway Proving Ground and Electric Power Research Institute) has shown that these data are highly uncertain (especially for stable conditions). The option to use observed values of $i_z$ is still retained in the model, in case instruments become more reliable in the future.

- The default value of overwater $i_z$ for neutral and unstable conditions is assumed to equal (0.2 m/s)/u(m/s), which is the median value of $i_z$ observed at the Carpinteria field experiment for those stabilities.

- The stability class D $f_z$ formula is used for overwater dispersion if the overwater stability class equals A, B, C, or D. This assumption reflects the fact that vertical dispersion is less intense over water than land, and can be approximated by the vertical shape factor appropriate for neutral conditions (Hanna and DiCristofaro, 1988).

- The "trigger" for stability class G is $d\theta/dz \geq$ to $0.04^{\circ}C/m$.

These vertical dispersion procedures make sense based on an understanding of the meteorological data and of the basic scientific principles of vertical turbulence and dispersion. However, as pointed out earlier, the vertical term in the dispersion equation also involves the mixing depth, the plume elevation, and fumigation rate. If vertical data from field experiments become available, the algorithms can be tested and possibly further improved.

### 2.5.3 Dispersion Parameters at Land/Sea Interface

At the land/sea interface, where stabilities and turbulence intensities may change, the new dispersion rates are accounted for by means of a virtual source. This calculation is performed in the following steps:

1) The values of $\sigma_y$ and $\sigma_z$ due to overwater dispersion and calculated at the land/water or TIBL interface are denoted as $\sigma_{yB}$ and $\sigma_{zB}$. If a source is not located in the marine environment, these values are set to zero.

2) The overland formulations for $\sigma_y$ and $\sigma_z$ are determined on the basis of the stability class and the availability of turbulence intensity data. The formulations can be based upon turbulence intensity data (Equations (2-36) and (2-37)) or upon the Pasquill-Gifford curves These formulations all yield $\sigma_y$ and $\sigma_z$ as a function of x. To find

-the virtual distances for $\sigma_{yB}$ and $\sigma_{zB}$, the equations are inverted to solve for x. The solutions for virtual distances are computed separately for $\sigma_{yB}$ and $\sigma_{zB}$.

3) The OCD model simulates a source located at a virtual distance, $x_v$, upwind from the land/sea interface. A different value of $x_v$ is used for calculation of overland $\sigma_y$ than is used for calculation of $\sigma_z$. Plume dispersion from the virtual source locations is then simulated with overland $\sigma_y$ and $\sigma_z$ equations, which yield results consistent with $\sigma_{yB}$ and $\sigma_{zB}$ at the land/sea interface.

## 2.6 Calculation of the Boundary Layer Over Water

Turbulence intensities and stability stratification are estimated from observations and from theoretical results for the overwater surface boundary layer. If available, observed turbulence intensities can be substituted directly into Equations (2-36) and (2-37). As stated earlier, only observed values of $i_y$ are recommended for use when running the OCD model. Otherwise turbulence intensities can be estimated within the model from bulk aerodynamic principles and boundary layer formulas using observations of u, T, RH, and Ts. Boundary layer formulas are also used to estimate stability classes in order to define $f_z(x)$ and to define inputs for the coastal fumigation module. The following sections describe the details of the OCD boundary layer parameterizations.

### 2.6.1 Humidity

The humidity is expressed in terms of the mass ratio of water vapor to dry air, referred to as the mixing ratio, w. The relative humidity at the water surface is assumed to be 100%. The mixing ratio, w, is usually not observed directly but can be computed from the following formulas:

$$w = 0.622\ e/(p-e) \quad , \tag{2-40}$$

$$e = RH \cdot e_s \quad ,$$

where e is the water vapor partial pressure (mb),
p is the total atmospheric pressure (assumed to be 1000 mb),

w is the mixing ratio, and
es is the saturation water vapor pressure.

An empirical equation for $e_s$ was developed by Lowe (19771 for the specific purpose of computer applications:

$$e_s = a_0 + T(a_1 + T(a_2 + T(a_3 + T(a_4 + T(a_5 + a_6T))))) \qquad (2\text{-}41)$$

where
$a_0$ = 6.107799961 mb
$a_1$ = 4.436518521 x $10^{-1}$ mb/°K
$a_2$ = 1.428945805 x $10^{-2}$ mb/°$K^2$
$a_3$ = 2.650648471 x $10^{-4}$ mb/°$K^3$
$a_4$ = 3.031240396 x $10^{-6}$ mb/°$K^4$
$a_5$ = 2.034080948 x $10^{-8}$ mb/°$K^5$
$a_6$ = 6.136820929 x $10^{-11}$ mb/°$K^6$

°C
It is assumed that T is in °K and $e_s$ is in mb.

If the wet bulb temperature $T_w$ is reported rather than relative humidity, the following equation suggested by Hess (19591 is used to estimate the mixing ratio:

$$w(T) = \frac{w_s(T_w) - \frac{C_p}{L_h}(T-T_w)}{1 + \frac{C_{pv}}{L_h}(T-T_w)} \qquad (2\text{-}42)$$

where the latent heat $L_h$ (cal/g) equals 593 - 0.566T for T in degrees C in the range from 0°C to 100°C, the specific heat $C_p$ equals 0.240 cal/g°C, and $C_{pv}$ equals 0.441 cal/g°C. The parameter $w_s(T_w)$ is the value of the saturation mixing ratio at temperature $T_w$.

### 2.6.2 Virtual Temperature

The equation of state for moist air, an ideal gas, can be expressed in terms of the dry air gas constant by defining a new temperature denoted as the "virtual". temperature:

$$T_v = (1 + 0.61\ w)T\ , \tag{2-43}$$

$$T_{vs} = (1 + 0.61\ w_s)T\ . \tag{2-44}$$

In these equations, the mixing ratio is used to approximate specific humidity. The virtual temperature is the temperature that dry air would have if its pressure and volume were equal to those of a given sample of moist air. The use of the virtual temperature in the OCD formulation accounts for the effects of moisture while retaining the common application of the equation of state for dry air and its associated constants. In many of our equations the virtual potential temperature, $\theta_v$, is used, approximated by $\theta_v = T_v + 0.01z$ where temperature is in °K and height in meters.

### 2.6.3 Drag Coefficient and Bulk Transfer Coefficient for Heat

The concept of the "drag coefficient" becomes important in quantifying the transfer (flux) of heat and momentum within the surface layer of the atmosphere. These fluxes are then used to determine profiles of wind speed and temperature in the surface layer. The drag coefficient, $C_u$, is defined as the ratio of the momentum flux to the kinetic energy of the atmosphere:

$$C_u \equiv u_*^2/u^2 \tag{2-45}$$

where u is normally measured at a height of 10 m. The neutral momentum drag coefficient, $C_{uN}$, over water is observed to depend upon the 10 m wind speed as follows (Garratt, 1977),

$$C_{uN} = (0.75 + 0.067\ u) * 10^{-3} \tag{2-46}$$

where u is in m/s.

The bulk-transfer coefficient for heat, $C_T$, is defined by using the ratio of the heat flux to the product of u and $(T_s-T)$,

$$C_T = w'T'/[u(\theta_s - \theta)] , \tag{2-47}$$

where u and $\theta$ are observed at a height of 10 m. The empirical relation used for $C_T$ for nearly-neutral conditions is $C_{TN} = 1.3 \times 10^{-3}$, where the subscript N refers to neutral conditions. Observations show that $C_{TN}$ is not a function of wind speed.

2.6.4 Calculation of the Monin-Obukhov Length

Determination of the Monin-Obukhov length L requires wind, temperature, and humidity observations. The Monin-Obukhov length, defined as

$$L = (u_*^3/0.4)/(-g\overline{w'T'}/T), \tag{2-48}$$

may be written in drag coefficient form, by combining Equation (2-48) with Equations (2-46) and (2-47) such that,

$$L = (C_{uN}^{3/2}\, u^2/0.4)/(gC_{TN}\,(\theta_v - \theta_{vs})/\theta_v) . \tag{2-49}$$

With substitution of constants for g and $C_{TN}$, this equation can be approximated as:

$$L = \frac{\theta_v \quad C_{uN}^{3/} \qquad u^2}{5.096 \times 10^{-3}\ \theta_v - \theta_{vs}} \tag{2-50}$$

where L is in meters, u is in m/s, and $\theta$ is in °K. This relation is valid only if wind and temperature observations are taken at the 10-m height. A general procedure used to estimate L given observations at an arbitrary height $z_1$ involves several steps including an iteration:

1) Estimate the 10-m wind speed using a scaling factor representative of neutral conditions and a typical $z_o$ value of $10^{-4}$ m by means of Equation (2-53) in the next subsection:

$$u(10\ \text{m}) = u(z_1)\ \frac{11.51}{(\ln z_1 + 9.21)}. \qquad (2\text{-}51)$$

2) Similarly, the temperature profile is obtained from Equation (2-54):

$$\theta_v(10\ \text{m}) - \theta_{vs} = (\theta_v(z_1) - \theta_{vs})\ \frac{11.51}{(\ln z_1 + 9.21)}. \qquad (2\text{-}52)$$

3) Use Equation (2-49) to calculate L.

41 Use Equation (2-66) to calculate $z_o$.

5) Recompute $u_*$ and $\theta_*$ using L computed in step 3 and $z_o$ computed in step 4.

6) Recompute u (10 m) and $\theta_v$ (10 m) using the new $u_*$ and $\theta_*$.

71 Iterate through entire procedure again resulting in new more accurate values for L, $u_*$ and $\theta_*$ until the desired precision is obtained.

For low values of $|L|$, the above procedures lead to exceptionally strong vertical potential temperature gradient values. Such values are confined by theory to a very shallow layer roughly equal to L. Conditions in such a shallow layer, often less than 10 m in depth, are not representative of heights for which typical offshore pollutant releases will occur. Consequently the formulas should not be extrapolated to stack height during hours when $|L|$ is less than about 5 m. In the OCD model arbitrary limitations are imposed on the possible values of L: positive values below 5 meters are set to 5 meters, and negative values between -5 meters and zero are set to -5 meters. Otherwise, the boundary layer formulas would lead to unrealistic predictions at. stack height. L is small and negative (about -10 m) on strongly convective days, about -100 m on windy days with some solar heating, and approaches infinity in purely mechanical turbulence. At night, with downward heat flux, L is positive and small in light-wind stable conditions (Panofsky and Dutton, 1984).

### 2.6.5 Wind and Temperature Profiles

Wind and temperature profiles in the overwater boundary layer are modeled using the surface fluxes $u_*^2$ and $u_*\theta_*$ calculated from the bulk aerodynamic methods discussed above. Schacher et al. (1982) report that, on the basis of several years of verification, this method appears valid for determining surface layer fluxes over water. These formulas replace the assumptions concerning wind speed profile power laws and vertical potential temperature gradients found in MPTER. The discrete, six-class stability system is replaced in the OCD model by the continuous variable L.

Relationships for wind speed and the air-sea temperature difference as a function of height are given by:

$$u = \frac{u_*}{.4}\left[\ln\frac{z}{z_0} - \Psi_u\left(\frac{z}{L}\right)\right] , \tag{2-53}$$

$$\theta_v - \theta_{vs} = 0.74\,\frac{\theta_{v*}}{.4}\left[\ln\frac{z}{z_0} - \Psi_\theta\left(\frac{z}{L}\right)\right] , \tag{2-54}$$

where 0.4 is the von Karman constant and $z_o$ is the roughness length (Lo and McBean, 19781. These expressions are obtained by integration of the following differential equations:

$$\frac{du}{dz} = \frac{u_*}{.4z}\,\phi_u\left(\frac{z}{L}\right) , \tag{2-55}$$

$$\frac{d\theta_v}{dz} = \frac{\theta_{v*}}{.4z}\,\phi_\theta\left(\frac{z}{L}\right) . \tag{2-56}$$

The parameter=@,, is the virtual potential temperature at height $z$. The dimensionless functions $\Psi_u$, $\Psi_\theta$, $\phi_u$, and $\phi_\theta$ are defined below. The scaling temperature $\theta_{v*}$ is equal to the heat and moisture flux $(\theta_v'w')$ divided by $-u_*$.

The stability of the atmospheric marine boundary layer is primarily determined by the amount of sensible and latent heat released to the atmosphere from the water surface. The scaling virtual temperature, $\theta_{v*}$, and the friction velocity, $u_*$, are the two most important parameters for quantification of the atmospheric turbulence in the boundary layer. These two parameters can be combined to calculate the Monin-Obukhov length, L, in terms of $u_*$ and $\theta_{v*}$:

$$L = \theta_v u_*^2 / 0.4 g \theta_{v*} \ . \qquad (2\text{-}57)$$

The dimensionless functions $\Psi_u$, $\Psi_\theta$, $\phi_u$, and $\phi_\theta$ are defined as follows (Businger, 1973):

$$\phi_u\left(\frac{z}{L}\right) = (1-15\ z/L)^{-1/4} \qquad \frac{z}{L} < 0 \qquad (2\text{-}58)$$

$$= 1 + 4.7\ z/L \qquad \frac{z}{L} \geq 0 \qquad (2\text{-}59)$$

$$\phi_\theta\left(\frac{z}{L}\right) = 0.74\left(1-9\ z/L\right)^{-1/2} \qquad \frac{z}{L} < 0 \qquad (2\text{-}60)$$

$$= 0.74\left(1 + 6.5\ z/L\right) \qquad \frac{z}{L} \geq 0 \qquad (2\text{-}61)$$

$$\Psi_u\left(\frac{z}{L}\right) < 0 = 2\ \ln\left(\frac{1+\phi_u^{-1}}{2}\right) + \ln\left(\frac{1+\phi_u^{-2}}{2}\right) - 2\tan^{-1}\phi_u^{-1} + \frac{\pi}{2} \qquad (2\text{-}62)$$

$$\Psi_u\left(\frac{z}{L}\right) \geq 0 = -4.7\ z/L \qquad (2\text{-}63)$$

$$\Psi_\theta\left(\frac{z}{L} < 0\right) = 2 \ln\left(\frac{1 + \phi_\theta^{-1}}{2}\right) \tag{2-64}$$

$$\Psi_\theta\left(\frac{z}{L}\right) \geq 0 = -6.5\ z/L \tag{2-65}$$

The "roughness length" $z_o$ is defined at the height at which the wind speed goes to zero when it is linearly extrapolated in a graph in which observed u is plotted versus $\ln z$. In OCD it is calculated from

$$z_o(m) = 2.0 \times 10^{-6}\ u_{10}^{2.5}\ (m/s), \tag{2-66}$$

a formula derived by Hosker (1974) to represent the effective roughness length of a deep-water surface as a function of a 10-m wind speed.

### 2.6.6 Calculation of Turbulence Intensities and Wind Speed at Stack Top

If it is not measured directly, the wind speed at stack-top height is calculated from the boundary layer profile equations listed above. Suppose the wind speed is observed at height $z_1$. The value of $u_*$, the friction velocity, is calculated from Equation (2-53) after L has been determined. Equation (2-53) is then used to compute the wind speed at the release height $z_2$, recognizing that this procedure is valid only if $z_2$ is not much greater than $|L|$. If $z_2$ is greater than L, then the wind speed at $z_2$ is assumed to equal the wind speed at L.

If turbulence intensity observations are not available, then $i_y$ and $i_z$ are calculated for the release height from formulas suggested by Hanna (1981):

$$i_y = \frac{\sigma_v}{u} = \frac{u_* F_y(z_i/L)}{u} \tag{2-67}$$

$$i_z = \frac{\sigma_w}{u} = \frac{u_* F_z(z/L)}{u} \tag{2-68}$$

where

$$F_Y = 1.7 \qquad L > 0,\ u > 10 \text{ m/s (Neutral)} \qquad (2\text{-}69)$$

$$F_Y = (4.9-0.5\ z_i/L)^{1/3} \qquad L < 0 \text{ (Unstable1} \qquad (2\text{-}70)$$

$$F_z = 1.3 \qquad L \geq 0 \text{ (Stable/Neutral)} \qquad (2\text{-}71)$$

$$F_z = 1.3\ (1-3\ z/L)^{1/3} \qquad L < 0 \text{ (Unstable)} \qquad (2\text{-}72)$$

The parameter $z_i$ is the mixing depth, which is observed to average about 500 m over water (see Appendix C). The leading constant, 4.9, in Equation (2-70) is different from that recommended by Panofsky et al. (1977), but is used so that $F_y$ given by Equation (2-70) approaches 1.7 as L approaches zero. The variation of $F_y$ and $F_z$ with L during unstable conditions in Equations (2-70) and (2-72) follows recommendations of Panofsky et al. (1977) directly.

The special case of stable light-wind conditions is not included in Equations (2-69) through (2-72) because experience has shown (Hanna, 19831 that $i_Y$ is observed to be much larger than predicted by boundary layer theory under these conditions. This increase in $i_y$ is caused by meandering mesoscale eddies.

Based on an analysis of wind speed and lateral turbulence data from R/V **Acania** (see Figure 2-2), Hanna et al. (1985) found that $\sigma_v \simeq 0.5$ m/s provided a best fit to the data (with much scatter). They also found that $\sigma_v \simeq 0.18$ m/s provided a lower bound to the data points. The $\sigma_v \simeq 0.5$ m/s relation has been verified at a number of other sites (e.g., Hanna (1983) demonstrated its validity at Cinder Cone Butte, Idaho). Consequently, this relation was built into the default formula for $i_Y$ in the OCD/3 model.

Recent analyses of the field data from several coastal tracer experiments (Ventura Fall and Winter, Pismo Beach Summer and Winter, Cameron Summer and Winter, and Carpinteria $SF_6$, $CF_3Br$ and Fumigation) suggest that the $\sigma_v \simeq 0.5$ m/s relation may be valid, on the average, but is not

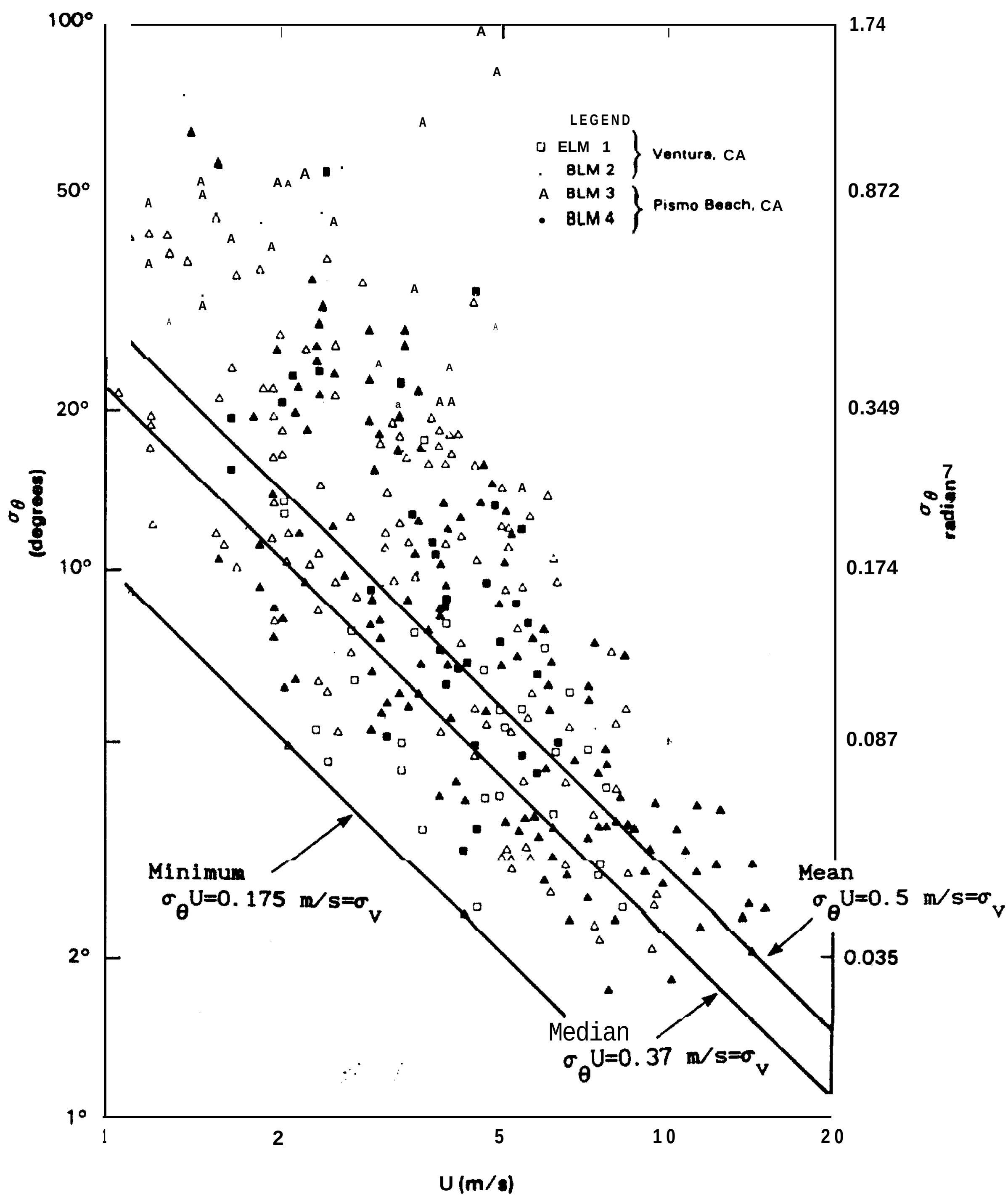



Figure 2-2. Observation of $\sigma_\theta$ plotted versus wind speed. Instruments were at a height of 20.5 m on a research vessel (Schacher et al., 1982) operated off the California coast.

sufficiently conservative to capture the set of worst case conditions for air quality. In order to provide a better-estimate of the default $\sigma_v$ for worst-case air quality conditions, the meteorological data from the highest four observed concentration hours at each of the above field experiments were analyzed. The median $\sigma_v$ was found to be 0.37 m/s for these hours. The lowest concentrations observed during these experiments were also examined, for which the median $\sigma_v$ was found to be 0.77 m/s. It can be concluded that the observed concentrations are correlated with the observed $\sigma_v$, and that if an air quality model is required to more accurately simulate the highest concentrations, then a default $\sigma_v$ = 0.37 m/s or $i_y$ = .37/u where u is in m/s should be used in the model. The formula is limited to conditions with wind speed less than 8 m/s, since the data for u > 8 m/s in the figure suggest that $i_y$ or $\sigma_\theta$ is constant with a value of about 0.05 at high wind speeds. In the model, the maximum $i_y$ predicted by the two equations (.37/u or $(u_*/u)\ F_y$) is used, in order to assure that there are no discontinuities in $i_y$.

If turbulence intensity measurements are taken at a height of $z_1$ which is not equal to the release height $z_2$, then the observations are scaled to $z_2$ using the theoretical ratio of the wind speeds at the two heights:

$$i_y(z_2) = i_y(z_1)\ u(z_1)/u(z_2) \tag{2-73}$$

$$\frac{u(z_1)}{u(z_2)} = \frac{\ln(z_1/z_o) - \Psi_u(z_1/L)}{\ln(z_2/z_o) - \Psi_u(z_2/L)} \tag{2-74}$$

and it is assumed that $\sigma_v$ is constant. From Equation (2-74), with $u_*$ constant, it can be shown that the following formula can be used to extrapolate $i_z$:

$$i_z(z_2) = i_z(z_1)(u(z_1)/u(z_2))(F_z(z_2/L)/F_z(z_1/L)), \tag{2-75}$$

where $F_z$ relationships are obtained from Equations (2-69) to (2-72). These formulas are all built into the OCD model.

### 2.6.7 Determination of Stability Class

In order to specify overwater $f_z(x)$ in Equation (2-39) and to trigger stable plume rise formulas and coastline fumigation, it is necessary to estimate the overwater stability class following a classification scheme similar to the Pasquill-Gifford-Turner scheme in EPA models. Golder's (1972) methods are used, in which roughness length $z_o$ and Monin-Obukhov length L are used to estimate stability class following the boundary layer formulas given above. For $z_o$ in the range from $10^{-4}$ to $10^{-3}$m (corresponding to the typical overwater 5 m/s to 10 m/s wind speeds), the following relations are valid:

| | Stability Class |
|---|---|
| $-10\ m \leq L < 0m$ | B |
| $-25\ m \leq L < -10\ m$ | C |
| $\lvert L \rvert > 25\ m$ | D |
| $10 < L \leq 25\ m$ | E |
| $0 < L \leq 10\ m$ | F |

Note that L must include virtual temperature in this procedure. In practice, the OCD model will replace any calculated $|L|$ whose magnitude is less than 5 m with a value of -5 m or 5 m depending upon the sign of L, since the profile Equations (2-53) and (2-54) will produce unreasonable wind and temperature profiles as L approaches zero. This procedure is followed in order to avoid erroneous wind and temperature profiles during extreme stabilities. L is also used to calculate the overwater vertical potential temperature gradient $(d\theta/dz)$ if the input value of $d\theta/dz$ is unstable or if there are no observed values, using the following formulation:

$$d\theta/dz = 0 \qquad \text{for } L \leq 0$$

$$d\theta/dz = 12.037\ \theta_*/L \qquad \text{for } L > 5$$

$$d\theta/dz = 0.05 \qquad \text{for } L = 5$$

A very stable condition is also defined which is triggered by $d\theta/dz$ greater than or equal to $4^\circ C/100$ m, a value which occurs only with advection of warm air over a cold water surface. These extreme stabilities cause $\sigma_z$ to be very small, as described in Section 2.5.

## 2.7 Changes in Plume Dispersion Over Land

Turbulence intensities over water and land are probably different at any given time, due to differences in underlying surface roughnessand surface heating. For example, Sethuraman et al. (1982) found that turbulence intensities increased from 0.05 to 0.30 as the air passed from the ocean over Long Island on a summer afternoon. Therefore, the OCD model permits the rate of plume dispersion to change as the plume crosses the internal boundary layer generated at the shoreline.

For non-fumigation conditions, the overland $\sigma_y$ and $\sigma_z$ values are determined using either

a) Draxler (for $\sigma_y$) and Pasquill-Gifford (for $\sigma_z$) curves, based upon the overland stability class, or

b) on-site $i_y$ and iz values, from which $\sigma_y$ and $\sigma_z$ are derived. The values of $i_Y$ and iz at stack-top height ($z_2$) are derived from observations at height $z_1$ by multiplying by a scaling factor assuming near-neutral conditions:
$\ln(z_1/z_o)/\ln(z_2/z_o)$.

If missing, overland values of $i_z$ are defaulted to Briggs' (19731 rural $i_z$ as function of stability. The transition between overwater and overland dispersion is handled by a virtual source technique, described in Section 2.5. The exact location of the land/water transition depends upon the shape of a sloping internal boundary layer, as pictured schematically in Figure 2-3 for a fumigation example. **Fumigation will** occur if the following conditions are met (assuming that flow is onshore):

- overwater stability class is E or greater;
- overland stability class is A, B, or C;

The overland friction velocity can be calculated from Equation (2-53), given a user-specified value of $z_o$ and an estimated value of the overland Monin-Obukhov length L. The overland value of L is obtained from Golder's (1972) graph, which has been simplified for the OCD model as shown in Table 2-5.

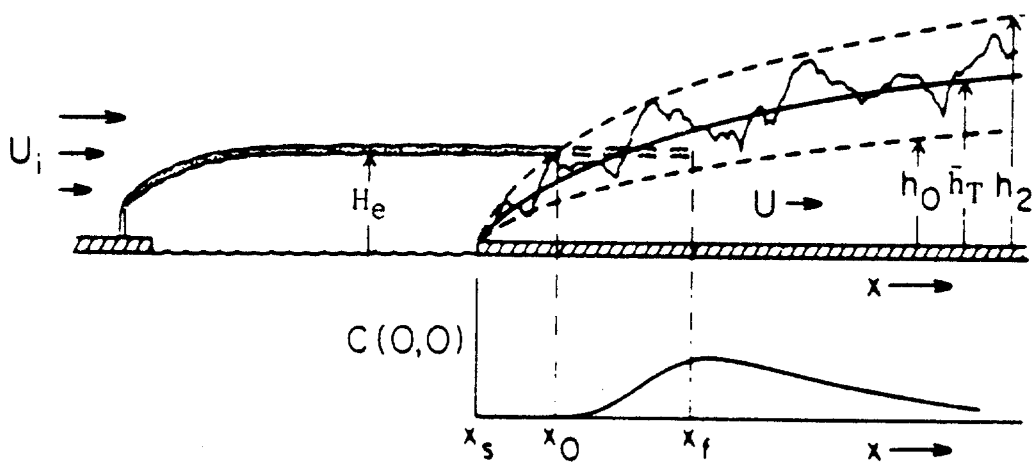



Figure 2-3. Illustration of the shoreline fumigation situation: a compact smoke plume **from a** stack at effective height $H_e$ drifts above a shallow boundary layer over water. Its interception by the mixed layer over heated ground does not commence until $h_2(x_o) = H_e$, and is not completed aloft until a distance $x_f - x_o$ **further. A** sketch of the dimensionless surface concentra**tion** along the fumigant axis, **C(0,0)** as a function of x is shown below the internal boundary layer **(Deardorff** and Willis, 19821.

TABLE '2-5

REPRESENTATIVE VALUES OF THE OVERLAND
MONIN-OBUKHOV LENGTH, L **(m)** (FROM GOLDER, 19721

| Stability Class | Surface Roughness Length, m co.003 | 0.003-0.03 | 0.03-0.3 | >0.3 |
|---|---|---|---|---|
| A | -4. | -6. | -8. | -10. |
| B | -8. | -10. | -16. | -20. |
| C | -15. | -25. | -50. | -100. |
| D | 9999. | 9999. | 9999. | 9999. |
| E | 15. | 25. | 50. | 100. |
| F | 5. | 10. | 15. | 20. |

2.7.1 Thermal Internal Boundary Layer (TIBL)

Stunder and Sethuraman (1985) have tested several theoretical and empirical formulas for the TIBL height, and Venkatram (1986) has presented a physical framework for the description of the TIBL height, $h_T$. He suggested a generalized theoretical equation for $h_T$, but pointed out that more work is needed to better define the parameters in the equation. The underlying physical principle is that the heat added to the boundary layer as it flows over the land is used to warm the air and form an adiabatic layer at the base of the initial stable overwater temperature profile. However, it is difficult to estimate the magnitude of the surface heat flux. Data on the overwater temperature profile are hardly ever available.

In the original development of the OCD/3 model in 1983, a search was conducted for an equation for $h_T$ that would be theoretically correct, would agree with available data, and would be capable of producing reasonable predictions for all hours of the year. Like the EPA regulatory models, the OCD model was intended to be applied to a year or more of hourly data. Several of the formulas mentioned by Stunder and Sethuraman (1985) tended to produce reasonable results for a limited range of conditions, but tended to "blow up" (i.e., produce very small or very large values of $h_T$) during some hours. For example, if the overwater potential temperature gradient approaches zero, the TIBL height prediction becomes very large. Similarly, if the overland sensible heat flux is small, the TIBL height prediction is very small. It was concluded that these models were not robust, since they permitted large variations in the value of $h_T$ and were quite sensitive to uncertainties in input parameters such as the overwater potential temperature gradient.

It was discovered during the course of that investigation that many of the available data could be fit by a model that permits no variation in $h_T$ with meteorological conditions at a given downwind distance. The OCD model uses the following empirical formulas for the TIBL height:

$$h_T = 0.1x \qquad (x \leq 2000 \text{ m}) \qquad (2\text{-}76)$$

$$h_T = 200 + 0.03\ (x-2000) \qquad (x > 2000 \text{ m}) \qquad (2\text{-}77)$$

where x is the distance inland from the shoreline.

More recent data from Australia (Rayner, 1987) further justify this TIBL height assumption, as shown in Figure 2-4, which summarizes data from three coastal experiments at widely scattered locations:

| | |
|---|---|
| Long Island, NY (BNL) | Raynor et al. (1979) |
| Lake Erie, Ontario (Nanticoke) | Kerman et al. (1982) |
| Bunbury, Australia | Rayner (19871 |

Further discussions of these results are given in Hanna (19881. It is seen that the robust model given by Equations (2-76) and (2-77) passes through the middle of the data, and that most of the data are within a factor of two of the prediction. The new Australian data are in very good agreement ($\pm$ 20%) with the curve at distances ranging from 1 to 14 km. The data from the BNL BL6 experiment are consistently a factor of two above the predicted curve, but are said to be associated with vigorous convection over Long Island (Raynor et al., 1979). Perhaps a future modification to this curve could account for the slight variability of $h_T$ with intensity of overland convection or with wind speed.

There are no observations of TIBL height over coastal areas with complex terrain. Consequently, there are no observational or theoretical justifications for any complex assumptions concerning the TIBL height. In the OCD/4 model, the simplest assumption is made that the TIBL is terrain following, i.e., the TIBL height above the local terrain at a given distance inland equals that over flat terrain at the same distance inland.

It is also possible that marine air with a neutral or unstable stratification can flow onto the land on a clear night, resulting in a stable layer that develops at the surface. At the base of this stable layer is a mixed layer that begins at the shoreline and deepens with increasing distance inland. The depth h of this mixed layer will approach a constant value derived by Zilitinkevich (19751,

$$h = 0.4\ (u_* L/f)^{1/2} \tag{2-78}$$

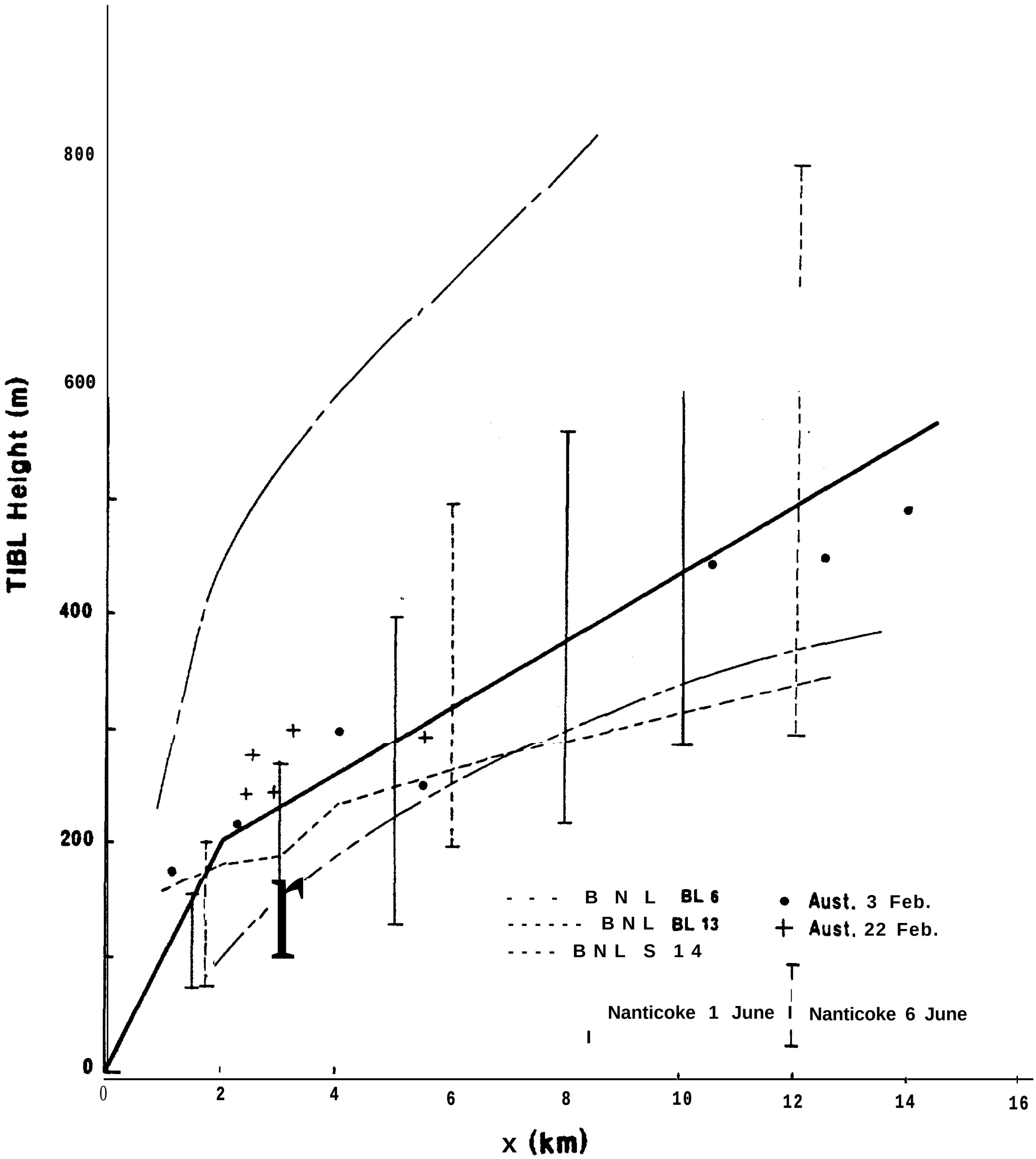



Figure 2-4. Empirical formula for TIBL height (thick solid line) plotted along with observations from a number of field studies. BNL data are from Raynor et al. (1979), Nanticoke data are from Kerman et al. (1982), and Australian data are from Rayner (19871.

where f is the Coriolis parameter ($f = 2\Omega$ sin (latitude1 and $\Omega$ is the angular velocity of the earth's rotation). The parameters $u_*$ and L refer to the overland boundary layer. Therefore, for stable conditions over land the stable internal boundary layer (SIBL) is capped at the height defined by Equation (2-78), such that $h_T = \min(h_T, h)$. As the plume travels into the stable layer above the land surface, the overland dispersion will decrease.

### 2.7.2 Fumigation

The OCD/3 model contains two alternative methods for calculating fumigation (i.e., vertical dispersion after the plume passes through the TIBL); one method involves the Deardorff and Willis (19821 fumigation algorithm, which is based on observations of mixed layer growth in a laboratory convection tank. After testing this empirical algorithm in several specific real-world applications, it was discovered that the TIBL slopes for which the model was derived were usually less than those that would occur in most coastal areas. Consequently the OCD (Version 4) model eliminates this option.

The other alternative method for calculating fumigation in the OCD model is a virtual source method, where the vertical dispersion over land proceeds as if the atmosphere is unstable. But a virtual source distance is calculated as the distance upwind from the point of TIBL intersection where the source would be if an unstable dispersion rate were present in the overwater atmosphere, and $\sigma_z$ had its given value at the point of TIBL intersection.

The model currently uses the maximum of concentrations predicted by (1) the Turner (1969) complete vertical mixing assumption and (2) the OCD virtual source assumption. This procedure involving the maxima is necessary for plume sources near the ground, where vertical plume growth in the overland boundary layer is governed by ambient turbulence rather than TIBL growth (see Figure 2-5). The point at which a plume enters the TIBL, which is important for defining the transition from overwater dispersion to overland dispersion, follows a straight-line path from source to receptor (see Figure 2-6). The Turner formula assumes that after the plume centerline intersects the TIBL it is uniformly mixed vertically between the surface and the mixing depth $h_T$.

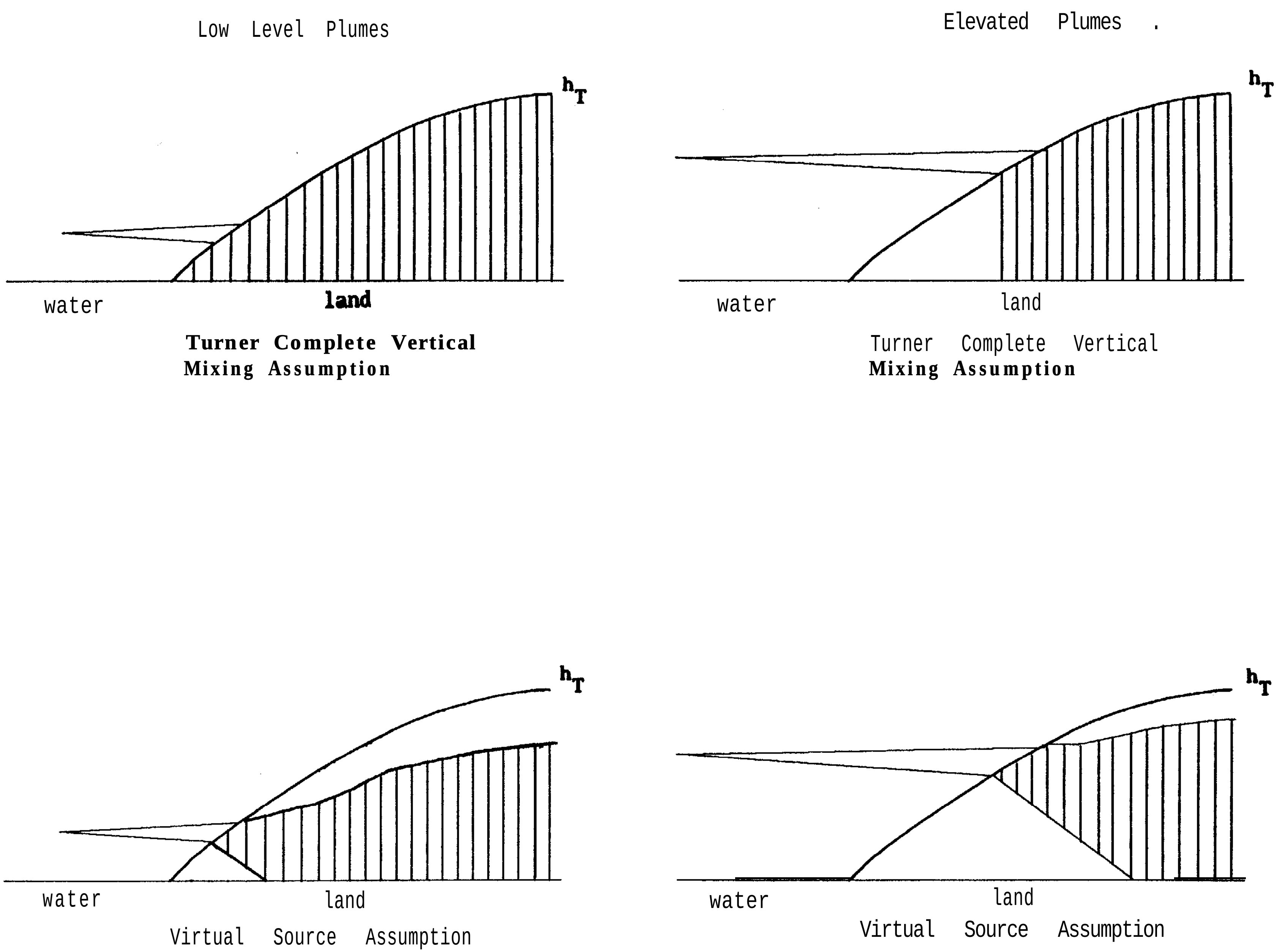



Figure 2-5. Schematic diagrams of alternate scenarios used to calculate fumigation.

