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Evaluation of the COARE-AERMOD Alternative Modeling Approach Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas

1 Introduction

The purpose of this document is to provide support for alternative regulatory dispersion modeling practices following the EPA *Guideline of Air Quality Models, Section 3.2 Use of Alternative Models.* The memorandum was requested by EPA following our presentation on November 22, 2010, when ENVIRON provided most of these results to EPA Region 10, EPA OAQPS, Shell, and Air Sciences.[1] The current analysis supports ongoing studies to develop an air quality modeling approach suitable for Shell's proposed exploratory drilling sources in the Beaufort and Chukchi Seas.

The regulatory modeling approach for most onshore applications is the AERMOD modeling system. The current regulatory approach for offshore projects is a much older model, the Offshore Coastal Dispersion (OCD) model. OCD has not been updated for many years and does not reflect the latest scientific advancements found in the AERMOD modeling system. The proposed alternative approach allows the use of the more recent AERMOD system but bypasses the AERMET meteorological preprocessor using the Coupled Ocean Atmosphere Response Experiment (COARE) air-sea flux algorithm[2] and overwater meteorological measurements.

In a previous analysis, ENVIRON compared this proposed approach to the current guideline OCD model and found the two techniques were not equivalent given the same basic meteorological and source characteristics.[3] Since the modeling approaches differed significantly, per *Guideline Section 3.2.2.d.iv* EPA requested an evaluation of the COARE-AERMOD procedures to ensure that the proposed alternative approach was not biased toward underestimates. In the current study ENVIRON presents a model evaluation analysis using data from offshore tracer experiments to address EPA concerns and the requirements of the *Guideline.* The remainder of this document describes the rationale for the alternative COARE-AERMOD approach, the model evaluation datasets, and the results of the evaluation.

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[1] ENVIRON 2010a. *COARE-AERMOD Model Evaluation, Topics for Discussion, November 22, 2010*, *Power Point Presentation.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, October 24, 2010.

[2] Version 3.0 of the COARE algorithm with journal references and a User's Manual can be accessed at: ftp://ftp.etl.noaa.gov/users/cfairall/wcrp_wgsf/computer_programs/cor3_0/ and http://www.coaps.fsu.edu/COARE/flux_algor/

[3] ENVIRON 2010b. *Comparison of OCD vs COARE-AERMOD, Support for Simulation of Shell Exploratory Drilling Sources in the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, October 24, 2010.

2 Rationale for Approach

The current EPA guideline model for offshore sources is the OCD model. OCD has not been updated for many years and several of the dispersion model components and procedures are not consistent with AERMOD. The AERMOD modeling system is the recommended approach for onshore new source review. Important routines in OCD that are independent of the onshore/offshore setting are inconsistent with current regulatory practices as embodied within AERMOD, namely:

- OCD does not contain routines for processing either missing data or hours of calm meteorology. Such processing must be performed with a custom post-processing program.
- OCD does not contain the latest regulatory PRIME downwash algorithm. Most of the exploratory drilling sources are located on ships or rigs where downwash effects are important.
- The PVMRM[4] and OLM[5] methods are not included in OCD. These techniques are crucial for assessing the new 1-hour NO2 ambient standard.
- The new PM2.5, 1-hour NO2, and 1-hour SO2 ambient standards are based on the 98th, 98th, and 99th percentile concentrations, respectively. These probabilistic standards and the EPA methods recommended for estimating design concentrations must be obtained by post-processing the hourly OCD output files. Such calculations are expected to be included in an upcoming version of AERMOD.
- OCD does not contain a volume source routine and the area source routine only considers circular areas without allowance for any initial vertical dispersion. Moving ships in previous permitting analyses were characterized as series of adjacent volume sources.[6] This characterization would not be possible with OCD.
- Although OCD contains routines to simulate the boundary layer over the ocean, the surface energy flux algorithms are outdated and have been replaced within the scientific community by the COARE air-sea flux algorithms.
- The early and late portions of the drilling season in the Arctic Ocean include land use characterized by sea-ice, not water. As in overland applications, AERMOD would be the preferred model during these periods.

The AERMOD modeling system depends on the AERMET meteorological pre-processor. AERMET was developed primarily to simulate meteorological processes driven by the diurnal cycle of solar heating over land. The marine boundary layer behaves in a fundamentally different manner because the ocean does not respond the same to diurnal heating and cooling effects. Improvements that could be made to AERMET-AERMOD include:

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[4] Plume Volume Molar Ratio Method, used to limit NO-to-NO2 conversion based on available ozone.

