

# AERMOD Modeling System Updates Related to Overwater Modeling Applications

## Overview of Issue

For three decades, the Offshore and Coastal Dispersion Model (OCD) has been the EPA's preferred model (i.e. listed in Appendix A of the *Guideline*) for estimating near field air pollutant impacts from overwater emission sources, for both deep water and shoreline applications. OCD has remained the preferred model in these environments due to its treatment of downwash effects from raised, open offshore drilling platforms and the capability to model coastal fumigation at and beyond the shoreline.

The OCD model was developed in the early 1980's by the former Minerals Management Service (MMS), now the Bureau of Ocean Energy Management (BOEM). The EPA approved OCD version 3 (OCD3) as a preferred *Guideline* model in January 1988 (53 FR 392). The downwash algorithms in Version 3 were developed and tested for land-based structures rather than raised platforms and were updated in OCD version 4 (OCD4) in 1989 based on wind tunnel studies of offshore platforms by Petersen (1986). Version 4 also included science updates to the fumigation algorithms, the treatment of the dispersion coefficients  $\sigma_y$  and  $\sigma_z$ , plume reflection, the implementation of the critical streamline using the RTDM approach, and the addition of line and area source types (DiCristofaro et al., 1989). The subsequent release, version 5 in 1997 included a graphical user interface (GUI) to make the model more user friendly. Version 5 also included changes to the input data formats and pre- and post-processor programs, but no revisions were made to model formulation (Chang and Hahn, 1997). The last update to OCD occurred in January 2000, released as OCD5 version 00006 which included a few bug fixes as described in the OCD Model Change Bulletin #3.<sup>1</sup> Though OCD remains an EPA preferred model, it does not include the more recent scientific advancements reflected in the AERMOD modeling system. However, to consider replacing the OCD model with the AERMOD modeling system as the preferred model for overwater emission sources, EPA would need to incorporate science updates related to: 1) platform downwash, 2) shoreline/coastal fumigation, and 3) allow for better characterization of the marine boundary layer. The following briefly compares AERMOD and OCD with respect to these three needed updates to AERMOD:

- Platform downwash: The downwash algorithms in AERMOD were designed specifically to model downwash effects from solid, rectangular, ground-based structures. OCD better accounts for the flow under and through raised lattice structures common to deep water offshore drilling platforms.
- Shoreline/coastal fumigation: OCD can account for the location of the shoreline via user input and separately characterize the marine and over land boundary layers by accepting separate meteorological inputs for the two distinct boundary layer environments. By defining the two boundary layers, OCD can account for the Thermal Internal Boundary Layer (TIBL) which is responsible for fumigation. AERMOD is limited to a single set of boundary layer parameters which define a homogeneous boundary layer throughout the entire modeling domain without any spatial variability.

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<sup>1</sup> <https://www3.epa.gov/ttn/scram/mcbs/ocdz3.txt>

- Marine boundary layer: AERMET, the meteorological processor for AERMOD, was designed to process land-based meteorology and does not account for the air-sea interactions needed to characterize the marine boundary layer.

## Current Implementation in AERMOD

### Platform Downwash

Building downwash is modeled in AERMOD using the Plume Rise Model Enhancements (PRIME) algorithms which are integrated into AERMOD for point sources. The development PRIME was sponsored by the Electric Power Research Institute (EPRI) with a focus on: 1) enhanced plume dispersion coefficients from the turbulent wake, and 2) reduced plume rise from descending streamlines in the lee of the building and the increased entrainment in the wake (EPRI, 1997).

PRIME is based on wind tunnel and field data collected for solid, ground-based structures and does not take into account air flow under raised buildings or through the lattice structures typical of offshore platforms. The PRIME model reduces plume rise based on streamline deflection near the building, vertical wind speed shear, enhanced dilution from the turbulent wake and reduction in velocity. Plume mass is partitioned between two wake regions: a near-wake cavity of recirculating mass adjacent to the building and a far-wake with enhanced dispersion. Dispersion of the recirculated cavity mass is based on building geometry and is assumed to be uniformly mixed. Mass is re-emitted from the cavity into the far-wake region at the boundary of the cavity and combined with the portion of the plume that was not drawn into the cavity. The rate of dispersion in the far-wake region is based on source location, release height, and building geometry. Dispersion in the near-wake is determined with a probability density function, while dispersion in the far-wake is based on an eddy diffusivity model. Beyond the wake, the total concentration at a given location is based on a weighting of the concentration computed by PRIME and the concentration computed by AERMOD ignoring downwash. The weighting parameter decreases exponentially with vertical, lateral, and downwind distance from the wake.