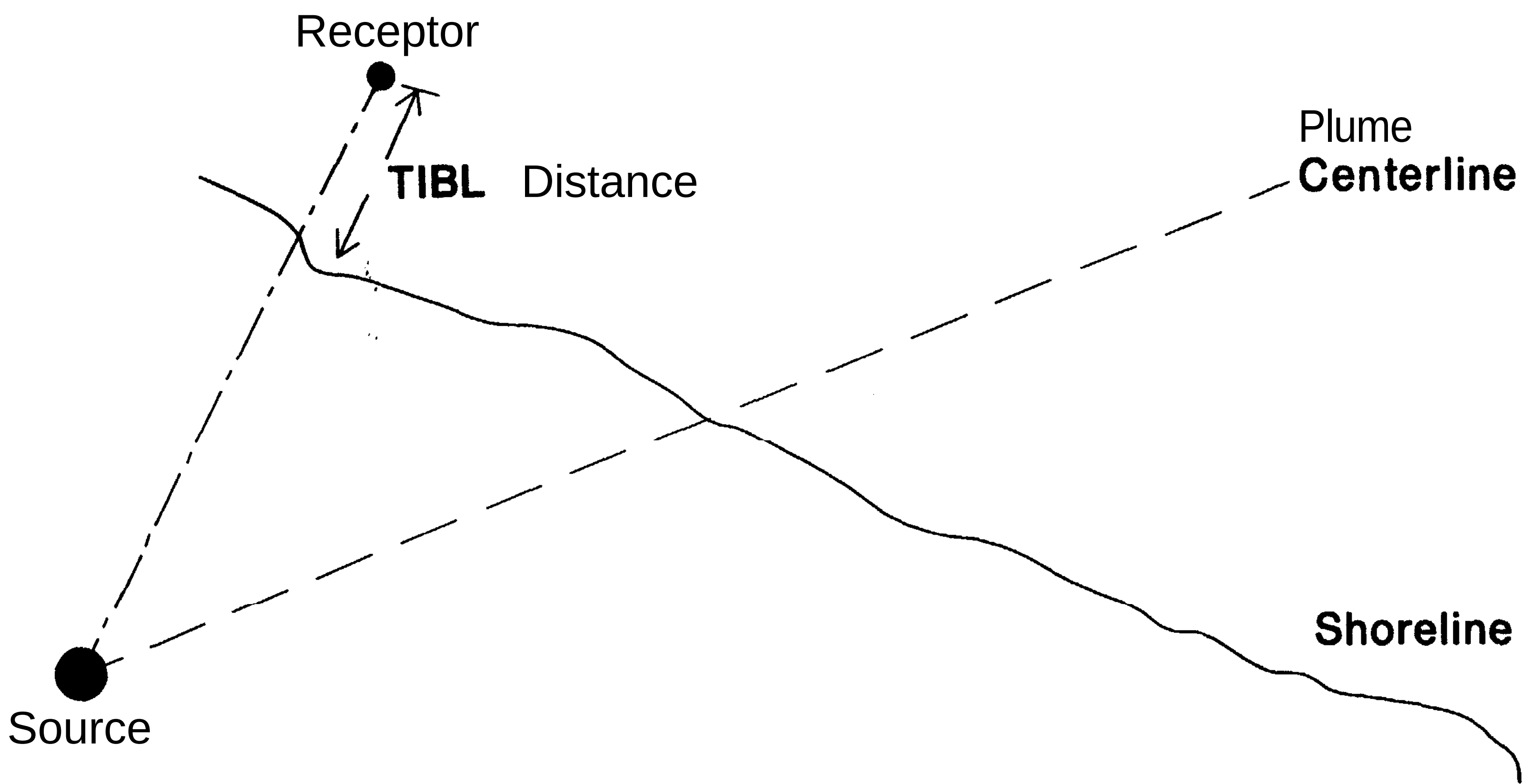



Figure 2-6. The distance used by OCD to estimate the TIBL height.

The EPA's Shoreline Dispersion Model (PEI, 19881 was tested as a candidate for use as an OCD fumigation algorithm, but it was discovered that it was not applicable to sources with small buoyancy fluxes.

## 2.8 Overland Mixing Height

Most coastal regions will show a complex variation of mixing depth, with different values well out to sea and well inland, and a sloping interface layer (TIBL) near the coastline. There are several assumptions that must be made in the model regarding the effective mixing depth for the plume as it passes through this complex region. Since the OCD/3 model contained a complex and scientifically unproven method to account for the variation of mixing depth in complex terrain, some changes to the code were made. These changes are made to correct logical errors and are not justified by any observations. It is noted that the mixing depth, $h_m$, is a very important factor in determining the ground level concentration, since the concentration approaches an inverse proportionality to $h_m$ as mixing proceeds.

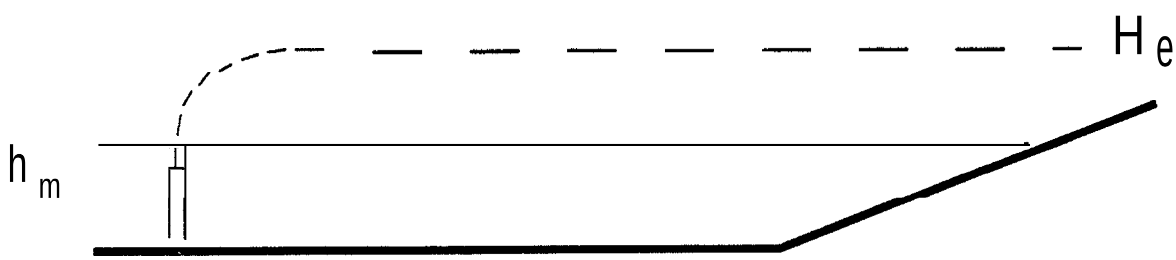
Some of the factors important to this problem are shown schematically in Figure 2-7. First consider the plume while it is still overwater:

(a) If $H_e > h_m$, then vertical mixing is assumed to be unlimited

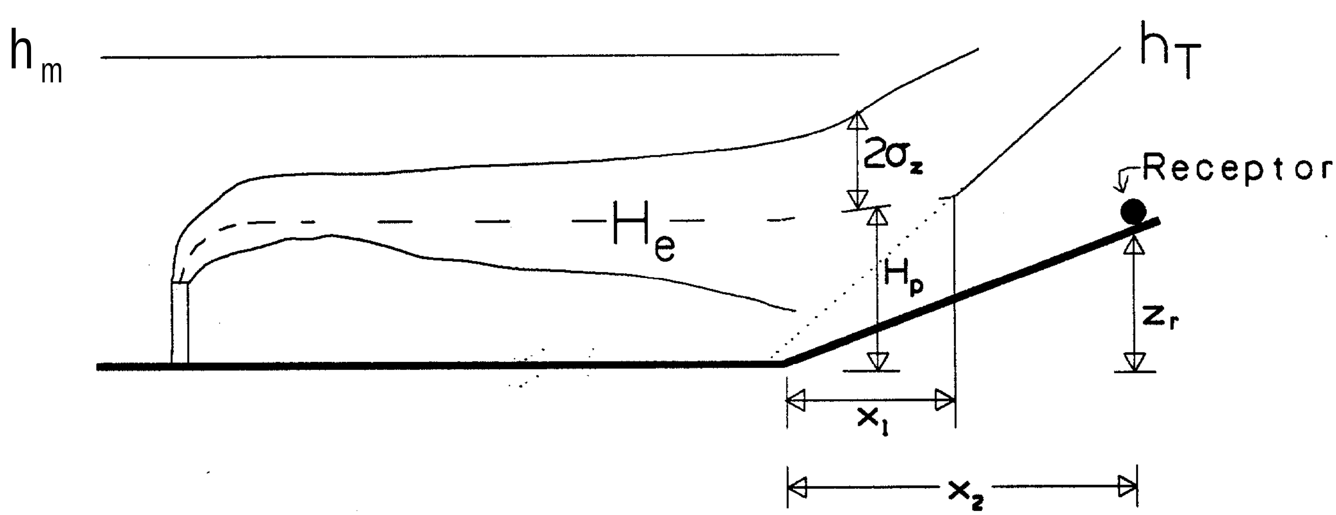
(b) If $H_e < h_m$, then vertical mixing is assumed to be capped or limited by $h_m$,

where $H_e$ is the effective plume height and $h_m$ is the marine mixing depth. The unlimited mixing assumption in part (a) generally has little effect, . since the atmosphere is stable at that elevation and vertical mixing of the plume by turbulence is minimal.

When the plume comes onshore during conditions when the overland stability class is stable, unlimited vertical mixing is assumed. If the overland stability is unstable or neutral, and if the plume centerline trajectory intersects the TIBL (whose height is referred to as $h_T$), the mixing depth ($h_m$) is given by the maximum of the plume top at the point it enters the TIBL and the TIBL height at the location of the receptor,




**a)** Stable overland and $H_e > h$ -- Unlimited mixing is assumed, since the the plume is always **in** stake air.




**b)** Not stable overland and $H_e << h_m$ -- Mixing is limited by either $h_T$ or $H_p + 2\sigma_z - Sx_1$.

$H_e$: Plume centerline height above water
$h_m$: **Marine** mixing depth
$H_p$: **Plume** centerline height above mean sea level
$h_T$: TIBL height above terrain surface
$z_r$: Receptor elevation
$S$: Terrain slope

Figure 2-7. Schematic diagram of possible mixing depth scenarios.

$$h_m = \max\left(H_p + 2\,\sigma_z(x_1) - S\,x_1,\; h_T(x_2)\right) . \tag{2-79}$$

The plume top is assumed to be located at an elevation of $2\sigma_z$ above $H_p$, which is the plume centerline height above mean sea level. The parameter $x_1$ is the distance from the shore to the point of TIBL interception by the plume centerline, $x_2$ is the distance from the shore to the receptor, and S is the mean slope of the terrain between the shore and the receptor (see Figure 2-7). Note that the plume height $H_p$ is calculated for these conditions from the formulas

$$H_p = 0.5\,H_e + Sx \text{ for } z_r > H_e \tag{2-80}$$

$$H_p = H_e + 0.5\,Sx \text{ for } z_r \le H_e \tag{2-81}$$

where $z_r$ is the elevation of the receptor. It is assumed in Equations (2-80) and (2-81) that the "half-height" correction applies over terrain, as used in the EPA's COMPLEX I and II models.

The purpose of the "max" specification in Equation (2-79) is to avoid squeezing the plume unrealistically into a shallow layer as it passes through the TIBL, which would violate principles of mass conservation. The revised formulation in OCD/4 is an improvement over the OCD/3 formulation, which did not account for the plume path correction for terrain or the fact that mixing is effectively unlimited if the plume is in a stable layer.

## 2.9 Plume Behavior Near Terrain Obstacles

Several components of the OCD model treatment of dispersion over complex terrain have been modified, and detailed discussions are given in the report by Hanna and DiCristofaro (19881.

### 2.9.1 Critical Streamline Height in Complex Terrain

The OCD/3 model calculates the plume trajectory in complex terrain in a similar manner as the EPA models Valley and COMPLEX I and II, which employ an empirical assumption for the lifting of the plume centerline. The standard option for PG stability classes E and F simulates the plume trajectory calculated by the Valley (Burt, 1977) model. The Valley model (and the COMPLEX models1 assumes that, for stability classes E and F, the plume travels toward nearby terrain with no vertical deflection until the centerline of the plume comes to within 10 m of the local terrain surface. Thereafter, the centerline is deflected to maintain a stand-off distance of 10 m from the terrain surface. For neutral or unstable conditions, COMPLEX I and II permit different (nonimpingement) plume trajectory assumptions than the Valley model. For stability classes A through D, the model allows the plume centerline to rise over the terrain but at a height less than its initial height over flat terrain. Its actual height at any point is computed from its initial height, the local terrain height, and a plume path coefficient (PPC).

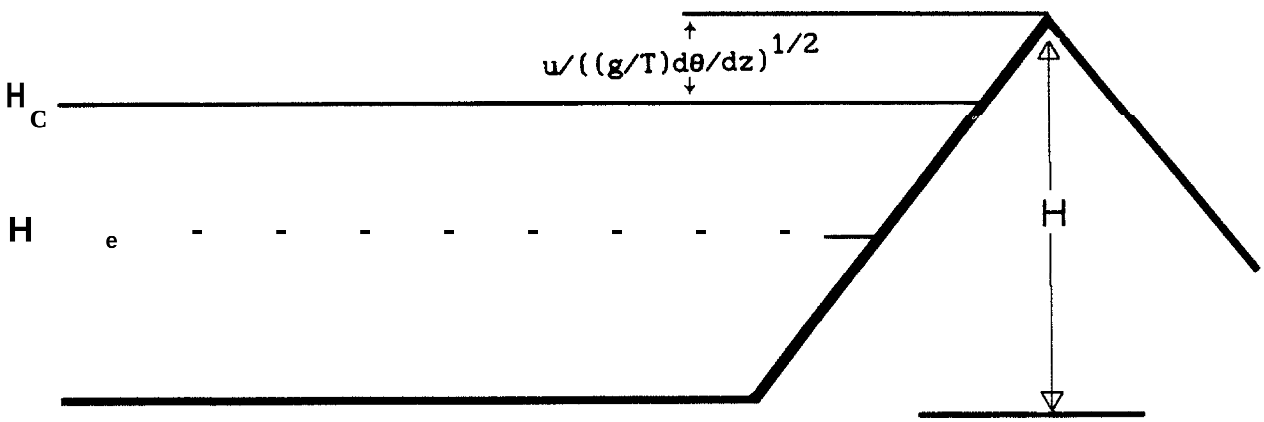
The OCD/4 version uses an improved method to calculate deflection around or over terrain. This procedure is not based on specific observations in coastal zones but is taken from recent theories and observations of transport over simple hill shapes. Much theoretical, laboratory, and field research over the past few years supports the use of the concept of the critical streamline height (Snyder et al., 1985). Given the terrain height, $H_{ter}$, the wind speed, u, and the temperature gradient at plume height, $d\theta/dz$, a critical streamline height, $H_c$, is calculated:

$$H_c = H_{ter} - u/((g/T)d\theta/dz)^{1/2} \quad (2\text{-}82a)$$

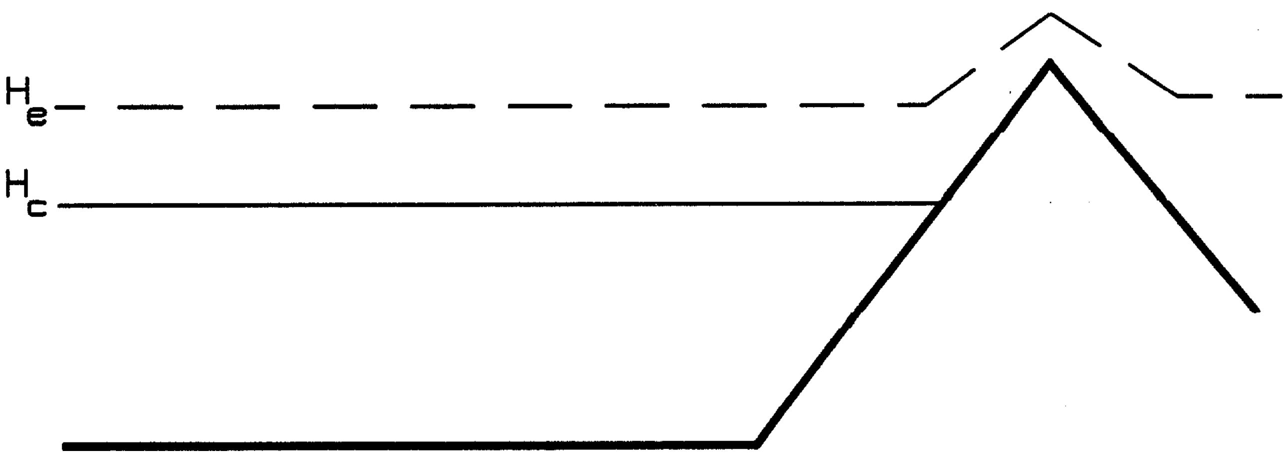
or

$$H_c = H_{ter} - u/N \quad (2\text{-}82b)$$

where N is the Brunt-Vaisala frequency. If the initial plume elevation, $H_e$, is below $H_c$, then no lifting of' the plume is assumed to occur and the plume path coefficient (PPC) equals 0.The plume path coefficient (PPC), which varies from 0.0 to 1.0, describes the relative amount of vertical deflection of the plume centerline by the terrain. Consequently, the plume experiences no vertical deflection if PPC=0.0 and is "terrain following" if PPC=1.0. These parameters are drawn in Figure 2-7. If $H_e$ is above $H_c$, then PPC equals 0.5 and partial lifting of the plume occurs (see Figure Z-81. This lifting is calculated with respect to $H_c$ rather than with respect to the ground surface under $H_c$.




a) He < Hc: No vertical deflection of the plume (PPC = 0.0).




b) $H_e \geq H_c$: Vertical deflection of the plume, assuming PPC = 0.5, 'referred to $H_c$.

Figure 2-8. Plume deflection near terrain, as assumed in the OCD model. $H_e$ = plume elevation, H = hill height, $H_c$ = critical dividing streamline height.

If $H_{eo}$ is the effective plume height over the water, then the adjusted plume height above local terrain (referred to msl), $H_a$, is given by the following:

$$H_a = PPC \cdot (H_{eo} - H_c) \qquad \text{for } H(x) > H_{eo} \qquad (2\text{-}83)$$

$$H_a = H_{eo} - (1-PPC) \cdot (H(x) + H_c) \qquad \text{for } H(x) \leq H_{eo} \qquad (2\text{-}84)$$

where $H(x)$ is the local terrain height and PPC is the plume path coefficient. If the temperature gradient, $d\theta/dz$, is not available (i.e., $H_c$ cannot be calculated or $N < 0$), the model reverts to the following assumptions:

PPC = 0.0 for overland stability classes E, F, and G,

PPC = 0.5 for overland stability classes A, B, C, and D.

These PPC conventions are similar to default assumptions in the EPA UNAMAP models MPTER and COMPLEX I.

As with the Valley and COMPLEX models, OCD assumes that the plume travels toward nearby terrain with no vertical deflection until the centerline of the plume comes to within $z_{min}$, a "miss distance" that is an input to the model. Currently, EPA recommends setting $z_{min}$ to 10 m. Before running OCD in complex terrain, the local MMS agency should be contacted for guidance in setting a value for $z_{min}$.

For those cases when the local terrain height is greater than the effective plume height $(H(x) > H_{eo})$ and the plume is released below $H_c$, then the model conservatively assumes that the plume stays a distance of $z_{min}$ above the hill surface. Receptors located above plumes flowing over large mountains and receptors in the lee of the terrain will conservatively have large concentrations calculated. Users are cautioned when applying the OCD model in these situations.

### 2.9.2 Reflection in Complex Terrain

The OCD/3 model contains the RTDM (ERT, 1982) algorithm for calculating reflection from the ground surface in complex terrain. This procedure is quite long since it contains many mathematical procedures and is time-consuming on the computer. The revised OCD/4 model has greatly simplified this procedure by completely eliminating the old methodology and replacing it with a simple but equivalent procedure from the EPA's TUPOS program (Turner et al., 1986):

1) Calculate ground-level concentration $C_1$ with complete reflection using terrain height and plume path correction factor (PPC) (i.e., PPC = 0.5 for classes A-D, PPC = 0 for classes E and F).

2) Calculate concentration $C_2$ with complete reflection using the Gaussian formula with flat terrain at the height $rH_e$, where $H_e$ is the smaller of $H_e$ and $H_i - H_e$, and $H_e$ is the initial plume centerline height above the ground surface upstream of the hill and $H_i$ is the mixing depth. The factor r is given in TUPOS by the following formulas:

$$
\begin{aligned}
r &= 1 && \text{for } \sigma_z/H_e \le 0.71 \\
r &= 2.01428 - 1.42857\,(\sigma_z/H_e) && \text{for } 0.71 < \sigma_z/H_e \le 0.85 \\
r &= 2.925 - 2.5\,(\sigma_z/H_e) && \text{for } 0.85 < \sigma_z/H_e \le 0.93 \\
r &= 5.25 - 5.0\,(\sigma_z/H_e) && \text{for } 0.93 < \sigma_z/H_e \le 0.97 \\
r &= 13.3333\,(1 - \sigma_z/H_e) && \text{for } 0.97 < \sigma_z/H_e < 1 \\
r &= 0 && \text{for } \sigma_z/H_e \ge 1
\end{aligned}
$$

3) Let concentration $C = \min(C_1, C_2)$

The new procedure requires much less computer time (by several orders of magnitude). The purpose of both sets of procedures is to prevent the plume centerline concentration from increasing with downwind distance due to reflection from the ground surface. In most terrain situations these calculations result in a minor correction to the basic dispersion formula.

## 2.10 OCD Concentration Equation

### 2.10.1 Point Sources

The OCD concentration equation, based on the standard Gaussian diffusion model (Gifford, 19681, accounts for the multiple eddy reflections from both the ground and the stable layer (Bierly and Hewson, 1962, Turner, 1970):

$$C = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\left(\frac{\theta' - \theta}{\sigma_{\theta_C}}\right)^2\right)\left[\exp\left(-\frac{1}{2}\left(\frac{z - h_e}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{z + h_e}{\sigma_z}\right)^2\right)\right.$$

$$+ \sum_{N=1}^{J}\left(\exp\left(-\frac{1}{2}\left(\frac{z - h_e - 2Nz_i}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{z + h_e - 2Nz_i}{\sigma_z}\right)^2\right)\right.$$

$$\left.\left. + \exp\left(-\frac{1}{2}\left(\frac{z - h_e + 2Nz_i}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{z + h_e + 2Nz_i}{\sigma_z}\right)^2\right)\right)\right] \quad (2\text{-}85)$$

where z is the receptor height above ground level, $h_e$ is the effective plume height, and zi is the mixing height. The first exponential term $\exp\left(-\frac{1}{2}\left(\frac{\theta' - \theta}{\sigma_{\theta_C}}\right)^2\right)$ makes use of a polar coordinate system where $\theta'$ is the direction from the source to receptor, $\theta$ is the wind direction, and $\sigma_{\theta_C}$ is given by

$$\sigma_{\theta_C} = \frac{\sigma_\theta}{1 + 0.9(T/1000)^{1/2}} \quad (2\text{-}86)$$

where $\sigma_\theta$ is measured at the source and T is the travel time. Equation (2-86) represents the Draxler $\sigma_Y$ equation as formulated for a polar system.

The concentration equation presented in (2-85) is used for point, area, and line source emissions.

### 2.10.2 Area Sources

For an area source (Figure 2-9a), the source region is approximated by the user by a series of just touching circular areas (Figure 2-9b), such that the emission rate in each area is Qi. Each area source as approximated by an effective circle with radius, $r_i$, is modeled as a point source using Equation (2-85). The maximum number of circles that may be used is five. It is recommended that the diameter associated with the total area source be kept to

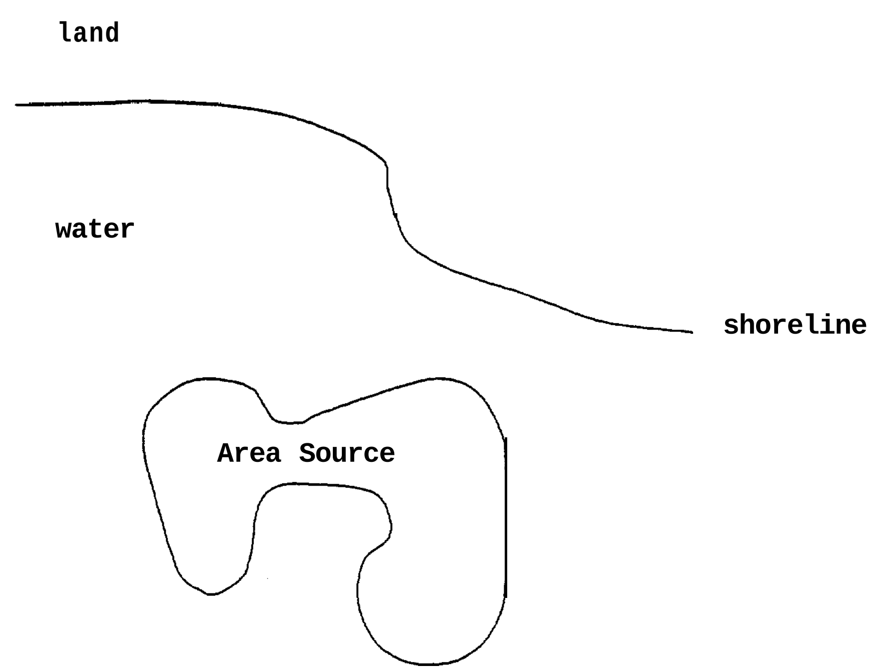



Figure 2-9a. Overwater area source example.

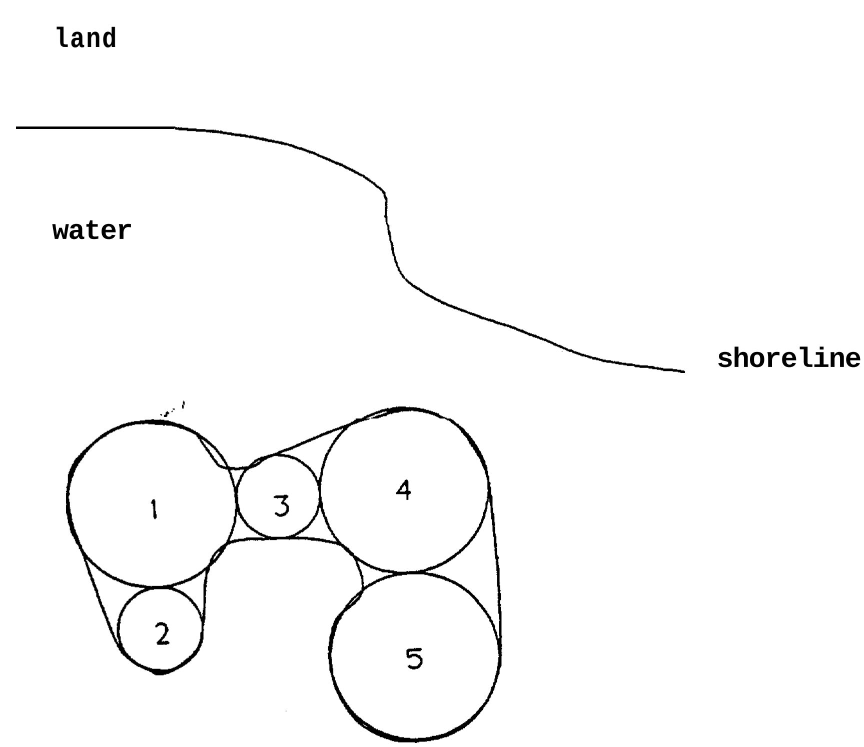



Figure 2-9b. Use of 5 effective circles to model an overwater area source.

10 km or less, A virtual source procedure with $\sigma_y = r_i/\sqrt{2}$ is used to calculate distance for the appropriate overwater stability class. Further details of how a model run should be set up for an area source are presented in Section 3.

The area source calculations from OCD should be used for guidance purposes only. This simplified area source calculation does not account for an area source such as an oil-spill fire which would vary in diameter and surface temperature through time. It also does not account for the predominant pollutant type of soot particulates and the fire-induced buoyancy which differ from typical stack emissions. In order to model an oil-spill fire, it is recommended that several OCD runs be made in screening mode for a variety of area source parameters and the results used for guidance only.

### 2.10.3 Line Sources

The emissions from a line source or moving ship (Figure 2-10) are represented as a series of point sources for N segments along the path of the ship. The OCD model automatically sets N to ten. As discussed in Section 3 in more detail, the user is required to input the starting and ending x, y coordinates of the ship, the emission rate (Q), the meteorology associated with each segment, and the number of hours it takes the ship to travel from start to end (NPER).

A virtual source procedure with

$$\sigma_y = \frac{x_{1.5} - x_{0.5}}{\sqrt{2}} \tag{2-87}$$

is used to calculate the virtual source distance. The concentration at each receptor is represented by the sum of each concentration using Equation (2-85) calculated for the midpoint of each of the N line segments.

For line sources, the emission rate input to the model is the same for each segment. However, the concentrations must be adjusted within the model to account for time averaging. This is accomplished by adjusting the line source emission rate, such that:

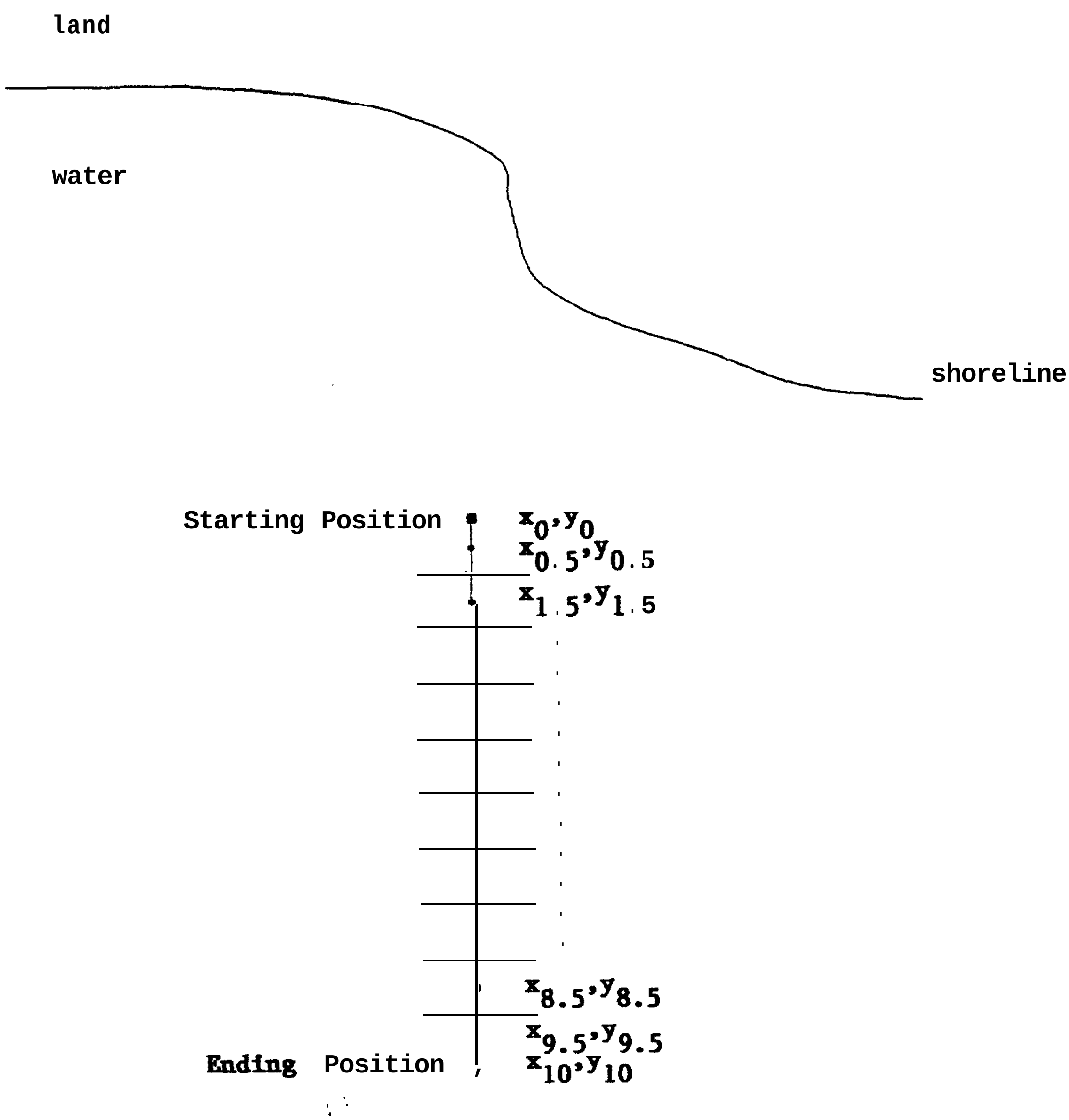



Figure 2-10. Line source representation.

$$Q_{seg} = Q\,(NPER \cdot 60)/(NSEGS \cdot \tau) \tag{2-88}$$

where $\tau$ is the OCD averaging time or 60 minutes, NPER is the number of hours it takes the ship to travel from start to finish, and NEGS is the number of segments. Therefore, Q for a line source segment taking into account the time averaging adjustment reduces to

$$Q_{seg} = Q\,(NPER/NSEGS)\ . \tag{2-89}$$

The representation of line sources in OCD has been developed only for use in screening or worst-case modeling analyses. The typical travel time of a ship traveling from port to an offshore oil facility is less than 24 hours; therefore, line sources can only be modeled for a maximum of 24-hours using OCD. For line sources, the model is set up such that the user must input the meteorology for each line segment. Thus, since NSEGS is set to ten within the model, the user must supply ten "segment" inputs for overland and overwater meteorology. If it takes the boat twenty hours to travel from the port to the platform, then each "segment" of meteorology input to the model represents a two-hour average. Likewise, the "segment" meteorology for a five-hour boat trip represents 30-minute averages. Since the line source option should only be used for screening modeling purposes, it is recommended that the overland and overwater meteorology be kept the same for all segments within an OCD run. Separate OCD runs can then be made for different worst case (screening) meteorological conditions. Before using OCD for regulatory permitting applications, the local MMS agency should be contacted for guidance.

# 3. USER'S INSTRUCTIONS

Section 3.1 of this chapter presents a detailed discussion of the OCD model input stream. Section 3.2 contains a general discussion of the data requirements of the OCD model including emissions data, receptor data, overland and overwater meteorological data, and specifications of the land-sea interface. Users preparing to make an OCD run should use Section 3.1 as the primary guide for constructing the input run stream. Elements requiring further explanation are discussed in Section 3.2. A discussion of the OCD output files is presented in Section 3.3. Program modification suggestions for other computers are presented in Section 3.4 and job control considerations are presented in Section 3.5. Finally, sample OCD input and output files for the test cases supplied with the model are presented in Section 3.6.

## 3.1 OCD Model Input Stream

The OCD input run stream involves 16 groups of input parameters. For any particular run some of these groups may be omitted depending upon program options selected. In any case, the groups are ordered sequentially from type 1 to type 16 followed by formats for hourly input data. Groups that must be presented are labeled "mandatory" while those that are present depending upon an option setting are labeled "conditional." They are discussed in detail below.

### OCD Groups 1, 2, and 3: Title Lines (Mandatory)

The OCD model reads 3 title lines to be used as page headers in the printed output. These lines are referred to as OCD Groups 1, 2, and 3. up to 80 characters may be included in each line. The three header lines must be present, even if one or more lines are to be left blank.

### OCD Group 4: Control Parameters and Constants (Mandatory)

OCD Group 4 consists of one line of control parameters and constants separated by spaces or commas, as defined by the order of variables listed below:

- starting year for this run (last 2 digits);
- starting Julian day for this run;
- starting hour for this run;
- number of averaging periods to be run;
- number of hours in an averaging period (not to exceed **24);**
- pollutant indicator (3 = $SO_2$, 4 = TSP, 5 = $NO_x$, 6 = CO, 7 = blank)
- number of significant point sources (0-25);
- a fifth averaging time to be included in the high five tables (other than 1, 3, 8, and 24 hours; an input of 0 will not add a fifth averaging period);
- conversion factor that converts user horizontal length units (by multiplication] to kilometers; and
- conversion factor that converts user height units (by multiplication1 to meters.

The pollutant indicator is only used for header labels. The number of significant point sources are only used for output purposes. For example, if the user is modeling three sources and only one is identified as a significant source, then additional output will only be produced for that one specified source.

OCD Group 5: Main Model Options (Mandatory)

In OCD Group 5, the main model options are specified on one input line by means of a series of "0" or "1" entries. For each option, a "1" means to use an option, a "0" means that the option is not used. The user must use caution; some options are worded such that a "1" means to delete printout or not to activate a technical feature. The options, which are entered in free format, are described in **Table 3-1.**

Option 24 **(IOPT(24))** indicates that a source is on land and that the wind speeds would not be modified. As is discussed in Section 3.2.4, if the overwater wind speed is not known, then the default wind speed is a modified land wind speed. For overland sources, the default wind speed should not be modified. If there are missing wind speeds, OCD should not be run for both overland and water sources at the same time. Separate runs should be made.

TABLE 3-1

## CONTENTS OF OCD GROUP 5*: MAIN MODEL OPTIONS

| Variable | Description |
|---|---|
| IOPT(1) | Use terrain edjustmants |
| IOPT(2) | Do NOT use stack-tip downwash |
| IOPT(3) | Do NOT use gradual plum? rise |
| IOPT(4) | Use buoyancy-induced dispersion |
| IOPT(5) | Overland meteorological data is formatted (group 16) |
| IOPT(6) | Read hourly emissions. Filename is "EMIS.DAT" |
| IOPT(7) | Specify significant sources |
| IOPT(8) | Input radial distances, generate polar coordinate receptors |
| IOPT(9) | DELETE emissions with height table |
| IOPT(10) | DELETE resultant meteorological data summary for averaging period |
| IOPT(11) | DELETE hourly contributions of significant sources |
| IOPT(12) | DELETE meteorological data on hourly contributions |
| IOPT(13) | DELETE case-study printout of plume transport and dispersion on hourly contributions |
| IOPT(14) | DELETE hourly summary of receptor concentrations |
| IOPT(15) | DELETE meteorological data on hourly summary |
| IOPT(16) | DELETE case-study printout of ptune transport and dispersion on hourly summary |
| IOPT(17) | DELETE averaging period contributions |
| IOPT(18) | DELETE averaging period summary |
| IOPT(19) | DELETE average concentrations and high-five table for the entire run |
| IOPT(20) | Source Type<br>0 = Point Source<br>1 = Area Source<br>2 = Line Source |
| IOPT(21) | CREATE summary output file called "EXTRA.OUT" |
| IOPT(22) | Write hourly concentrations to disk or tape. Filename is "CONC.BIN" |
| IOPT(23) | CREATE table of annual impact assessment from non-permanent activities |
| IOPT(24) | Land Source (Do Not Wodify Wind Speed) |
| IOPT(25) | Specify pollutant decay rate via chemical transformation |

* 1 line, values entered in free format: 1 = use, 0 = do not use

OCD **Group 6:** .-Overland Wind and Terrain Mandatory1

OCD Group 6 consists of one line that describes the overland anemometer height, the surface roughness length, the minimum miss distance, and the latitude of the source region. These values are entered in free format, in the order listed below:

- overland anemometer height (ml;
- surface roughness length **(m);**
- minimum miss distance for a plume above the ground at the receptor location **(m);** and
- latitude of source region **(deg).**

OCD Group 7: Source Description (Mandatory)

OCD Group 7 includes up to three lines for each source, plus a final line consisting of the delimiter word **"ENDP."** Lines one and two are mandatory for each source. If modeling a line source **(IOPT(20)** = 2 of OCD group **5),** a third line of data containing the x and y coordinates of the end point must be supplied before the line containing the delimiter word **"ENDP."** Details of format specifications for group 7 are given in Table 3-2. The source "ground" level elevation should be the height above water level, which is not necessarily at mean sea level elevation for inland bodies of water. This elevation should be the height of a platform above the water for structures on **"stilts."** For ships or other overwater structures in contact with the water, this elevation should be zero. Stack-top and building height are then referenced relative to this base elevation for the source. Variable **SOURCE(7, NPT)** is the stack inside diameter **(m)** for point or line sources and the diameter **(m)** of a circle for area sources.