[5] Ozone Limiting Method, used to limit NO-to-NO2 conversion based on available ozone.

[6] Previous permitting analyses were conducted using the ISCST3 dispersion model and a screening meteorological data set.

- The surface roughness over the ocean varies with wind speed and wave conditions, and is not a constant.
- AERMET uses the solar angle as an indication of the transition between daytime and nighttime boundary layer régimes. Over the ocean, the stability of the boundary layer does not respond as a strong function of solar heating, but is driven more by advection and horizontal differences in sea surface temperature. Unstable conditions can occur during the night, and stable conditions during the day.
- AERMET does not explicitly include the effects of moisture in the assumed temperature and wind speed profiles. The Monin-Obukhov length and convective velocity scale estimated by AERMET also do not incorporate moisture effects. The effect of surface moisture fluxes is typically stronger over the ocean than over land.
- AERMOD does not contain routines for elevated platform downwash. Note that such platforms are currently not planned for exploratory drilling in the Beaufort and Chukchi Seas.
- AERMOD cannot simulate shoreline fumigation or dispersion affected by non-homogenous conditions either in space or time. Based on previous analyses, the higher impacts occur well offshore near the drilling activities, so AERMOD's inability to consider non-homogenous conditions is less critical than for longer range transport simulations.

In our opinion, under *Guideline Section 3.2.2.b (3)* there is no regulatory preferred model for offshore sources subject to downwash, especially an approach that incorporates procedures to assess the new 1-hour NO2 ambient standard. The alternative approach we propose is to replace AERMET with the COARE air-sea flux method providing a meteorological input file that is more consistent for marine applications. Our basic assumption is that given an appropriate characterization of meteorology conditions over water, the diffusion algorithms within AERMOD should perform in a fashion similar to the results found in the many field studies that lead to it becoming the EPA Guideline model over land.[7] AERMOD would be used for the dispersion model predictions and would be applied in a manner consistent with new source review procedures over land. This would allow the PVMRM, calms processing, volume source, and design concentration calculating procedures in AERMOD to be applied to sources located within the marine boundary layer. It would also allow a single dispersion model to be used to simulate the entire drilling season.

3 Alternative Model Guideline Requirements

The EPA requirements for alternative models are provided in *Section 3.2 Use of Alternative Models*. Under *Section 3.2.2.b (3)* and *Section 3.2.2.e*, an alternative model may be approved if there is no preferred model for the specific application, provided:

[7] EPA, 2003. *AERMOD: Latest Features and Evaluation Results.* EPA, OAQPS, Research Triangle Park, NC 27711, EPA-454/R-03-003, June 2003.

i. The model has received a scientific peer review: Both components of the proposed alternative modeling approach have received extensive peer review in the scientific literature. Peer reviewed references for AERMOD can be found on the EPA Support Center for Regulatory Atmospheric Modeling (SCRAM).[8] The COARE bulk air-sea flux algorithms have also been peer reviewed in several different scientific journals.[2,9]

ii. The model has been demonstrated to be applicable to the problem on a theoretical basis: Arguments for the theoretical basis of both COARE and AERMOD are contained in the scientific literature mentioned in (i) above.

iii. The databases which are necessary to perform the analysis are available and adequate: The meteorological collection program to support regulatory modeling for Shell Exploratory Drilling sources in the Arctic Ocean have been approved by EPA Region 10 and include a meteorological site on a low relief barrier island embedded in the marine layer, buoys, and a thermal profiler. The tracer field experiments used to evaluate the COARE-AERMOD approach in the subsequent sections of this study were also used as the basis for the current offshore regulatory model OCD.

iv. Appropriate performance evaluations of the model have shown that the model is not biased towards underestimates: Individual performance evaluations have been performed for both AERMOD and the COARE flux method in the peer reviewed literature. The remainder of this study assesses model performance of the combined COARE-AERMOD alternative modeling procedures.

v. A protocol on methods and procedures to be followed has been established: A modeling protocol for Shell Exploratory sources in the Arctic is currently being prepared outlining specific methods and procedures for the COARE-AERMOD application. User's manuals for both COARE and AERMOD are available from the SCRAM and COARE websites referred to previously. The specific procedures, programs and databases used in the current analysis will be provided to EPA in a separate submittal.

The remainder of this study addresses Item (iv) where predictions from COARE-AERMOD are compared to observations from three tracer studies.