### Shoreline/Coastal Fumigation and Marine Boundary Layer

As stated previously, AERMOD cannot model shoreline/coastal fumigation. Furthermore, AERMET cannot adequately represent marine environments. The parameterization of the boundary layer by AERMET is based on surface and upper air meteorology collected at a single location to represent the entirety of the modeling domain. For most applications of AERMOD, the surface data are either hourly site-specific observations collected near the facility or National Weather Service (NWS) observations collected at a nearby airport. Upper air data are collected twice per day by the NWS. Observations of parameters such as wind speed, wind direction, temperature, and cloud cover are processed through the AERMET meteorological preprocessor to compute hourly values for boundary layer parameters such as surface friction velocity, Monin-Obukhov length, and mixing height. While the boundary layer varies with time, based on observations, AERMOD assumes it is uniform throughout the modeling domain for a given hour.

AERMET was designed for overland applications and assumes a diurnal cycle of heating and cooling of land surfaces in which heat flux at the surface is positive during the day and negative at night. This results in unstable conditions during the day and stable conditions at night. Diurnal patterns over large water bodies are far less dramatic than over land. This is due to the heat capacity of water compared to land surfaces. Water takes longer to heat up and retains heat much longer after the energy source is

removed. Stability in the marine boundary layer is more of a response to air-sea temperature difference and wind speed than the diurnal heating and cooling of the surface. While there can be a stark contrast between the two atmospheric boundary layers at the shoreline interface, AERMOD knows of only one which is assumed to be land-based.

The AERCOARE program (EPA, 2012) has been developed as a preprocessor for overwater meteorological data as a counterpart to AERMET to better characterize the marine boundary layer. Though not yet part of the regulatory version of the AERMOD system, prior to the development of the AERCOARE program, the EPA Model Clearinghouse concurred with EPA Region 10's approval of the use of the AERCOARE algorithms as an alternative program to preprocess meteorological data for applications in the Arctic ice-free environments of the Beaufort and Chukchi Seas (EPA, 2011). Until AERCOARE is adopted as a regulatory preprocessor for AERMOD, the EPA anticipates there will be additional requests to use AERCOARE which will, over time, establish a solid foundation for more timely approval per Appendix W, Section 3.2.2. However, the use of AERCOARE does not address the bigger issue of shoreline and coastal fumigation.

## Summary of Current Literature or Research

### Platform Downwash

The only research that EPA found related to downwash from raised platforms and porous and lattice structures is the original wind tunnel studies performed by Petersen (1986) which is implemented in OCD and subsequent wind tunnel studies performed by Petersen and Lout (2012).

#### *Petersen, 1986*

Petersen conducted wind tunnel experiments for offshore drilling platforms to assess the building wake algorithm in the OCD model. Experiments were performed for three typical oil platforms. Additional wind tunnel experiments were conducted to simulate two cases from a past tracer field experiment that had previously been carried out in the Gulf of Mexico (Dabberdt, et al., 1982). Petersen demonstrated that a raised platform can have a significant effect on dispersion, and that the formulation in the OCD model at the time was not sufficient. OCD underestimated the horizontal and vertical dispersion coefficients when there was a significant wake effect. Petersen proposed changes to the calculation of the dispersion coefficients which were incorporated into the OCD model with some modification based on the work of Hanna and DiCristofaro (1988). Petersen's work also demonstrated that the building height in OCD should be modified to be the height of the top of the platform relative to the sea surface rather than the height relative to the bottom of the platform. The platform downwash algorithm in the current version of the OCD model reflects the combined work of Petersen, Hanna, and DiCristofaro as described in Volume I of the 1989 OCD4 User's Guide (MMS, 1989).

#### *Petersen and Lout, 2012*

While the majority of this work focuses on downwash issues related to the PRIME algorithms and the building preprocessor BPIPFRM, specific to rectangular solid structures, included is discussion on the streamline calculation for lattice and streamlined structures. Through wind tunnel experiments, Petersen and Lout demonstrated that lattice structures upwind or downwind of a stack enhances dispersion, but the streamlines remain horizontal and does not impact the ground close to the stack or structure as in the case of a solid building.