OCD Group **8:** Specified Significant Sources (Conditional)

OCD Group 8 consists of one line and is used only if option 7 (specify significant sources) in Group **5** is set to 1. A significant source is defined as one for which a printout of its contribution to an hourly or averaging period concentration is desired. The number of significant sources is specified and the significant point source numbers (obtained from the order

Table 3-2

CONTENTS OF OCD GROUP 7*: SOURCE DESCRIPTION

| Variable | Description |
|---|---|
| LINE ONE: FORMAT(3A4) | |
| RNAME | 12-character point source name |
| LINE TWO: FREE FORMAT | |
| SOURCE(1, NPT) | x coordinate of point source, user units<br>x coordinate of circle center for area source, user units<br>x coordinate of starting point for line source, user units |
| SOURCE(2, NPT) | y coordinate of stack, user units<br>y coordinate of circle center for area source, user units<br>y coordinate of starting point for line source, user units |
| SOURCE(3, NPT) | pollutant emission rate (g/s) |
| SOURCE(4, NPT) | height of building or obstacle at or near stack location (m) relative to platform or water level, depending upon base elevation specified below (ELP). |
| SOURCE(5, NPT) | height of stack-top (m) above ground (if on land), or above platform Level (if at see on "stilts"), or above sea level (if floating on the water) |
| SOURCE(6, NPT) | stack gas temperature (°K) |
| SOURCE(7, NPT) | stack-top inside diameter (m) for point or line sources<br>circle diameter (m) for area sources |
| SOURCE(8, NPT) | stack gas exit velocity (m/s) |
| SOURCE(9, NPT) | deviation of stack angle from the vertical (degrees) |
| ELP (NPT) | elevation of ground, water, or platform base at stack location, relative to the water surface (see text) |
| SOURCE(11, NPT) | building width used to compute platform downwash (m) |
| LINE THREE: FREE FORMAT (FOR LINE SWRCES ONLY) | |
| xSTOP, ySTOP | x and y coordinates of ending point for line source, USER UNITS |

*Up to three lines of data are input for each stack. The last card contains "ENDP" in columns 1-4.

used in Group 7 Source Description1 are identified. The contents of the source group are given in Table 3-3. The input data are free formatted.

OCD Group 9: Overland Meteorological Data Identifiers (Conditional)

OCD Group 9 consists of one line and is required if overland meteorological data are supplied in binary form (if option 5 (overland meteorological data is formatted1 in Group 5 is set to 0). The following variables are specified in the order given, separated by spaces or commas:

1) surface station identifier code (5 digits),
21 year of surface data (2 digits),
31 upper air station identifier code (5 digits),
4) year of upper air data (2 digits).

OCD Group 10: Polar Coordinate Receptors (Conditional)

OCD Group 10 is used to define ring distances for polar coordinate receptors. It consists of one line and is required only if option 8 (polar coordinate system1 in Group 5 is set to 1. The line consists of the following information, with data items separated by a comma or a space in the order specified:

- 5 radial distances (user units) for the rings (for fewer than 5 rings, use zeros after the distances desired to complete the 5 input values);
- x coordinate of the center of the concentric rings (user coordinates); and
- y coordinate of the center of the concentric rings (user coordinates).

To minimize confusion, the ring distances should be specified in increasing magnitude.

OCD Group 11: Polar Coordinate Receptor Elevations (Conditional)

OCD Group 11 consists of 36 lines and is used only if options 1 (use terrain adjustments1 and 8 (polar coordinates) in Group 5 (main model options) are set to 1. One line of data is input for each of 36 azimuths (separated by

TABLE 3-3

CONTENTS OF OCD GROUP 8: SIGNIFICANT SOURCES*

| Variable | Description |
|---|---|
| NPT | Number of user-specified significant point sources (l-251 |
| MPS(1) | Point source number of the first significant point source |
| MPS(NPT) | Point source number of the second significant point source |
| • | |
| • | |
| • | |
| MPS(NPT) | Point source number of the last significant point source |

*All data are free formatted separated by blanks or commas.

10°). For each azimuth, the ground elevations for the receptors along that radial are specified in user height units in the order that the ring distances are specified in group 10 (polar coordinate receptors). The elevations should be referenced from water level, which may not be sea level for inland bodies of water. If all 5 rings are not used, zeros or blanks can be used for elevations of the extra rings. The values to be entered for each azimuth direction are described in Table 3-4. All data entered per line are free formatted.

OCD Group 12: Other Receptor Locations and End Delimiter (Conditional)

Any polar coordinate receptors generated using OCD Groups 10 and 11 can be supplemented by discrete (arbitrarily-placed) receptors described in OCD Group 12. One line is used for each receptor. The total of the polar coordinate receptors and the arbitrarily-placed receptors cannot exceed 180. After the last discrete receptor is specified (if any), a line containing the end delimiter "ENDR" must be supplied. The format of this discrete receptor information is shown in Table 3-5. Note that the receptor height (ZR) above local ground level (i.e., flagpole receptor) and the terrain elevation toward which the source to receptor is aligned (HTER) are in meters. Care should be taken in selecting flagpole receptors such that ZR should not be greater than plume height. The VDF subroutine which calculates the vertical distribution function does not accurately account for flagpole receptor heights greater than plume height. Specification of HTER must be made relative to a particular source. Thus, if two or more offshore sources are a significant distance apart, the same value of HTER may not apply to each source depending on the alignment. For such cases, in order to examine the effects of multiple sources, it may be necessary to make multiple runs, each with a different hill height for the receptor or receptors of interest. The local MMS agency should be contacted for advice.

OCD Group 13: Special Options Concerning Additional Meteorological Data (Mandatory)

Code settings for the 9 special options concerning additional meteorological data are set on the one line of input that is referred to as OCD Group 13. In addition, the elevations of overwater anemometer and temperature sensors are specified. See Table 3-6 for details.

## TABLE 3-4

CONTENTS OF OCD GROUP 11:
POLAR COORDINATE RECEPTOR ELEVATIONS*

| Variable | Description |
|---|---|
| IDUM | azimuth indicator of receptor radial for which elevations are given, 1-36 (e.g., 18 refers to receptors to the south) |
| ELRDUM(1) | ground-level elevation (user height units) relative to the water surface at location of first receptor along the radial (order of receptors along radial depends upon the order of ring distances specified in type 10) |
| ELRDUM(2) | ground-level elevation (user height units) relative to the water surface at location of second receptor along the radial ground-level elevation |
| . | |
| . | |
| ELRDUM(5)** | ground-level elevation (user height units) relative to the water surface at location of the tenth receptor along the radial |

* All data per line are free formatted separated by blanks or commas. A total of 36 lines are entered for this group.

** If 5 rings are not used, zeros can be entered for columns pertaining to unused rings.

TABLE 3-5

CONTENTS OF OCD GROUP 12: DISCRETE RECEPTOR LOCATIONS*

| Variable | Format | Columns | Description |
|---|---|---|---|
| RNAME | 2A4 | l-8 | 8-character receptor name |
| RREC | F10.3 | 9-18 | x-coordinate of receptor (user units) |
| SREC | F10.3 | 19-28 | y-coordinate of receptor (user units) |
| ZR | F10.3 | 29-38 | receptor height above local ground level (m) |
| ELR | F10.3 | 39-48 | ground elevation relative to the water surface at receptor location (user height units) |
| HTER | F10.3 | 49-58 | terrain elevation toward which source to receptor is aligned (used for Hc calculation1 (m) |

---

: last receptor line (if any), an end delimiter card must be included with columns l-4.

TABLE 3-6

CONTEXTS OF OCD GROUP 13*: SPECIAL OPTIONS FOR ADDITIONAL METEOROLOGICAL DATA

Option codes: 0 = not provided or do not use
1 = provided, unless otherwise specified

| Variable | Description |
|---|---|
| JOPT(1) | Overwater wind direction provided |
| JOPT(2) | Overwater wind speed provided |
| JOPT(3) | Overwater vertical potential temperature data (°K/m) are provided |
| JOPT(4) | Overwater humidity, specified as follows:<br>1 = relative humidity (%) is provided<br>2 = wet bulb temperature (°K) is provided<br>3 = dew point temperature (°K) is provided |
| JOPT(5) | Overland horizontal and vertical turbulence intensity data is provided |
| JOPT(6) | Water surface temperature, specified as follows:<br>1 = water surface temperature (°K) is provided<br>2 = air minus water temperature (°K) is provided |
| JOPT(7) | Overwater wind direction shear (degrees/m) is provided |
| JOPT(8) | Overwater horizontal turbulence intensity data is provided |
| JOPT(9) | Overwater vertical turbulence intensity data is provided |
| HWANE | Height above water level of overwater anemometer |
| HWT | Height above water level of overwater air temperature sensor |

---

* One line only is included in this group; values are entered in free format separated by commas or spaces.

.

OCD Group 14: Chemical Transformation Rates (Conditional)

OCD Group 14 consists of 2 input lines and is included only if option 25 (specify pollutant decay rate via chemical transformation) from Group S (main model options) is set to 1. The first line contains the latitude, longitude, and time zone of the site, separated by spaces or commas. The latitude and longitude are expressed in degrees (including fraction) and are both positive north of the equator and west of Greenwich, England. The time zone indicates the number of hours that the time standard used for the hourly data input is behind GMT, This number is positive in the United States (e.g., equals 5 for Eastern Standard' Time).

The second line contains 12 monthly climatological values of the pollutant decay rate (%/hour) separated by spaces or commas. The decay rate used should be representative of daytime hours; it is assumed to be zero at night.

OCD Group 15: Shoreline Geometry (Mandatory)

This mandatory OCD Group 15 describing shoreline geometry consists of an initial parameter followed by one line per row of grid rectangles on the area to be mapped. The last line contains the end delimiter word "ENDS." Values contained on the first line, in free format, are specified in the following order:

- x coordinate of the northwest corner of the mapped area (user units);
- y coordinate of the northwest corner of the mapped area (user units);
- the number of grid rectangles along the x axis (map columns not to exceed 60);
- the number of grid rectangles along the y axis (map rows not to exceed 60);
- the length of each grid Ax (user units) (See Section 3.2.5);
- the length of each grid Ay (user units) (See Section 3.2.5);
- the minimum along wind width (user units) for a land or water body to be considered significant; and

average distance from source to shoreline (user units).

As discussed in Section 3.2.5, the average distance from the source to the shoreline is only used to determine the range of acceptable values for Ax and Ay. One only needs to determine whether the average distance is less than or greater than 2 km.

For each row of grid rectangles to be mapped, a line of input follows starting at the top [north edge) of the mapped area. Starting in column 1, each input column represents one grid rectangle, proceeding from left to right. In each column, an "L" signifies dominance by land, and a "W" is used for water. A blank persists the previous significant character (either "L" or "W") found to the left. The first character must always be an "L" or "W". For further details see Section 3.2.5.

After the last row of characters is specified, an end delimiter line containing "ENDS" in columns l-4 must be included.

OCD Group 16: Overland Meteorology in Card-Image Format (Conditional)

OCD Group 16 is included if option 5 (overland meteorological data is on cards) in Group 5 is set to 1. One line is included for each hour of meteorology. The data for each hour is entered in free format with each value separated from adjacent values by spaces or commas. The meteorological input data are discussed in Section 2.1.3. The order of the hourly input data is as follows:

- year,
- Julian day,
- hour,
- overland stability class,
- overland wind speed (m/s),
- overland ambient air temperature (°K),
- overland wind direction (degrees from North, from which the wind blows ), and
- overland mixing height (m).

## Formats for Hourly Input Data

### Hourly Overwater Meteorological Data (Mandatory)

Overwater data are free formatted one line per hour as shown in Table 3-7. Missing values are denoted by a user-provided value of -999. However, the OCD model will treat a value that is clearly out of range as missing (see Table 3-7) and will use a substitute value. The choice of a substitute for each meteorological parameter is noted in Table 3-7. Note that there are no substitution values for overwater mixing height, overwater humidity, overwater air temperature, and surface water temperature. If any of these parameters have values outside the valid ranges listed in Table 3-7, execution of the code will stop. If any of these values are missing, the model will stop, producing an error message. The filename containing the hourly overwater meteorological data must be "WMET.DAT."

### Hourly Emissions Data (Conditional)

For each pollutant source specified in the OCD input run stream, one emissions rate per hour may be input to the model if option 6 (read hourly emissions1 of Group 5 is set to 1. One line of input should be provided for each stack on an hourly basis, in the order that the stacks are listed in the input run stream. The filename containing the hourly emissions data must be "EMIS.DAT." Each line is free formatted with data separated by blanks or commas listed in the following order:

Year,
Julian Day,
Hour,
Pollutant emission rate (g/s),
Stack gas exit velocity (m/s), and
Stack gas temperature (°K).

## 3.2 Data Requirements

The data needs of the OCD model are more complex than those of most air quality models, since meteorological data that are representative of both overland and overwater conditions must be provided. In addition, geographic locations of land and water-covered areas must be input to OCD. Emissions and receptor data specifications are relatively routine, although the user has the

TABLE 3-7

CONTENTS OF HOURLY OVERWATER METEOROLOGY AND OVERLAND TURBULENCE DATA FILE*

| Data Element | Valid Data Range | Substitute if Missing |
|---|---|---|
| Year | 00-99 | |
| Julian Day | 1-366 | |
| Hour | 1-24 | |
| Wind Direction (deg) | 1-360 | Overland value |
| Wind Speed (m/s) | 1-99 | Modified overland value |
| Mixing Height (m) | 1-10,000 | |
| Humidity (see JOPT(4) in Group 13) | 0-100% RH | |
| Overwater air temperature (°K) | 200-330 | |
| Surface water temperature (see JOPT(6) in Group 13) | 260-320 | - |
| Vertical wind direction shear (deg/m) | 0-180 | Zero |
| Overwater turbulence intensity, $i_y$ component | 0.0-2.0 | Parameterized (see Section 2) |
| Overwater turbulence intensity, $i_z$ component | 0.0-1.0 | Parameterized (see Section 2) |
| Overland turbulence intensity, $i_y$ component | 0.0-2.0 | Briggs (1973) rural default |
| Overland turbulence intensity, $i_z$ component | 0.0-1.0 | Briggs (1973) rural default |
| Overwater vertical potential temperature gradient (°K/m) | 0.0-0.5 | Parameterized (see Section 2) |

*All data are free formatted separated by spaces or commas.

option of providing hourly emissions for input to OCD. One is able to model point, area, or line sources with the OCD model. Users preparing to make an OCD run should use Section 3.1 as the primary guide for constructing the input run stream. In this section, elements requiring further explanation are discussed. The user can refer to this section as a reference for trouble shooting.

### 3.2.1 Source Data

The point source information required by the OCD model is the same as that used in most air quality dispersion models except for the following input variables: the stack angle from the vertical, the height of the stack top above its base, and the height of the building at or near the stack location. In some situations on offshore platforms, stacks may protrude from a building at an angle that departs from the vertical. In such a case, momentum plume rise is a function of the stack angle, but buoyancy rise is not affected. The height of the stack top for a tilted stack is not specified in terms of the stack length, but rather the height above the reference base height. For a horizontal stack protruding from a building from an opening 15 meters above a platform level, the stack top height would be 15 meters. The height of the building itself is used in building downwash calculations.

Multiple sources can be handled by the OCD model, and the following information is required for each stack:

- The x and y coordinates of the point source, circle center for area source, or starting location for line source (user units). The x and y coordinates of the ending location for line source (user units). The OCD model limits line sources to one per model run.
- Pollutant emission rate (g/s).
- Width and height of a building or similar obstacle (m) at or near the stack location. If on land, this value is the height of the top of the building above base elevation. If over water, this value is the height of the top of the building above platform base (if on stilts) or above water level (if the obstacle is in contact with the water).
- Area source height or stack-top height (m) for point or line source. For a vertical stack, this is the same as the stack height; that is, the height above ground level or platform level. For a non-vertical stack, the value input should be the height of the center of the stack top above ground or platform level.
- Diameter (m) of the effective circle representing the area source.

- Ending line source position (user units).
- Stack gas temperature (°K).
- Stack inside diameter (m) for point or line sources or circle diameter (m) for area sources.
- Stack gas exit velocity (m/s).
- Angle of the stack from the vertical (degrees). A value of zero degrees refers to a vertical stack, 90° to a horizontal stack, and angles greater than 90° to downwind pointing exhaust vents.
- Elevation of the stack base above the water surface (user height units). This value refers to the elevation of the ground level above the water surface if over land or to the height of the platform if over water. It should be'provided for overwater sources whether or not terrain is to be considered so that the proper wind speed and turbulence intensity values are calculated by the OCD model.

The format specifications for the above source information are presented in Section 3.1 (Table 3-2). A sample of OCD Group 7 for two point sources is given in Figure 3-la and for a line source in Figure 3-lb.

Hourly emissions information, if available or necessary, consists of the input of pollutant emission rate, stack gas exit velocity, and stack gas temperature. The data are free formatted and the specifications for hourly emissions information are presented in Section 3.1. Results of stack test measurements should be used to determine how these parameters vary as a percentage of full capacity if significant load variations are common. If a source has constant emission parameter values, hourly information is not necessary.

A graphical depiction of how an area and line source are modeled by OCD is presented in Section 2.10.

Regulated pollutants of interest for OCD model applications include sulfur dioxide ($SO_2$), total suspended particulates (TSP), nitrogen oxides ($NO_x$), and carbon monoxide (CO). These pollutants are assigned numerical codes ranging from 3 for $SO_2$ to 6 for CO. Only one pollutant is modeled in a single OCD run. However, concentrations due to impacts from a single source can be scaled by an appropriate factor by the ANALYSIS postprocessor (see Appendix B) to yield concentration estimates for other pollutants. Pollutants other than the four mentioned above can be used in an OCD run; the use of

```
GEN.  STACK
3.91 0.75 0.4 10.0 15.0 477.0 0.5 65.0 90.0 20. 8.
FLARE
3.97 0.77 1.0 10.0 20.0 810.9 0.5 60.0  0.0 20. 8.
ENDP
```

Figure 3-la. Sample OCD Group 7 for two point sources. The stack parameters are free formatted.

```
BOAT  SOURCE
6.18 10.10 4.0 0.0 2.0 750. 0.3 20.4 90.0 0. 0.
3.98 0.80
ENDP
```

Figure 3-lb. Sample OCD Group 7 for a line source. The stack parameters and the x and y coordinates of the ending point are free formatted.

**pollutant indicator** code 7 in OCD Group 4 (see Section 3.1) will yield a blank for the name of the pollutant.

A significant source is defined as one for which a printout of its contribution to an hourly or averaging period concentration is desired. The number of significant sources can range from zero to 25. IOPT(7) of OCD Group 5 (see Table 3-1) controls whether sources should be specified as significant. Partial concentrations attributable to these sources can be printed for each averaging period (but not for the whole run time period), and the volume of printout can be very large. Significant sources are best used to investigate contributions during short-term periods of interest. Contributions from individual sources can be obtained by first using separate OCD runs, and then combining the results with the ANALYSIS postprocessor.

The specification for pollutant half-life (IOPT(25) of OCD Group 5 must be set to 1) is found in OCD Group 14 in an expanded form. The decay, or chemical transformation rate, of the modeled pollutant is assumed to occur only during daylight hours. The latitude, longitude, and time zone of the source region is specified to enable the OCD model to calculate the hours of daylight. The time zone value tells the model how many 'hours it is behind Greenwich Mean Time (GMT), the time standard used for the input data of daylight conditions. Twelve monthly climatological values of the pollutant decay rate are entered in % decay per hour. Zero decay is assumed at night.

### 3.2.2 Receptor Data

If IOPT(8) of OCD Group 5 is employed, polar coordinate receptor positions are generated internally in OCD about a user specified location for one to five radial distances:.- Thirty-six receptors are generated for each distance. If all five distances are used, 180 receptors are generated, which is the maximum number of receptors allowed in OCD. Note that the distances (and also the center of the polar coordinate grid) are specified in user units. If IOPT(8) of Group 5 is employed to generate the polar coordinate receptors and IOPT(1) of Group 5 is employed to included terrain adjustments, the ground-level elevations of these receptors must be entered using OCD Group 11 (see Table 3-4). A mixture of some (or no) polar coordinate rings combined with discretely placed receptors can be used in the OCD model up to a total of

180 receptors. A sample of OCD Groups 10 and 11 for three radial distances is given in Figure 3-2a.

The OCD model permits receptor ground-level elevations to be above the elevation of stack tops. For discrete receptors only, the terrain in the vicinity of the modeled receptor (HTER) can be input through Group 12. This parameter is used to calculate the critical-dividing-streamline height which is used to estimate the terrain correction factor. The value of HTER for each receptor should be based on a careful inspection of the highest terrain in the vicinity of the modeled receptor. For example, as shown in Figure 3-3, if receptors 1 and 2 are placed on various elevations of Hill A with a height of 100 m; receptors 3 and 4 are placed on the shoreline far away from the influence of any terrain; and receptors 5 and 6 are placed on Hill B with a height of 300 m, then the values of HTER for receptors 1 and 2 should be 100 m; for receptors 3 and 4, 0 m; and for receptors 5 and 6, 300 m. Notice that hill C with an elevation of 400 m should not be considered for receptors 1 through 6. If a value of zero is input for HTER, then the default stability dependent plume path correction (PPC) coefficients are used.

Receptors can be specified discretely with the following information provided:

- x,y coordinates of the receptor (user units);
- receptor height above local ground level (or above the water surface if over the water);
- receptor ground-level elevation above the water surface (user height units). This value is needed only for applications using the terrain adjustment option; and
- terrain elevation toward which the source and receptor are aligned. This choice is rather subjective, but should represent local terrain within about 1 km of the receptor rather than terrain at larger distances. For example, a mountain 10 km from the receptor should not be considered.

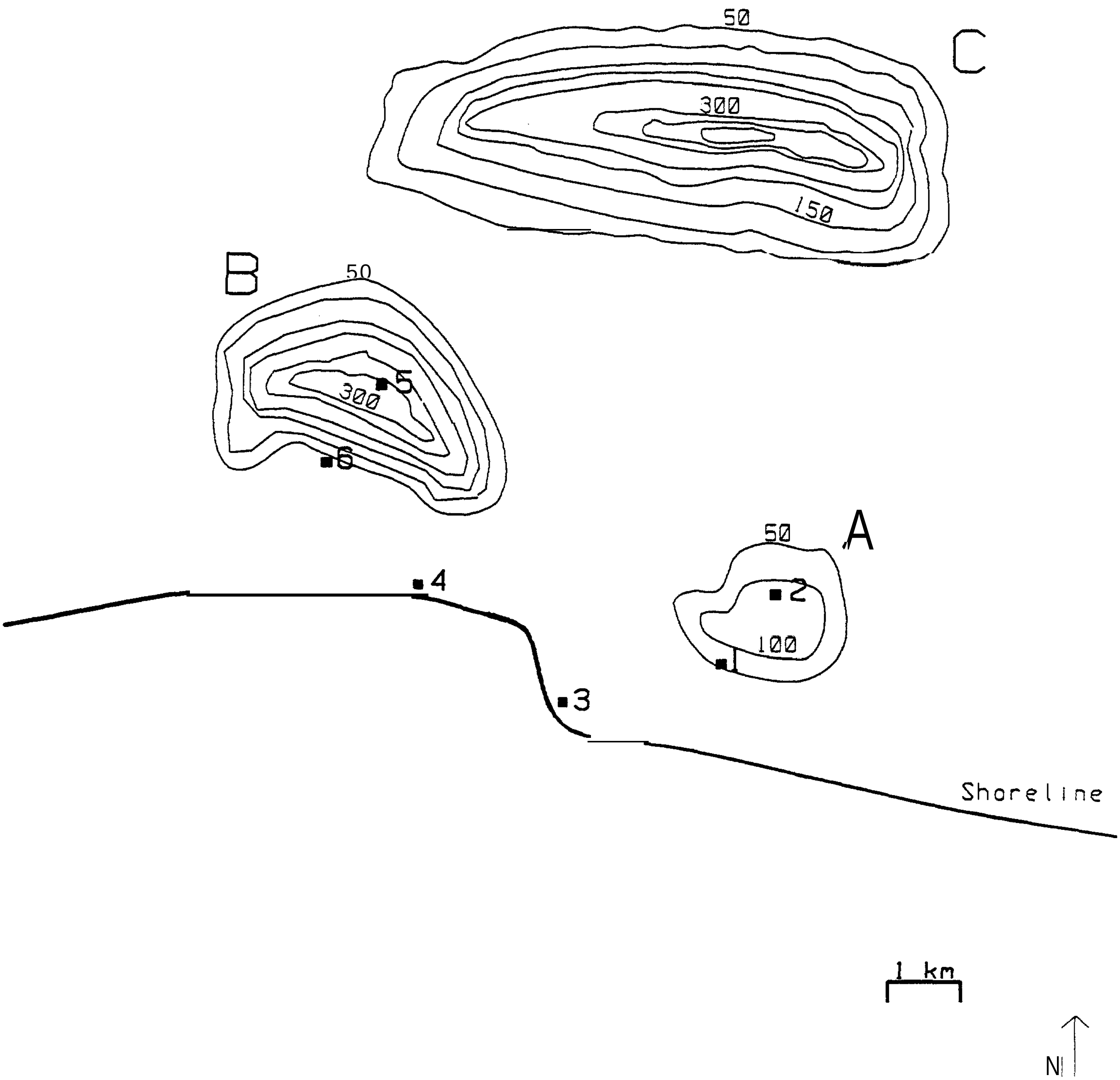
The format specifications for discrete receptor locations (Group 121 are presented in Section 3.1 (see Table 3-5). An example of OCD Group 12 for five discrete receptors is given in Figure 3-2b.

```
10. 11. 12.  Q.  0. 3.91 0.75
1   O.  0.  0.  Q.  0.
2   0.  0.  0.  0.  0.
3   0.  0.  0.  0.  0.
4   0.  0.  0.  0.  0.
5  10. 20. 30.  0.  0.
6  20. 30. 30.  0.  0.
7  20. 30. 30.  0.  0.
8  IO. IO. 20.  0.  0.
9  10. 30. 40.  0.  0.
I0 10. 30. 50.  0.  0.
11 IO. 30. 60.  0.  0.
12 20. 20. 60.  0.  0.
13 20. 20. 50.  0.  0.
I4 10. 20. 30.  0.  0.
I5 10. IO. 20.  0.  0.
I6 IO. IO. 20.  0.  0.
I7  0.  0.  0.  0.  0.
I8  0.  0.  0.  0.  0.
I9  0.  0.  0.  0.  0.
20  0.  0.  0.  0.  0.
21  0.  0.  0.  0.  0.
22  0.  0.  0.  0.  0.
23  0.  0.  0.  0.  0.
24  0.  0.  0.  0.  0.
25  0.  0.  0.  0.  0.
26  0.  0.  0.  0.  0.
27  0.  0.  0.  0.  0.
28  0.  0.  0.  0.  0.
29  0.  0.  0.  0.  0.
30  0.  0.  0.  0.  0.
31  0.  0.  0.  0.  0.
32  0.  0.  0.  0.  0.
33  0.  0.  0.  0.  0.
34  0.  0.  0.  0.  0.
35  0.  0.  0.  O.  0.
36  0.  0.  0.  0.  0.
```

Figure 3-2a. Sample OCD Groups IO and II for three radial distances. Each line is free formatted.

```
Column   Number
123456789012345678901234567890123456789012~567
REC.   I       8.74      9.80        0.        50.      100.
REC.   2       9.50     10.76        0.       100.      100.
REC.   3       6.58      9.20        0.        10.        0.
REC.   4       4.68     10.76        0.        10.        0.
REC.   5       4.10     13.48        0.       300.      300.
REC.   6       3.36     12.48        0.        50.      300.
ENDR
```

Figure 3-2b. Sample OCD Group I2 for discrete receptors. Each line is formatted as per Table 3-5. The first two lines indicate the column number and are only for the user's benefit. These two lines should not be input to the model.




Contour Interval
50 m

Figure 3-3. Graphical representation of the method used to estimate **HTER**.

### 3.2.3 Overland Meteorological Data

The meteorological data representing overland conditions can be provided by the user in the same manner as for all standard EPA models. The data can be provided in either of two forms:

- a binary data file prepared with the RAMMET preprocessor (as described in the CRSTER (EPA, 1977) manual) (Note: Wind direction is a flow vector the OCD model converts to a wind direction); or
- hourly data in card-image format, with the values arranged in the following order (free format):

  year,
  Julian day,
  hour,
  stability class,
  wind speed (m/s),
  ambient temperature (°K),
  wind direction from which the wind blows (degrees), and
  mixing height (m).

If an overland meteorological input file is prepared by the EPA preprocessor RAMMET and the starting data is not at the beginning of the data set, the data in the overland input file is read until the starting data are found. At the same time, hourly data in the overwater meteorological input file and the emissions file, if available, are read and discarded. The OCD model checks the dates and time of all input files being used to ensure that the dates and hours agree with each other.

If the overland meteorological data are not in binary format (OCD group 14), then the first data record determines the starting date and hour. The first record of the overwater and emissions data files must start at the same hour.

The overland anemometer height above ground level and the representative surface roughness length are specified in Group 6. The surface roughness length should be estimated from an examination of vegetation and other obstacles to wind flow within a 3-km radius of the anemometer site. Table 3-8 lists typical surface roughness lengths for various types of environments. A composite value for the site in question can be obtained by weighting the

TABLE 3-8

TYPICAL SURFACE ROUGHNESS LENGTHS[1] FOR VARIOUS GROUND COVERS

| Ground Cover | Surface Roughness Length, meters |
|---|---|
| water surface[2] | 0.00001-0.004 |
| snow surface | 0.0005-0.001 |
| fallow field or low grass | 0.01-0.03 |
| high grass | 0.03-0.10 |
| desert, sand dunes | 0.05-0.10 |
| flat rural, few trees[3] | 0.003-0.03 |
| rural, rolling terrain, few trees[3] | 0.01-0.15 |
| woods[3] | 1.00 |
| suburban[3] | 0.5-1.5 |
| urban[3] | 1.5-4.0 |
| dense vegetation cover | 1/8 of the average canopy height[4] |

[1] Reference: Counihan (1975), Priestley (1959), Hess (1959)

[2] roughness length increases with increasing wind speed

[3] roughness length increases for taller or more closely spaced obstacles to wind flow, or for higher terrain obstacles.

[4] Brutsaert (19751

value for each type of ground cover according to its fraction of area coverage near the site. Accuracy to within a factor of 2 is acceptable, since the OCD model uses the logarithm of the surface roughness length.

As explained in Section 2, the wind speed profile exponents that are commonly used in many EPA air quality models are not used in the OCD model. If the overwater $d\theta/dz$ is greater than zero and the terrain (HTER) in the vicinity of the modeled receptor is greater than zero, then the plume path

correction (PPC) factor is determined internally within the model depending on whether the plume is above or below the critical dividing streamline height. Otherwise, the model uses the stability-dependent PPC factors which are defaulted in the model. A value of 1.0 for the PPC factor allows full response of the plume to terrain factors, i.e., it simulates the plume rising over terrain features. A value of zero simulates plumes that level off and remain at the same mean-sea-level elevation. A minimum miss distance for a plume in rough terrain is specified for the OCD model through OCD Group 5. Closer plume centerline approaches to the ground are not allowed in the model. EPA currently recommends using a minimum miss distance of 10 m. The local MMS agency should be contacted concerning the input value of the minimum miss distance.

If turbulence intensity data representative of overland conditions are available, the user is encouraged to use the on-site data in lieu of the Briggs (19731 rural coefficients which the model defaults to. The turbulence intensity values should be measured as close to a typical plume height level as possible. If the overland turbulence intensity values are used by OCD but are missing for a given hour, default values from the Briggs curves are substituted. Computation of $\sigma_y$ and $\sigma_z$ values are discussed in more detail in Section 2. If overland turbulence intensity data are available, they must be input to OCD via an auxiliary file (see Table 3-7).

In the OCD model, overwater observations of wind direction and wind speed are assumed to apply to both overwater and overland areas. If on-site meteorological observations over the water are not available, then hourly overland values are used. If overwater measurements of wind direction and wind speed are available, then the only overland meteorological data used in the OCD model is the overland stability class, temperature, and turbulence data (optional).

### 3.2.4 Overwater Meteorological Data

The OCD model requires knowledge of the overwater boundary layer. In general, wind speeds are higher, turbulence intensities are lower, and afternoon mixing depths are lower over water than over land. Stabilities are usually much closer to neutral over water and bear little relation to Pasquill-Gifford stability classes determined over land. In fact, the boundary layer is often unstable at night and stable in the daytime over water.

A complete set of overwater meteorological data includes hourly observations of the parameters listed below:

- wind direction,
- wind speed ($u$),
- mixing height ($z_i$),
- relative humidity (RH),
- air temperature ($T_a$),
- surface water temperature ($T_s$),
- vertical wind direction shear ($\Delta WD/\Delta z$),
- vertical temperature gradient ($d\Theta/dz$), and
- turbulence intensities, horizontal and vertical components ($i_y$, $i_z$).

The overwater mixing height, overwater humidity (relative humidity, wet bulb temperature, or dew point temperature), overwater air temperature, and the water surface temperature (or air minus water temperature) must be available for every modeled hour in order to run the OCD model. There are no defaults for these four parameters. It is the user's responsibility to provide a complete overwater meteorological data set containing the above mandatory information. A discussion of available meteorological data for offshore sources is presented in Appendix C, Offshore Meteorological Data Collection Instrumentation.

A 10-m measurement height for all parameters except $i_Y$ and $i_z$ is desirable, but the model will accept measurements from other (usually higher) heights. The complete set of these data will be taken only during research-grade diffusion experiments, but the OCD model is sufficiently general to handle incomplete data bases.

In the absence of any information on overwater stability, the OCD model will estimate the Monin-Obukhov length from hourly values of overwater $T_a$, RH, u, and $T_s$. The calculation of overwater stability is very sensitive to the air-water temperature difference, $T_a - T_s$. When this difference is close to zero, a one degree error in either $T_a$ or $T_s$ can cause the calculated stability to change from stable to unstable. For this reason, it is recommended that $T_a$ and $T_s$ observations be input directly to the model only if the measurements are taken at the same place and time, e.g., on an automated buoy or on an oil platform. In the absence of such measurements, $T_a - T_s$ can be estimated or can be set equal to 0.0 as a first approximation.

If possible, the water and air temperature difference measurement should be obtained by a thermocouple device linking the two measurement heights, rather than by the use of two independent thermometers. The error in the calibration of individual thermometers may be of the same magnitude as the temperature difference required as input to the OCD model. A discussion of available meteorological instrumentation and data collection systems is presented in Appendix C.

If the overwater wind speed is not known, it can be estimated by default within the model from on-shore measurements using a simple empirical relation devised by Hsu (19811:

$$u_{sea} = 3u_{land}^{2/3} \tag{3-1}$$

where u is in m/s. The OCD model will adjust any final wind speeds up to 1 m/s if the-value is less than 1 m/s. This formula is based on data from several outer continental shelf regions and leads to $u_{sea}/u_{land}$ equal to about 1.75 for $u_{land}$ equal to 5 m/s. In any case, the sea and land wind speeds are assumed equal so as to prevent unrealistic mass-convergence or divergence at the coastal zone. For land sources, IOPT(24) in OCD Group 5 (see Table 3-1) should be set to 1 so that wind speeds are not altered.

The minimum onshore wind speeds input to the model should NOT be limited to 1 m/s if these data are to be used to calculate offshore wind speeds. The user is cautioned that the EPA preprocessor **RAMMET** limits wind speeds to 1 m/s.

There are no simple methods for extrapolating wind directions offshore. The OCD model arbitrarily sets the land and sea wind directions equal to each other.

The wind, temperature, and turbulence profiles in the marine environment are used to determine overwater plume transport and dispersion. Wind speed, overwater and water surface temperatures, and overwater relative humidity can be used to estimate complete profiles of all variables using boundary layer theory. The difference between the air and sea temperature is of particular importance. The absolute values of these temperatures are not as critical, although they do slightly affect the computations of plume buoyancy and moisture flux between the air and the sea.

The development of the algorithm for computing the Monin-Obukhov length is based upon measurements of wind, temperature, and humidity at a height of 10 m above sea level. The OCD model scales measurements taken at other heights to the 10 m level. Optimum results are obtained for measurements taken as close to 10 meters as possible, but satisfactory results can be obtained for measurements at heights up to 100 meters.

Measurements of the horizontal component of turbulence intensity are recommended. Such measurements should be taken over the water rather than at or near the shore because significant changes in the turbulence intensity can occur as air flow approaches the shoreline.

Because accurate measurements of $\sigma_w$ are difficult to obtain on a floating platform subjected to sea motion, the user is encouraged to use default values for $\sigma_w$. Tests have shown that the OCD model performs better using predicted vertical turbulence intensity values rather than measured values (See Section **4)**.

The mixing height is difficult to measure and the model is relatively sensitive to mixing height, which can be 100 m or less over the sea. The plume from a low level source will become uniformly mixed in such a shallow layer before it has traveled more than 5 or 10 km. Measurement of mixing heights at sea or at the shoreline with an acoustic sounder or radiosonde ascents should be considered.

Hourly measurements of vertical wind directional shear ($\Delta WD/\Delta z$) or vertical potential temperature gradient ($d\Theta/dz$) are usually available only for research-grade experiments, but may be feasible on the support structure of an elevated platform. The vertical wind directional shear is set to zero if it is not available. The vertical potential temperature gradient is computed from the Monin-Obukhov length if it is not measured. The measured or parameterized value of $d\Theta/dz$ becomes important in very stable conditions, when the vertical plume spread is a function of $d\Theta/dz$. If strong inversions are expected at a particular site, $d\Theta/dz$ should be measured by instruments on the platform structure or ship.

### 3.2.5 Specification of the Land-Sea Interface

In order to simulate the transition between marine and land-based environments, the OCD model must be given detailed knowledge of the shoreline. The form of this input information is complicated by the fact that multiple sources must be considered and by the often complex nature of the shoreline itself. Such features as bays, inlets, lagoons, barrier islands, and peninsulas are often present. A general approach adopted for the OCD model is to require the user to overlay a grid on the area of interest, and to specify presence of mostly land or water in each grid rectangle. The following rules and limitations apply to this land/water mapping:

- the grid elements are rectangles, oriented north-south (y axis) and east-west (x axis); the x and y lengths of a grid rectangle may be different;
- a variable number of rectangles can be specified along the x and y axes, subject to a maximum of 60 in either direction;
- the mapped area must include all of the coastline transition zone of interest;
- the grid size should be small enough so that good shoreline resolution is attained;
- $\Delta X$ = 0.05 to 0.08 km and $\Delta y$ = 0.03 to 0.06 km for average distance from source to shoreline $\leq$ 2.0 km; and

- AX= 0.2 to 0.4 km and Ay = 0.1 to 0.3 km for average distance from source to shoreline > 2.0 km. For OCS activities which occur three or more miles offshore, these grid limitations should be used.

An example of how an area of interest is to be mapped is shown in Figure 3-4. A grid has been overlaid on the portion of the shoreline which is to be modeled. Note that the grid overlay does not have to include the receptors and/or sources which are to be modeled. For each rectangle, the user must decide whether land or water dominates. The grid information is input to OCD via Group 15. Although it is not necessary for receptors or sources to be located on the grid, it is very important that a gridded land sector be included between all sources and overland receptors; otherwise, the model assumes the receptor is over water.

A sample card Group 15 that represents the area in Figure 3-4 is shown in Figure 3-5. The first line of input in Figure 3-5 contains the free-formatted x and y coordinates of the upper left (northwest) corner of the mapped area, the number of grid rectangles along the x and y axis, the Ax and Ay lengths of each grid rectangle, the minimum along wind distance, and the average distance from the source to shoreline. The average distance is only used to determine the appropriate grid values. The user only needs to determine whether or not the average distance from the source to the shoreline is less than or greater than 2 km. All distances are in user units. Since there are no islands or peninsulas, a nominal value of 1 km has been used for the minimum along wind distance. The land/water designations for each grid rectangle follow, with one entire row of information input per line starting at the top of the map. Each line consists of a series of the letters "L" and "W," representing land and water, respectively, and proceeding from left to right. For any given row, persistence may be used for either land or water. That is, blanks are interpreted as a continuation of the last "L" or "W" specified to the left. The first column of each line (row) must be designated as "L" or "W" to start with.