4 Evaluation Methods and Data Sets

The COARE-AERMOD alternative modeling approach was assessed by comparing predictions to the observations obtained from three offshore tracer studies: Pismo Beach, CA; Cameron, LA, and Carpinteria, CA. These studies are a subset of the data used to evaluate OCD,[10] the current EPA Guideline model for offshore sources, and more recently, CALPUFF the model preferred

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[8] The EPA SCRAM Website is at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

[9] Brunke, et. al., 2003. Which Aerodynamic Algorithms are Least Problematic in Computing Ocean Surface Turbulent Fluxes? *J. of Climate*, Vol. 16, PP. 619-635.

[10] Chang, J.C. and K.J. Hahn, 1997. *User's Guide for the Offshore and Coastal Dispersion (OCD) Model Version 5.* MMS Contract No. 1435-96-PO-51307, November, 1997. Available from: http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#ocd.

by MMS (now BOEMRE) for permitting within their jurisdiction.[11] This section provides the rationale for the selection of these data sets, describes the data sets, outlines the procedures for the application of the COARE algorithm, describes the assembly of the meteorological data for AERMOD, and presents the statistical methods that were used to compare COARE-AERMOD predictions to measurements within the field programs.

4.1 Overwater Tracer Data Sets

The three model evaluation data sets used in the current study were provided by EPA Region 10 from the archives supporting development of the MMS version of CALPUFF and OCD Version 4.[12] The Pismo Beach and Cameron data sets were selected because the studies occur under a range of overwater atmospheric stabilities that are similar to the range observed by Shell buoy measurements over the Arctic Ocean. The tracer measurements in these two studies occur in level terrain near the shoreline downwind of offshore tracer releases. The proximity of the measurements to the shoreline and the absence significant air modification over the land are the reasons these experiments were selected as they are most similar to permit applications in the Arctic Ocean. At the request of EPA Region 10, model predictions were also evaluated with observations from the Carpinteria complex terrain tracer study, where shoreline measurements were observed on a bluff. The Carpinteria data set had much lighter winds and the transport distances were less than the other two studies.

4.1.1 Pismo Beach

The Pismo Beach experiment was conducted during December 1981 and June 1982. A depiction of land use, release point locations and receptor sites are shown in Figure 1 based on the files from the MMS CALPUFF evaluation archives.[11] The tracer was released from a boat mast height of 13.1-13.6 m above the water. Peak concentrations occurred near the shoreline at sampling distances from 6 to 8 kilometers away. The Pismo Beach evaluation database consists of 31 samples.

Table 1 lists the overwater meteorological data used in the current study. These same data were also used in previous OCD and CALPUFF evaluations. A description of the data collection and preparation can be found in the MMS and OCD model evaluation reports with references to the original field studies. The range of winds and air-sea temperature differences are similar to the range observed by the Reindeer Island buoy operated by Shell in the Beaufort Sea.

Examination of the meteorological data in Table 1 reveals several inconsistencies between the air-sea temperature difference and the virtual potential lapse rate. The virtual potential temperature lapse rate sometimes indicates a stable boundary layer (positive) when the air-sea

[11] Earth Tech, 2006. *Development of the Next Generation of Air Quality Models for the Outer Continental Shelf (OCS) Applications, Final Report: Volume 1.* Prepared for MMS, Contract 1435-01-01-CT-31071, March 2006.

[12] DiCristofaro, D.C. and S.R. Hanna. *OCD The Offshore and Coastal Dispersion Model, Version 4, Volume I: User's Guide.* MMS Contract No. 14-12-001-30396, November 1989.

temperature difference is unstable (negative).[13] Either there was a low mixed layer not reflected by the mixing height measurements in Table 1, or one of the measurements is not representative of the boundary layer profile. The previous OCD model evaluation relied on a measured vertical temperature lapse rate, so to be consistent with the earlier studies, in our evaluation we adjusted the air-sea temperature difference to be at least as stable as indicated by the virtual temperature lapse rate. The revised estimates are shown in Table 1.

Table 2 shows the source-to-receptor relationships and the release characteristics assumed for the COARE-AERMOD simulations. All simulations where performed with a unit emission rate and without plume rise. Building downwash from the release boat was considered using the dimensions shown in Table 2. As in the original OCD and CALPUFF evaluations, only peak concentration predictions and observations for each hour are compared in the current evaluation. In order to ensure that plume centerlines travelled over the receptor with the highest observed concentration, a constant westerly wind was assumed and predictions were obtained at a single receptor located the correct distance east of the release point.