## Shoreline/Coastal Fumigation

Much of the literature found on shoreline and coastal fumigation dates back to the 1970's through the 1990's. While peer reviewed studies seem to be less prevalent today, the literature is not totally void. The following literature reflects much of the more recent work, recognizing that the structure of the TIBL is more complex than once thought.

### *EPA, 1987*

This work analyzed and evaluated two base shoreline fumigation models: the CRSTER Shoreline Fumigation Model (CSFM) and the Misra Shoreline Fumigation Model (MSFM) (Misra, 1980). Variations of the MSFM were also evaluated. The researchers found that the most significant factor affecting coastal dispersion is the shape of the TIBL. A steep TIBL results in higher concentrations closer to the stack. The study concluded that the MSFM was the better performer at predicting ground-level concentrations from stack releases at the shoreline, and convective velocity scaling is a better for characterizing dispersion in the TIBL than the standard Pasquill-Gifford curves. The MSFM was selected as the shoreline fumigation sub-model for the EPA's Shoreline Dispersion Model (SDM) (EPA, 1988) based on this analysis and evaluation.

### *Nazir et al., 2004*

This work discusses past probability density function (PDF) models and proposes an improved PDF model to predict coastal fumigation that is time efficient. The researchers used a convective limit assumed by Weil and Brower (1984) and the slab model to determine the height of the TIBL. Restricted to onshore flows and strong convection, the model is applicable in the range of  $1.2 < U/w^* < 6$ , where  $U/w^*$  is a stability index in which  $U$  is the mean wind speed and  $w^*$  is the convective velocity. The model also takes into account the skewness of the vertical convective turbulence which others do not. An error analysis demonstrates minimum error relative to observed values.

### *Yuan et al., 2006*

Observations from a tracer field experiment performed near the coast south of Los Angeles in Wilmington, CA were used to study the dispersion of near ground-level emissions in an urban coastal environment. Prior studies of coastal fumigation were primarily limited to plume behavior of elevated releases as they come into contact with the TIBL. This field study occurred during daytime hours during onshore flows. Tracer concentrations of SF<sub>6</sub> were monitored along five arcs ranging from 100 to 5000 meters downwind of the emission source. The authors concluded that stable onshore flow can limit the height of the TIBL. The depth of the TIBL can be limited to a height of 150 m out to 5000 meters from the shoreline. In addition, the vertical dispersion of a ground-level source appears limited to the height of the capping stable overwater boundary layer that is advected with onshore flow. The authors also concluded that buildings near low-level releases affect the vertical spread of the plume and should be considered.

### *Park and Seok, 2007*

The focus of this work was to develop a new statistical approach for selecting an appropriate model applicable to coastal dispersion. The researchers developed a single statistical index using fuzzy inference in which eight different statistical measures (e.g., fractional bias, normalized mean square error, etc.) were taken as premise part variables. The method was evaluated using two different fumigation models and a total of eight modeling schemes based. In addition, the ISCST3 and ADMS3

models were also included. Using this new statistical approach, the Lyons and Cole (1973) fumigation model was found to be the better performer.

*Hara et al., 2009*

Wind tunnel experiments and numerical simulations were performed for two temperature profiles to simulate the TIBL associated with a sea breeze. The two temperature profiles represented a weakly stratified and highly stratified case. The purpose of this work was to study the following: 1) the effect of atmospheric stability over the sea on the streamwise change in the turbulent structure, 2) transport processes in the TIBL, and 3) the growth of the TIBL. Wind tunnel experiments were performed in a thermally stratified wind tunnel. Numerical simulations were performed using a finite-difference method for a volume that was 11 m long, 1.6 m wide, and 1 m high. The governing equations included the Navier-Stokes, continuity, and energy equations. Changes in the mean temperature and wind speed in the lower layer suggest the TIBL developed due to heating the land surface while vertical profiles of temperature, heat flux, and turbulence changed as expected with increasing distance inland. Turbulence statistics in the TIBL varied accordingly with the temperature profile. The estimated TIBL heights from the wind tunnel and numerical simulations were in good agreement suggesting also that wind tunnel and numerical simulations reproduced the growth of the TIBL.