The OCD model prints the map information so that the user can check the distribution of land and water features (see Figure 3-6). The map scale may be distorted on the printout, even if Ax and Ay are the same, with the x axis being stretched by a factor of about 1.2. The OCD model shows locations of

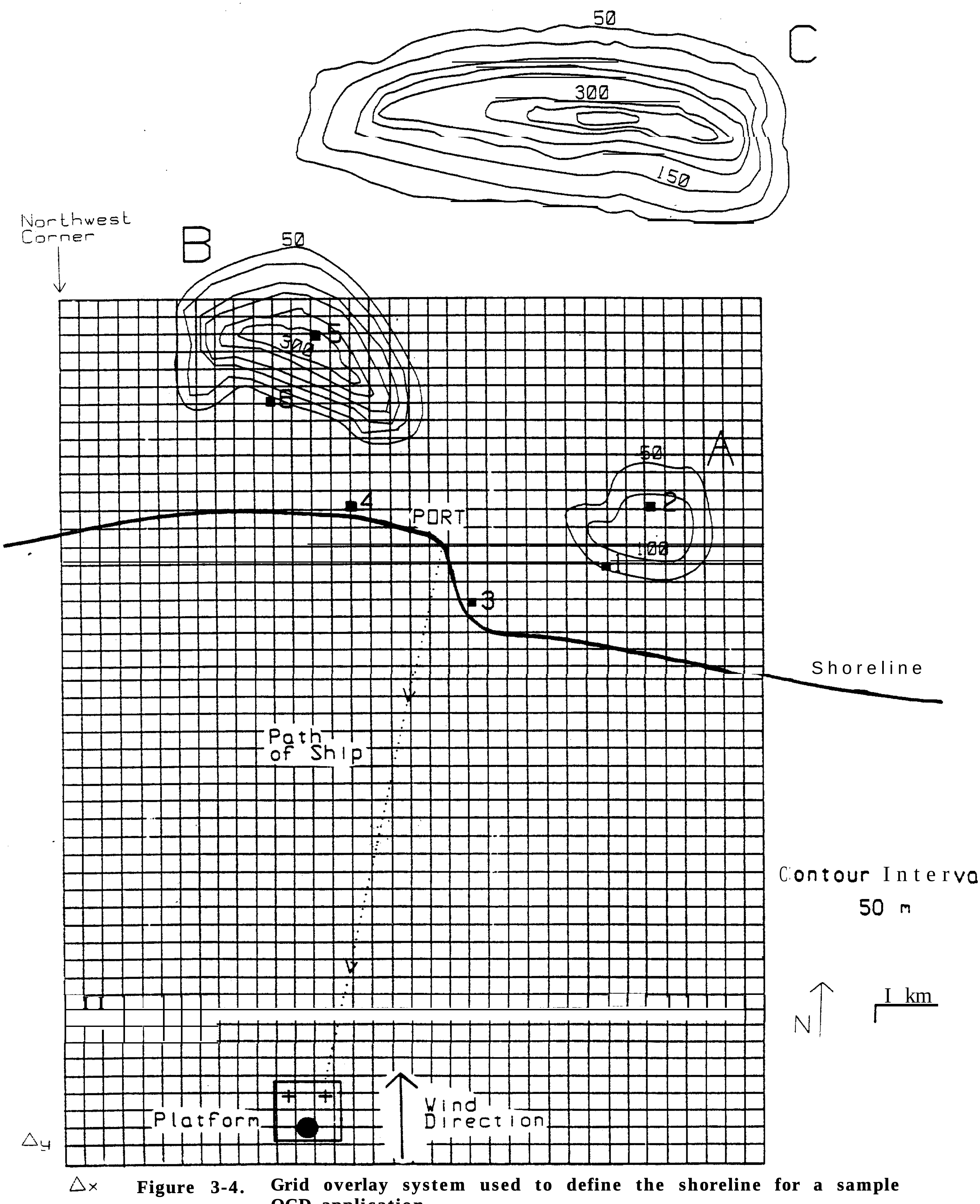



**Figure 3-4. Grid overlay system used to define the shoreline for a sample OCD application.**

```
0.0 14.1 36 50 0.313 0.282 1. 9.
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
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LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLL LLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLW         WLLLLLLLLLLLLLLLLLLLLL
W                WLLLLLLLLLLLLLLLLLL
W                 WLLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                   WLLLLLLLLLLLLLLL
W                    WLLLLLLLLLLLLLL
W                        WLLLLLLLLLL
W                             WLLLLL
W                                 WL
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
ENDS
```

Figure 3-5. Sample OCD Group 15 input stream for the example shown in Figure 3-4.

```
LAND-WATER MPP ING:
COORDINATES OF THE NORTHWEST CORNER OF THE MAP IN USER UNITS ARE (      0.000,      14.100)
# OF GRID RECTANGLES ALONG THE X-AXIS (I.E., THE NUMBER OF GRID COLUMNS) = 36
# OF GRID RECTANGLES ALONG THE Y-AXIS (I.E., THE NUMBER OF GRID ROWS) = SO
LENGTH OF THE (X,Y) SIDES OF A GRID RECTANGLE (USER UNITS) = (      0.313,      0.2821, OR (      0.113,      0.282) KM.
MINIMUM SIGNIFICANT WIDTH OF LAND OR WATER BODY ALONG WIND DIRECTION (USER UNITS) =      1.000
AVERAGE DISTANCE BETWEEN SOURCE AND SHORELINE (USER UNITS) =      9.000

MAP OF USER-SPECIFIED LAND/WATER DISTRIBUTION; L = LAND AREA, (BLANK) = WATER AREA
RANGE OF X:     0,000 TO    11.268; RANGE OF Y:     0.000 TO    14.100:   GRID (X,Y) LENGTHS = (     0.313,     0.282) USER UNITS


●   L L L L L L L L L L L L L L L L L L L ' L L L L L L L L L L L L L L +
L L L L L L L L  L L L L L L L L L  L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L  L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L  L L L L L L L L L L L L L L L L L L L L
L L L  L L L L L  L L L L L L  L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L  L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L  L L L L L L L L L L L L L L L L L
L L L L L L L L L  L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L                       L L L L L L L L L L L L L L L L L L L L L
                                    L L L L L L L L L L L L L L L L L L
                                      L L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                          L L L L L L L L L L L L L L L
                                            L L L L L L L L L L L L L L
                                                    L L L L L L L L L L
                                                              L L L L L
                                                                      L
```

Figure 3-6. OCD Representation of User-Specified Land/Water distribution map.

point sources and receptors on the map (see examples in Section 3.61, using the symbol "S" for the source and "*" for the receptor.

The mapped area should be chosen carefully to cover the entire shoreline between all sources and all receptors with the greatest possible resolution. For a relatively straight shoreline oriented in a N-S or E-W direction, the resolution can be maximized by minimizing the grid length of whichever dimension is perpendicular to the shore. The uncertainty in the model representation of the location of the shoreline can be as large as one-half the length of the rectangle's x or y dimension, whichever is perpendicular to the shoreline.

There is a natural uncertainty in shoreline location (for ocean coasts) due to tides. Tidal effects vary widely from place to place depending on such effects as local shoreline topography and tidal range (the difference in sea level between high and low tide). The tidal range varies with the phases of the moon, peaking at new and full moons. In addition, storm surges can greatly raise the water level, especially if the peak of the storm coincides with high tide and even more so during full or new moons. Nautical charts show the shoreline at both mean high water and mean low water. For model input purposes, the average between these positions should be chosen. Preferably, the grid should be chosen so that the error in the grid representation is similar in magnitude to the natural variability of the shoreline. Note that the extreme limits of the shoreline are far greater than those shown on the charts, which are mean high and low tide marks, due to the factors mentioned above.

Many areas of the Atlantic and Gulf coasts have barrier islands or spits separated from the mainland by lagoons and salt marshes. In these areas the distinction between land and water is somewhat blurred. Salt marshes, however, should be input as land since they are mainly covered with grasses, and therefore have the roughness characteristics of land, even though the latent heat fluxes are likely to be much higher. Lagoons should be input as water even though the boundary layer over lagoons is probably very different than that over open ocean, primarily due to warmer water temperatures and lower roughness.

Such features as barrier beaches and lagoons complicate the model shoreline definition since OCD considers only one transition from water to land. The question arises as to which shoreline should be considered to be the controlling transition for defining dispersive turbulence regimes. This depends on the width, along the wind direction, of the underlying land or water. For instance, if a plume crosses a very narrow barrier beach and then a wide lagoon, the shore of the lagoon (on the mainland side) should be considered as the controlling shoreline. For the opposite case, where the plume crosses a relatively wide barrier beach and narrow lagoon, the outer beach should be considered as the shoreline. The nature of these crossings may vary greatly depending upon wind direction. To enable the model to neglect insignificant water bodies or land masses, the user is required to select a value for the minimum significant distance (see OCD Group 15 in Section 3.11. As the model determines the position of each transition along the plume path, it also computes the distance between adjacent transitions. If this distance is less than the minimum value, both transitions are neglected. Therefore, this is an important parameter for specifying how the model treats complex shorelines.

In choosing the minimum width, the user should consider the estimated plume height and the slope of the TIBL, which is 0.1 up to a height of 200 m. If the distance between shorelines is less than ten times the plume height, the plume will not enter the TIBL until after it has crossed the second shoreline. Therefore, as a guideline value for the minimum significant distance, we suggest a maximum of ten times the estimated plume height.

### 3.2.6 Model Options

The OCD model has 25 main options (OCD Group 5) and 9 special options (OCD Group 13) relating to the availability of overwater data. Main options 1 to 4 deal with technical features such as terrain adjustment, stack-tip downwash, gradual plume rise, and buoyancy-induced dispersion. Main option 6 is used to read hourly emissions data as described in Section 3.1.

The main options concerning printed output should be selected with care. For a production run of the OCD model, all printout relating to hourly and averaging period summaries should be suppressed (specify "1" for main options 9-18). The average concentrations and high-five table produced using main option 19 are useful, although these can also be provided by the ANALYSIS postprocessor.

Main option 20 controls the source type: point, area, or line source.

Main options 21-23 control certain printed output. Option 21 is used by OCD to create a summary output file named "EXTRA.OUT" which prints out hourly concentrations along with other important model parameters. This output file should be used by the user who wishes to avoid the voluminous "OCD.OUT" file. Main option 22 is used by OCD to write the concentration files to disk. For each hour, concentrations for each receptor are written to disk (in grams per cubic meter) preceded by 4 integers summarizing the hour's meteorology: overwater mixing height, overwater wind direction and wind speed, and overwater stability class. The output file name is "CONC.BIN." The resulting file can be used directly as input to the ANALYSIS postprocessor. Main option 23 is set to 1 if a table of annual impact assessment from non-permanent activities is desired. For example, the annual impacts from a 30-day modeled operation would be tabulated.

Option 24 should be set if the source is overland. The wind speed is not modified as per Equation (3-1).

Main option 25 is set to 1 if pollutant decay is to be considered. If so, the site latitude, longitude, and time zone information as well as monthly climatological values of daytime decay rates (%/hour) must be provided in group 15.

### 3.2.7 Recommendations for Screening Runs and General Use

The OCD model can be used for the following situations:

- all modeled stationary sources (point or area) and receptors located offshore (no land features need be present for an OCD run);
- any combination of stationary sources located offshore or on land near the coast (with coastline resolution limitations taken into account);
- any combination of receptors located at sea or on land; and
- modeling of line sources limited to screening type analyses of 24 hours or less.

The **grid resolution** is the only limit to the complexity of the shoreline that can be modeled. However, islands and other intervening land masses between a source and a receptor may be ignored (treated as water) depending on their width. The definition of small coastline features is limited to the grid resolution. The OCD model should not be used for inland areas where the plume is below the TIBL and overwater dispersion is not occurring. Other air quality models (such as **MPTER)** exist that are suitable for such situations.

Use of the OCD model is not restricted to certain latitudes or regions of the world. The model is quite applicable, for example, in polar regions such as coastal and offshore areas in the vicinity of Alaska. Offshore areas that are ice-covered should be treated as ice-covered land areas because characteristics of sensible and latent heat transfer over an ice surface more closely resemble overland behavior. However, the choice of a stability class over this surface (external to the OCD model) should take into account the surface roughness and albedo characteristics over ice. The standard Pasquill-Gifford-Turner stability classification method is not adequate for ice-covered surfaces. If ice coverage varies significantly during the year, the OCD model should be run separately on a seasonal basis.

As the distance between a source and receptor increases, the assumption of steady-state conditions becomes less valid. For example, with a 2 m/s transport wind speed, the plume requires 4 hours to travel about 30 kilometers. For very long plume travel distances (such as 50 km and beyond1 or very low wind speeds, the assumption of steady-state conditions is likely to lead to conservative (high) concentration estimates.

The location and magnitude of.maximum modeled concentrations will depend . upon the number and distribution of model receptors. Determining appropriate receptor locations where the maximum concentrations would be expected requires some preliminary investigation. A short OCD run should be conducted with one row of model receptors covering a direction in which high concentrations are expected. Such a direction would probably involve the shortest distance between the source and the shoreline, and would be covered by closely-spaced model receptors. Input meteorology similar to that for **EPA's** PTPLU screening model can be used. For the OCD model, both overland and overwater input data are needed. For line sources, only 24 hours or less of screening analyses may be conducted. As described in Section 2.10, each line source is modeled as ten separate point sources. Ten "periods" of meteorology (land and water) must be input. It is recommended that OCD be run using the same set of meteorology for each of the ten periods. Then, separate OCD runs may be made as the screening meteorology changes.

For point and area sources, the deployment of model receptors for a run involving a long period of meteorological data should be based upon the screening results. Receptors should be placed at the critical inland distances or at the critical radial distances from the source for each of 36 directions with a 10° spacing. Other receptors might be placed at locations subject to lineup of 2 or more sources. If the OCD model is being run for regulatory purposes, the advice of the appropriate MMS regional meteorologist is recommended.

The user is urged to obtain as much representative overwater data as possible to improve the accuracy of the model results. In addition, hourly overland turbulence intensity data can be input to the OCD model on the same line with the overwater data. Specifications for the format of this data are given in Section 3.1.

## 3.3 OCD Output

### 3.3.1 Printed Output

The printed output consists of the following sections:

1) Mandatory output that prints all input options and specifications of sources, receptors, and land/sea map.

2) Output for each hour or averaging period which can include meteorological summaries, contributions of each significant source to total concentrations, the concentrations at each receptor, and case-study printout of plume transport and dispersion.

31 Average concentrations and a high-five table for the entire run.

Item 2 of the output listed above should be deleted for production runs of the OCD model. However, Item 2 is useful for study of model results for a short time period. The printout of hourly meteorology and the case-study display of plume transport and dispersion is unique to the OCD model because of its consideration of conditions over both land and water. An example of this printout is shown in Section 3.6. For each stack-receptor pair for which the plume's lateral miss distance is not extremely large, the OCD model prints information about several model components:

- the plume's axis position relative to the receptor location;
- the plume's height above the ground at the receptor location;
- distance to the shoreline;
- components of $\sigma_Y$ and $\sigma_Z$;
- horizontal and vertical terms in the Gaussian equation;
- the calculated concentration at the receptor;
- the effect of chemical transformation of the pollutant, terrain correction, and reflection adjustment; and
- the overland mixing height.

In addition, information about plume rise is included:

- effects of building downwash;
- momentum and buoyancy rise;
- stack-specific turbulence intensity values (a function of height);
- distance to final rise.

The user also has the option to print out an abbreviated listing of the OCD results using **IOPT(21)** of OCD Group 5 (see Table 3-1). If **IOPT(21)** is set to 1, a file named **"EXTRA.OUT"** is created which only contains one line of information per receptor per hour modeled. No input information is listed.

### 3.3.2 Disk File Output

If main option 22 in group 5 is set to 1, the OCD model writes hourly meteorological and receptor concentration data to disk or tape in binary form. Each hour's output contains 4 integer values relating to meteorological input data:

- overwater **mixing height,**
- overwater wind direction,
- overwater wind speed, and
- overwater stability class.

The four integer values are followed by modeled concentrations (in grams per cubic meter) for each receptor. The output file created is named

"CONC.BIN." The file created by this output procedure can be used directly by the ANALYSIS postprocessor (Appendix B).

### 3.3.3 Error Messages and Remedial Action

Eighteen error messages can be generated by OCD. Each of these will terminate program execution with STOP.

**Error Message 1** SET 0154

The first error message occurs if the user specifies the number of sources to be significant as more than 25 on OCD Group 4. The following error message is printed:

> NSIGP (THE NO. OF SIGNF POINT SOURCES) WAS FOUND TO EXCEED THE LIMIT (25). USER TRIED TO INPUT xxx SOURCES ********* EXECUTION TERMINATED **********

where xxx is the value put on Group 4 for the variable NSIGP.

The corrective action is to change the value of NSIGP on Group 4 to a value of 25 or less.

Error Message 2 SRE 0127

The second error message occurs if the user attempts to input more than the maximum number of point sources (250), or forgets to place an 'ENDPOINT' card following the last point source. The following error message is printed:

> USER TRIED TO INPUT MORE THAN 250 POINT SOURCES. THIS GOES BEYOND THE CURRENT PROGRAM DIMENSIONS.

The corrective action is to reduce the number of sources to 250 and/or to put the 'ENDPOINT' card behind the 250th source.

### Error Message 3

The third error message is printed if no sources were specified:

```
NPT = xxx I.E., EQUAL OR LESS THAN ZERO RUN TERMINATED ----
CHECK INPUT DATA
```

where xxx will be zero.

The corrective action is to revise the run stream so that it includes data for at least one point source.

### Error Message 4

The fourth error message is written when Option 7 is employed by the user to specify numbers of sources he wants to be considered as significant, but he specifies a number larger than the number of significant sources allowed for the run (NSIGP). The following error message is printed:

```
***ERROR --- USER TRIED TO SPECIFY xxx SIGNIFICANT SOURCES,
BUT IS ONLY ALLOWING yyy TOTAL SIGNIFICANT SOURCES IN THIS RUN.
*** RUN TERMINATED - CHECK INPUT DATA! ***
```

where xxx is the value of NPT from Group 8 and yyy is the value of NSIGP from Group 4.

The corrective action is to increase NSIGP (not to exceed 251 or to decrease the value of INPT to equal or less than NSIGP, and to eliminate all but that number **(INPT)** of sources on Group 8 following the value of INPT.

### Error Message 5

The fifth error message is written when Option 5 is zero, requiring meteorological data to be read from a tape or disk file. If the surface station identification and the year read from Group 9 do not match those given in the first record on the file, the following error message is printed:

SURFACE DATA IDENTIFIERS READ INTO MODEL (STATION = xxxxx, YEAR = yy) DO NOT AGREE WITH THE PREPROCESSOR OUTPUT FILE (STATION = wwwww, YEAR = zz)

where xxxxx and yy are read in on Group 9, and wwwww and zz are from the file.

Corrective action is to substitute the proper desired file or to change the identifiers on the card to match the data. The user should be careful to use the most representative meteorological data available.

**Error Message 6** MTC 0043

The sixth error message is similar to message six, occurring when meteorological data are read from a file when Option 5 is zero. If the upper air station identification for the station used to calculate mixing height and the year read from Group 9 do not match those given in the first record on the file, the following error message is printed:

MIXING HEIGHT IDENTIFIERS READ INTO MODEL (STATION = xxxxx, YEAR= yy) DO NOT AGREE WITH THE PREPROCESSOR OUTPUT FILE (STATION = wwwww, YEAR = zz)

Corrective action is to substitute the proper desired file or to change the identifiers on the card to match the data. The user should be careful to use the most representative meteorological data available.

**Error Message 7** PSL 0101

The seventh error message'occurs if both Option 1 for terrain and Option 8 to generate receptors equal 1 and the 36 elevation cards (Group 11) are out of sequence, or have been punched incorrectly. If the numbers 1 through 36 on the cards do not match the internally generated numbers 1 through 36, the following message is printed:

WRONG RECEPTOR ELEVATION CARD READ. READ CARD FOR AZIMUTH xxx SHOULD HAVE BEEN yyy.

The corrective action is to check the sequencing and formatting of all Group 11 cards and to correct any errors.

**Error Message 8**

The eighth error message occurs if the user attempts to enter more than 180 receptors or failed to place an 'ENDREC' card after the 180th receptor was generated or read. In other words, the user failed to put this card behind the last Group 11 card if 180 polar coordinate receptors were generated, or behind the Group 12 which generates the 180th receptor. The following message is printed:

> **** USER EITHER TRIED TO INPUT MORE THAN 180 RECEPTORS OR ENDREC WAS NOT PLACED AFTER THE LAST RECEPTOR CARD **** ******** EXECUTION TERMINATED *******

The corrective action is to reduce the number of receptors to no more than 180 and to place an ENDREC card at the proper place.

**Error Message 9**

The ninth error message occurs if no receptors have been generated or read in:

> NO RECEPTORS HAVE BEEN CHOSEN

The corrective action is to restructure the input run stream so that receptors are generated or read.

**Error Message 10**

The tenth error message occurs if Option 5 is zero, requiring meteorological data to be read from a file. If either the year or Julian day in the program execution does not match the year or day on the record on the meteorological data, the following message is printed:

> DATE ON MET. TAPE, yyddd, DOES NOT MATCH INTERNAL DATE, wwzzz

where yyddd are the year and day from the meteorological file and wwzzz are the year and day -generated in the execution of the program.

The corrective action is to determine the cause and correct the runstream, or the meteorological file, or both.

**Error Message 11** DAY 0011

The eleventh error message occurs if a value for the start hour of a period becomes zero or negative. The following message is printed:

> HOUR xxx IS NOT PERMITTED. HOURS MUST BE DEFINED BETWEEN
> 1 AND 24

where xxx is the value of IHSTBT.

The corrective action is to check the value of IHSTBT in Group 4.

**Error Message 12** HRC 0116

The twelfth error message occurs using Option 6 of Group 5 to read hourly emissions. If the combined year, Julian day and hour from the internal execution of the program do not match the similar date time group from the file, the following message is printed.

> DATE BEING PROCESSED IS = byydddhr DATE OF HOURLY POINT EMISSION
> RECORD IS = bxxeeeff *** PLEASE CHECK EMISSION RECORDS ***

The corrective action is to check the emission records or determine the reason why the internal date is in error.

**Error Message 13** SET 0157

The length of an averaging period must not exceed 24 hours due to computer core storage limitations. If the value of NAVG on Group 4 is out of range, an error message is printed:

NAVG (THE LENGTH OF AN AVERAGING PERIOD) WAS INPUT AS XXXX HOURS; IS NOT ALLOWED TO EXCEED 24 HOURS.

Error Message 14

Group 15 defines the land/water distribution. The number of grid rectangles along the x and y axis cannot exceed 60. If this rule is not followed, an error message is printed:

FATAL ERROR -- NX (XXX) AND/OR NY (XXX) ARE LARGER THAN 60 FOR LAND/WATER MAP. ---

**Error Message 15** SHR 0016

Group 15 must be terminated by an "ENDS". If this is missing or occurs prematurely, an error message is printed:

DELIMITER CARD "ENDS" NOT FOUND OR FOUND PREMATURELY AT END OF SHORELINE GEOMETRY SECTION.

**Error Message 16** AVL 0082

If overland meteorology is input, each hour must be in sequence for an OCD run. If the hours are out of sequence, an error message is printed:

FATAL ERROR: HOUR READ IN LAND METEOROLOGY INPUT FILE IS NOT IN SEQUENCE.

Error Message 17 ADD 0202

The date and hour associated with each overwater input record must agree with the data and hour of the overland data. If not, the following error message is printed:

DATE/HOUR OF LAND MET FILE (XX XXX XX) DOES NOT AGREE WITH DATE/HOUR OF OVERWATER MET FILE (XX XXX XX).

Error **Message** 18

If a premature end-of-file is encountered in the overwater meteorological data, an error message is printed:

END-OF-FILE ENCOUNTERED IN ADDITIONAL (OVERWATER1 METEOROLOGICAL DATA.
PROGRAM EXECUTION IS TERMINATED.

## 3.4 Program Modification for Other Computers

The OCD program is written in standard FORTRAN 77 and was compiled/tested using the Lahey Computer Systems, Inc. **Fortran** compiler (Version 3.001 and an IBM compatible computer. The Lahey compiler specific commands which must be changed in order to re-compile the program (if necessary) with other types of FORTRAN include:

CALL **UNDERO( LFLAG)** in the Main routine; line **OCDO4490**
This call checks all underflows (i.e., divide by zero).

The following OPEN statements in the subroutine SETUP may have to be changed depending upon the compiler:

```
OPEN(IN,FILE='INPUT.DAT',STATUS='OLD')                                        SET00370
OPEN(IO,FILE='OCD.OUT',STATUS='UNKNOWN',CARRIAGECONTROL='FORTRAN')SET00380
OPEN(15,FILE='EMIS.DAT',STATUS='OLD')                                         SET00890
OPEN(11,FILE='LMET.DAT',FORM='UNFORMATTED',STATUS='OLD')                      SET00900
OPEN( 7,FILE='EXTRA.OUT',STATUS='UNKNOWN')                                    SET00920
OPEN(12,FILE='CONC.BIN',FORM='UNFORMATTED',STATUS='UNKNOWN')                  SET00930
OPEN(13,FILE='WMET.DAT',STATUS='OLD')                                         SET00950
```

The following options were used in the compiling/testing of the OCD model:

Argument-list constants are protected
Remember **(SAVE)** local variables and arrays
INTEGER.4 as default
Line number traceback table generated
Adjustable arrays are not limited to 64K

## 3.5 Job Control Considerations

Several input and output files may be associated with a run of the OCD model. The contents of each file are summarized below.

| File Name | File Contents |
|---|---|
| INPUT.DAT | Input run stream (card types l-161 used to set model options and input values for sources, receptors, and land/sea distribution. |
| OCD.OUT | OCD printout; all model input options are printed, along with any user-requested summaries (hourly, for each averaging period, or for the entire run.) |
| EXTRA.OUT | Summary output file which lists hourly concentrations along with other important model parameters (one line of output per receptor per hour is produced). |
| LMET.DAT | Overland meteorology in binary format. |
| CONC.BIN | Binary file containing hourly concentrations at receptors plus an hourly summary of input meteorology. |
| WMET.DAT | User-created card-image file containing hourly overwater meteorology and overland turbulence intensity data. |
| EMIS.DAT | User-created card-image file containing hourly emissions data, 1 line per stack per hour. |

The mandatory and conditional input and output files from OCD are shown in Figure 3-7.

Computer speed comparisons of OCD/3 versus the revised OCD/4 model indicate that the new version of the model is five times faster than OCD/3. The costs of running OCD are proportional to the number of hours simulated, the number of sources, and the number of receptors. Costs can be kept to a minimum for a production run by deleting all hourly and averaging period summary output (set OCD Group 5 options 9 through 18 to "1"). Otherwise, a tremendous quantity of output may be generated.

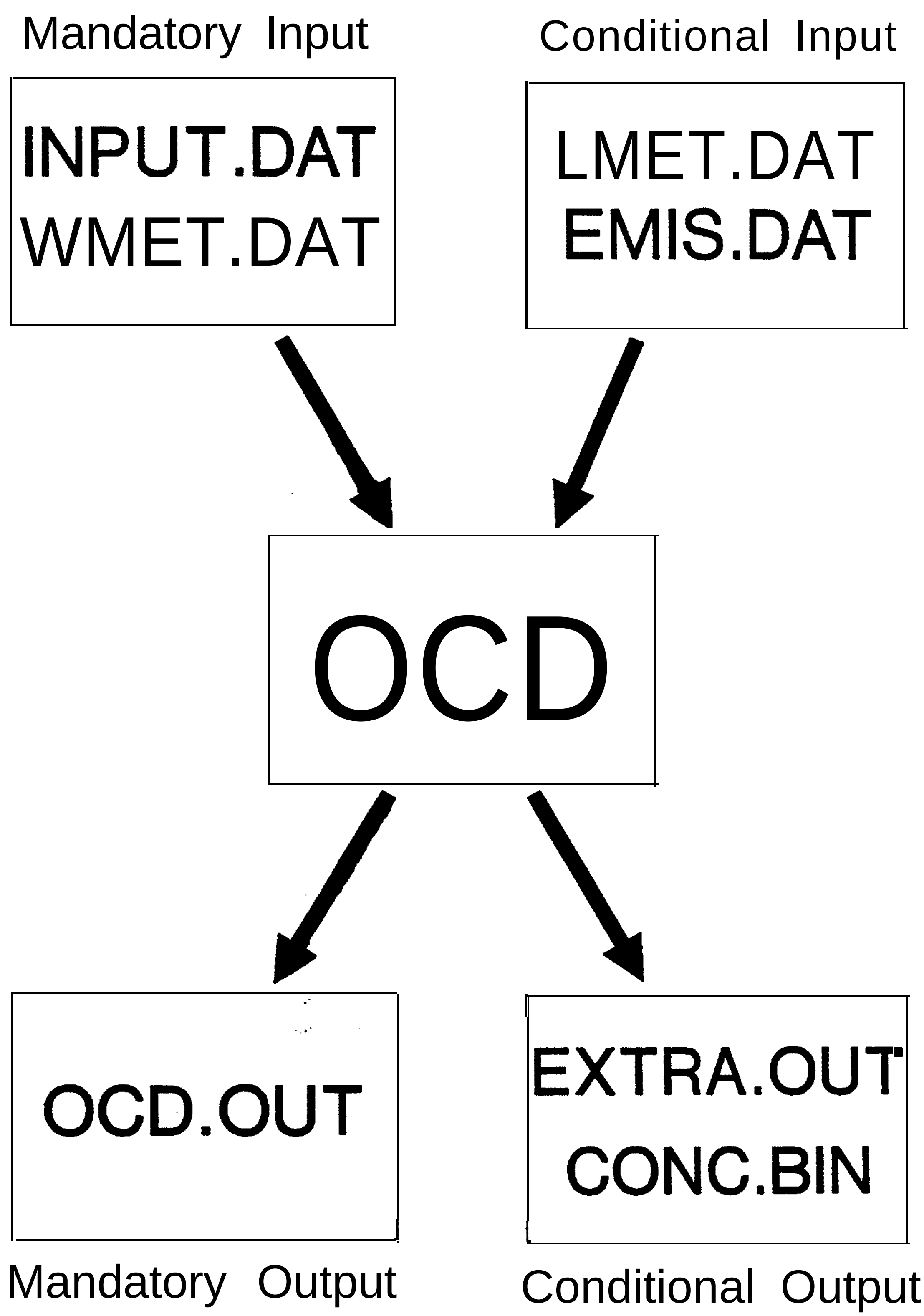


**Figure 3-7. Mandatory and conditional OCD input and output files.**

Prior to a production run, the user should test the OCD model for a few hours of input- and print out the results. For this test run, the use of the case-study printout capabilities is feasible. All input values to OCD should then be checked for accuracy. The map printout should be examined carefully to check the positions of land and water, sources, and receptors. Characteristics of plume transport and dispersion can be examined from the case-study printout.

### 3.6 Sample OCD Run

A sample of the OCD model that can be used to determine if the model has been properly installed on a user's computer system is presented in this section. The sample OCD run contained in this section is for a hypothetical installation consisting of one gas turbine, a flare, an area source contained on the platform, and a boat travelling from the port to the platform. The map shown in Figure 3-4 was used to defined the water/shore interface, and the source and receptor positions.

Each source type (Point, Area, and Line) must be modeled separately. The input run streams are presented in Figures 3-8 to 3-10. The additional (overwater) input meteorology are shown in Figure 3-11a for the point and area source test cases and in Figure 3-llb for the line source test case. The example is for one-hour using a southerly wind direction. Note that for the line source run, ten lines of meteorology must be input to the model for both the overland and overwater meteorological data. Each line of data corresponds to the line source segment. For this example, the same meteorology is assumed for all ten line segments. Printed output from the OCD model for the test case are shown in Figures 3-12 to 3-14. The total concentrations from all four sources are summarized in Table 3-10.

```
Column Number:
1234567890123456789012345678901234567890123456789012345678901234567
OCD TEST CASE 1
GENERATOR AND FLARE STACKS
10/31/89
88 1 1 1 1 5 10 1.0 1.0
1 0 1 1 1 0 1 0 1 1 1 1 1 1 1 1 1 0 1 0 1 0 0 0 0
10.0 0.10 10.0 29.9
GEN. STACK
3.91 0.75 0.4 10.0 15.0 477.0 0.5 65.0 90.0 20. 8.
FLARE
3.97 0.77 1.0 10.0 20.0 810.9 0.5 60.0 0.0 20. 8.
ENDP
1 1
REC.  1       8.74     9.80        0.        50.      100.
REC.  2       9.50    10.76        0.       100.      100.
REC.  3       6.58     9.20        0.        10.        0.
REC.  4       4.68    10.76        0.        10.        0.
REC.  5       4.10    13.48        0.       300.      300.
REC.  6       3.36    12.48        0.        SO.      300.
ENDR
 1 1 1 1  0 2  0 1 0 18.0 18.0
0.0 14.1  36 SO 0.313 0.282  1. 9.
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLW         WLLLLLLLLLLLLLLLLLLLLL
W                WLLLLLLLLLLLLLLLLLL
W                 WLLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                   WLLLLLLLLLLLLLLL
W                    WLLLLLLLLLLLLLL
W                        WLLLLLLLLLL
W                             WLLLLL
W                                 WL
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
ENDS
88 1 1 3 2.5 293.0 180 500
```

Figure 3-8. Sample point source input stream.

```
Column Number:
123456789012345678901234567890123456789012345678901234~67
OCD TEST CASE 2
AREA SOURCE
10/31/89
88 1 1 1 1 5 0 0 1.0 1.0
1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 0 1 1 1 0 0 0 0
10.0 0.10 10.0 29.9
AREA SOURCE
3.95 0.72 1.0 10.0 11.00 375. 20. 0.0 0.0 20. 0.0
ENDP
REC.     1     8.74     9.80     0.     50.     100.
REC.    2     9.50    10.76    0.     100.    loo.
REC.     3     6.58     9.20     0.     10.       0.
REC.    4     4.68     10.76    0.     10.       0.
REC.   5    4.    10    13.48    0.     300.    300.
REC.     6     3.36     12.48    0.     50.     300.
ENDR
1 1 1 1 0 2 0 1 0 18.0 18.0
0.0 14.1 36 50 0.313 0.282 1. 9.
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLW         WLLLLLLLLLLLLLLLLLLLLL
W                WLLLLLLLLLLLLLLLLLL
W                 WLLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                   WLLLLLLLLLLLLLLL
W                    WLLLLLLLLLLLLLL
W                        WLLLLLLLLLL
W                             WLLLLL
W                                 WL
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
ENDS
88 1 1 3 2.5 293.0 180 500
```

Figure 3-9. Sample area source input stream.

```
Column Number:
1234567890123456789012345678901234567690123456789012345678901236567
OCD TEST CASE 3
LINE SOURCE
10/31/89
88 1 1 1 1 5 0 0 1.0 1.0
1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 0 1 2 1 0 0 0 0
10.0  0.10  10.0  29.9
BOAT  SOURCE
6.18  10.10  4.0  0.0  2.0  750.  0.3  20.4  90.0  0.0  0.0
3.98  0.80
ENDP
REC.    1    8.74    9.80    0.      SO.     100.
REC.    2    9.50    10.76   0.      100.    100.
REC.    3    6.58    9.20    0.      10.     0.
REC.    4    4.68    10.76   0.      10.     0.
REC.    5    4.10    13.48   0.      300.    300.
REC.    6    3.36    12.48   0.      so.     300.
ENDR
1 1 1 10 2 0 1 0 18.0 18.0
0.0  14.1  36  SO  0.313  0.282  1.  9.
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
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LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
LLLLW         WLLLLLLLLLLLLLLLLLLLLL
W                WLLLLLLLLLLLLLLLLLL
W                 WLLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                  WLLLLLLLLLLLLLLLL
W                   WLLLLLLLLLLLLLLL
W                    WLLLLLLLLLLLLLL
W                        WLLLLLLLLLL
W                             WLLLLL
W                                 WL
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
W                                  W
WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
ENDS
88  1  1  3  2.5  293.0  180  500
88  1  2  3  2.5  293.0  180  500
88  1  3  3  2.5  293.0  180  500
88  1  4  3  2.5  293.0  180  500
88  1  5  3  2.5  293.0  180  500
88  1  6  3  2.5  293.0  180  500
88  1  7  3  2.5  293.0  180  500
88  1  8  3  2.5  293.0  180  500
88  1  9  3  2.5  293.0  180  500
88  1  10  3  2.5  293.0  180  500
```

Figure 3-10. Sample line source input stream.

```
88 1 1 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
```

Figure 3-lla. Sample overwater input meteorology file for point and area source test cases. The data are free formatted.

```
88 1 1 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 2 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 3 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 4 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 5 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 6 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 7 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 8 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 9 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
88 1 10 180.0 1.0 500.0 50.0 293.0 -1.0 0.0 0.03 0.02 0.03 0.02 0.0
```

Figure **3-11b.** Sample overwater input meteorology file for line source test case. The data are free formatted.

Figure 3-12. Sample output from OCD/4 for the point source test case presented in Section 3.6.

```
                    OFFSHORE AND COASTAL DISPERSION (OCD) MODEL, VERSION 4

                   OCD TEST CASE 1
                   GENERATOR AND FLARE STACKS
                   10/31/89
                          GENERAL INPUT INFORMATION

THIS RUN OF THE OCD MODEL IS FOR THE POLLUTANT NOX FOR    1  1-HOUR PERIODS.
CONCENTRATION ESTIMATES BEGIN ON HOUR- 1, JULIAN DAY- 1, YEAR-1988.
1.0 USER LENGTH UNIT IN THE HORIZONTAL =      1.0000000    KILOMETERS.
 1 SIGNIFICAXT SOURCES ARE TO BE CONSIDERED.
 THIS RUN WILL NOT CONSIDER ANY POLLUTANT LOSS.
1.0 USER LENGTH UNIT IN THE VERTICAL =      1.0000000   METERS.
   OPTION      OPTION LIST                    OPTION SPECIFICATION : 0= IGNORE OPTION
                                                                     1= USE OPTION
                    --TECHNICAL   OPTIONS--
     1        CONSIDER  TERRAIN  ADJUSTMENTS                           1
     2        DO NOT INCLUDE STACK DOWNWASH CALCULATIONS               0
     3        DO NOT INCLUDE GRADUAL PLUME RISE CALCULATIONS           1
     4        CALCULATE INITIAL PLUME SIZE DUE TO BUOYANCY             1
                    --INPUT   OPTIONS--
     5        READ MET DATA FROM CARDS                                 1
     6        READ HOURLY EMISSIONS                                    0
     7        SPECIFY  SIGNIFICANT  SOURCES                            1
     8        READ RADIAL DISTANCES TO GENERATE RECEPTORS              0
                    --PRINTED   OUTPUT   OPTIONS--
     9        DELETE EMISSIONS WITH HEIGHT TABLE                       1
    10        DELETE MET DATA SUMMARY FOR AVG PERIOD                   1
    11        DELETE  HOURLY  CONTRIBUTIONS                            1
    12        DELETE MET DATA ON HOURLY CONTRIBUTIONS                  1
    13        DELETE PLUME RISE/TRANSPORT ON HRLY CONTRIBUTIONS        1
    14        DELETE  HOURLY  SUMMARY                                  1
    15        DELETE MET DATA ON HRLY SUMMARY                          1
    16        DELETE PLUME RISE/TRANSPORT ON HRLY SUMMARY              1
    17        DELETE  AVG-PERIOD  CONTRIBUTIONS                        1
    18        DELETE  AVERAGING  PERIOD  SUMMARY                       0
    19        DELETE AVG CONCENTRATIONS AND HI-S TABLES                1
                    --OTHER CONTROL AND OUTPUT OPTIONS--
    20        SOURCE TYPE (O-POINT; l-AREA; 2=LINE)                    0
    21        CREATE SUMMARY OUTPUT FILE CALLED EXTRA.OUT              1
    22        WRITE HOURLY CONC TO DISK OR TAPE                        0
    23        CALCULATE ANNUAL IMPACT FROM NON-PERMANENT ACTIVITIES    0
    24        LAND SOURCE (DO NOT MODIFY WIND SPEED)                   0
    25   CALCULATE  POLLUTANT  CHEMICAL TRANSFORMATION RATE            0
  LAND ANEMOMETER HEIGHT (METERS) =      10.00
 LAND SURFACE ROUGHNESS LENGTH (METERS) =    0.10000

 MINIMUM DISTANCE FOR PLUME ABOVE TERRAIN (METERS) = 10.0
 LATITIDE OF SOURCE REGION (DEG) = 29.90
```

POINT SOURCE INFORMATION

| SOURCE | EAST COORD (USER UNITS) | NORTH' COORD | EMISSION RATE (G/SEC) | BUILDING HEIGHT (M) | STACK TOP HT (M) | STACK TEMP (K) | STACK DIAM (M) | EXIT VELOCITY (M/SEC) | STACK ANGLE (DEG FROM VERT) | GRD-LVL ELN. (USER HT UNITS) | BUOY FLUX (F) M**4/S**3 (CALCULATED) | BLDG WIDTH (M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 GEN. STACK | 3.910 | 0.750 | 0.40 | 10.00 | 15.0 | 477.0 | 0.5 | 65.0 | 90.0 | 20.00 | 15.37 | 8.00 |
| 2 FLARE | 3.970 | 0.770 | 1.00 | 10.00 | 20.0 | 810.9 | 0.5 | 60.0 | 0.0 | 20.00 | 23.49 | 8.00 |

SIGNIFICANT NOX POINT SOURCES

| RANK | CHI-MAX (MICROGRAMS/M**3) | SOURCE NO. |
|---|---|---|
| 1 | 5.51 | 2 |

ADDITIONAL INFORMATION ON SOURCES:

USER SPECIFIED 1 (NOT) SIGNIFICANT POINT SOURCES AS LISTED BY POINT SOURCE NUMBER:

1

EMISSION INFORMATION FOR 2 (NPT) POINT SOURCES HAS BEEN INPUT

1 SIGNIFICANT POINT SOURCES(NSIGP) ARE TO BE USED FOR THIS RUN

THE ORDER OF SIGNIFICANCE(IMPS) FOR 25 OR LESS POINT SOURCES USED IN THIS RUN AS LISTED BY POINT SOURCE NUMBER:

1

RECEPTOR INFORMATION

| RECEPTOR | IDENTIFICATION | EAST COORD (USER UNITS) | NORTH COORD | RECEPTOR HT ABV LOCAL GRD LVL (METERS) | RECEPTOR GROUND LEVEL ELEVATION (USER HT UNITS) | HTER (M) |
|---|---|---|---|---|---|---|
| 1 | REC. 1 | 0.740 | 9.800 | 0.0 | 50.00 | 100.0 |
| 2 | REC. 2 | 9.500 | 10.760 | 0.0 | 100.00 | 100.0 |
| 3 ' | REC. 3 | 6.580 | 9.200 | 0.0 | 10.00 | 0.0 |
| 4 ' | REC. 4 | 4.680 | 10.760 | 0.0 | 10.00 | 0.0 |
| 5 | REC. 5 | 4.100 | 13.480 | 0.0 | 300.00 | 300.0 |
| 6 | REC. 6 | 3.360 | 12.480 | 0.0 | 50.00 | 300.0 |

• ONE ASTERISK INDICATES THAT THE ASSOCIATED RECEPTOR(S) HAVE A GROUND LEVEL ELEVATION LOWER THAN THE LOWEST SOURCE BASE ELEVATION. CAUTION SHOULD BE USED IN INTERPRETING CONCENTRATIONS FOR THESE RECEPTORS.

• * TWO ASTERISKS INDICATE THAT THE ASSOCIATED RECEPTOR(S) HAVE GROUND LEVEL ELEVATIONS ABOVE THE LOWEST STACK TOP.

OPTION SETTINGS FOR INCLUSION OF ADDITIONAL METEOROLOGY ARE LISTED BELOW:

| | | |
|---|---|---|
| OPTION 1: OVERWATER WIND DIRECTION | 1 | (1-PROVIDED, 0-NOT PROVIDED, OR DO NOT USE) |
| OPTION 2: OVERWATER WIND SPEED | 1 | (1-PROVIDED, 0-NOT PROVIDED, OR DO NOT USE) |
| OPTION 3: OVERWATER VERT. POT. TEMP. GRAD. DATA | 1 | (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE) |
| OPTION 4: OVERWATER HUMIDITY | 1 | (1-RELATIVE HUMIDITY ( ), 2=WET BULB TEMPERATURE (DEG K), 3=DEW POINT TEMPERATURE (DEG K)) |
| OPTION 5: OVERLAND TURBULENCE DATA | 0 | (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE) |
| OPTION 6: WATER SURFACE TEMPERATURE | 2 | (1=WATER SURFACE TEMP (DEG K), P-AIR MINUS WATER TEMP (DEG K)) |
| OPTION 7: WIND DIRECTION SHEAR DATA | 0 | (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE) |
| OPTION 9: OVERWATER TURBULENCE DATA (Y-COMPONENT) | 1 | (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE) |
| OPTION 9: OVERWATER TURBULENCE DATA (Z-COMPONENT) | 0 | (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE) |

ANEMOMETER HEIGHT (ABOVE WATER LEVEL) FOR OVERWATER DATA = 18.00 METERS.
AIR TEMPERATURE SENSOR HEIGHT (ABOVE WATER LEVEL) FOR OVERWATER DATA = 18.00 METERS.

LAND-WATER MAPPING:
COORDINATES OF THE NORTHWEST CORNER OF THE MAP IN USER UNITS ARE ( 0.000, 14.100)
# OF GRID RECTANGLES ALONG THE X-AXIS (I.E., THE NUMBER OF GRID COLUMNS) = 36
# OF GRID RECTANGLES ALONG THE Y-AXIS (I.E., THE NUMBER OF GRID ROWS) = 50
LENGTH OF THE (X,Y) SIDES OF A GRID RECTANGLE (USER UNITS) = ( 0.313, 0.282), OR ( 0.313, 0.282) KM.
MINIMUM SIGNIFICANT WIDTH OF LAND OR WATER BODY ALONG WIND DIRECTION (USER UNITS) = 1.000
AVERAGE DISTANCE BETWEEN SOURCE AND SHORELINE (USER UNITS) = 9.000

MAP OF USER-SPECIFIED LAND/WATER DISTRIBUTION; L = LAND AREA, (BLANK) = WATER AREA

RANGE OF X: 0.006 TO 11.268; RANGE OF Y: 0.000 TO 14.100; GRID (X,Y) LENGTHS = ( 0.313, 0.282) USER UNITS

```
+L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L +
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
 L L L L                       L L L L L L L L L L L L L L L L L L L L L
                                     L L L L L L L L L L L L L L L L L L
                                       L L L L L L L L L L L L L L L L L
                                         L L L L L L L L L L L L L L L L
                                         L L L L L L L L L L L L L L L L
                                         L L L L L L L L L L L L L L L L
                                           L L L L L L L L L L L L L L L
                                             L L L L L L L L L L L L L L
                                                     L L L L L L L L L
                                                             L L L L L
                                                                     L
```

MAP OF LAND/WATER, MODEL RECEPTORS (*), AND POINT SOURCES (S); L = LAND , (BLANK) = WATER AREA; SOME SYMBOLS MAY BE OVERWRITTEN
RANGE OF X: 0.000 TO.. 11.268; RANGE OF Y: 0.000 TO 14.100; GRID (X,Y) LENGTHS = ( 0.313, 0.282) USER UNITS

```
+ L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L +
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L ● L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L * L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L ● L L L L L L L L L L L L L L L ' L L L L L
L L L L                       L L L L L L L L L L L L L L L L L L L L L
                                    L L L L L L L L L L L L L L L L L L
                                      L L L L L L L L L L L L L L L L L
                                        L L L L L L L * L L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                        L * L L L L L L L L L L L L L L
                                          L L L L L L L L L L L L L L L
                                            L L L L L L L L L L L L L L
                                                    L L L L L L L L L L
                                                              L L L L L
                                                                      L
```

OCD TEST CASE 1
--GENERATOR AND FLARE STACKS
10/31/89

l-HOUR AVERAGE NOX SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 88/ 1 START HOUR: 1

| RECEPTOR NO. | NAM!% | EAST COORD | NORTH COORD | RECEPTOR HT ABV GRD (M) | RECEPTOR GRD-LVL ELEV (USER HT UNITS) | TOTAL FROM SIGNIF POINT SOURCES | TOTAL FROM ALL SOURCES | CONCENTRATION RANK |
|---|---|---|---|---|---|---|---|---|
| 1 | REC. 1 | 0.74 | 9.80 | 0.0 | 50.0 | 0.0000 | 0.0000 | 6 |
| 2 | REC. 2 | 9.50 | 10.76 | 0.0 | 100.0 | 0.0000 | 0 .oooo | 5 |
| 3 * | REC. 3 | 6.58 | 9.20 | 0.0 | 10.0 | 0.0025 | 0.0100 | 4 |
| 4 • | REC. 4 | 4.66 | 10.76 | 0.0 | 10.0 | 2.1690 | 1.3014 | 1 |
| 5 | REC. 5 | 4.10 | 13.48 | 0.0 | 300.0 | 0.7934 | 2.0174 | 3 |
| 6 | REC. 6 | 3.36 | 12.40 | 0.0 | 50.0 | 1.6079 | 7.2151 | 2 |

Figure 3-13. Sample output from OCD/4 for the area source test case presented in Section 3.6.

```
                OFFSHORE AND COASTAL DISPERSION (OCD) MODEL, VERSION 4

               OCD TEST CASE 2
               AREA SOURCE
               10/31/89
                     GENERAL INPUT INFORMATION

THIS RUN OF THE OCD MODEL IS FOR THE POLLUTANT NOX FOR    1  1-HOUR PERIODS.
CONCENTRATION ESTIMATES BEGIN ON HOUR- 1, JULIAN DAY- 1, YEAR-1988.
1.0 USER LENGTH UNIT IN THE HORIZONTAL =     1.0000000   KILOMETERS.
 0 SIGNIFICANT SOURCES ARE TO BE CONSIDERED.
 THIS RUN WILL NOT CONSIDER ANY POLLUTANT LOSS.
1.0 USER LENGTH UNIT IN THE VERTICAL =     1.0000000   METERS.
  OPTION     OPTION LIST                    OPTION SPECIFICATION : 0- IGNORE OPTION
                                                                   1= USE OPTION
                 --TECHNICAL OPTIONS--
    1      CONSIDER TERRAIN ADJUSTMENTS                            1
    2      DO NOT INCLUDE STACK DOWNWASH CALCULATIONS              1
    3      DO NOT INCLUDE GRADUAL PLUME RISE CALCULATIONS          1
    4      CALCULATE INITIAL PLUME SIZE DUE TO BUOYANCY            1
                 --INPUT OPTIONS--
    5      READ MET DATA FROM CARDS                                1
    6      READ HOURLY EMISSIONS                                   0
    7      SPECIFY SIGNIFICANT SOURCES                             0
    8      READ RADIAL DISTANCES TO GENERATE RECEPTORS             0
                 --PRINTED OUTPUT OPTIONS--
    9      DELETE EMISSIONS WITH HEIGHT TABLE                      1
   10      DELETE MET DATA SUMMARY FOR AVG PERIOD                  1
   11      DELETE HOURLY CONTRIBUTIONS                             1
   12      DELETE MET DATA ON HOURLY CONTRIBUTIONS                 1
   13      DELETE PLUME RISE/TRANSPORT ON HRLY CONTRIBUTIONS       1
   14      DELETE HOURLY SUMMARY                                   1
   15      DELETE MET DATA ON HRLY SUMMARY                         1
   16      DELETE PLUME RISE/TRANSPORT ON HRLY SUMMARY             1
   17      DELETE AVG-PERIOD CONTRIBUTIONS                         1
   18      DELETE AVERAGING PERIOD SUMMARY                         0
   19      DELETE AVG CONCENTRATIONS AND HI-5 TABLES               1
                 --OTHER CONTROL AND OUTPUT OPTIONS--
   20      SOURCE TYPE (0=POINT; 1-AREA; 2=LINE)                   1
   21      CREATE SUMMARY OUTPUT FILE CALLED EXTRA.OUT             1
   22      WRITE HOURLY CONC TO DISK OR TAPE                       0
   23      CALCULATE ANNUAL IMPACT FROM NON-PERMANENT ACTIVITIES   0
   24      LAND SOURCE (DO NOT MODIFY WIND SPEED)                  0
   25      CALCULATE POLLUTANT CHEMICAL TRANSFORMATION RATE        0
 LAND ANEMOMETER HEIGHT (METERS) =     10.00
 LAND SURFACE ROUGHNESS LENGTH (METERS) =    0.10000

 MINIMUM DISTANCE FOR PLUME ABOVE TERRAIN (METERS) = 10.0
 LATITIDE OF SOURCE REGION (DEG) = 29.90
```

AREA SOURCE INFORMATION

| SOURCE | EAST COORD (USER UNITS) | NORTH COORD (USER UNITS) | EMISSION RATE (G/SEC) | BUILDING HEIGHT (M) | SOURCE HEIGHT (M) | SOURCE TEMP (K) | AREA DIAM (M) | EXIT VELOCITY (M/SEC) | STACK ANGLE (DEG FROM VERT) | GRD-LVL ELEV. (USER HT UNITS) | BUOY FLUX (F) M**4/S**3 (CALCULATED) | BLDG WIDTH (M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 AREA SOURCE | 3.950 | 0.720 | 1.00 | 10.00 | 11.0 | 375.0 | 20.0 | 0.0 | 0.0 | 20.00 | 0.00 | 0.00 |

ADDITIONAL INFORMATION ON SOURCES:

EMISSION INFORMATION FOR 1 (NOT) POINT SOURCES HAS BEEN INPUT

0 SIGNIFICANT POINT SOURCES(NSIGP) ARE TO BE USED FOR THIS RUN

THE ORDER OF SIGNIFICANCE(IMPS) FOR 25 OR LESS POINT SOURCES USED IN THIS RUN AS LISTED BY POINT SOURCE NUMBER:

RECEPTOR INFORMATION

| RECEPTOR. | IDENTIFICATION | EAST COORD (USER UNITS) | NORTH COORD (USER UNITS) | RECEPTOR HT ABV MCAL GRD LVL (METERS) | RECEPTOR GROUND LEVEL ELEVATION (USER HT UNITS) | HTER (M) |
|---|---|---|---|---|---|---|
| 1 | REC. 1 | 8.740 | 9.800 | 0.0 | 50.00 | 100.0 |
| 2 | REC. 2 | 9.500 | 10.760 | 0.0 | 100.00 | 100.0 |
| 3 * | REC. 3 | 6.580 | 9.200 | 0.0 | 10.00 | 0.0 |
| 4 * | REC. 4 | 4.680 | 10.760 | 0.0 | 10.00 | 0.0 |
| 5 | REC. 5 | 4.100 | 13.480 | 0.0 | 300.00 | 300.0 |
| 6 | REC. 6 | 3.360 | 12.480 | 0.0 | 50.00 | 300.0 |

* ASTERISK INDICATES THAT THE ASSOCIATED RECEPTOR(S) HAVE A GROUND LEVEL ELEVATION LOWER THAN THE LOWEST SOURCE BASE ELEVATION. CAUTION SHOULD BE USED IN INTERPRETING CONCENTRATIONS FOR THESE RECEPTORS.

** TWO ASTERISKS INDICATE THAT THE ASSOCIATED RECEPTOR(S) HAVE GROUND LEVEL ELEVATIONS ABOVE THE LOWEST STACK TOP.

OPTION SETTINGS FOR INCLUSION OF ADDITIONAL METEOROLOGY ARE LISTED BELOW:

```
OPTION 1: OVERWATER WIND DIRECTION                  1    (1-PROVIDED, 0-NOT PROVIDED, OR DO NOT USE)
OPTION 2: OVERWATER WIND SPEED                      1    (1-PROVIDED, 0-NUT PROVIDED, OR DO NOT USE)
OPTION 3: OVERWATER VERT. POT. TEMP. GRAD.  DATA    1    (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE)
OPTION 4: OVERWATER HUMIDITY                        1    (1-RELATIVE HUMIDITY ( ), 2-WET BULB
                                                          TEMPERATURE (DEG K), J-DEW POINT TEMPERATURE (DEG K))
OPTION 5: OVERLAND TURBULENCE DATA                  0    (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE)
OPTION 6: WATER SURFACE TEMPERATURE                 2    (1-WATER SURFACE TEMP (DEG K),
                                                          2=AIR MINUS WATER TEMP (DEG K))
OPTION 7: WIND DIRECTION SHEAR DATA                 0    (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE)
OPTION 8: OVERWATER TURBULENCE DATA (Y-COMPONENT)   1    (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE)
OPTION 9: OVERWATER TURBULENCE DATA (E-COMPONENT)   0    (1-PROVIDED, 0-NOT PROVIDED OR DO NOT USE)

ANEMOMETER HEIGHT (ABOVE WATER LEVEL) FOR OVERWATER DATA = 18.00 METERS.
AIR TEMPERATURE SENSOR HEIGHT (ABOVE WATER LEVEL) FOR OVERWATER DATA = 18.00 METERS.
```

```
LAND-WATER MAPPING:
COORDINATES OF THE NORTHWEST CORNER OF THE MAP IN USER UNITS ARE (    0.000,    14.100)
# OF GRID RECTANGLES ALONG THE X-AXIS (I.E., THE NUMBER OF GRID COLUMNS) = 36
# OF GRID RECTANGLES ALONG THE Y-AXIS (I.E., THE NUMBER OF GRID ROWS) = 50
LENGTH OF THE (X,Y) SIDES OF A GRID RECTANGLE (USER UNITS) = (    0.313,    0.282), OR (    0.313,    0.282) KM.
MINIMUM SIGNIFICANT WIDTH OF LAND OR WATER BODY ALONG WIND DIRECTION (USER UNITS) =     1.000
AVERAGE DISTANCE BETWEEN SOURCE AND SHORELINE (USER UNITS) =     9.000
```

MAP OF USER-SPECIFIED LAND/WATER DISTRIBUTION: L = LAND AREA, (BLANK) = WATER AREA

RANGE OF X: 0.000 TO -11.2681 RANGE OF Y: 0.000 TO 14.100; GRID (X,Y) LENGTHS = ( 0.313, 0.282) USER UNITS

```
+ L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L +
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L                         L L L L L L L L L L L L L L L L L L L L L
                                      L L L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L L
                                          L L L L L L L L L L L L L L L L
                                          L L L L L L L L L L L L L L L L
                                          L L L L L L L L L L L L L L L L
                                            L L L L L L L L L L L L L L L
                                              L L L L L L L L L L L L L L
                                                      L L L L L L L L L L
                                                                L L L L L
                                                                        L
```

MAP OF LAND/WATER, MODEL RECEPTORS (*), AND POINT SOURCES (S); L = LAND, (BLANK) = WATER AREA; SOME SYMBOLS MAY BE OVERWRITTEN
RANGE OF X: 0.000 TO 11.268; RANGE OF Y: 0.000 TO 14.100; GRID (X,Y) LENGTHS = ( 0.313, 0.282) USER UNITS

```
+ L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L +
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L * L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L * L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L   *     L L L L L L L L L L L L L L * L L L L L
L L L L                         L L L L L L L L L L L L L L L L L L L L L
                                      L L L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L L
                                            L L L L L L L * L L L L L L L
                                            L L L L L L L L L L L L L L L L
                                            L * L L L L L L L L L L L L L L
                                              L L L L L L L L L L L L L L L
                                                L L L L L L L L L L L L L L
                                                        L L L L L L L L L L
                                                                  L L L L L
                                                                          L











                         S

+
```

OCD TEST CASE 2
AREA SOURCE
10/31/89

1-HOUR AVERAGE NOX SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 88/ 1 START HOUR: 1

| RECEPTOR NO. NAME | | EAST COORD | NORTH COORD | RECEPTOR HT ABV GRD (M) | RECEPTOR GRD-LVL ELEV (USER HT UNITS) | TOTAL FROM SIGNIF POINT SOURCES | TOTAL FROM ALL SOURCES | CONCENTRATION RANK |
|---|---|---|---|---|---|---|---|---|
| 1 | REC. 1 | 8.74 | 9.80 | 0.0 | 50.0 | 0.0000 | 0.0001 | 5 |
| 2 | REC. 2 | 9.50 | 10.76 | 0.0 | 100.0 | 0.0000 | 0.0000 | 6 |
| 3 | REC. 3 | 6.58 | 9.20 | 0.0 | 10.0 | 0.0000 | 1.0206 | 4 |
| 4 | REC. 4 | 4.68 | 10.76 | 0.0 | 10.0 | 0.0000 | 09.4789 | 1 |
| 5 | REC. 5 | 4.10 | 13.48 | 0.0 | 300.0 | 0.0000 | 77.6450 | 2 |
| 6 | REC. 6 | 3.36 | 12.48 | 0.0 | 50.0 | 0.0000 | 72.1184 | 3 |

Figure 3-14. Sample output from **OCD/4** for the line source test case presented in Section 3.6.

```
                OFFSHORE AND COASTAL DISPERSION (OCD) MODEL, VERSION 4

               OCD TEST CASE 3
               LINE SOURCE
               10/31/89
                        GENERAL INPUT INFORMATION

--- THIS RUN OF THE OCD MODEL IS FOR THE POLLUTANT NOX FOR   1 1-HOUR PERIODS.
    CONCENTRATION ESTIMATES BEGIN ON HOUR- 1, JULIAN DAY- 1, YEAR-1988.
    1.0 USER LENGTH UNIT IN THE HORIZONTAL =     1.0000000   KILOMETERS.
     0 SIGNIFICANT SOURCES ARE TO BE CONSIDERED.
     THIS RUN WILL NOT CONSIDER ANY POLLUTANT LOSS.
    1.0 USER LENGTH UNIT IN THE VERTICAL =     1.0000000   METERS.
      OPTION      OPTION LIST                  OPTION SPECIFICATION : 0- IGNORE OPTION
                                                                     1= USE OPTION
                      --TECHNICAL   OPTIONS--
        1     CONSIDER  TERRAIN  ADJUSTMENTS                          1
        2     DO NOT INCLUDE STACK DOWNWASH CALCULATIONS              1
        3     DO NOT INCLUDE GRADUAL PLUME RISE CALCULATIONS          1
        4     CALCULATE INITIAL PLUME SIZE DUE TO BUOYANCY            1
                      --INPUT   OPTIONS--
        5     READ MET DATA FROM CARDS                                1
        6     READ HOURLY EMISSIONS                                   0
        7     SPECIFY  SIGNIFICANT  SOURCES                           0
        8     READ RADIAL DISTANCES TO GENERATE RECEPTORS             0
                      --FRINTED  OUTPUT  OPTIONS--
        9     DELETE EMISSIONS WITH HEIGHT TABLE                      1
       10     DELETE MET DATA SUMMARY FOR AVG PERIOD                  1
       11     DELETE HOURLY CONTRIBUTIONS                             1
       12     DELETE MET DATA ON HOURLY CONTRIBUTIONS                 1
       13     DELETE PLUME RISE/TRANSPORT ON HRLY CONTRIBUTIONS       1
       14     DELETE HOURLY SUMMARY                                   1
       15     DELETE MET DATA ON HRLY SUMMARY                         1
       16     DELETE PLUME RISE/TRANSPORT ON HRLY SUMMARY             1
       17     DELETE AVG-PERIOD CONTRIBUTIONS                         1
       18     DELETE AVERAGING PERIOD SUMMARY                         0
       19     DELETE AVG CONCENTRATIONS AND HI-5 TABLES               1
                      --OTHER CONTROL AND OUTPUT OPTIONS--
       20     SOURCE TYPE (O-POINT; 1=AREA; 2=LINE)                   2
       21     CREATE SUMMARY OUTPUT FILE CALLED EXTRA-OUT             1
       22     WRITE HOURLY CONC TO DISK OR TAPE                       0
       23     CALCULATE ANNUAL IMPACT FROM NON-PERMANENT ACTIVITIES   0
       24     LAND SOURCE (DO NOT MODIFY WIND SPEED)                  0
       25     CALCULATE POLLUTANT CHEMICAL TRANSFORMATION RATE        0
      LAND ANEMOMETER HEIGHT (METERS) =      10.00
     LAND SURFACE ROUGHNESS LENGTH (METERS) =     0.10000

     MINIMUM DISTANCE FOR PLUME ABOVE TERRAIN (METERS) = 10.0
     LATITIDE OF SOURCE REGION (DEG) = 29.90
```

LINE SOURCE INFORMATION

| SOURCE | EAST COORD (USER | NORTH COORD UNITS) | EMISSION RATE (G/SEC) | BUILDING HEIGHT (M) | SOURCE HEIGHT (M) | SOURCE TEMP (K) | SOURCE DIAM (M) | EXIT VELCCITY (M/SEC) | STACK ANGLE (DEG FROM VERT) | GRD-LVL ELEV. (USER HT UNITS) | BUOY FLUX (F) M**4/S**3 (CALCULATED) | BLDG WIDTH (M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 BOAT SOURCE | 6.180 | 10.100 | 4.00 | 0.00 | 2.0 | 750.0 | 0.3 | 20.4 | 90.0 | 0.00 | 2.74 | 0.00 |

LINE SOURCE CONFIGURATION

STARTING COORDINATES (USER UNITS): 6.180 10.100

ENDING COORDINATES (USER UNITS): 3.980 0.800

NUMBER OF LINE SEGMENTS TO BE MODELED: 10

| SEGMENT X | SEGMENT Y | MIDPOINT X | MIDPOINT Y |
|---|---|---|---|
| 5.960 | 9.170 | 6.070 | 9.635 |
| 5.740 | 8.240 | 5.850 | 8.705 |
| 5.520 | 7.310 | 5.630 | 7.715 |
| 5.300 | 6.380 | 5.410 | 6.845 |
| 5.080 | 5.450 | 5.190 | 5.915 |
| 4.860 | 4.520 | 4.970 | 4.985 |
| 4.640 | 3.590 | 4.750 | 4.055 |
| 4.420 | 2.660 | 4.530 | 3.125 |
| 4.200 | 1.730 | 4.310 | 2.195 |
| 3.980 | 0.800 | 4.090 | 1.265 |

ADDITIONAL INFORMATION ON SOURCES:

EMISSION INFORMATION FOR 1 (NPT) POINT SOURCES HAS BEEN INPUT

0 SIGNIFICANT POINT SOURCES(NSIGP) ARE TO BE USED FOR THIS RUN

THE ORDER'OF SIGNIFICANCE(IMPS) FOR 25 OR LESS POINT SOURCES USED IN THIS RUN AS LISTED BY POINT SOURCE NUMBER:

RECEPTOR INFORMATION

| RECEPTOR | IDENTIFICATION | EAST COORD (USER | NORTH COORD UNITS) | RECEPTOR HT ABV LOCAL GRD LVL (METERS) | RECEPTOR GROUND LEVEL ELEVATION (USER HT UNITS) | HTER (M) |
|---|---|---|---|---|---|---|
| 1 | REC. 1 | 8.740 | 9.800 | 0.0 | 50.00 | 100.0 |
| 2 | REC. 2 | 9.500 | 10.760 | 0.0 | 100.00 | 100.0 |
| 3 | REC. 3 | 6.580 | 9.200 | 0.0 | 10.00 | 0.0 |
| 4 | REC. 4 | 4.680 | 10.760 | 0.0 | 10.00 | 0.0 |
| 5 | REC. 5 | 4.100 | 13.480 | 0.0 | 300.00 | 300.0 |
| 6 | REC. 6 | 3.360 | 12.480 | 0.0 | 50.00 | 300.0 |

* ONE ASTERISK INDICATES THAT THE ASSOCIATED RECEPTOR(S) HAVE A GROUND LEVEL ELEVATION LOWER THAN THE LOWEST SOURCE BASE ELEVATION. CAUTION SHOULD BE USED IN INTERPRETING CONCEETRATIONS FOR THESE RECEPTORS.

** TWO ASTERISKS INDICATE THAT THE ASSOCIATED RECEPTOR(S) HAVE GROUND LEVEL ELEVATIONS ABOVE THE LOWEST STACK TOP.

OPTION SETTINGS-FOR INCLUSION OF ADDITIONAL METEOROLOGY ARE LISTED BELOW:

| | | | |
|---|---|---|---|
| OPTION 1: | OVERWATER WIND DIRECTION | 1 | (l-PROVIDED, O-NOT PROVIDED, OR DO NOT USE) |
| OPTION 2: | OVERWATER WIND SPEED | 1 | (l-PROVIDED, O-NOT PROVIDED, OR DO NOT USE) |
| OPTION 3: | OVERWATER VERT. POT. TEMP. GRAD. DATA | 1 | (l-PROVIDED, O-NOT PROVIDED OR DO NOT USE) |
| OPTION 4: | OVERWATER HUMIDITY | 1 | (1=RELATIVE HUMIDITY ( ), 2=WET BULB TEMPERATURE (DEG K), 3=DEW POINT TEMPERATURE (DEG K)) |
| OPTION 5: | OVERLAND TURBULENCE DATA | 0 | (l-PROVIDED, O-NOT PROVIDED OR DO NOT USE) |
| OPTION 6: | WATER SURFACE TEMPERATURE | 2 | (l-WATER SURFACE TEMP (DEG K), Z-AIR MINUS WATER TEMP (DEG K)) |
| OPTION 7: | WIND DIRECTION SHEAR DATA | 0 | (l-PROVIDED, O-NOT PROVIDED OR DO NOT USE) |
| OPTION 8: | OVERWATER TURBULENCE DATA (Y-COMPONENT) | | (l-PROVIDED, O-NOT PROVIDED OR DO NOT USE) |
| OPTION 9: | OVERWATER TURBULENCE DATA (Z-COMPONENT) | 0 | (l-PROVIDED, O-NOT PROVIDED OR DO NOT USE) |

ANEMOMETER HEIGHT (ABOVE WATER LEVEL) FOR OVERWATER DATA = 18.00 METERS.
AIR TEMPERATURE SENSOR HEIGHT (ABOVE WATER LEVEL) FOR OVERWATER DATA = 18.00 METERS.

LAND-WATER MAPPING:
COORDINATES OF THE NORTHWEST CORNER OF THE MAP IN USER UNITS ARE ( 0.000, 14.100)
# OF GRID RECTANGLES AMNG THE X-AXIS (I.E., THE NUMBER OF GRID COLUMNS) = 36
# OF GRID RECTANGLES ALONG THE Y-AXIS (I.E., THE NUMBER OF GRID ROWS) = 50
LENGTH OF THE (X,Y) SIDES OF A GRID RECTANGLE (USER UNITS) = ( 0.313, 0.282), OR ( 0.313, 0.282) KM.
MINIMUM SIGNIFICANT WIDTH OF LAND OR WATER BODY ALONG WIND DIRECTION (USER UNITS) = 1.000
AVERAGE DISTANCE BETWEEN SOURCE AND SHORELINE (USER UNITS) = 9.000

**MAP** OF **USER-SPECIFIED** LAND/WATER DISTRIBUTION? L = LAND AREA, **(BLANK)** = WATER AREA

RANGE OF X: 0.000 TO **11.268;** RANGE OF Y: 0.000 TO 14.1001 GRID **(X,Y)** LENGTHS = ( 0.313, 0.282) USER UNITS

```
+ L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L +
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L                       L L L L L L L L L L L L L L L L L L L L L
                                    L L L L L L L L L L L L L L L L L L
                                      L L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                          L L L L L L L L L L L L L L L
                                            L L L L L L L L L L L L L L
                                                    L L L L L L L L L L
                                                              L L L L L
                                                                      L
```

MAP OF LAND/WATER, MODEL RECEPTORS (*), AND POINT SOURCES (S); L = LAND , (BLANK) = WATER AREA; SOME SYMBOLS MAY BE OVERWRITTEN
RANGE OF X: 0.000 TO 11.268; RANGE OF Y: 0.000 TO 14.100; GRID (X,Y) LENGTHS = ( 0.313, 0.282) USER UNITS

20 6.26

```
+ L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L +
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L * L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L * L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L L
L L L L L L L L L L L L L L * L L L L L L L L L L L L L L L * L L L L L
L L L L                       L L L L L L L L L L L L L L L L L L L L L
                                    L L L L L L L L L L L L L L L L L L
                                      L L L L L L L L L L L L L L L L L
                                      S L L L L L L L L * L L L L L L L
                                        L L L L L L L L L L L L L L L L
                                        L * L L L L L L L L L L L L L L
                                          L L L L L L L L L L L L L L L
                                    S       L L L L L L L L L L L L L L
                                                    L L L L L L L L L L
                                                              L L L L L
                                  S                                   L


                                  S



                                S


                              S


                              S


                            S



                          S


                          S
```

10.72
10.43
10.5
9.87

2.1

(0.0)

20 x 0.313 = 6.26
35 x 0.282 = 9.87

x = 5.95 - 6.26
Y = 9.59 - 9.87

OCD TEST CASE 3
LINE SOURCE
10/31/89

1-HOUR AVERAGE NOX SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 88/ 1 START HOUR: 1

| RECEPTOR NO. | NAME | EAST COORD | NORTH COORD | RECEPTOR HT ABV GRD (M) | RECEPTOR GRD-LVL ELEV (USER HT UNITS) | TOTAL FROM SIGNIF POINT SOURCES | TOTAL FROM ALL SOURCES | CONCENTRATION RANK |
|---|---|---|---|---|---|---|---|---|
| 1 | REC. 1 | 8.74 | 9.00 | 0.0 | 50.0 | 0.0000 | 0.0000 | 5 |
| 2 | REC. 2 | 9.50 | 10.76 | 0.0 | 100.0 | 0.0000 | 0 .0000 | 6 |
| 3 | REC. 3 | 6.50 | 9.20 | 0.0 | 10.0 | 0.0000 | 0.1030 | 4 |
| 4 | REC. 4 | 4.68 | 10.76 | 0.0 | 10.0 | 0.0000 | 137.4983 | 1 |
| 5 | REC. 5 | 4.10 | 13.40 | 0.0 | 300.0 | 0.0000 | SE.4522 | 2 |
| 6 | REC. 6 | 3.36 | 12.48 | 0.0 | 50.0 | 0.0000 | 33.9740 | 3 |

TABLE 3-10

SUMMARY OF PREDICTED CONCENTRATIONS ($\mu g/m^3$)
FOR THE TEST CASES

| Receptor | Point | Source Area | Line | Total |
|---|---|---|---|---|
| 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 0.0 | 1.0 | 0.1 | 1.1 |
| 4 | 7.4 | 89.5 | 137.8 | 234.7 |
| 5 | 3.1 | 77.7 | 88.8 | 169.6 |
| 6 | 7.2 | 72.3 | 34.1 | 113.6 |

# 4. MODEL EVALUATION AND RESULTS

Observations from four separate offshore and coastal diffusion experiments are available for evaluating the OCD model. A description of each of the four experiments is presented in Section 4.1. The methods used to pair the data are presented in Section 4.2. Finally, the model evaluation results for OCD/3 versus OCD/4 are presented in Section 4.3.

## 4.1 Description of Data Sets Used in Modeling Analysis

Field experiments at four sites are suitable for OCD model evaluation. There were three California experiments in Ventura, Pismo Beach, and Carpinteria and one Gulf of Mexico experiment in Cameron, Louisiana. Each experiment is further divided into a subset such as fall and winter hours, or $SF_6$, Fumigation, or Freon ($CF_3Br$) hours. This section discusses the characteristics of the data and the meteorological data to be used for input to the models for each experiment. A summary of the characteristics of each coastal experiment including the number of experiment hours, the source location and height, monitor locations, and the method of measuring turbulence observations, wind velocity, and vertical temperature profiles is presented in Table 4-l.

The field experiment data sets at Ventura, Pismo Beach, and Cameron have been divided into two parts: a developmental data set to be used in initial model derivation and testing, and an evaluation data set to be used only for final model evaluation. The latter data sets were used in the OCD/3 model evaluation reported by Hanna et. al.; (1985) and the OCD/4 model evaluation presented in Section 4.3. The Carpinteria data were not divided because the data set was of limited size. Each of the following subsections discusses the site, the measurements, the meteorological data, and the modelers' data base.

TABLE 4-1

Characteristics of Nine Coastal Experiments

| Site | Hours, this Analysis | Source | Turbulence Obs. | Wind Velocity | Vert. T Profile | Monitors |
|---|---|---|---|---|---|---|
| Ventura Fall | 9 | Boat, 13m, 5-7 km offshore | Boat $\sigma_\theta$ | Boat | Aircraft | arc 1: 0.5km onshore<br>arc 2: 6-8km onshore |
| Ventura Winter | 8 | Boat, 13m, 5-7 km offshore | Boat $\sigma_\theta$ | Boat | Aircraft | same as fall |
| Pismo Beach Summer | 16 | Boat, 13m, 6-8 km offshore | Boat $\sigma_\theta$ | Boat | Aircraft | arc 1: shoreline<br>arc 2: 6-8 km onshore |
| Pismo Beach Winter | 15 | Boat, 13m, 6-8 km offshore | Boat $\sigma_\theta$ | Boat | Aircraft | same as summer |
| Cameron Sumner | 9 | Platform, 13m, 7 km offshore | Shoreline, $\sigma_\theta$, $\sigma_w$ | Platform | Aircraft | shoreline arc |
| Cameron Winter | 17 | Platform, 13m, 7 km offshore | Shoreline $\sigma_\theta$, $\sigma_w$ | Platform | Aircraft | shoreline arc |
| Carpinteria $SF_6$ Complex Terrain | 18 | Boat, 20-30m, 0.3-0.7 km offshore | Tethersonde $\sigma_\theta$ | Tethersonde | Tethersonde | arc 1: shoreline<br>arc 2: 1 km onshore |
| Carpinteria Freon, Complex Terrain | 10 | Boat, 20-70m, 0.3-0.7 km offshore | Tethersonde $\sigma_\theta$ | Tethersonde | Tethersonde | arc 1: shoreline<br>arc 2: 1 km onshore |
| Carpinteria Fumigation | 9 | Boat, 70-100m, 0.3-0.7 km offshore | Tethersonde $\sigma_\theta$ | Tethersonde | Tethersonde | arc 1: shoreline<br>arc 2: 1 km onshore |

* At Cameron, the release on 2/15 and 2/24 was from a boat located about 4 km offshore.

### 4.1.1 Ventura

The evaluation data set from the Ventura, CA, site consists of nine hours from an experiment in the fall (September) of 1980 (Aerovironment, 1980) and eight hours from an experiment in the winter (January) of 1981 (Aerovironment, 1981). Further details on these experiments are given by Zannetti et al. (1981) and Schacher et al. (1982). The site map in Figure 4-1 shows that the tracer gas was emitted about 5 to 7 km offshore, and that two lines of monitors were located about 0.5 km inland and about 7.0 km inland. The elevation of the source was 13 m. The terrain was gently sloping.

Table 4-l provides an indication of the sources of the meteorological data to be used in the model runs. At the Ventura site, the wind speed and wind direction standard deviation observed on the boat are used. Vertical turbulence, $\sigma_w$, was not observed and hence is parameterized by the model. Mixing depths and vertical temperature profiles were obtained from aircraft profiles. Air-water temperature differences were observed by the boat.

Average overwater wind speed was about 4.5 m/s during both experiments. However, the overwater boundary layer was consistently unstable during the fall experiment and mostly stable during the winter experiment. A summary of the meteorological data used in the modeling analysis is given in Table 4-2.

The wind direction shear, overwater vertical turbulence intensity ($i_{zw}$), and the overland turbulence intensities ($i_{yl}$, $i_{zl}$) were not used in the modeling analysis. The wind direction was assumed to line up from the source to the monitor with the maximum observed concentration. Thus, the overwater wind direction listed in Table 4-2 is the direction from the source to the maximum observed concentration. As a result, the locations of the maximum observed and predicted concentrations coincided in their evaluation.

### 4.1.2 Pismo Beach

The evaluation data set from the Pismo Beach, CA, site consists of 15 hours from an experiment in the winter (December) of 1981 and 16 hours from an

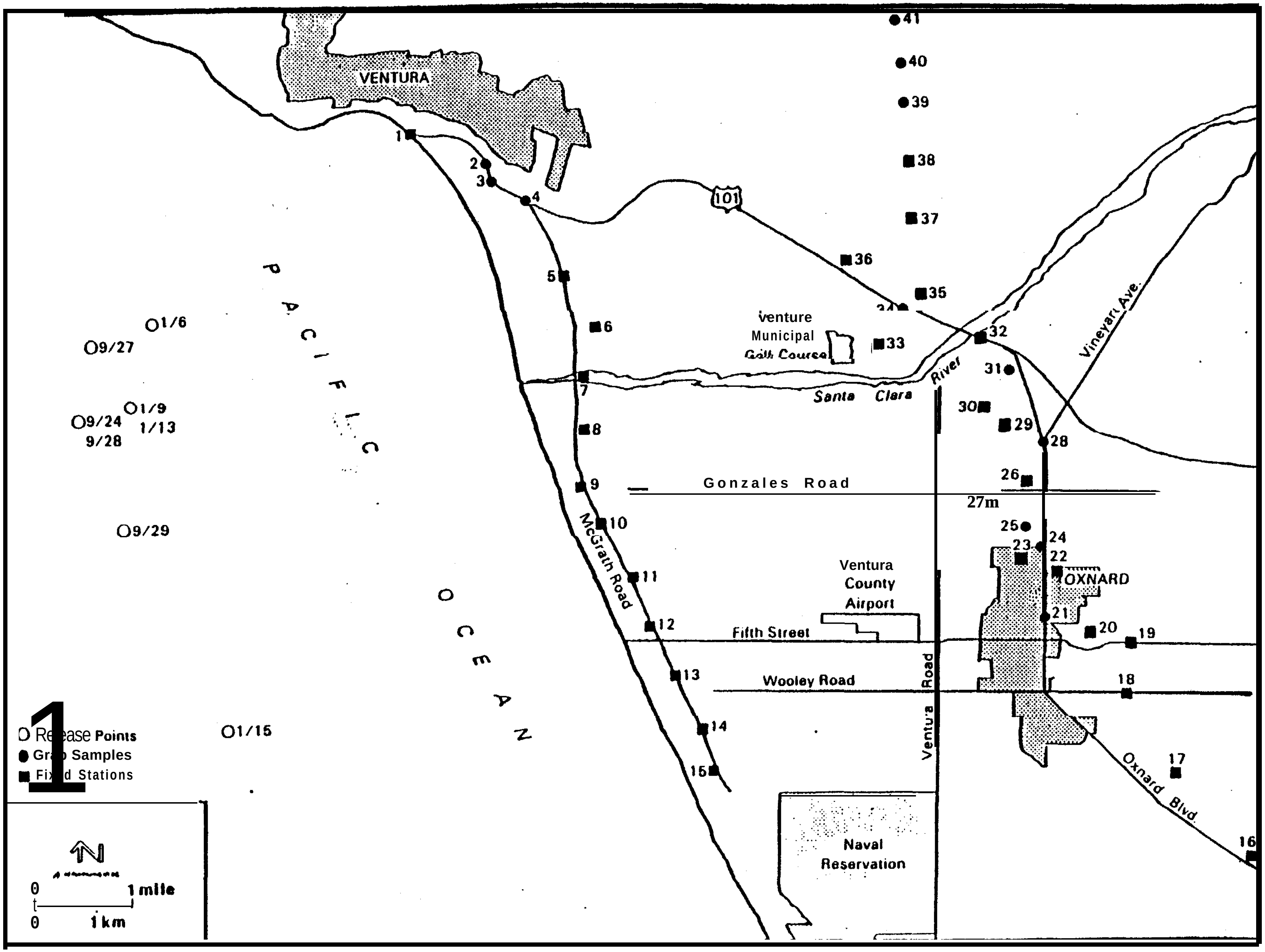



Figure 4-l. Tracer sampling sites used in the Ventura, California area experiment (sites have been renumbered for model evaluation).