*Calmet and Mestayer, 2015*

Calmet and Mestayer used large eddy simulation (LES) with high spatial resolution to research the identification of the TIBL and TIBL growth mechanisms. When the TIBL is impeded by topography, it can degenerate and difficult to identify by changes in the temperature. Their concluded that the best method for determining the TIBL depth is by using the minimum of the heat flux profiles. With regard to TIBL growth, using the ratio of friction velocity scale ( $u^*$ ) to the convective velocity scale ( $w^*$ ), they found that buoyancy is the dominant mechanism when  $u^*/w^* < 0.35$  and shear is dominant when  $u^*/w^* > 0.35$ . The height of the TIBL is constant when  $u^*/w^*$  is between 0.35 – 0.5, and the height of the TIBL decreases when  $u^*/w^* > 0.5$ .

Marine Boundary Layer

*Wong, et al., 2016*

This work describes the AERCOARE meteorological processor which incorporates the Coupled Ocean-Atmosphere Response Experiment (COARE) algorithms for predicting air-sea energy fluxes. AERCOARE was developed as an alternative to the AERMET meteorological processor to more appropriately characterize the marine boundary layer when using AERMOD rather than OCD to model offshore emission sources. Wong et al. summarize the differences between AERMOD and OCD and the benefits and disadvantages of each model when modeling overwater sources. The paper presents the results of an AERMOD performance evaluation that utilized AERCOARE to process meteorological data collected during four past overwater field studies of offshore emissions including Cameron, Louisiana; Carpinteria, California; Pismo Beach, California; and Ventura, California. The same studies were previously used to develop the OCD model and evaluation the CALPUFF model which contains the COARE algorithms. The researchers found that predicted concentrations were generally within a factor of two of the observed frequency distributions for three of the four field studies and comparable to both OCD and CALPUFF for the same field studies. Wong et al. concluded that AERMOD, utilizing meteorological data processed with AERCOARE was a viable alternative to the OCD model for many overwater regulatory applications.

## Considerations for Updates in Model System

Multiple initiatives are ongoing to collaborate with other federal agencies to address these overwater issues including the establishment of a team under the Interagency Workgroup on Air Quality Modeling (IWAQM) that provides for specific coordination with the Department of Interior (DOI)'s Bureau of Ocean Energy Management (BOEM). The IWAQM Overwater Team is expected to provide a forum for improving and/or developing air quality models and techniques for assessments of ambient air quality impacts that support Outer Continental Shelf (OCS) and other overwater regulatory applications. This partnership between EPA and BOEM will have a specific focus on near-field and long-range transport modeling of overwater emissions sources used to ensure compliance with National Ambient Air Quality Standards (NAAQS), Prevention of Significant Deterioration (PSD) increments, and visibility impact assessments for Class I areas. The IWAQM Overwater Team would also support ongoing and future studies, including research in marine and coastal water environments, necessary to refine and/or develop the aforementioned air quality models and techniques.

Platform downwash: EPA's Air Quality Modeling Group will leverage off of current and future work performed by the Office of Research and Development (ORD) focused on the downwash issues in AERMOD. ORD is currently conducting wind tunnel experiments and large eddy simulations (LES) to investigate deficiencies with the PRIME algorithms and the parameterization of buildings, particularly elongated buildings rotated from perpendicular relative to the wind flow.

In addition, a PRIME2 Advisory Committee has been formed by the Atmospheric Modeling and Meteorology subcommittee of the Air and Waste Management Association (AWMA). The PRIME2 committee was created for the purpose of providing a technical review forum to suggest improvements to the PRIME model and establish a process to review, approve, and implement new science into PRIME. The PRIME2 committee is investigating the issue of platform downwash, among others downwash issues (Petersen and Lout, 2012), and have recommended updates to PRIME and submitted them for EPA to review and consideration.

We will consider the inclusion of beta options in AERMOD that reflect peer-reviewed EPA/ORD research as well as peer-reviewed research presented by the PRIME2 committee related to near-term improvements to BPIPPRM and the PRIME algorithm to address platform downwash or a replacement of the current PRIME algorithm.

Shoreline/coastal fumigation: EPA will review the current shoreline fumigation models including the older screening algorithms in AERSCREEN and SCREEN3, the SDM based on the work of Mirsa (1980), and the more recent work discussed in the previous section. In collaboration with other federal agencies and the broader scientific community, EPA will identify an appropriate shoreline fumigation formulation and determine a path for inclusion into AERMOD.

AERCOARE: EPA will consider incorporating the COARE algorithms into AERMET to process the information similar to what is done with prognostic data (provided via MMIF tool) and then conduct the necessary testing and evaluations of the AERMOD modeling system.

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