# TABLE 4-2

## METEOROLOGICAL INPUT DATA FOR VENTURA, CALIFORNIA

| | | <------OBSERVED | | | | | | | | | | | | ------> | <------CALCULATED | | | ------> |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | HR | OVER-WATER WIND DIR | OVER-WATER WIND SPEED, M/SEC (REL HT) | OVER-WATER NIXING HEIGHT (M) | OVER-WATER/LAND STAB. CWS | OVER-WATER/LAND AIR TEMP (DEG K) | AIR MINUS SEA SFC TEMP (DEG K) | RH ( ) | WIND DIR SHEAR (DEG/M) | OVER-WATER HORIZ. TURB. INTEN. (IYW) | OVER-WATER VERT. TURB. INTEN. (IZW) | OVER-LAND HORIZ. TURB. INTEN. (IYL) | OVER-LAND VERT. TURB. INTEN. (IZL) | OVER-WATER VERT. POT. TEMP. GRAD. (K/M) | OVER-WATER MONIN-OBUKHOV LENGTH (M) | OVER-LAND MONIN-OBUKHOV LENGTH (M) | OVER-WATER SURFACE ROUGH. LENGTH (M) | OVER-WATER FRICTION VELOCITY (U*) (M/SEC) |
| 9/24/80 | 16 | 266. | 4.10 | 400. | 2/4 | 288/288 | -2.10 | 72. | 0.0000 | 0.140 | -0.999 | -0.999 | -0.999 | 0.000 | -9.89 | 9999.00 | .63E-04 | 0.1463 |
| 9/24/80 | 18 | 281. | 6.20 | 400. | 4/4 | 288/288 | -2.00 | 78. | 0.0000 | 0.114 | -0.999 | -0.999 | -0.999 | 0.000 | -29.11 | 9999.00 | .17E-03 | 0.2304 |
| 9/24/80 | 19 | 292. | 6.90 | 400. | 4/4 | 288/288 | -2.10 | 77. | 0.0000 | 0.105 | -0.999 | -0.999 | -0.999 | 0.000 | -36.08 | 9999.00 | .23E-03 | 0.2604 |
| 9/27/80 | 14 | 272. | 6.30 | 400. | 4/4 | 2881288 | -1.90 | 80. | 0.0000 | 0.082 | -0.999 | -0.999 | -0.999 | 0.000 | -32.11 | 9999.00 | .18E-03 | 0.2340 |
| 9/27/80 | 19 | 272. | 6.10 | 400. | 4/4 | 289/289 | -1.00 | 80. | 0.0000 | 0.063 | -0.999 | -0.999 | -0.999 | 0.000 | -49.36 | 9999.00 | .16E-03 | 0.2210 |
| 9/28/80 | 18 | 265. | 3.10 | 250. | 2/4 | 290/290 | -1.00 | 80. | 0.0000 | 0.077 | -0.999 | -0.999 | -0.999 | 0.010 | -9.81 | 9999.00 | .32E-04 | 0.1042 |
| 9/29/80 | 14 | 256. | 3.30 | 100. | 3/2 | 289/289 | -0.80 | 76. | 0.0000 | 0.087 | -0.999 | -0.999 | -0.999 | 0.025 | -12.93 | -16.00 | .37E-04 | 0.1109 |
| 9/29/80 | 16 | 264. | 5.10 | 100. | 4/3 | 289/289 | 0.00 | 76. | 0.0000 | 0.068 | -0.999 | -0.999 | -0.999 | 0.025 | -109.15 | -50.00 | .10E-03 | 0.1734 |
| 9/29/80 | 18 | 264. | 5.20 | 50. | 4/4 | 289/289 | -0.10 | 76. | 0.0000 | 0.091 | -0.999 | -0.999 | -0.999 | 0.025 | -90.99 | 9999.00 | .11E-03 | 0.1784 |
| 1/ 6/81 | 16 | 276. | 4.00 | 50. | 5/4 | 290/290 | 1.60 | 60. | 0.0000 | 0.394 | -0.999 | -0.999 | -0.999 | 0.010 | 18.69 | 9999.00 | .41E-04 | 0.0975 |
| 1/ 6/81 | 17 | 283. | 5.10 | 50. | 4/4 | 291/291 | 1.70 | 58. | 0.0000 | 0.232 | -0.999 | -0.999 | -0.999 | 0.010 | 34.67 | 9999.00 | .83E-04 | 0.1342 |
| 1/ 6/81 | 18 | 276. | 4.90 | 50. | 4/5 | 290/290 | 1.80 | 60. | 0.0000 | 0.166 | -0.999 | -0.999 | -0.999 | 0.010 | 26.06 | 50.00 | .72E-04 | 0.1205 |
| 1/ 9/81 | 15 | 286. | 4.70 | 100. | 4/4 | 288/288 | -0.90 | 87. | 0.0000 | 0.059 | -0.999 | -0.999 | -0.999 | 0.000 | -32.60 | 9999.00 | .87E-04 | 0.1634 |
| 1/ 9/81 | 16 | 277. | 4.60 | 100. | 4/4 | 2881288 | -0.50 | 85. | 0.0000 | 0.084 | -0.999 | -0.999 | -0.999 | 0.000 | -46.95 | 9999.00 | .82E-04 | 0.1570 |
| 1/ 9/81 | 18 | 274. | 4.90 | 100. | 4/5 | 288/288 | -0.30 | 87. | 0.0000 | 0.054 | -0.999 | -0.999 | -0.999 | 0.000 | -81.68 | 50.00 | .95E-04 | 0.1665 |
| 1/13/81 | 15 | 274. | 5.80 | 50. | 4/4 | 290/290 | 1.40 | 65. | 0.0000 | 0.206 | -0.999 | -0.999 | -0.999 | 0.010 | 59.50 | 9999.00 | .12E-03 | 0.1699 |
| 1/13/81 | 17 | 242. | 4.20 | 50. | 4/4 | 289/289 | 0.40 | 84. | 0.0000 | 0.150 | -0.999 | -0.999 | -0.999 | 0.010 | 129.21 | 9999.00 | .59E-04 | 0.1243 |

experiment in-the summer (June) of 1982 (Dabberdt et al., 1983; Brodzinsky et al., 1982 and Schacher et al., 19821. A site map is given in Figure 4-2, where it can be seen that the tracer releases took place about 5 to 7 km offshore and the major monitoring arc was located at the shoreline.

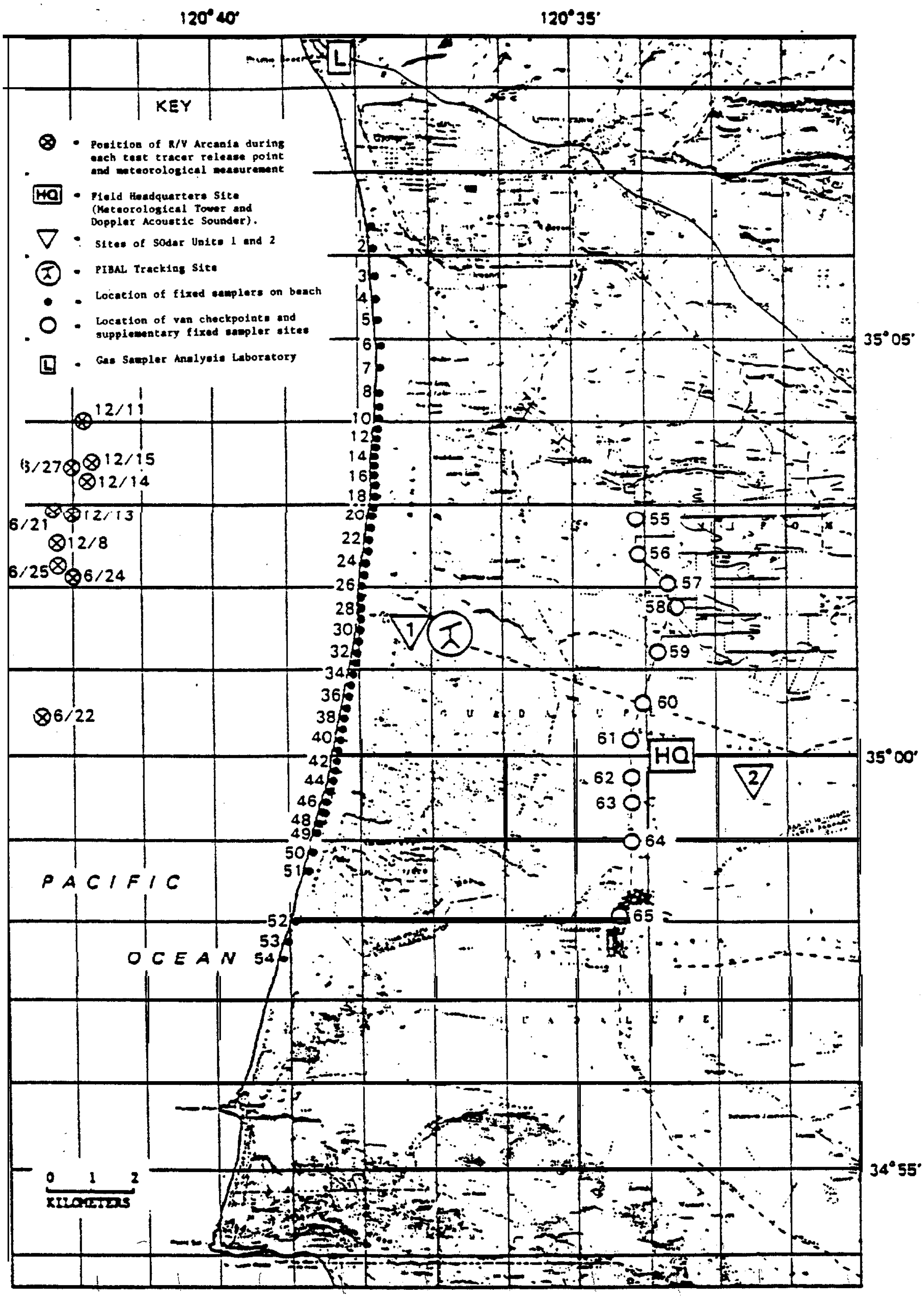
The terrain was generally flat near the shoreline. Wind speeds averaged about 5 m/s for both experiments. The overwater boundary layer was quite stable for the summer experiment, and moderately stable for most of the winter experiment.

The methods of compiling meteorological input data were similar at Pismo Beach and Ventura. At both sites, wind speed, $\sigma_\theta$, and air-water temperature difference were taken from the boat, and $d\theta/dz$ was taken from an aircraft profile. The wind direction was assumed to be lined up with the monitor with maximum observed concentration. A summary of the meteorological input data used in the modeling analysis for Pismo Beach is presented in Table 4-3.

### 4.1.3 Cameron

The third experimental site is located on the coast of the Gulf of Mexico, in Cameron, Louisiana. The terrain is very flat and the line of monitors is located on the shoreline. The evaluation data set consists of 9 hours from an experiment in the summer (July) of 1981 and 17 hours from an experiment in the winter (February) of 1982. Most of the tracer gas releases were from an oil platform 7 km offshore, although two releases were from a boat 4 km offshore. A site map is given in Figure 4-3.

The wind speed and air-water temperature difference observed on the oil platform are recommended for use in the model. Lateral turbulence, $\sigma_\theta$, was observed only at a shoreline tower, and it is assumed that this measurement is representative of offshore conditions. The vertical temperature gradient was observed by an aircraft. The wind direction is assumed to be lined up with the monitor with the maximum observed concentration. Table 4-4 lists the meteorological input data for the Cameron experiments used in the OCD model analysis.




12 mi

Figure 4-2. Tracer sampling sites used in the Pismo Beach experiment (sites have been renumbered for model evaluation).

TABLE 4-3

METEOROLOGICAL INPUT DATA FOR PISMO BEACH, CALIFORNIA

| | | <------ | ------ | ------ | ------ | ------ | OBSERVED | ------ | ------ | ------ | ------ | ------ | ------ | ------ | -----> | <------ | CALCULATED | -----> |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | HR | OVER-WATER WIND DIR | OVER-WATER WIND SPEED, M/SEC (REL HT) | OVER-WATER NIXING HEIGHT (M) | OVER-WATER/LAND STAB. CLASS | OVER-WATER/LAND AIR TEMP (DEG K) | AIR MINUS SEA SFC TEMP (DEG K) | RH ( ) | WIND DIR SHEAR (DEG/M) | OVER-WATER HORIZ. TURB. INTEN. (IYW) | OVER-WATER VERT. TURB. INTEN. (IZW) | OVER-LAND HORIZ. TURB. INTEN. (IYL) | OVER-LAND VERT. TURB. INTEN. (IZL) | OVER-WATER VERT. POT. TEMP. GRAD. (K/M) | OVER-WATER MONIN-OBUKHOV LENGTH (M) | OVER-LAND MONIN-OBUKHOV LENGTH (M) | OVER-WATER SURFACE ROUGH. LENGTH (M) | OVER-WATER FRICTION VELOCITY (U*) (M/SEC) |
| 12/ 8/81 | 15 | 261. | 2.20 | 100. | 6/3 | 288/288 | 1.30 | 67. | 0.0000 | 0.166 | -0.999 | -0.999 | -0.999 | 0.030 | 5.00 | -50.00 | .63E-05 | 0.0257 |
| 12/ 8/81 | 16 | 284. | 1.60 | 100. | 6/4 | 288/288 | 1.20 | 7s. | 0.0000 | 0.229 | -0.999 | -0.999 | -0.999 | 0.030 | 5.00 | 9999.00 | .26E-05 | 0.0182 |
| 12/11/81 | 14 | 275. | 4.50 | 600. | 4/3 | 286/286 | -0.40 | 74. | 0.0000 | 0.098 | -0.999 | -0.999 | -0.999 | 0.010 | -43.44 | -50.00 | .78E-04 | 0.1533 |
| 12/11/81 | 15 | 283. | 5.40 | 600. | 4/3 | 286/286 | 0.00 | 73. | 0.0000 | 0.080 | -0.999 | -0 , 999 | -0.999 | 0.010 | -139.56 | -50.00 | .12E-03 | 0.1847 |
| 12/11/81 | 17 | 289. | 8.60 | 700. | 4/4 | 286/286 | 0.10 | 84. | 0.0000 | 0.037 | -0.999 | -0.999 | -0.999 | 0.010 | • | 9999.00 | .37E-03 | 0.3157 |
| 12/11/81 | 19 | 305. | 7.90 | 900. | 4/6 | 286/286 | 0.20 | 81. | 0.0000 | 1.000 | -0.999 | -0.999 | -0.999 | 0.010. | | 15.00 | .30E-03 | 0.2839 |
| 12/13/81 | 14 | 289. | 5.40 | so. | 4/4 | 286/286 | -0.80 | 95. | 0.0000 | 0.016 | -0.999 | -0.999 | -0.999 | 0.000 | -59.23 | 9999.00 | .12E-03 | 0.1893 |
| 12/13/81 | 1s | 260. | 6.10 | SO. | 4/3 | 285/285 | -0.80 | 97. | 0.0000 | 0.042 | -0.999 | -0.999 | -0.999 | 0.000 | -82.58 | -50.00 | .16E-03 | 0.2172 |
| 12/13/81 | 17 | 301. | 7.90 | so. | 7/4 | 286/286 | 0.30 | 92. | 0.0000 | 0.033 | -0.999 | -0.999 | -0.999 | 0.060 | 465.67 | 9999.00 | .29E-03 | 0.2779 |
| 12/14/81 | 13 | 292. | 7.70 | so. | 4/4 | 287/287 | 1.30 | 79. | 0.0000 | 0.021 | -0.999 | -0.999 | -0.999 | 0.020 | 97.74 | 9999.00 | .25E-03 | 0.2508 |
| 12/14/81 | 15 | 292. | 10.90 | so. | 4/3 | 286/286 | 0.40 | so. | 0.0000 | 0.021 | -0.999 | -0.999 | -0.999 | 0.020 | 853.87 | -50.00 | .65E-03 | 0.4162 |
| 12/14/81 | 17 | 296. | 9.90 | so. | 4/4 | 287/287 | 0.90 | 88. | 0.0000 | 0.031 | -0.999 | -0.999 | -0.999 | 0.020 | 260.23 | 9999.00 | .SOE-03 | 0.3601 |
| 12/15/81 | 13 | 304. | 5.60 | so. | 4/3 | 286/286 | 0.30 | 88. | 0.0000 | 0.257 | -0.999 | -0.999 | -0.999 | 0.010 | 255.46 | -50.00 | .12E-03 | 0.1806 |
| 12/15/81 | 14 | 299. | 6.10 | so. | 4/4 | 288/288 | 1.10 | 83. | 0.0000 | 1.000 | -0.999 | -0.999 | -0.999 | 0.010 | 60.92 | 9999.00 | .14E-03 | 0.1809 |
| 12/15/81 | 19 | 321. | 1.60 | so. | 6/6 | 289/289 | 3.40 | 70. | 0.0000 | 1.000 | -0.999 | -0.999 | -0.999 | 0.030 | 5.00 | 15.00 | .26E-05 | 0.0182 |
| 6/21/82 | 15 | 276. | 4.30 | 800. | 5/4 | 2881288 | 1.50 | 84. | 0.0000 | 0.024 | -0.999 | -0.999 | -0.999 | 0.008 | 14.41 | 9999.00 | .46E-04 | 0.0874 |
| 6/21/82 | 16 | 269. | 3.80 | 800. | 5/4 | 2871287 | 1.40 | 86. | 0.0000 | 0.037 | -0.999 | -0.999 | -0.999 | 0.008 | 10.72 | 9999.00 | .32E-04 | 0.0680 |
| 6/21/82 | 17 | 261. | 2.70 | 800. | 6/4 | 287/287 | 1.50 | 87. | 0.0000 | 0.120 | -0.999 | -0.999 | -0.999 | 0.008 | 5.00 | 9999.00 | .10E-04 | 0.0320 |
| 6/21/82 | 18 | 276. | 3.00 | 800. | 6/4 | 287/287 | 1.20 | 89. | 0.0000 | 0.358 | -0.999 | -0.999 | -0.999 | 0.008 | 6.33 | 9999.00 | .16E-04 | 0.0409 |
| 6122182 | 15 | 274. | 3.70 | 700. | 6/3 | 289/289 | 1.70 | 80. | 0.0000 | 0.106 | -0.999 | -0.999 | -0.999 | 0.001 | 8.31 | -50.00 | .28E-04 | 0.0590 |
| 6/22/82 | 16 | 268. | 5.20 | 700. | 5/4 | 289/289 | 2.10 | 78. | 0.0000 | 0.058 | -0.999 | -0.999 | -0.999 | 0.005 | 17.0s | 9999.00 | .77E-04 | 0.1146 |
| 6/22/82 | 19 | 289. | 3.20 | 700. | 6/4 | 287/287 | 1.30 | 84. | 0.0000 | 0.187 | -0.999 | -0.999 | -0.999 | 0.005 | 7.49 | 9999.00 | .19E-04 | 0.0479 |
| 6/24/82 | 13 | 269. | 3.90 | 600. | 4/3 | 288/288 | .0.90 | Ii. | 0.0000 | 0.527 | -0.999 | -0.999 | -0.999 | 0.010 | 25.07 | -50.00 | .41E-04 | 0.0919 |
| 6/24/82 | 15 | 269. | 1.30 | 600. | 4/4 | 288/288 | 0.60 | 84. | 0.0000 | 0.131 | -0.999 | -0.999 | -0.999 | 0.010 | 101.05 | 9999.00 | .10E-03 | 0.1611 |
| 6/25/82 | 12 | 286. | 5.60 | 100. | 5/3 | 289/289 | 2.20 | 76. | 0.0000 | 0.024 | -0.999 | -0.999 | -0.999 | 0.010 | 20.33 | -50.00 | .95E-04 | 0.1316 |
| 6/25/82 | 13 | 280. | -6.50 | 100. | 5/3 | 289/289 | 2.60 | 80. | 0.0000 | 0.028 | -0.999 | -0.999 | -0.999 | 0.010 | 23.85 | -50.00 | .14E-03 | 0.1632 |
| 6/25/82 | 15 | 286. | 9.80 | 100. | 4/4 | 288/288 | 2.60 | 82. | 0.0000 | 0.096 | -0.999 | -0.999 | -0.999 | 0.010 | 77.71 | 9999.00 | .45E-03 | 0.3276 |
| 6/25/82 | 16 | 288. | 9.10 | 100. | 4/4 | 288/288 | 2.90 | 82. | 0.0000 | 0.016 | -0.999 | -0.999 | -0.999 | 0.010 | 54.84 | 9999.00 | .36E-03 | 0.2866 |
| 6/25/82 | 17 | 290. | 9.50 | 100. | 4/4 | 288/288 | 3.20 | 81. | 0.0000 | 0.021 | -0.999 | -0.999 | -0.999 | 0.010 | 55.53 | 9999.00 | .40E-03 | 0.3023 |
| 6/27/82 | 16 | 287. | 12.70 | 100. | 4/4 | 287/287 | 3.40 | 93. | 0.0000 | 0.019 | -0.999 | -0.999 | -0.999 | 0.010 | 112.70 | 9999.00 | .88E-03 | 0.4654 |
| 6/27/82 | 18 | 285. | 10.20 | 100. | 4/4 | 288/288 | 3.70 | 94. | 0.0000 | 0.136 | -0.999 | -0.999 | -0.999 | 0.010 | S3.41 | 9999.00 | .48E-03 | 0.3272 |

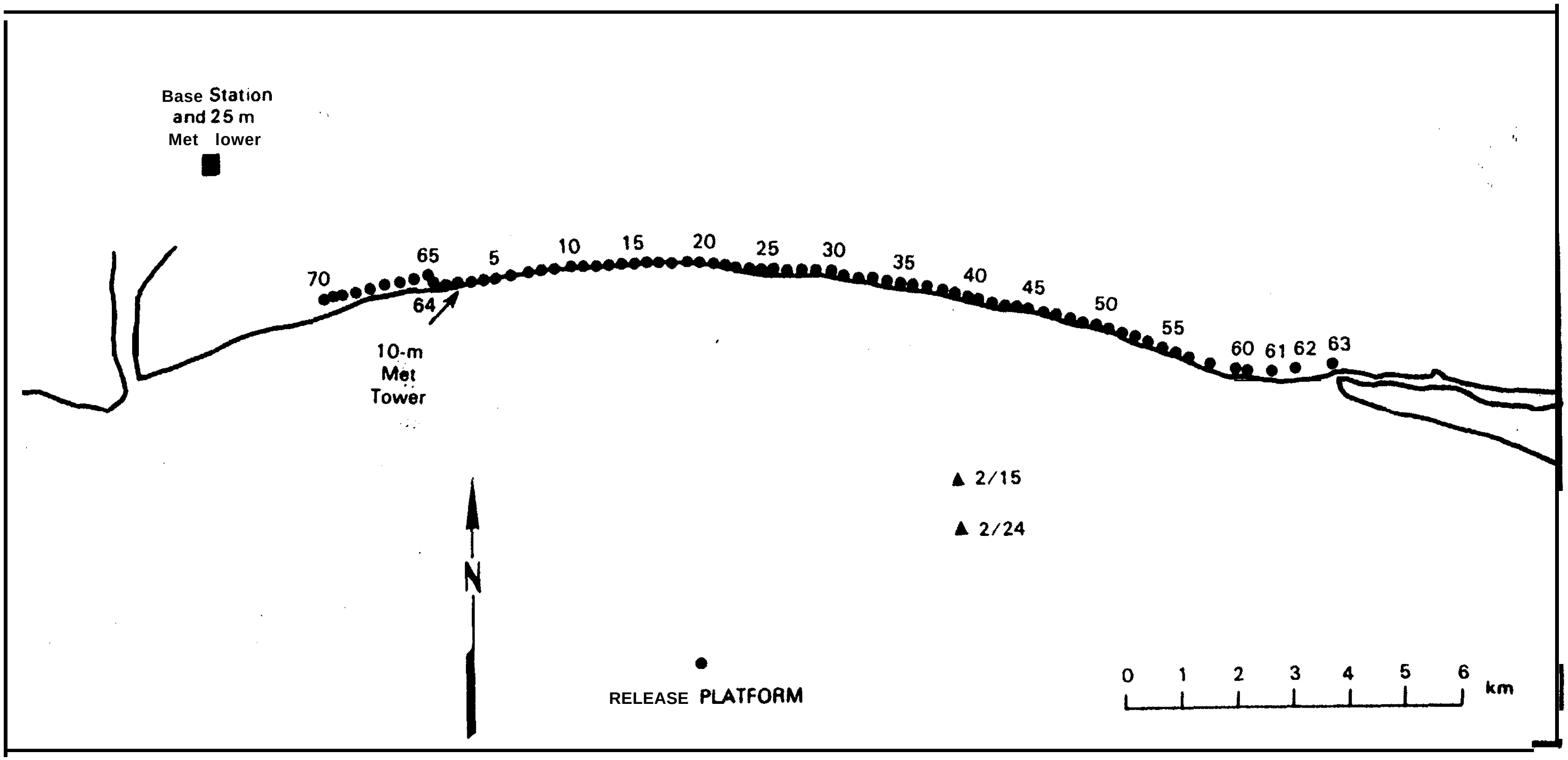



Figure 4-3. Tracer sampling sites used in the Cameron, LA experiment (sites have been renumbered for model evaluation). The tracer release points for 2/15 and 2/24 are indicated by triangles.

TABLE 4-4

METEOROLOGICAL INPUT DATA FOR CAMERON, LOUISIANA

| | | <----- | ----- | ----- | ----- | ----- | ----- | OBSERVED | ----- | ----- | ----- | ----- | ----- | ----> | <----- | CALCULATED | ----- | ----> | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | HR | OVER-WATER WIND DIR | OVER-WATER WIND SPEED, N/SEC (REL HT) | OVER-WATER MIXING HEIGHT (M) | OVER-WATER/LAND STAR. CLASS | OVER-WATER/LAND AIR TEMP (DEG K) | AIR MINUS SEA SFC TEMP (DEG K) | RH ( ) | WIND DIR SHEAR (DEG/M) | OVER-WATER HORIZ. TURB. INTEN. (IYW) | OVER-WATER VERT. TURB. INTEN. (IZW) | OVER-LAND HORIZ. TURB. INTEN. (IYL) | OVER-LAND VERT. TURB. INTEN. (IZL) | OVER-WATER VERT. POT. TEMP. GRAD. (K/N) | OVER-WATER MONIN-OBUKHOV LENGTH (M) | OVER-LAND MONIN-OBUKHOV LENGTH (M) | OVER-WATER SURFACE ROUGH. LENGTH (M) | OVER-WATER FRICTION VELOCITY (U*) (U/SEC) | |
| 7/20/81 | 14 | 202. | 4.60 | 900. | 2/2 | 302/302 | -2.70 | 63. | 0.0000 | 0.112 | -0.999 | -0.999 | -0.999 | 0.000 | -9.27 | -16.00 | .85E-04 | 0.1711 | |
| 7/20/81 | 15 | 210. | 4.90 | 900. | 2/1 | 303/303 | -2.60 | 64. | 0.0000 | 0.096 | -0.999 | -0.999 | -0.999 | 0.000 | -9.43 | -9.00 | .95E-04 | 0.1790 | |
| 7/23/81 | 17 | 232. | 4.30 | 225. | 3/2 | 304/304 | -1.40 | 13. | 0.0000 | 0.093 | -0.999 | -0.999 | -0.999 | 0.000 | -11.90 | -16.00 | .72E-04 | 0.1546 | |
| 7/23/81 | 19 | 229. | 5.10 | 225. | 3/3 | 304/304 | -1.20 | 74. | 0.0000 | 0.093 | -0.999 | -0.999 | -0.999 | 0.000 | -19.71 | -50.00 | .11E-03 | 0.1959 | |
| 7/27/81 | 20 | 176. | 2.10 | 400. | 2/4 | 300/300 | -4.40 | 92. | 0.0000 | -0.999 | -0.999 | -0.999 | -0.999 | 0.000 | -5.00 | 9999.00 | .12E-04 | 0.0679 | |
| 7/27/81 | 22 | 151. | 4.50 | 450. | 2/6 | 300/300 | -4.50 | 92. | 0.0000 | -0.999 | -0.999 | -0.999 | -0.999 | 0.000 | -6.36 | 15.00 | .81E-04 | 0.1691 | |
| 7/29/81 | 16 | 219. | 4.60 | 420. | 2/2 | 3031303 | -2.20 | 69. | 0.0000 | 0.169 | -0.999 | -0.999 | -0.999 | 0.000 | -9.97 | -16.00 | .85E-04 | 0.1694 | |
| 7/29/81 | 17 | 240. | 5.00 | 430. | 3/1 | 303/303 | -2.00 | 69. | 0.0000 | 0.113 | -0.999 | -0.999 | -0.999 | 0.000 | -12.92 | -9.00 | .10E-03 | 0.1952 | |
| 7/29/81 | 19 | 241. | 5.00 | 450. | 3/4 | 303/303 | -1.70 | 69. | 0.0000 | 0.169 | -0.999 | -0.999 | -0.999 | 0.000 | -14.16 | 9999.00 | .10E-03 | 0.1943 | |
| 2/15/82 | 16 | 142. | 5.70 | 200. | 7/4 | 287/287 | 0.00 | 99. | 0.0000 | -0.999 | -0.999 | -0.999 | -0.999 | 0.060 | [illegible] | 9999.00 | .14E-03 | 0.1935 | |
| 2/15/82 | 11 | 134. | 5.60 | 200. | 7/4 | 287/287 | -0.90 | 99. | 0.0000 | -0.999 | -0.999 | -0.999 | -0.999 | 0.060 | -69.85 | 9999.00 | .14E-03 | 0.1986 | 821 |
| 2/15/82 | 20 | 147. | 5.90 | 200. | 7/4 | 287/287 | -0.40 | 97. | 0.0000 | -0.999 | -0.999 | -0.999 | -0.999 | 0.060 | -141.00 | 9999.00 | .15E-03 | 0.2076 | 85 |
| 2/17/82 | 14 | 119. | 3.30 | 200. | 6/3 | 289/289 | 2.10 | 93. | 0.0000 | 0.043 | -0.999 | -0.999 | -0.999 | 0.030 | 5.00 | -50.00 | .20E-04 | 0.0431 | |
| 2/17/82 | 15 | 195. | 3.70 | 200. | 5/3 | 288/288 | 0.90 | 93. | 0.0000 | 0.134 | -0.999 | -0.999 | -0.999 | 0.030 | 16.91 | -50.00 | .36E-04 | 0.0915 | |
| 2/17/82 | 16 | 210. | 4.30 | 200. | 4/3 | 288/288 | 0.60 | 93. | 0.0000 | 0.069 | -0.999 | -0.999 | -0.999 | 0.030 | 39.90 | -50.00 | .59E-04 | 0.1161 | -- |
| 2/17/82 | 17 | 206. | 3.50 | 200. | 4/4 | 288/288 | -0.20 | 93. | 0.0000 | 0.066 | -0.999 | -0.999 | -0.999 | 0.030 | -130.31 | 9999.00 | .42E-04 | 0.1109 | 459 |
| 2/17/82 | 19 | 193. | 3.50 | 200. | 4/5 | 287/287 | -0.70 | 93. | 0.0000 | 0.036 | -0.999 | -0.999 | -0.999 | 0.030 | -29.2s | 50.00 | .43E-04 | 0.1157 | 478 |
| 2/22/82 | 14 | 171. | 5.20 | 100. | 4/2 | 2911291 | 1.30 | 75. | 0.0000 | 0.047 | -0.999 | -0.999 | -0.999 | 0.030 | 40.94 | -16.00 | .95E-04 | 0.1462 | |
| 2/22/82 | 16 | 172. | 4.70 | 100. | 4/4 | 2911291 | 0.90 | 76. | 0.0000 | 0.042 | -0.999 | -0.999 | -0.999 | 0.030 | 54.04 | 9999.00 | .76E-04 | 0.1349 | |
| 2/22/82 | 11 | 192. | 4.50 | 100. | 4/4 | 291/291 | 0.80 | 76. | 0.0000 | 0.049 | -0.999 | -0.999 | -0.999 | 0.030 | 60.07 | 9999.00 | .69E-04 | 0.1297 | |
| 2/23/82 | 14 | 152. | 4.90 | SO. | 6/3 | 292/292 | 3.70 | 94. | 0.0000 | 0.011 | -0,999 | -0.999 | -0.999 | 0.025 | 6.96 | -50.00 | .57E-04 | 0.0774 | |
| 2/23/82 | 11 | 165. | 6.20 | 90. | 4/4 | 291/291 | 2.30 | 99. | 0.0000 | 0.056 | -0.999 | -0.999 | -0.999 | 0.025 | 25.95 | 9999.00 | .14E-03 | 0.1649 | |
| 2/24/82 | 15 | 143. | 3.70 | 50. | 7/4 | 293/293 | 5.00 | 49. | 0.0000 | 0.049 | -0.999 | -0.999 | -0.999 | 0.047 | 5.00 | 9999.00 | .24E-04 | 0.0496 | |
| 2/24/82 | 16 | 143. | 3.70 | 50. | 7/4 | 293/293 | 4.60 | 50. | 0.0000 | 0.056 | -0.999 | -0.999 | -0.999 | 0.047 | 5.00 | 9999.00 | .25E-04 | 0.0497 | |
| 2/24/82 | 11 | 140. | 3.50 | 50. | 7/4 | 2931293 | 4.70 | 50. | 0.0000 | 0.057 | -0.999 | -0.999 | -0.999 | 0.047 | 5.00 | 9999.00 | .21E-04 | 0.0459 | |
| 2/24/82 | 19 | 156. | 4.10 | 50. | 7/5 | 291/291 | 2.70 | 52. | 0.0000 | 0.046 | -0.999 | -0.999 | -0.999 | 0.047 | 9.56 | 50.00 | .42E-04 | 0.0751 | |

### 4.1.4 Carpinteria

The fourth experimental site is located in Carpinteria, CA (Johnson and Spangler, 1986), where there is a 30-50 m shoreline bluff and terrain rises to 600 m a few kilometers inland. A site map is given in Figure 4-4 and the meteorological input data used in the modeling analysis are presented in Table 4-5. The monitoring network was set up in two slightly different locations. The experiment at the first location (the complex terrain study) consisted of 18 hours of $SF_6$ tracer data, where the release was from a tube held by a tethersonde cable. The release height ranged from about 20 to about 30 m, and the offshore distance was 0.3 to 0.7 km. Because this distance was much less than the offshore distance at the other sites, the maximum C/Q observed at the shoreline is relatively large. Concurrent with 10 of these $SF_6$ hours, another tracer (freon) was released from a tube at a height of 20 to 70 m. The experiment at the second location (the fumigation study) consisted of 9 periods of $SF_6$ data, where the release height was increased to 70 to 100 m and the monitoring network was shifted to a slightly more level location adjacent to the location used for the complex terrain study. The model evaluation exercise emphasizes the line of monitors located near the shoreline, at the top of the 30-50 m shoreline bluff.

All data were collected during September, 1985. The median wind speed was 1.7 m/s, which is a factor of two to three less than the median wind speeds observed at the other experiment sites. The overwater stability covered a wide range, with a slight tendency towards stable conditions. The median lateral turbulence intensity ($i_y$) was 0.31, which is a factor of two to five greater than that observed at the other sites (since we know that $i_y \propto u^{-1}$, this result is cons&tent with the wind speed difference discussed above).

Input overwater meteorological data (see Table 4-5) were taken from the tethersonde site (the location of the tracer gas release). Air-sea temperature differences were taken from the oil platform, and wind directions were assumed to be lined up with the monitor showing maximum observed concentrations.

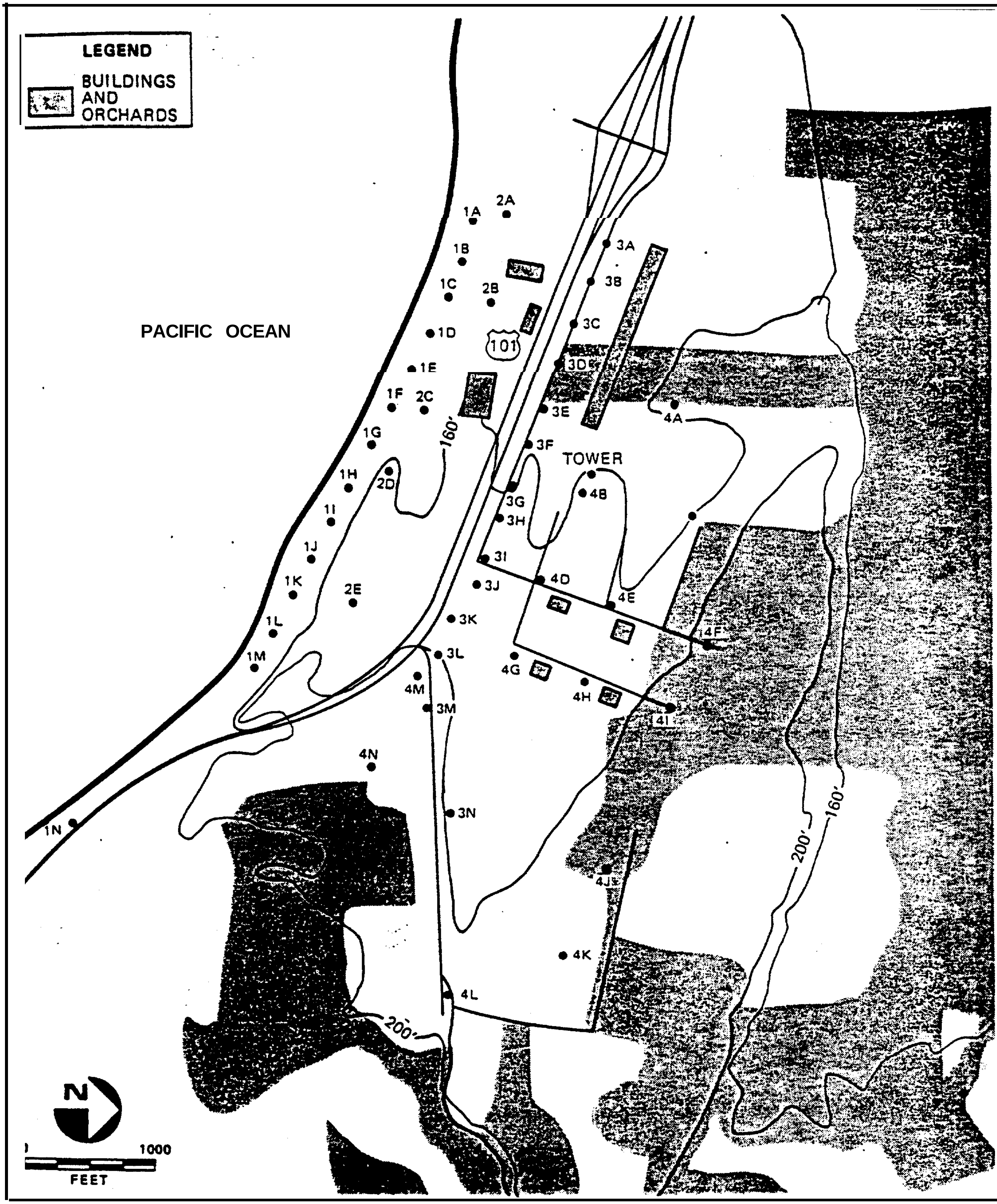



Figure 4-4. Tracer sampling sites used in the terrain effects portion of the Carpinteria, CA experiment.

# TABLE 4-5

## METEOROLOGICAL INPUT DATA USED FOR CARPINTERIA, CALIFORNIA

| | DATE | HR | OVER-WATER WIND DIR | OVER-WATER WIND SPEED, U/SEC (REL HT) | OVER-WATER MIXING HEIGHT (M) | OVER-WATER/LAND STAB. CLASS | OVER-WATER/LAND AIR TEMP (DCG K) | AIR MINUS SEA SFC TEMP (DEG K) | RH ( ) | WIND DIR SHEAR (DEG/M) | OVER-WATER HORIZ. TURB. INTEN. (IYW) | OVER-WATER VERT. TURB. INTEN. (IZW) | OVER-LAND HORIZ. TURB. INTEN. (IYL) | OVER-LAND VERT. TURB. INTEN. (IZL) | WATER VERT. POT. TEMP. GRAD. (K/M) | OVER-WATER MONIN-OBUKHOV LENGTH (M) | OVER-LAND MONIN-OBUKHOV LENGTH (M) | OVER-WATER SURFACE ROUGH. LENGTH (M) | OVER-WATER FRICTION VELOCITY (U*) (M/SEC) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OBSERVED | | | | | | | | | | | | | CALCULATED | | | |
| SF6 Hours | 9/19/85 | 9 | 260. | 1.30 | 500. | 2/2 | 289/291 | -1.10 | 79. | 0.0000 | 0.506 | -0.999 | -0.999 | -0.999 | 0.000 | -5.00 | -16.00 | .36E-05 | 0.0377 |
| | 9/19/85 | 10 | 235. | 1.30 | 500. | 2/2 | 290/291 | -0.90 | 79. | 0.0000 | 0.541 | -0.999 | -0.999 | -0.999 | 0.000 | -5.00 | -16.00 | .36E-05 | 0.0317 |
| | 9/19/85 | 11 | 214. | 2.60 | 500. | 2/2 | 290/292 | -0.70 | 80. | 0.0000 | 0.454 | -0.999 | -0.999 | -0.999 | 0.000 | -8.64 | -16.00 | .20E-04 | 0.0936 |
| | 9/19/85 | 12 | 253. | 3.10 | 500. | 3/2 | 290/292 | -0.70 | 80. | 0.0000 | 0.646 | -0.999 | -0.999 | -0.999 | 0.000 | -12.79 | -16.00 | .31E-04 | 0.1012 |
| | 9/22/85 | 9 | 221. | 1.00 | 500. | 4/2 | 291/292 | 0.50 | 71. | 0.0000 | 0.629 | -0.999 | -0.999 | -0.999 | 0.020 | 211.45 | -16.00 | .16E-05 | 0.0230 |
| | 9/22/85 | 10 | 251. | 1.20 | 500. | 4/3 | 290/293 | 0.30 | 91. | 0.0000 | 0.314 | -0.999 | -0.999 | -0.999 | 0.020 | 64.39 | -50.00 | .22E-05 | 0.0258 |
| | 9/22/85 | 11 | 254. | 2.40 | 500. | 6/3 | 290/292 | 1.00 | 92. | 0.0000 | 0.140 | -0.999 | -0.999 | -0.999 | 0.020 | 5.00 | -50.00 | .45E-05 | 0.0219 |
| | 9/22/85 | 12 | 248. | 2.80 | 500. | 6/3 | 289/292 | 1.10 | 91. | 0.0000 | 0.314 | -0.999 | -0.999 | -0.999 | 0.020 | 5.00 | -50.00 | .77E-05 | 0.0259 |
| | 9/25/85 | 10 | 164. | 1.00 | 500. | 6/1 | 294/296 | 2.90 | 60. | 0.0000 | 0.990 | -0.999 | -0.999 | -0.999 | 0.010 | 5.00 | -9.00 | .66E-06 | 0.0100 |
| | 9/25/85 | 11 | 164. | 1.60 | 500. | 6/2 | 294/296 | 2.30 | 70. | 0.0000 | 0.174 | -0.999 | -0.999 | -0.999 | 0.010 | 5.00 | -16.00 | .67E-06 | 0.0104 |
| | 9/25/85 | 12 | 166. | 1.00 | 500. | 6/2 | 294/297 | 2.10 | 90. | 0.0000 | 0.499 | -0.999 | -0.999 | -0.999 | 0.010 | 5.00 | -16.00 | .22E-06 | 0.0064 |
| | 9/25/85 | 13 | 175. | 1.00 | 500. | 6/2 | 295/297 | 2.70 | 90. | 0.0000 | 0.332 | -0.999 | -0.999 | -0.999 | 0.010 | 5.00 | -16.00 | .22E-06 | 0.0064 |
| | 9/28/85 | 10 | 156. | 5.40 | 500. | 4/3 | 291/293 | -0.60 | 85. | 0.0000 | 0.157 | -0.999 | -0.999 | -0.999 | 0.000 | -57.03 | -50.00 | .12E-03 | 0.1976 |
| | 9/28/85 | 11 | 115. | 3.20 | 500. | 3/3 | 291/293 | -0.90 | 84. | 0.0000 | 0.192 | -0.999 | -0.999 | -0.999 | 0.000 | -13.39 | -50.00 | .34E-04 | 0.1059 |
| | 9/28/85 | 13 | 235. | 1.50 | 500. | 2/2 | 291/293 | -0.60 | 82. | 0.0000 | 0.192 | -0.999 | -0.999 | -0.999 | 0.000 | -1.00 | -16.00 | .52E-05 | 0.0449 |
| | 9/28/85 | 14 | 215. | 2.10 | 500. | 2/2 | 292/294 | -0.30 | 92. | 0.0000 | 0.209 | -0.999 | -0.999 | -0.999 | 0.000 | -9.99 | -16.00 | .12E-04 | 0.0652 |
| | 9/29/85 | 11 | 244. | 3.40 | 500. | 4/2 | 291/292 | -0.30 | 86. | 0.0000 | 0.332 | -0.999 | -0.999 | -0.999 | 0.000 | -30.74 | -16.00 | .38E-04 | 0.1096 |
| | 9/29/85 | 12 | 239. | 3.10 | 500. | 3/3 | 291/292 | -0.40 | 99. | 0.0000 | 0.097 | -0.999 | -0.999 | -0.999 | 0.000 | -22.31 | -50.00 | .30E-04 | 0.0996 |
| Fumigation Hours | 10/1/85 | 10 | 216. | 2.00 | 500. | 2/1 | 290/292 | -0.90 | 92. | 0.0000 | 0.349 | -0.999 | -0.999 | -0.999 | 0.000 | -5.00 | -9.00 | .10E-04 | 0.0617 |
| | 10/3/85 | * | 165. | 1.00 | 500. | 7/1 | 299/299 | 2.10 | 99. | 0.0000 | 0.227 | -0.999 | -0.999 | -0.999 | 0.070 | 3.00 | -9.00 | .13E-06 | 0.0052 |
| | 10/3/85 | 11 | 216. | 1.90 | 500. | 7/1 | 298/299 | 3.40 | 96. | 0.0000 | 0.646 | -0.999 | -0.999 | -0.999 | 0.130 | 5.00 | -9.00 | .51E-06 | 0.0095 |
| | 10/4/85 | 10 | 217. | 1.70 | 500. | 6/2 | 295/297 | 3.30 | 70. | 0.0000 | 0.262 | -0.999 | -0.999 | -0.999 | 0.010 | 5.00 | -16.00 | .29E-06 | 0.0075 |
| | 10/4/85 | ** | 231. | 2.60 | 500. | 6/2 | 295/297 | 3.30 | 72. | 0.0000 | 0.209 | -0.999 | -0.999 | -0.999 | 0.010 | 5.00 | -16.00 | .77E-06 | 0.0116 |
| | 10/4/85 | 11 | 196. | 1.70 | 500. | 6/2 | 294/297 | 3.30 | 76. | 0.0000 | 0.244 | -0.999 | -0.999 | -0.999 | 0.010 | 5.00 | -16.00 | .29E-06 | 0.0075 |
| | 10/5/85 | ** | 171. | 1.30 | 500. | 4/1 | 294/295 | 0.70 | 67. | 0.0000 | 0.541 | -0.999 | -0.999 | -0.999 | 0.020 | -72.53 | -9.00 | .31E-05 | 0.0325 |
| | | | | 1.50 | 500. | 4/1 | 294/295 | 0.70 | 65. | 0.0000 | 0.349 | -0.999 | -0.999 | -0.999 | 0.020 | -25.75 | -9.00 | .46E-05 | 0.0400 |
| | 9/22/85 | 12 | 195. | 1.00 | 100. | 2/1 | 295/296 | 0.70 | 63. | 0.0000 | 0.541 | -0.999 | -0.999 | -0.999 | 0.010 | -6.70 | -9.00 | .18E-05 | 0.0266 |
| | | | | 2.40 | 500. | 6/3 | 290/292 | 1.00 | 92. | 0.0000 | 0.140 | -0.999 | -0.999 | -0.999 | 0.020 | 5.00 | -50.00 | .45E-05 | 0.0219 |
| | | | | 2.80 | 500. | 6/3 | 289/292 | 1.10 | 91. | 0.0000 | 0.314 | -0.999 | -0.999 | -0.999 | 0.020 | 5.00 | -50.00 | .77E-05 | 0.0259 |
| Freon Hours | | | | 3.80 | 500. | 3/3 | 292/293 | -0.70 | 84. | 0.0000 | 0.192 | -0.999 | -0.999 | -0.999 | 0.000 | -20.11 | -50.00 | .48E-04 | 0.1240 |
| | 9/26/85 | 13 | 262. | 4.00 | 500. | 3/3 | 292/293 | -1.00 | 81. | 0.0000 | 0.209 | -0.999 | -0.999 | -0.999 | 0.000 | -16.60 | -50.00 | .55E-04 | 0.1332 |
| | 9/28/85 | 10 | 156. | 5.40 | 500. | 4/3 | 291/293 | -0.60 | 85. | 0.0000 | 0.157 | -0.999 | -0.999 | -0.999 | 0.000 | -57.03 | -50.00 | .12E-03 | 0.1976 |
| | 9/28/85 | 11 | 177. | 3.20 | 500. | 3/3 | 291/293 | -0.90 | 94. | 0.0000 | 0.192 | -0.999 | -0.999 | -0.999 | 0.000 | -13.39 | -50.00 | .34E-04 | 0.1059 |
| | 9/28/85 | 13 | 230. | 1.50 | 500. | 2/2 | 291/293 | -0.60 | 92. | 0.0000 | 0.192 | -0.999 | -0.999 | -0.999 | 0.000 | -5.00 | -16.00 | .52E-05 | 0.0449 |
| | 9/28/85 | 14 | 215. | 2.10 | 500. | 2/2 | 292/294 | -0.30 | 92. | 0.0000 | 0.209 | -0.999 | -0.999 | -0.999 | 0.000 | -9.91 | -16.00 | .12E-04 | 0.0652 |
| | 9/29/85 | 12 | 233. | 3.10 | 500. | 3/3 | 291/292 | -0.40 | 88. | 0.0000 | 0.097 | -0.999 | -0.999 | -0.999 | 0.000 | -22.31 | -50.00 | .30E-04 | 0.0996 |

* 9:30

** 10:30

## 4.2 Methods of Pairing Data

Each of the nine experiments (at four sites) described above is treated as a separate block of data and evaluated independently. To remove the effects of varying source emission rate, the normalized concentration, C/Q, is used. For each experiment hour a maximum observed and predicted concentration is defined. Because the wind direction has been assumed to be given by the direction from the source to the monitor with the maximum observed concentration, the observed and predicted maximum concentrations are forced to always occur at the same location. Consequently, the sizes of the data sets at each site are equal to the number of hours in that data set.

| | |
|---|---|
| Ventura Fall | 9 hours |
| Ventura Winter | 8 hours |
| Pismo Beach Summer | 16 hours |
| Pismo Beach Winter | 15 hours |
| Cameron Summer | 9 hours |
| Cameron Winter | 17 hours |
| Carpinteria $SF_6$ | 18 hours |
| Carpinteria Freon | 9 hours |
| Carpinteria Fumigation | 9 hours |

The total number of hours is 110. The model evaluation procedure is applied to each of the nine data blocks.

## 4.3 Model Evaluation and Results

The OCD/3 and revised OCD/4 models are evaluated for nine experiments at the four sites described in Section 4.1. Two sets of model runs for each version of OCD (Version 3 and 4) are compared: 1) using observed lateral turbulence intensity $i_Y$ and 2) using predicted lateral turbulence intensity $i_y$. Statistical tests are applied to the sets of observations and model predictions in order to determine whether the differences are significant between the models and the observations and between the various model options.

An arbitrary scoring scheme is used to combine all the statistical results into a final "score." In addition, the individual model errors are plotted versus meteorological parameters such as wind speed in order to determine whether the errors are independent of these variables.

4.3.1 Model Results for Maximum Concentration for Each Hour

The maximum observed normalized concentrations (C/Q) for each hour of each of the nine experiments are compared with OCD/3 and OCD/4 using observed values of $i_Y$ and predicted values of $i_Y$ in Tables 4-6 to 4-14. A statistical summary of each of the experiments including the average and maximum concentration, standard deviation, fractional bias (FB), normalized mean square error (NMSE), and the correlation (R) are also included in Tables 4-6 to 4-14. FB, NMSE, and R are defined by:

$$FB = 2\,(\bar{C}_o - \bar{C}_p)/(\bar{C}_o + \bar{C}_p) \qquad (4\text{-}1)$$

$$NMSE = \overline{(C_o - C_p)^2}/(\bar{C}_o\,\bar{C}_p) \qquad (4\text{-}2)$$

$$R = \overline{(C_o - \bar{C}_o)(C_p - \bar{C}_p)}/\sigma_{C_o}\,\sigma_{C_p} \qquad (4\text{-}3)$$

Note from the definitions given above, a negative value of FB indicates that the model is overpredicting.

The observed and predicted overall maximum normalized concentrations for each experiment are summarized in Table 4-15. The ratio of predicted to observed $(C_p/C_o)$ maximum normalized concentrations are also presented in parenthesis following the $C_p$ entry in the table. The model performance varies from experiment to experiment, with underpredictions by a factor of two at one experiment and overpredictions of a factor of two at another. For OCD/3, the model overpredicts the maximum concentrations at four of the nine experiments using $i_y$ (Observed1 data and the model overpredicts at three of the nine experiments using $i_y$ (Predicted1 data. For OCD/4, the model overpredicts at five of the nine experiments using $i_y$ (Observed) data. Using $i_y$ (Predicted) data, OCD/4 overpredicts and underpredicts an equal number of four experiments with one experiment having a maximum predicted concentration within one

TABLE 4-6

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR CAMERON, SUMMER HOURS ($\mu s/m^3$)

| Date | Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 7/20/81 | 14 | 1.1 | 0.2 | 0.2 | 1.7 | 2.3 |
| 7/20/81 | 15 | 0.8 | 0.2 | 0.2 | 2.4 | 1.6 |
| 7/23/81 | 17 | 1.9 | 0.8 | 0.7 | 2.1 | 2.0 |
| 7/23/81 | i8 | 3.0 | 0.7 | 0.7 | 2.0 | 2.1 |
| 7/27/81 | 2 0 | 0.4 | 0.8 | 0.8 | 1.6 | 1.6 |
| 7/27/81 | 2 2 | 0.4 | 0.3 | 0.3 | 1.5 | 1.5 |
| 7/29/81 | 16 | 0.6 | 0.2 | 0.3 | 1.2 | 1.8 |
| 7/29/81 | 17 | 0.7 | 0.2 | 0.3 | 1.3 | 1.4 |
| 7/29/81 | 19 | 0.2 | 0.2 | 0.3 | 0.7 | 1.7 |
| Statistics: | | | | | | |
| Average | | 1.0 | 0.4 | 0.4 | 1.6 | 1.8 |
| Maximum | | 3.0 | 0.8 | 0.8 | 2.4 | 2.3 |
| St. Dev. | | 0.8 | 0.2 | 0.2 | 0.5 | 0.3 |
| Frac. Bias | | | 0.900 | 0.878 | -0.456 | -0.544 |
| NMSE | | | 2.412 | 2.360 | 0.519 | 0.599 |
| Correlation | | | 0.551 | 0.511 | 0.559 | 0.612 |

TABLE 4-7

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR CAMERON, WINTER HOURS ($\mu s/m^3$)

| Date | Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 2/15/82 | 16 | 9.1 | 12.8 | 12.8 | 15.1 | 15.1 |
| 2/15/82 | 17 | 5.4 | 9.3 | 9.6 | 13.8 | 12.4 |
| 2/15/82 | 20 | 20.6 | 11.8 | 11.8 | 16.1 | 16.1 |
| 2/17/82 | 14 | 9.7 | 20.6 | 6.0 | 13.9 | 5.4 |
| 2/17/82 | 15 | 2.9 | 1.7 | 1.7 | 2.4 | 3.2 |
| 2/17/82 | 16 | 2.2 | 2.4 | 1.4 | 4.0 | 3.2 |
| 2/17/82 | 17 | 8.8 | 2.6 | 3.0 | 3.6 | 2.2 |
| 2/17/82 | 18 | 1.8 | 4.0 | 2.1 | 7.0 | 2.4 |
| 2/22/82 | 14 | 1.7 | 3.3 | 1.6 | 4.1 | 2.7 |
| 2/22/82 | 16 | 2.8 | 4.0 | 1.6 | 6.5 | 3.5 |
| 2/22/82 | 17 | 6.2 | 3.6 | 1.6 | 6.0 | 3.6 |
| 2/23/82 | 14 | 3.8 | 25.6 | 2.9 | 23.4 | 3.5 |
| 2/23/82 | 17 | 2.7 | 2.6 | 1.8 | 4.1 | 3.8 |
| 2/24/82 | 15 | 13.5 | 17.9 | 6.4 | 29.6 | 14.2 |
| 2/24/82 | 16 | 27.8 | 15.3 | 6.4 | 25.4 | 14.2 |
| 2/24/82 | 17 | 37.0 | 17.2 | 7.1 | 28.9 | 15.7 |
| 2/24/82 | 19 | 35.0 | 8.0 | 3.1 | 31.4 | 16.2 |
| Statistics: | | | | | | |
| Average | | 11.2 | 9.6 | 4.8 | 13.8 | 8.1 |
| Maximum | | 37.0 | 25.6 | 12.8 | 31.4 | 16.2 |
| St. Dev. | | 11.4 | 7.3 | 3.7 | 10.0 | 5.8 |
| Frac. Bias | | | 0.159 | 0.809 | -0.208 | 0.325 |
| NMSE | | | 1.124 | 2.866 | 0.361 | 0.757 |
| Correlation | | | 0.389 | 0.378 | 0.792 | 0.791 |

TABLE 4-8

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 and OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR CARPINTERIA, SF6 HOURS (µs/m )

| Date | Exp/Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 9/19/85 | 1/9 | 18.9 | 6.6 | 19.7 | 7.8 | 13.9 |
| 9/19/85 | 1/10 | 21.4 | 8.7 | 39.0 | 11.8 | 22.4 |
| 9/19/85 | 1/11 | 36.4 | 6.5 | 27.7 | 11.4 | 36.2 |
| 9/19/85 | 1/12 | 22.4 | 3.5 | 16.1 | 4.8 | 25.9 |
| 9/22/85 | 3/9 | 83.8 | 16.0 | 19.5 | 34.7 | 54.6 |
| 9/22/85 | 3/10 | 87.8 | 23.7 | 19.1 | 35.7 | 36.3 |
| 9/22/85 | 3/11 | 102.0 | 33.3 | 23.7 | 47.8 | 43.6 |
| 9/22/85 | 3/12 | 13.6 | 17.3 | 29.4 | 23.5 | 53.1 |
| 9/25/85 | 5/10 | 43.9 | 29.3 | 50.8 | 93.1 | 191.9 |
| 9/25/85 | 5/11 | 78.5 | 73.3 | 46.0 | 231.4 | 177.6 |
| 9/25/85 | 5/12 | 41.2 | 60.5 | 59.3 | 152.4 | 195.8 |
| 9/25/85 | 5/13 | 108.8 | 91.5 | 65.0 | 187.2 | 169.1 |
| 9/28/85 | 7/10 | 14.0 | 7.0 | 14.9 | 11.0 | 23.6 |
| 9/28/85 | 7/11 | 12.9 | 9.8 | 18.9 | 19.1 | 31.6 |
| 9/28/85 | 7/13 | 14.1 | 7.8 | 13.1 | 16.1 | 12.5 |
| 9/28/85 | 7/14 | 14.7 | 7.0 | 14.5 | 15.0 | 17.8 |
| 9/29/85 | 8/11 | 15.0 | 4.2 | 15.3 | 5.7 | 17.3 |
| 9/29/85 | 8/12 | 20.6 | 11.7 | 12.6 | 24.4 | 17.8 |
| Statistics: | | | | | | |
| Average | | 41.7 | 23.2 | 28.0 | 51.8 | 63.4 |
| Maximum | | 108.8 | 91.5 | 65.0 | 231.4 | 195.8 |
| St. Dev. | | 33.1 | 25.1 | 16.3 | 66.4 | 65.5 |
| Frac. Bias | | | 0.569 | 0.391 | -0.217 | -0.413 |
| NMSE | | | 0.93s | 0.910 | 1.383 | 1.43s |
| Correlation | | | 0.700 | 0.451 | 0.596 | 0.477 |

TABLE 4-9

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR CARPINTERIA, FUMIGATION HOURS ($\mu s/m^3$)

| Date | Exp/Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 10/1/85 | 9/10 | 4.5 | 1.8 | 5.1 | 4.2 | 8.0 |
| 10/3/85 | 11/930 | 5.2 | 0.0 | 0.4 | 0.2 | 0.2 |
| 10/3/85 | 11/11 | 4.6 | 4.2 | 7.4 | 9.0 | 24.5 |
| 10/4/85 | 12/10 | 8.9 | 3.8 | 3.9 | 9.8 | 11.4 |
| 10/4/85 | 12/1030 | 4.5 | 2.7 | 2.9 | 9.7 | 13.4 |
| 10/4/85 | 12/11 | 15.2 | 0.3 | 0.6 | 2.7 | 3.0 |
| 10/5/85 | 13/10 | 11.6 | 1.3 | 13.6 | 2.3 | 4.4 |
| 10/5/85 | 1311030 | 4.4 | 3.8 | 20.5 | 6.5 | 9.2 |
| 10/5/85 | 13/11 | 2.7 | 4.0 | 23.6 | 8.0 | 11.6 |
| Statistics: | | | | | | |
| Average | | 6.8 | 2.4 | 8.7 | 5.8 | 9.5 |
| Maximum | | 15.2 | 4.2 | 23.6 | 9.8 | 24.5 |
| St. Dev. | | 3.9 | 1.6 | 8.1 | 3.4 | 6.7 |
| Frac. Bias | | | 0.949 | -0.235 | 0.161 | -0.327 |
| NMSE | | | 2.624 | 1.816 | 0.967 | 1.403 |
| Correlation | | | -0.538 | -0.371 | -0.409 | -0.450 |

TABLE 4-10

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR CARPINTERIA, $CF_3Br$ HOURS ($\mu s/m^3$)

| Date | Exp/Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 9/22/85 | 3/11 | 18.1 | 28.7 | 20.2 | 26.7 | 24.9 |
| 9/22/85 | 3/12 | 6.9 | 11.3 | 18.8 | 10.7 | 23.6 |
| 9/26/85 | 6/12 | 25.0 | 6.6 | 12.3 | 11.3 | 16.8 |
| 9/26/85 | 6/13 | 7.6 | 5.5 | 10.6 | 10.4 | 16.9 |
| 9/28/85 | 7/10 | 4.7 | 4.7 | 10.2 | 10.4 | 23.8 |
| 9/28/85 | 7/11 | 4.0 | 7.9 | 16.0 | 13.6 | 22.7 |
| 9/28/85 | 7/13 | 10.9 | 7.1 | 11.9 | 16.0 | 12.5 |
| 9/28/85 | 7/14 | 11.2 | 6.0 | 12.4 | 13.5 | 16.0 |
| 9/29/85 | 8/12 | 4.8 | 8.6 | 9.2 | 16.1 | 11.7 |
| Statistics: | | | | | | |
| Average | | 10.4 | 9.6 | 13.5 | 14.3 | 18.8 |
| Maximum | | 25.0 | 28.7 | 20.2 | 26.7 | 24.9 |
| St. Dev. | | 6.7 | 7.0 | 3.7 | 4.9 | 4.8 |
| Frac. Bias | | | 0.075 | -0.265 | -0.320 | -0.577 |
| NMSE | | | 0.609 | 0.406 | 0.428 | 0.723 |
| Correlation | | | 0.356 | 0.225 | 0.313 | -0.044 |

TABLE 4-11

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR PISMO BEACH, WINTER HOURS ($\mu s/m^3$)

| Date | Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 12/8/81 | 15 | 6.8 | 8.5 | 6.3 | 6.0 | 5.9 |
| 12/8/81 | 16 | 7.0 | 8.3 | 6.2 | 8.0 | 7.9 |
| 12/11/81 | 14 | 5.0 | 1.2 | 1.5 | 2.0 | 2.3 |
| 12/11/81 | 15 | 4.9 | 1.4 | 1.7 | 2.3 | 2.6 |
| 12/11/81 | 17 | 3.9 | 1.9 | 1.2 | 2.3 | 2.0 |
| 12/11/81 | 19 | 3.2 | 0.1 | 1.2 | 0.3 | 4.1 |
| 12/13/81 | 14 | 3.3 | 18.0 | 4.9 | 12.0 | 2.9 |
| 12/13/81 | 15 | 1.9 | 6.1 | 4.3 | 3.9 | 2.8 |
| 12/13/81 | 17 | 3.5 | 10.8 | 5.8 | 13.7 | 9.8 |
| 12/14/81 | 13 | 9.2 | 9.6 | 3.3 | 5.0 | 2.3 |
| 12/14/81 | 15 | 4.5 | 6.5 | 2.3 | 2.6 | 1.7 |
| 12/14/81 | 17 | 5.6 | 5.2 | 2.6 | 2.4 | 2.0 |
| 12/15/81 | 13 | 1.8 | 1.0 | 3.0 | 1.6 | 6.3 |
| 12/15/81 | 14 | 0.9 | 0.3 | 3.2 | 0.2 | 2.5 |
| 12/15/81 | 19 | 4.2 | 1.2 | 4.0 | 2.0 | 8.8 |
| Statistics: | | | | | | |
| Average | | 4.4 | 5.3 | 3.4 | 4.3 | 4.3 |
| Maximum | | 9.2 | 18.0 | 6.3 | 13.7 | 9.8 |
| St. Dev. | | 2.1 | 4.9 | 1.7 | 3.9 | 2.7 |
| Frac. Bias | | | -0.198 | 0.245 | 0.023 | 0.025 |
| NMSE | | | 0.986 | 0.458 | 0.891 | 0.609 |
| Correlation | | | 0.309 | 0.189 | 0.191 | 0.008 |

TABLE 4-12

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR PISMO BEACH, SUMMER HOURS ($\mu s/m^3$)

| Date | Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 6/21/82 | 15 | 4.8 | 8.9 | 1.8 | 15.0 | 4.2 |
| 6/21/82 | 16 | 2.3 | 7.1 | 2.1 | 10.4 | 4.0 |
| 6/21/82 | 17 | 2.7 | 9.4 | 6.2 | 6.8 | 6.0 |
| 6/21/82 | 18 | 4.4 | 1.2 | 2.5 | 2.2 | 6.5 |
| 6/22/82 | 15 | 4.6 | 3.0 | 2.4 | 4.4 | 4.7 |
| 6/22/82 | 16 | 2.9 | 3.0 | 1.9 | 4.0 | 3.3 |
| 6/22/82 | 19 | 2.7 | 2.1 | 2.5 | 3.9 | 6.4 |
| 6/24/82 | 13 | 1.5 | 0.5 | 1.9 | 0.7 | 3.5 |
| 6/24/82 | 15 | 2.3 | 1.2 | 1.6 | 1.5 | 2.8 |
| 6/25/82 | 12 | 7.8 | 5.9 | 1.7 | 6.5 | 2.6 |
| 6/25/82 | 13 | 4.5 | 4.7 | 1.8 | 5.4 | 2.7 |
| 6/25/82 | 15 | 2.3 | 0.9 | 1.5 | 0.9 | 2.1 |
| 6/25/82 | 16 | 3.7 | 5.4 | 1.7 | 5.3 | 2.3 |
| 6/25/82 | 17 | 2.9 | 4.1 | 1.6 | 4.1 | 2.2 |
| 6/27/82 | 16 | 2.6 | 3.2 | 1.0 | 4.2 | 1.3 |
| 6/27/82 | 18 | 2.8 | 0.6 | 1.4 | 0.8 | 2.0 |
| Statistics: | | | | | | |
| Average | | 3.4 | 3.8 | 2.1 | 4.8 | 3.5 |
| Maximum | | 7.8 | 9.4 | 6.2 | 15.0 | 6.5 |
| St. Dev. | | 1.5 | 2.8 | 1.1 | 3.6 | 1.6 |
| Frac. Bias | | | -0.108 | 0.480 | -0.324 | -0.027 |
| NMSE | | | 0.550 | 0.748 | 0.806 | 0.366 |
| Correlation | | | 0.346 | -0.060 | 0.370 | 0.046 |

TABLE 4-13

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR VENTURA, FALL HOURS ($\mu s/m^3$)

| Date | Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 9/24/80 | 16 | 0.7 | 0.3 | 0.4 | 1.0 | 1.5 |
| 9/24/80 | 18 | 0.3 | 0.5 | 0.6 | 1.1 | 2.0 |
| 9/24/80 | 19 | 0.3 | 0.4 | 0.5 | 0.9 | 1.6 |
| 9/27/80 | 14 | 0.6 | 0.7 | 0.7 | 1.3 | 1.7 |
| 9/27/80 | 19 | 0.7 | 0.9 | 0.8 | 1.6 | 1.7 |
| 9/28/80 | 18 | 2.1 | 1.0 | 0.9 | 1.9 | 1.4 |
| 9/29/80 | 14 | 0.5 | 2.2 | 2.6 | 1.3 | 1.1 |
| 9/29/80 | 16 | 2.8 | 2.0 | 2.2 | 1.9 | 1.8 |
| 9/29/80 | 18 | 1.0 | 3.1 | 4.6 | 1.7 | 2.1 |
| Statistics: | | | | | | |
| Average | | 1.0 | 1.2 | 1.5 | 1.4 | 1.6 |
| Maximum | | 2.8 | 3.1 | 4.6 | 1.9 | 2.1 |
| St. Dev. | | 0.8 | 0.9 | 1.3 | 0.4 | 0.3 |
| Frac. Bias | | | -0.211 | -0.396 | -0.351 | -0.491 |
| NMSE | | | 0.837 | 1.452 | 0.363 | 0.717 |
| Correlation | | | 0.367 | 0.255 | 0.805 | 0.043 |

TABLE 4-14

COMPARISON OF MAXIMUM OBSERVED NORMALIZED CONCENTRATIONS (C/Q) WITH OCD/3, OCD/4, AND OCD/CPM USING OBSERVED AND PREDICTED VALUES OF $i_y$ FOR VENTURA, WINTER HOURS($\mu s/m^3$)

| Date | Hour | Observed | OCD/3 $i_y$(Obs) | OCD/3 $i_y$(Pred) | OCD/4 $i_y$(Obs) | OCD/4 $i_y$(Pred) |
|---|---|---|---|---|---|---|
| 1/6/81 | 16 | 1.1 | 0.5 | 1.4 | 0.7 | 2.5 |
| 1/6/81 | 17 | 2.3 | 0.7 | 1.5 | 0.8 | 2.2 |
| 1/6/81 | 18 | 2.3 | 1.0 | 1.6 | 1.7 | 3.3 |
| 1/9/81 | 15 | 2.3 | 2.5 | 2.3 | 2.6 | 2.0 |
| 1/9/81 | 16 | 3.0 | 1.9 | 2.5 | 1.9 | 2.0 |
| 1/9/81 | 18 | 3.0 | 2.0 | 1.8 | 3.7 | 2.9 |
| 1/13/81 | 15 | 1.5 | 0.6 | 1.4 | 0.7 | 1.9 |
| 1/13/81 | 17 | 1.5 | 2.7 | 3.3 | 1.6 | 2.6 |
| Statistics: | | | | | | |
| Average | | 2.1 | 1.5 | 2.0 | 1.7 | 2.4 |
| Maximum | | 3.0 | 2.7 | 3.3 | 3.7 | 3.3 |
| St. Dev. | | 0.6 | 0.8 | 0.6 | 1.0 | 0. s |
| Frac. Bias | | | 0.360 | 0.081 | 0.216 | -0.119 |
| NMSE | | | 0.355 | 0.185 | 0.173 | 0.122 |
| Correlation | | | 0.371 | 0.090 | 0.726 | 0.120 |

TABLE 4-15

COMPARISON OF OVERALL MAXIMUM NORMALIZED CONCENTRATIONS ($\mu s/m^3$)*
FOR OCD/3 AND OCD/4 USING OBSERVED AND PREDICTED VALUES OF $i_Y$

| Experiment | Observed | OCD/3 $i_y$ (Obs) | OCD/3 $i_Y$ (Pred) | OCD/4 $i_y$ (Obs) | OCD/4 $i_y$ (Pred) |
|---|---|---|---|---|---|
| Cameron - Winter | 37.0 | 25.6 (0.69) | 12.8 (0.35) | 31.4 (0.85) | 16.2 (0.44) |
| Cameron - Summer | 3.0 | 0.8 (0.27) | 0.8 (0.271 | 2.4 (0.80) | 2.3 (0.77) |
| Carpinteria - SF6 | 108.8 | 91.5 (0.84) | 65.0 (0.60) | 231.4 (2.13) | 195.8 (1.80) |
| Carpinteria - Fumigation | 15.2 | 4.2 (0.28) | 23.6 (1.55) | 9.8 (0.65) | 24.5 (1.61) |
| Carpinteria - $CF_3Br$ | 25.0 | 28.7 (1.15) | 20.2 (0.811 | 26.7 (1.07) | 24.9 (0.996) |
| Pismo - Winter | 9.2 | 18.0 (1.961 | 6.3 (0.68) | 13.7 (1.49) | 9.8 (1.06) |
| Pismo - Summer | 7.8 | 9.4 (1.21) | 6.2 (0.79) | 15.0 (1.941 | 6.5 (0.83) |
| Ventura - Winter | 3.0 | 2.8 (0.93) | 3.3 (1.10) | 3.7 (1.23) | 3.3 (1.10) |
| Ventura - Fall | 2.8 | 3.1 (1.111 | 4.6 (1.641 | 1.9 (0.68) | 2.1 (0.751 |
| Average | | (0.94) | (0.87) | (1.20) | (1.04) |
| Median | 9.2 | 9.4 | 6.3 | 13.7 | 9.8 |
| Number of Experiments: | | | | | |
| Overpredictions | | 4 | 3 | 5 | 4 |
| Underpredictions | | 5 | 6 | 4 | 4 |
| Within 1X | | 0 | 0 | 0 | 1 |

* The numbers in parentheses are the ratio of predicted to observed ($C_p/C_o$).

percent of the maximum observed concentration. Moreover, the average ($C_o$ Max)/($C_p$ Max) for' the nine experiments is 0.87 for OCD/3 and 1.04 for OCD/4 using iy (Predicted). Based on this simple statistical analysis, OCD/4 is better than OCD/3 using $i_y$ (Predicted) data, which is the recommended method for running the model. When using $i_y$ (Observed) data, OCD/4 overpredicts while OCD/3 underpredicts with an average ($C_o$ Max)/($C_p$ Max) of 0.94 for OCD/3 and 1.20 for OCD/4. The highest observed concentration for all nine experiments (108.8 $\mu s/m^3$ at the Carpinteria, SF6 experiment) is underpredicted by OCD/3 and overpredicted by OCD/4 using both $i_y$ (Observed) and $i_y$ (Predicted) values.

The ratios of OCD/4 model predictions to observations, $C_p/C_o$, for the Cameron and Carpinteria (SF6 hours) data, plotted as a function of wind speed for observed and predicted values of $i_y$, are shown in Figures 4-5 and 4-6, respectively. In Figure 4-5, for the Cameron experiment the summer hours are labeled with S and the winter hours are labeled with W. The horizontal lines represent ± factor of four scatter (outer set of lines), ± factor of two scatter (lines two and four), and no scatter (inner line). The performance of a good model should not vary with meteorological conditions. Visual inspection of Figure 4-5a (Cameron) for the observed $i_y$ model run suggests that there is no trend, but that there is a slight tendency towards overprediction at all wind speeds. For the observed $i_y$ model runs, the plot shows 58% of the predictions within a factor of two and 85% of the predictions within a factor of four of the observations. The plotted points for the predicted $i_y$ model runs (Figure 4-5b) display some curvature with respect to wind speed. Predicted $i_y$ is inversely proportional to wind speed; therefore, the model predicts too small a value for $i_y$ at large wind speeds (leading to overpredictions, because C a $\sigma_y^{-1}$). The observed $i_y$ model run for the $SF_6$ hours at Carpinteria (Figure 4-6a) displays an equal distribution of over- and under-predictions with almost all plotted points within a factor of four of the observations. The plotted points for the predicted $i_y$ model runs (Figure 4-6b) show a tendency towards overpredicting the observed concentrations.

The OCD/4 values of $C_p/C_o$ for the Ventura data are plotted as a function of air temperature ($T_{air}$) minus sea surface temperature ($T_{sea}$) for observed and predicted values of $i_y$ in Figure 4-7. The winter hours are labeled with W and the fall hours are labeled with F. Figure 4-7a indicates that for

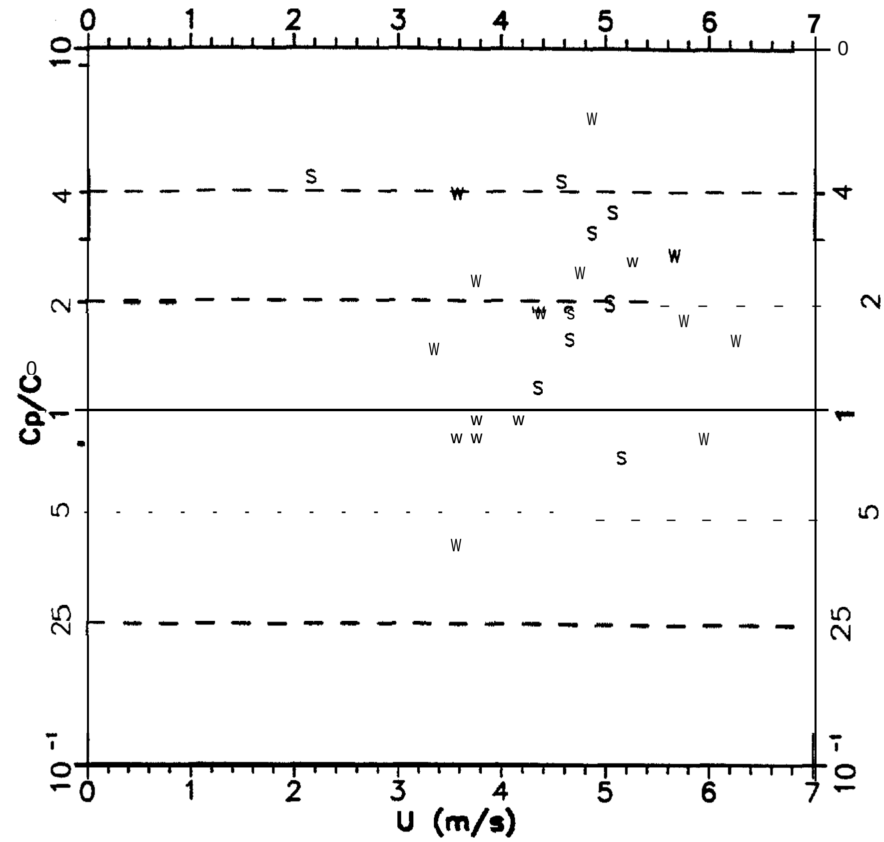



Figure **4-5a.** The ratio of predicted to observed ($C_p/C_o$) concentrations for the OCD/4 model using observed $i_y$ plotted versus wind speed at Cameron for the maximum concentration anywhere on the monitoring arc for each hour. The "W" denotes winter and the "S" denotes summer.

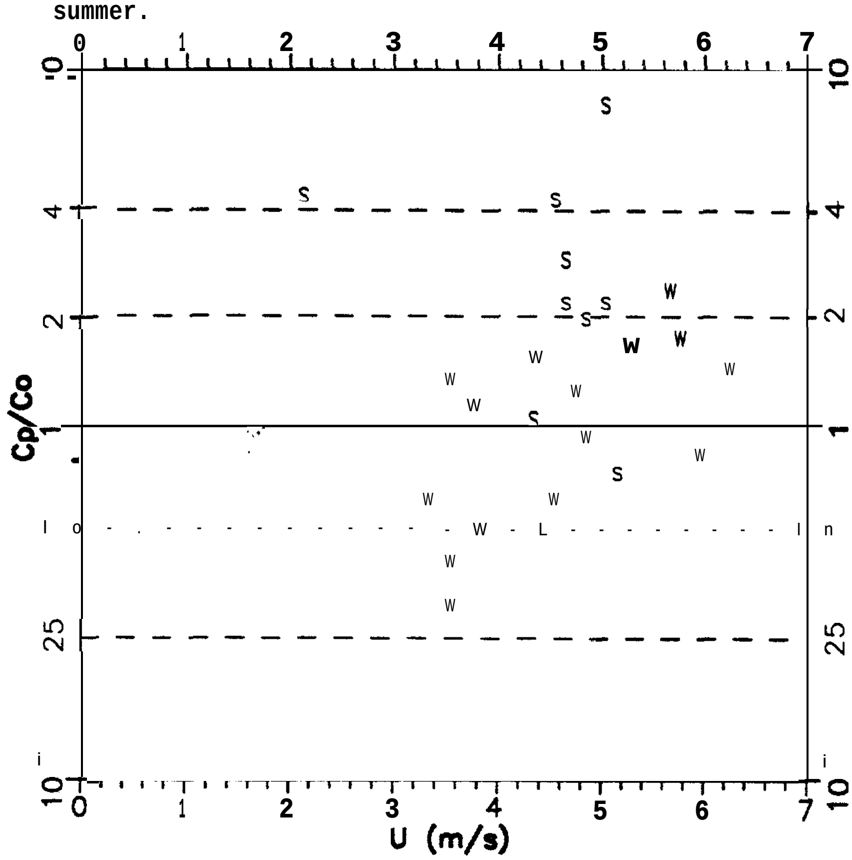



Figure **4-5b.** Same as Figure **4-5a** except predicted $i_y$

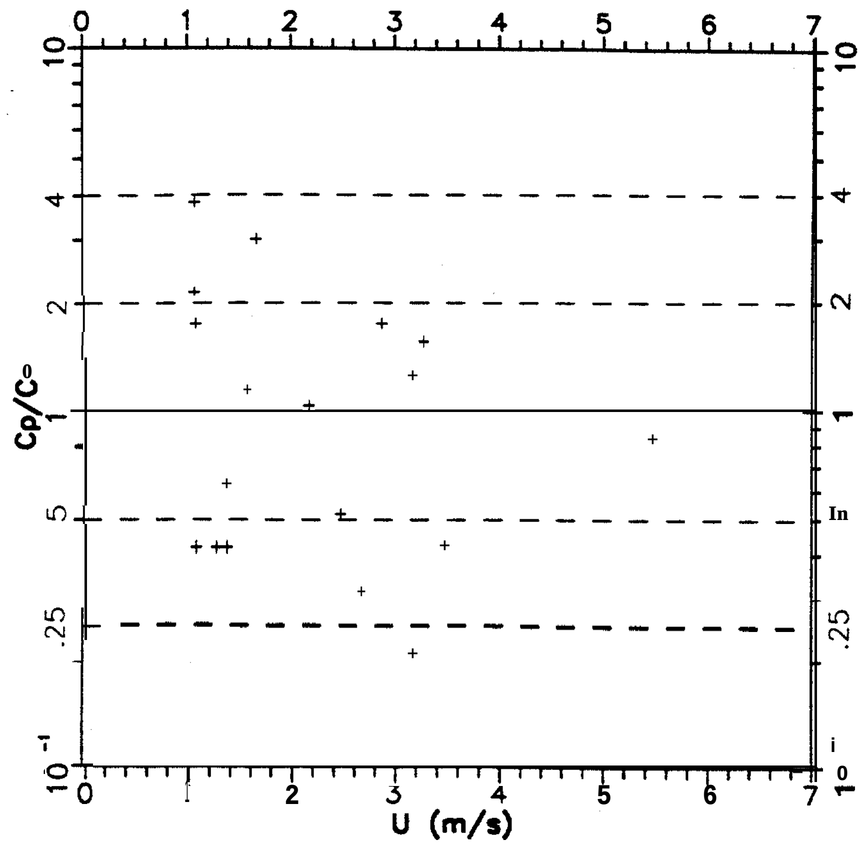


Figure 4-6a. The ratio of predicted to observed $(C_p/C_o)$ concentrations for the OCD/4 model using observed $i_y$ plotted versus wind speed at Carpinteria ($SF_6$ Hours) for the maximum concentration anywhere on the monitoring network for each hour.

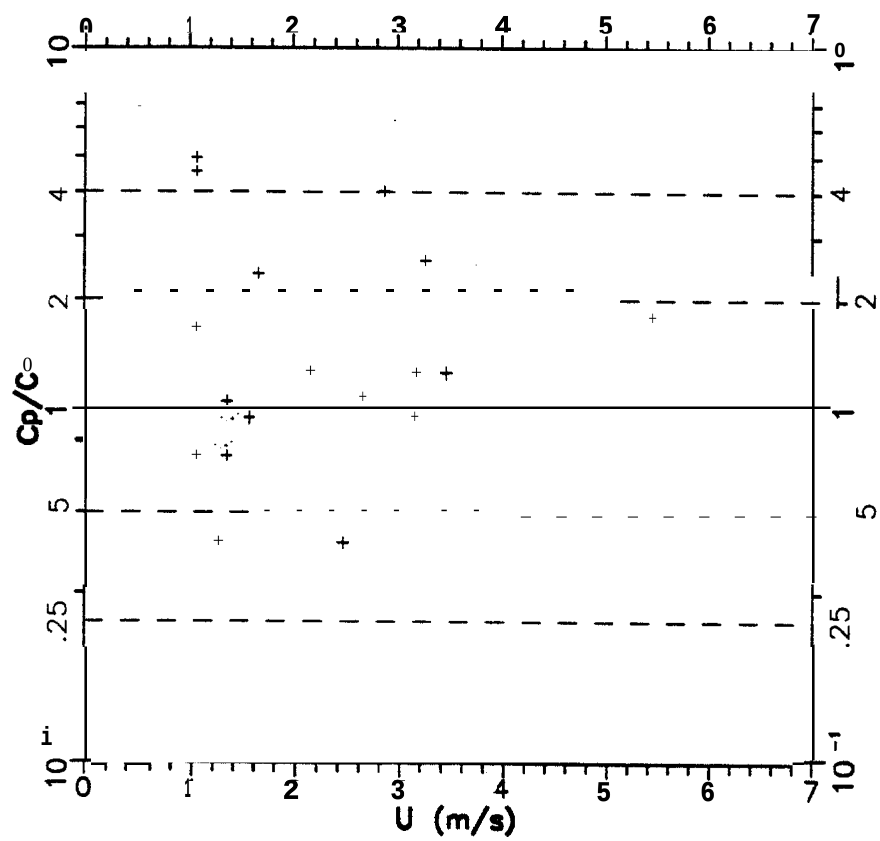


Figure 4-6b. Same as Figure 4-6a except predicted $i_y$.

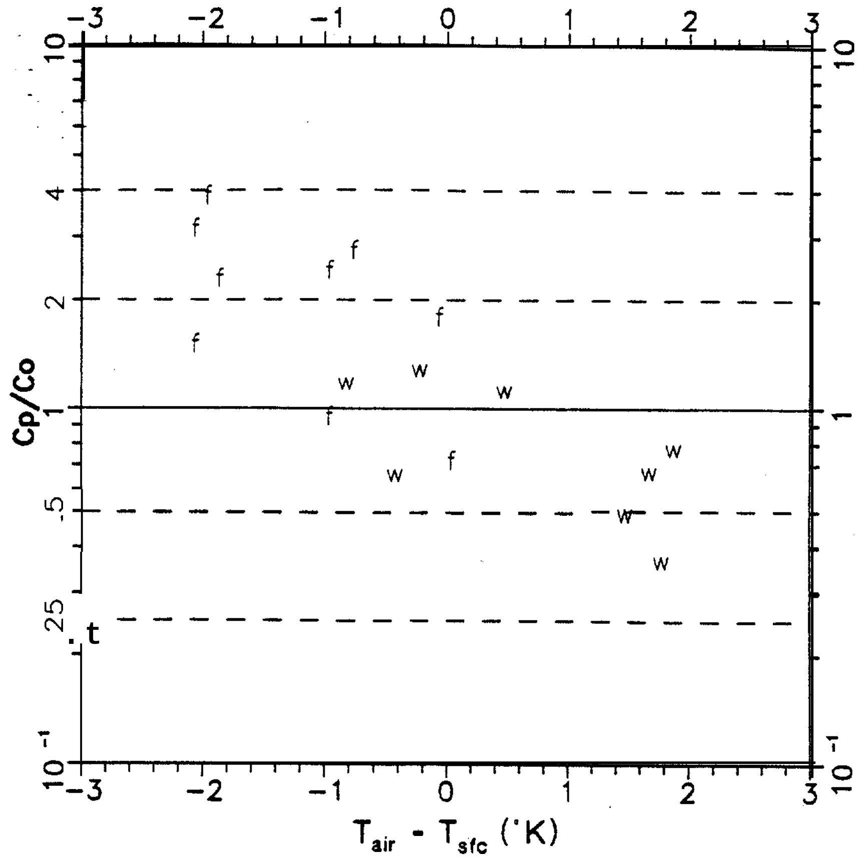



Figure 4-7a. The ratio of predicted to observed ($C_p$ /$C_o$ ) concentrations for the OCD/4 model using observed $i_y$ plotted versus air minus sea surface temperatures at Ventura for the maximum concentration anywhere on the monitoring arc for each hour. The "W" denotes winter and the "F" denotes fall.

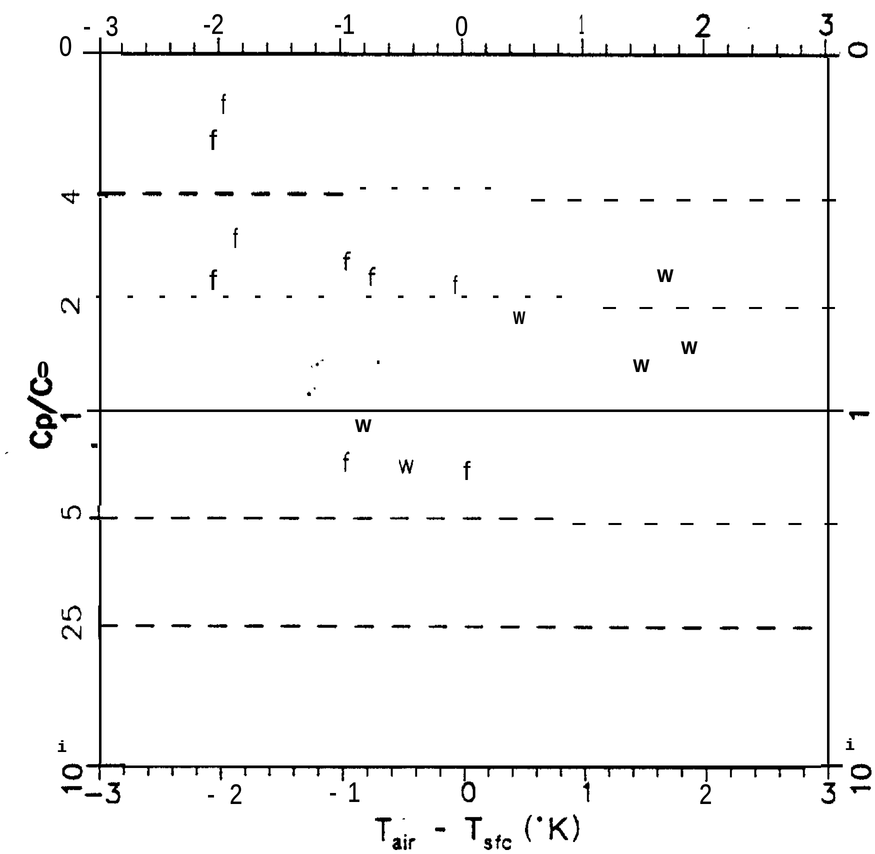



Figure 4-7b. Same as Figure 4-7a except predicted $i_y$.

observed $i_y$ model runs, the model tends to underpredict as $T_{air}-T_{sea}$ becomes more stable in the winter. Conversely, as $T_{air}-T_{sea}$ becomes unstable in the fall, the model tends to overpredict. This pattern is not discernible using the predicted $i_y$ model runs as shown in Figure 4-7b. The model tends to overpredict for both stable and unstable conditions.

The OCD/4 ratios of model predictions to observations for the Pismo data are plotted as a function of the overwater mixing height for observed and predicted values of $i_y$ in Figure 4-8. The summer hours are labeled with S and the winter hours are labeled with W. Both the observed and predicted $i_Y$ model runs display an almost equal distribution of over- and under-predictions. For the predicted $i_Y$ model runs, all the plotted points are within a factor of four of the observations and a majority of the points (63%) are within a factor of two of the observations.

The uncertainties associated with the OCD model are examined using a blocked bootstrap or jackknife resampling method to estimate whether there are significant differences in the fractional bias, normalized mean square error, and correlation. A perfect model would have FB = NMSE = 0.0 and R = 1.0. 95% confidence limits are calculated using bootstrap resampling for FB and R for each model, and the difference in FB, NMSE, and R between models. The bootstrap resampling method allows the standard deviation, $\sigma$, of any performance measure to be estimated, from which confidence limits can be calculated by the student-t procedure such that

$$95\%\ \text{Confidence Limits} = \text{Mean} +/- t_{95}\sigma(n/(n-1))^{1/2} \qquad (4\text{-}4)$$

where the student-t parameter, $t_{95}$, is given as a function of degrees of freedom, n-l.

If the confidence limits do not overlap zero, then the difference between the calculated statistic is not zero with 95% confidence. In general, it is difficult to show 95% significant differences between air quality models unless there are large quantitative differences in the model predictions (factor of two or greater) or the size of the data set is large (n = 100 or greater). A summary of FB, NMSE, and R for each data set are presented in Tables 4-16 thru 4-18. The statistics are presented for each model using

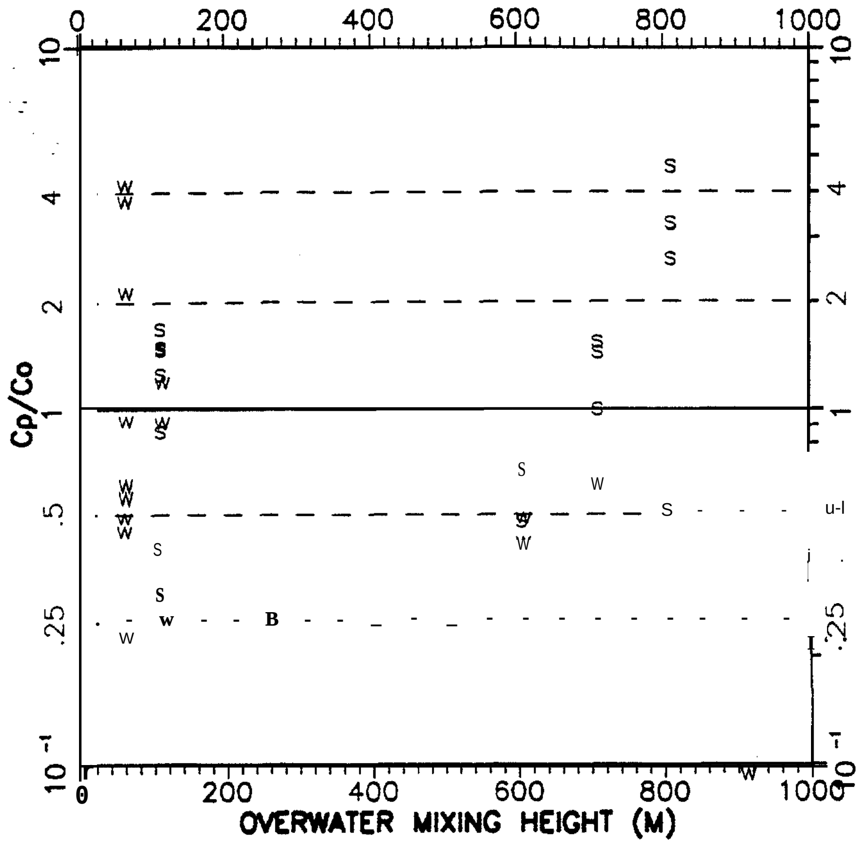



Figure 4-8a. The ratio of predicted to observed $(C_p/C_o)$ concentrations for the OCD/4 model using observed $I_y$ plotted versus overwater mixing heights at Pismo for the maximum concentration anywhere on the monitoring arc for each hour. The "W" denotes winter and the "S" denotes summer.

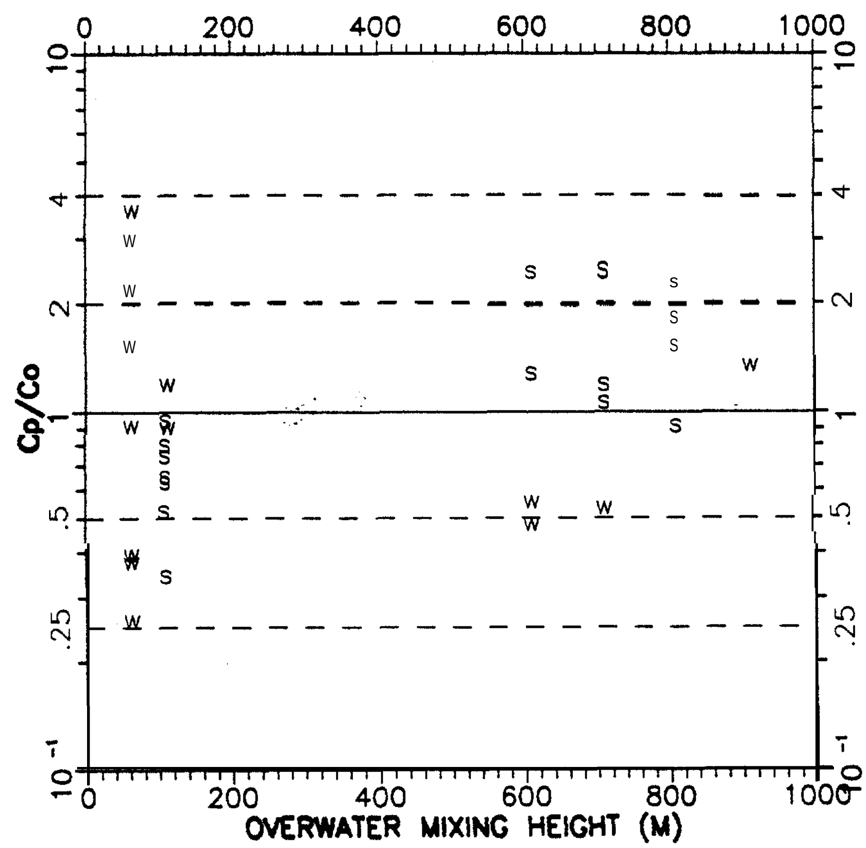



Figure 4-8b. Same as Figure 4-8a except predicted $i_y$

TABLE 4-16

EVALUATION OF FRACTIONAL BIAS (FB) FOR MAXIMUM C/Q DURING EACH EXPERIMENT

| Model Number: | | 1 | 2 | 3 | 4 | Models with FB Not Sig. Dif. from 0 | Model Pairs with ΔFB Not Sig. Dif. from 0 |
|---|---|---|---|---|---|---|---|
| | | OCD/3 | | OCD/4 | | | |
| Data Set | N | $i_y$ (Obs) | $i_y$ (Pred) | $i_y$ (Obs) | $i_y$ (Pred) | | |
| Cameron-Winter | 17 | 0.159 | 0.809 | -0.208 | 0.325 | 1, 3, 4 | l-4 |
| Cameron-Summer | 9 | 0.900 | 0.878 | -0.456. | -0.544 | -3 | 1-2, 3-4 |
| Carpinteria - $SF_6$ | 18 | 0.569 | 0.391 | -0.217 | -0.413 | 3, 4 | 1-2, 3-4 |
| Carpinteria - Fumigation | 9 | 0.949 | -0.235 | 0.161 | -0.327 | 2, 3, 4 | 2-3, 2-4 |
| Carpinteria - $CF_3Br$ | 9 | 0.075 | -0.265 | -0.320 | -0.577 | 1, 2, 3 | l-2, 2-3, 3-4 |
| Pismo - Winter | 15 | -0.198 | 0.245 | 0.023 | 0.025 | 1, 2, 3, 4 | l-3, 1-4, 2-3, 2-4, 3-4 |
| Pismo -Summer | 16 | -0.108 | 0.480 | -0.324 | -0.027 | 1, -3, 4 | 1-4, 3-4 |
| Ventura - Fall | 9 | -0.211'. | -0.396 | -0.351 | -0.491 | 1, 2, 3, 4 | 1-2, 1-3, 1-4, 2-3, 2-4, 3-4 |
| Ventura - Winter | 8 | 0.360 | 0.081 | 0.216 | -0.119 | 1, 2, 3, 4 | 1-3, 1-4, 2-3, 2-4, 3-4 |
| Median | | 0.159 | 0.245 | -0.217 | -0.327 | | |

TABLE 4-17

EVALUATION OF NORMALIZED MEAN SQUARE ERROR (NMSE) FOR MAXIMUM C/Q DURING EACH EXPERIMENT

| Model Number | | 1 | 2 | 3 | 4 | Model Pairs with |
|---|---|---|---|---|---|---|
| | | OCD/3 | | OCD/4 | | NMSE Not Sig. |
| Data Set | N | $i_y$ (Obs) | $i_y$ (Pred) | $i_y$ (Obs) | $i_y$ (Pred) | Dif. from 0 |
| Cameron - Winter | 17 | 1.124 | 2.866 | 0.361 | 0.757 | All |
| Cameron - Summer | 9 | 2.412 | 2.360 | 0.519 | 0.599 | All |
| Carpinteria - SF6 | 18 | 0.935 | 0.910 | 1.383 | 1.435 | All |
| Carpinteria - Fumigation | 9 | 2.624 | 1.816 | 0.967 | 1.403 | All |
| Carpinteria - $CF_3Br$ | 9 | 0.609 | 0.406 | 0.428 | 0.723 | All |
| Pismo - Winter | 15 | 0.986 | 0.458 | 0.891 | 0.609 | All |
| Pismo - Summer | 16 | 0.550 | 0.748 | 0.806 | 0.366 | All |
| Ventura - Fall | 9 | 0.837 | 1.452 | 0.363 | 0.717 | All |
| Ventura - Winter | 8 | 0.355 | 0.185 | 0.173 | 0.122 | All |
| Median | | 0.935 | 0.910 | 0.519 | 0.717 | |

TABLE 4-18

RESULTS OF CORRELATION (R) FOR MAXIMUM C/Q DURING EACH EXPERIMENT*

| Model Number: | | 1 | 2 | 3 | 4 | Models with |
|---|---|---|---|---|---|---|
| | | OCD/3 | | OCD/4 | | R Sig. Dif. |
| Data Set | N | $i_y$ (Obs) | $i_y$ (Pred) | $i_y$ (Obs) | $i_y$ (Pred) | from 0 |
| Cameron - Winter | 17 | 0.389 | 0.378 | 0.792 | 0.791 | 3, 4 |
| Cameron - Summer | 9 | 0.551 | 0.511 | 0.559 | 0.612 | 3, 4 |
| Carpinteria - SF6 | 18 | 0.700 | 0.451 | 0.596 | 0.477 | 1, 3, 4 |
| Carpinteria - Fumigation | 9 | -0.538 | -0.371 | -0.409 | -0.450 | None |
| Carpinteria - $CF_3$ Br | 9 | 0.356 | 0.225 | 0.313 | -0.044 | None |
| Pismo - Winter | 15 | 0.309 | 0.189 | 0.191 | 0.008 | None |
| Pismo - Summer | 16 | 0.346 | -0.060 | 0.370 | 0.046 | None |
| Ventura - Fall | 9 | 0.367 | 0.255 | 0.805 | 0.043 | 3 |
| Ventura - Winter | 8 | 0.371 | 0.090 | 0.726 | 0.120 | 3 |
| Median | | 0.367 | 0.225 | 0.559 | 0.046 | |

*There are no model pairs for any data set with AR significantly different from zero.

observed and predicted values of $i_y$.

As shown in Table 4-16, the fractional bias for the Cameron field studies is best for the OCD/4 model using observed values of $i_Y$. For the Cameron winter experiment, only the OCD/3 model using predicted values of $i_Y$ is significantly different from zero. Because the confidence limits overlap zero, the difference between OCD/3 ($i_y$ Obs) and OCD/4 ($i_y$ Pred) are not significantly different with 95% confidence. However, for the Cameron summer experiment, only the FB for the OCD/4 ($i_y$ Obs) model is not significantly different from zero. As stated earlier, a model is best when it's FB is zero. Moreover, the difference in FB between OCD/3 and OCD/4 is significantly different from 0. For this data set, it can be concluded with 95% confidence that the OCD/4 model is significantly better than OCD/3.

At Cameron, the results of the correlation analysis, as shown in Table 4-18, indicate that for both the winter and summer data sets, only OCD/4 has a value of R that is significantly different from zero., Thus, in terms of R, OCD/4 is significantly better than OCD/3 with 95% confidence.

Concentrating on the $SF_6$ hours of the Carpinteria experiments, as shown in Table 4-16, only the FB for OCD/4 is not significantly different from zero. The difference in FB between OCD/3 and OCD/4 is significantly different from zero. Therefore, with 95% confidence it can be concluded that OCD/4 is significantly better than OCD/3 using this data set. The $CF_3Br$ data set is much more limited in data than the $SF_6$ data set. Only FB for OCD/4 ($i_y$ Pred) is significantly different from zero. FB is not significantly different from zero for the other three models examined. Differences between OCD/3 and OCD/4 are significantly different from zero. Thus, it is difficult to conclude from the $CF_3Br$ data set whether one-model is better than the other. For the fumigationdata set, only FB for OCD/3 ($i_y$ Obs) is significantly different from zero and the difference in FB between OCD/3 and OCD/4 is not significantly different from zero. Thus, as with the $CF_3Br$ data set, it is difficult to conclude whether one model is better than the other. For both the complex terrain ($SF_6$ and $CF_3Br$) and fumigation data sets, the performance statistics of the OCD/4 model are not always significantly better than the statistics of the OCD/3 model. The OCD/4 is preferred because (1) it is more conservative than the OCD/3 model and (2) its components are based on improved technical research.

As shown in Table 4-18, for the Carpinteria data set only, OCD/3 ($i_Y$ Pred) for SF6 has a correlation that is not significantly different from zero. Thus, with respect to $i_y$ (Pred) for Carpinteria, OCD/4 is significantly better with 95% confidence than OCD/3. For the $CF_3Br$ and fumigation data sets, no models have a correlation that is significantly different from zero. Therefore, in terms of R for the $CF_3Br$ and fumigation data sets, one model is not better than another.

For the Pismo and Ventura experiments, the differences in FB between OCD/3 and OCD/4 are not significantly different from zero with 95% confidence. Thus, in terms of FB, one model is not better than another. None of the models have a correlation that is significantly different from zero for the Pismo experiments. However, OCD/4 ($i_y$ Obs) for Ventura has a correlation that is significantly different from zero. In terms of R, OCD/4 ($i_y$ Obs) is significantly better than OCD/3 using the Ventura database.

As shown in Table 4-17, the evaluation of the normalized mean square error (NMSE) indicates that no model pairs have an NMSE that is not significantly different from zero. Thus, in terms of NMSE, one model is not significantly better than the other.

The major challenge with this statistical model evaluation exercise is how to combine the results from the various experiments. Tables 4-16 thru 4-18 indicate that for some experiments OCD/4 performs best, whereas in other experiments OCD/3 performs best. Therefore, an arbitrary scoring scheme is used to combine all the results, into a final "score." The weighting method used to score each model is as follows:

1) A model receives one point each time its FB is lowest in magnitude, each time its NMSE is lowest, and each time its R is highest.

2) A model receives one point each time its FB is not significantly different from zero, and each time its R is significantly different from zero.

3) The model with lowest FB receives one point in each exercise in which a comparison with another model shows that differences in FB or AFB are significantly different from zero at the 95% confidence level.

This-procedure is also applied to NMSE and **R** (but in the case of **R**, the mode-l with the highest value and AR not significantly different from zero is the best one).

Assuming that it is more important for a model to exhibit a low mean bias and the fact that correlations are generally so low that differences are not significant, the FB, NMSE, and R results are tallied using relative weights of 1.0, 0.5, and 0.5, respectively. It is therefore assumed that the best model will have the highest score.

The scoring evaluation results for **OCD/3** and **OCD/4** using only observed values of $i_y$ are presented in Table 4-19 and using only predicted values of $i_Y$ are presented in Table 4-20. For these two sets of model comparisons, OCD/4 is the better model for both observed and predicted values of $i_Y$.

TABLE 4-19

SCORING EVALUATION FOR OCD/3 AND OCD/4 USING OBSERVED $i_Y$*

| Model | Lowest FB | Lowest NMSE | Highest R | FB Not Sig. Dif. from 0 | R Sig. Dif. from 0 | Highest R with AR Not Sig. Dif. From 0 | Score |
|---|---|---|---|---|---|---|---|
| OCD/3 | 4 (4.0) | 2 (1.0) | 4 (2.0) | 6 (6.0) | 1 (0.5) | 4 (2.0) | 15.5 |
| OCD/4 | 5 (5.0) | 7 (3.5) | 5 (2.51 | 9 (9.0) | 5 (2.5) | 5 (2.5) | 25.0 |

TABLE 4-20

SCORING EVALUATION FOR OCD/3 AND OCD/4 USING PREDICTED $i_Y$*

| Model | Lowest FB | Lowest NMSE | Highest R | FB Not Sig. Dif. from 0 | R Sig. Dif. from 0 | Highest R with AR Not Sig. Dif. From 0 | Score |
|---|---|---|---|---|---|---|---|
| OCD/3 | 5 (5.0) | 3 (1.5) | 4 (2.0) | 5 (5.0) | 0 (0.0) | 4 (2.0) | 15.5 |
| OCD/4 | 4 (4.0) | 6 (3.0) | 5 (2.51 | 7 (7.0) | 3 (1.51 | 5 (2.51 | 20.5 |

*The first number in each column represents the number of times the model meets the specified statistical criteria. The number in parentheses represents the score once the relative weight has been applied.

No model received points for 1) Lowest FB with AFB significantly different from zero or 2) Lowest NMSE with ANMSE significantly different from zero.

# REFERENCES


Aerovironment, Inc., 1980 and 1981: *Offshore Tracer Study, Vol. I: Tracer Gas and Meteorological Data,* prepared for Pacific OCS Offices by Aerovironment, Inc., Pasadena, CA, Report Numbers rDP-80-056 and rDO-81-008.

Bierly, E.W. and E.W. Hewson, 1962: Some Restrictive Meteorological Conditions to be Considered in the Design of Stacks. *J. Appl. Heteorol.*, 1, 3, 383-390.

Briggs, G.A. 1969: *Plume Rise.* USAEC Critical Review Series, TID-25075, Clearinghouse for Federal Scientific and Technical Information.

Briggs, G.A., 1973: Diffusion Estimates for Small Emissions. ATDL Cont. 79, ATDL, P.O. Box E, Oak Ridge, TN.

Briggs, G.A., 1975: Plume Rise Predictions In: *Lectures on Air Pollution and Environmental Impact Analysis.* 29 September-3 October 1975 Boston, MA, Am. Meteorol. Soc., 45 Beacon St., Boston, MA 59-111.

Briggs, G.A., 1984: Plume Rise and Buoyancy Effects. Chapter 8 In: *Atmospheric Science and Power Production.* (D. Randerson, Ed. ) DOE/TIC-27601 (DE840051771 National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161, pp 327-366.

Brodzinsky, R., et al., 1982: *Central California Coastal Air Quality Model Validation Study:* Data Compilation for December 1981 Field Experiment, 2 Volumes, prepared for Pacific OCS Office by SRI International, Menlo Park, CA, 94025.

Brodzinsky, R., W.B. Johnson, B.K. Cantrell, L. Jones, R.E. Stiles, G.H. Taylor, C.R. Scholle and C.L. Seward, 1982: *Central California Coastal Air Quality Model Validation Study:* Data Compilation for June 1982 Field Experiment, 2 Volumes, prepared for Pacific OCS Office by SRI International, Menlo Park, CA 94025.

Brutsaert, W., 1975: Comments on Surface Roughness Parameters and the Height of Dense Vegetation. *J. Met. Soc. Japan, 53, 96-97.*

Businger, J.A., 1973: Turbulence Transfer in the Atmospheric Surface Layer. *Workshop in Micrometeorology,* Am. Meteorol. Soc., 45 Beacon St., Boston, MA, 67-100.

Catalano, J.A., 1986: Single-Source (CRSTER) Model, Addendum to the User's Manual. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

Chan, W.H., R.J. Vet, M.A. Lusis, J.E. Hunt and R.D.S. Stevens, 1980: Airbourne Sulfur Dioxide to Sulfate Oxidation Studies of the INCO 381m Chimney Plume. *Atmos. Environ.,* 14, 1159-1170.

Cole, H.S. and J.-E. Summerhays, 1979: A Review of Techniques Available for Estimating Short-Term $NO_2$ Concentrations. *J. Air Pollution Control Assoc.*, 29, 812-817.

Counihan, J., 1975: Adiabatic Atmospheric Boundary Layers. A Review and Analysis of Data from the Period 1880-1972. *Atmos. Environ. 9, 871-906.*

Cramer, H.E., G.M. DeSanto, K.R. Dumbauld, P. Morgenstern and R.N. Swanson, 1964: Meteorological Prediction Techniques and Data System. GCA tech. Rep. No. 64-3-G, March 1, 1964.

Dabbert, W.F., W.B. Johnson, R. Brodzinsky and R.E. Ruff, 1983: *Central California Coastal Air Quality Model Validation Study:* Data Analysis and Model Evaluation, prepared for Pacific OCS Office by SRI International, Menlo Park, CA 94025.

Deardorff, J.W. and G.E. Willis, 1982: Ground Level Concentrations Due to Fumigation into an Entraining Mixing Layer. *Atmos. Environ. , 16,* 1159-1170.

Dittenhoefer, A.C. and R.G. de Pena, 1979: Sulfate Aerosol Production and Growth in Coal-Operated Power Plant Plumes. Proceedings of CACGP Symp. on Trace Gases and Aerosols, J. Geophys. Res.

Draxler, R.R., 1976: Determination of Atmospheric Diffusion Parameters. *Atmos. Environ.,* 10, 2259-2263.

Eatough, D.J., B.E. Richter, N.L. Eatough and L.D. Hansen, 1981: Sulfur Chemistry in Smelter and Power Plant Plumes in the Western U.S. *Atmos. Environ.* , 15, 2241-2254.

ERT, 1982: User's Guide to the Rough Terrain Diffusion Model (RTDM). ERT No. M2209-585, Environmental Research and Technology, Inc., Concord, MA, 225 pp.

EPA, 1977: User's Manual for Single Source (CRSTER) Model. EPA-450/Z-77-013 OAQPS, Research Triangle Park, NC 213 pp. (NTIS PB 2713601.

EPA, 1980: User's Guide for MPTER. EPA-600/8-80-016, Research Triangle Park, NC 27711.

EPA, 1986: Guideline on Air Quality Models (Revised). EPA-450/2-78-027R, Reearch Triangle Park, NC 27711.

Forrest, J. and L. Newman, 1977: Further Studies of the Oxidation of Sulfur Dioxide in Coal-Fired Power Plant Plumes. *Atmos. Environ.* , 11, 465-474.

Forrest, J., R. Garber and L. Newman, 1979: Formation of Sulfate, Ammonium and Nitrate in an Oil-Fired Power Plant Plume. *Atmos. Environ., 13, 1287-1297.*

Forrest, J., R. Garber and L. Newman, 1981: Conversion Rates in Power Plants Based on Filter Pack Data: The Coal-Fired Cumberland Plume. Presented at Symposium on Plumes & Visibility: Measurements & Model Components. Grand Canyon, AZ, Nov. 10-14. *Atmos. Environ.,* 15, 2273-2282.

Garber, R.W., J. Forrest and L. Newman, 1981: Conversion Rates in Power Plant Plumes Based on Filter Pack Data: The Oil-Fired Northport Plume. *Atmos. Environ.*, 15, 2283-2292.

Garratt, J.R., 1977: Review of Drag Coefficients over Oceans and Continents. Mon. Wea. Rev., 105, 915-929.

Gifford, F.A., 1968: An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: *Meteorology and Atomic Energy-1968*, pp 66-116. D.H. Slade (ed.). USAEC Report TID-24190.

Gillani, N., S. Kohli and W.G. Wilson, 1981: Gas-to-Particle Conversion of Sulfur in Power Plant Plumes-I. Parameterization of the Conversion Rate for Dry, Moderately Polluted Ambient Conditions. *Atmos. Environ.*, 15, 2293-2313.

Golder, D., 1972: Relations Among Stability Parameters in the Surface Layer. *Bound. Lay. Meteorol.*, 3, 47-58.

Hanna, S.R., 1981: Turbulent Energy and Lagrangian Time Scales in the Planetary Boundary Layer. *Fifth Symposium on Turbulence, Diffusion, and Air Pollution*, AMS, 61-62.

Hanna, S.R., 1983: Lateral Turbulence Intensity and Plume Meandering During Stable Conditions. *J. Climate and Appl. Heteorol.*, 22, 1424-1430.

Hanna, S.R., 1988: Air Quality Model Evaluation and Uncertainty, *J. Air Poll. Control Assoc.*, 38, 406-412.

Hanna, S.R., G.A. Briggs, J. Deardorff, B.A. Egan, F. Gifford and F. Pasquill, 1977: "AMS Workshop on Stability Classification Schemes and Sigma Curves." *Bull. Am. Met. Soc.*, 58, 12, 1305-1309.

Hanna, S.R. and D.C. DiCristofaro, 1988: Development and Evaluation of the OCD/API Model. Final Report, API Pub. 4461, API, Washington, D.C.

Hanna, S.R., L.L. Schulman, R.J. Paine and J.E. Pleim, 1984: User's Guide to the Offshore and Coastal Dispersion (OCD) Model. MMS Document No. 84-0069. MMS, 12203 Sunrise Valley Drive, Reston, VA 22091.

Hanna, S.R., L.L. Schulman, R.J. Paine, J.E. Pleim and M. Baer, 1985: Development and Evaluation of the Offshore and Coastal Dispersion Model. *JAPCA*, 35, 1039-1047.

Heffter, J.L., 1965: The Variation of Horizontal Diffusion Parameters with Time for Travel Periods of One Hour or Longer. *J. Appl. Meteorol.*, 4, 153-156.

Hegg, D.A. and P.V. Hobbs, 1980: Measurements of Gas-to-Particle Conversion in the Plumes from Five Coal-Fired Electric Power Plants. *Atmos. Environ.*, 14, 99-116.

Hess, S. L., 1959: *Introduction to Theoretical Meteorology.* Holt, Rinehart and Winston, New York, pp 61, 277.

Hosker, R.P., 1974: A Comparison of Estimation Procedures for Overwater Plume Dispersion. *Proceedings of* the *Symposium on Atmospheric Diffusion and Air Pollution,* American Meteorological Society, 281-288.

Hsu, S.A., 1981: Models for Estimating Offshore Winds from Onshore Meteorological Measurements. Bound. Lay. *Meteorol., 20,* 341-352.

Husar, R.B., D.E. Patterson, J.D. Husar and N.V. Gillani, 1978: Sulfur Budget of a Power Plant Plume. *Atmos. Environ.,* 12, 549-568.

Irwin, J.S., 1983: Estimating Plume Dispersion--A Comparison of Several Sigma Schemes. *J. Clim.* and *Appl. Meteorol., 22,* 92-114.

Jackson, N.A., 1976: The Propagation of Modified Flow Downstream of a Change in Roughness, *Q. J. Roy. Met. Soc.,* 102, 924.

Johnson, V.C. and T.C. Spangler, 1986: Tracer Study Conducted to Acquire Data for Evaluation of Air Quality Dispersion Models, prepared by WESTEC Services, Inc., San Diego, CA for API, Washington.

Kerman, B., R. Michle, R. Portelli, N. Trivett and P. Misra, 1982: The Nanticoke Shoreline Diffusion Experiment, June 1978, II. Internal Boundary Layer Structure." *Atmos. Environ.,* **16, 423-427.**

Kerman, B., 1982: A Similarity Model of Shoreline Fumigation, *Atmos. Environ.,* **16, 467-477.**

Kondo, J., 1975: Air-Sea Bulk Transfer Conditions in Diabatic Conditions. *Bound. Lay. Meteorol., 9,* 91-112.

Lemone, M., 1978: The Marine Boundary Layer. Proceedings of Workshop on the Planetary Boundary Layer, AMS, pp. 182-234.

Lo, A.K. and G.A. McBean, 1978: On the Relative Errors in Methods of Flux Calculations. *J. Appl. Meteorol.,* 17, 1704-1711.

Lowe, P.R., 1977: An Approximating Polynomial for the Computation of Saturation Vapor Pressure. *J. Appl. Meteorol.,* **16, 100-103.**

Lusis, M.A., K.G. Anlauf, L.A. Barrie and H.A. Wiebe, 1978: Plume Chemistry Studies at a Northern Alberta Power Plant. *Atmos. Environ.,* **12, 2429-2437.**

Lusis, M.A. and L. Shenfeld, 1982: The Seasonal Dependence of Atmospheric Deposition and Chemical Transformation Rates for Sulfur and Nitrogen Compounds. Draft Final Report of the Atmospheric Science Review Sub-Gioup of Work Group 2: Atmospheric Science Review of Transboundary Air Pollution.

Nieuwstadt, F.T.M., 1977: The Dispersion of Pollutants over a Water Surface, Eighth International Technical Meeting on Air Pollution, Modeling and It's Applications, NATO/CCMS Doc. No. 80, pp. 337-359.

Panofsky, H.A. and J.A. Dutton, 1984: *Atmospheric Turbulence.* John Wiley and Sons, New York, NY.

Panofsky,' H.A., H. Tennekes, D.H. Lenschow and J.C. Wyngaard, 1977: The Characteristics of Turbulent Velocity Components in the Surface Layer under Convective Conditions. *Bound. Lay. Meteorol.*, 11, 355-361.

Pasquill, F., 1976: Atmospheric Dispersion Parameters in Gaussian Plume Modeling: Part II, Possible Requirements for Change in the Turner Workbook Values. Report EPA-600/4-760306. USEPA, Research Triangle Park, NC 27711.

PEI, 1988: User's Guide to SDM--A Shoreline Dispersion Model. EPA-45014-88-017, EPA/OAQPS, Research Triangle Park, NC 27711.

Petersen, R.L., 1986: Wind Tunnel Investigation of the Effect of Platform-Type Structures on Dispersion of Effluents from Short Stacks. *JAPCA, 36*, 1347-1352.

Priestley, C., 1959: *Turbulent* Transfer *in the Lower Atmosphere.* The University of Chicago Press, Chicago, P. 21.

Raynor, G., S. Sethuraman and R. Brown, 1979: Formation and Characteristics of Coastal Internal Boundary Layers During Onshore Flow. *Bound. Lay. Meteorol.*, 16, 487-514.

Rayner, K., 1987: Dispersion of Atmospheric Pollutants from Point Sources in a Coastal Environment. Ph.D. Thesis, Murdoch University, Murdoch, Western Australia .

Richards, L.W., J.A. Anderson, D.L. Blumenthal, A.A. Brandt, J.A. McDonald, N. Waters, E.S. Macias and P.S. Bhardwaja, 1980: The Chemistry, Aerosol Physics and Optical Properties of a Western Coal-Fired Power Plant Plume. *Atmos. Environ.*, 15, 211-2134.

Schacher, G.E., K.L. Davidson and C.W. Fairall, 1982: Atmospheric Marine Boundary Layer Convective Mixing Velocities in the California Coastal Region. *Atmos. Environ.*, 16, 1183-1192.

Sethuraman, S., G.S. Raynor and R.M. Brown, 1982: Variation of Turbulence in a Coastal Thermal Internal Boundary Layer. Preprints, Third Joint. Conf. on Applic. of Air Poll. Meteorol., AMS, Boston, MA.

Snyder, W.H., R. S. Thompson, R.E. Eskridge, R.E. Lawson, I.P. Castro, J.T. Lee, J.C.R. Hunt and Y. Ogawa, 1985: The Structure of Strongly Stratified Flow over Hills: Dividing Streamline Concept. *J. Fluid Mech.*, 152, 249-288.

Strimaitis; D.G., R.J. Paine, B.A. Egan and R. J. Yamartino, 1988: EPA Complex Terrain Model Development: Final Report. EPA-600/53-88-006, Research Triangle Park, NC 27711.

Strimaitis, D.G., A. Venkatram and T.F. Lavery, 1983: A Model to Estimate Concentrations during Plume Impingement. *Preprints, Sixth Symposium on Turbulence and Diffusion,* Am. Meteorol. Soc., 28-31.

Stunder, M. and S. Sethuraman, 1985: A Comparative Evaluation of the Coastal Internal Boundary-Layer Height Equations. *Bound.* Lay. *Meteorol., 32,* 177-204.

Turner, D., 1969: *Workbook of Atmospheric Dispersion Estimates.* Office of Air Programs Publication No. AP-26. U.S. EPA, Research Triangle Park, NC.

Turner, D.B., 1970: Workbook of Atmospheric Dispersion Estimates. PHS Publication No. 999-AP-26. U.S. Department of Health, Education and Welfare. National Air Pollution Control Administration, Cincinnati, Ohio.

Turner, D.B., T. Chico and J.A. Catalano, 1986: TUPOS--A Multiple Source Gaussian Dispersion Algorithm using On-Site Turbulence Data. EPA/600/8-86/010, Research Triangle Park, NC 27711.

Venkatram, A., 1977: Internal Boundary Layer Development and Fumigation. *Atmos. Environ.,* 11, 479-482.

Venkatram, A., 1986: An Examination of Methods to Estimate the Height of the Coastal Internal Boundary Layer. *Bound. Lay. Meteorol., 36,* 149-156.

Weil, J.C. and R.P. Brower, 1984: An Updated Gaussian Plume Model for Tall Stacks. *J. Air Poll. Cont. Assoc., 34, 818-827.*

Zannetti, P., D.M. Wilbur, R.A. Baxter and G.E. Schacher, 1981: Southern California Offshore Air Quality Model Validation Study. AV-FB-81/559. Prepared by Aerovironment, Inc. under Contract No. AA851-CTO-56 with the Pacific OCS Office.

Zilitinkevich, S.S., 1975: Resistance Laws and Prediction Equations for the Depth of the Planetary Boundary Layer. *J. Atmos. Scf., 32, 741-752.*