4.1.2 Cameron

Figure 2 shows the land use, release points, receptors, and meteorological stations for the Cameron evaluation data set. Twenty-six tracer samples from the field studies in July 1981 and February 1982 were used in the evaluation. Tracer was released from both a boat and a low profile platform, from a height of 13 m. As in the Pismo Beach study, the receptors are located in flat terrain near the shoreline with transport distances ranging from 4 to 10 km.

The Cameron meteorological data used in the current analysis are shown in Table 3, and are based on the OCD and MMS CALPUFF model evaluation data set. The data set contains both very stable and fairly unstable conditions. Although the water and air temperatures are much higher than observed in the Arctic, the combination of surface energy fluxes results in similar atmospheric stabilities, especially for stable conditions. As with the Pismo Beach data, there are several hours of stable lapse rates accompanied by unstable air-sea temperature differences. For example on February 15, 1981 hour 1700, the air-sea temperature difference is -0.8 ºC, while the virtual potential temperature lapse rate is 0.06 ºC/m (extreme stability “G” in OCD). Over 10 m, this virtual potential temperature lapse rate would result in at least an air-sea temperature difference of +0.5 ºC. These contradictory data were resolved using the same methodology as in the Pismo Beach dataset.

Table 4 shows the source and receptor characteristics used in the Cameron tracer simulations. The platform releases were simulated without downwash and the boat releases assumed a building height of 7 m and a width (and length) of 20 m. A constant hypothetical wind direction was assumed and downwind receptor distances were varied to match the downwind distances of the measurement site with the highest observed concentration for each period.

[13] OCD contains a dispersion algorithm for very stable conditions that can only be triggered when the measured vertical potential temperature gradients exceeds 0.04 ºC/m. Such conditions are triggered irrespective of all other meteorological data provided to OCD. In this fashion, this variable can be used to override OCD’s normal dispersion algorithms when other evidence suggests extremely stable conditions have occurred.

4.1.3 Carpinteria

The Carpinteria tracer study was conducted in September and October 1985. Studies were conducted to examine offshore impacts to both complex terrain and shoreline fumigation. The current analysis only evaluated the complex terrain data set as the COARE-AERMOD approach cannot simulate shoreline fumigation. For permitting in the Chukchi and Beaufort Seas, shoreline fumigation is not an issue as the areas of interest are well offshore.

Figure 3 shows the land use and terrain for the Carpinteria field study. The shoreline receptors are located on a 20-30 m high bluff within 0.8 km to 1.5 km of the tethersonde release offshore. Two tracers were released with heights varying from 18 m to 61 m. The tethersonde was well above the anchor boat and downwash was not considered in the simulations.

Table 5 displays the meteorological data used in the current simulations and previous evaluations of OCD and CALPUFF. The winds were very light for most of the releases, especially considering the wind measurement heights were from 30 m to 49 m. The combined influences of low wind speeds and the air-sea temperature differences in Table 5 result in cases with unstable to very stable stratifications. Unlike the Pismo Beach and Cameron data sets, the virtual potential temperature lapse rates do not contradict the gradient inferred from the air-temperature difference measurements. One suspect aspect of the data is the constant mixed layer height of 500 m for the entire data set. In cases where plumes are not trapped under a strong inversion, CALPUFF and OCD are less sensitive to the mixing height than AERMOD. Thus uncertainty in the boundary layer height in this experiment may not have been important to the original investigators.

Table 6 lists the source release parameters used for the COARE-AERMOD simulations of the Carpinteria data set. Unlike the Pismo Beach and Cameron simulations, actual wind directions, source locations and receptor sites were used in the analysis to consider the effects of terrain elevation on the model predictions. Receptor elevations and scale heights for AERMOD were calculated with AERMAP (Version 09040) using 1/3 arc-second terrain data from the National Elevation Data (NED) set. The peak predicted concentration was compared to the peak measured concentration for each release.

4.2 COARE-AERMOD Overwater Data Set Procedures

The COARE-AERMOD meteorological data preparation involves two steps: 1) application of the COARE bulk air-sea flux algorithms to estimate the surface energy fluxes and 2) assembly of the meteorological data from the COARE algorithm with additional variables needed by AERMOD. A FORTRAN program was written that calls the COARE bulk air-sea flux algorithm subroutines provided by the authors of the method.[2] These same basic subroutines are also used by the MMS version of CALPUFF. Mixing height estimates and several other variables needed by AERMOD are not part of the COARE routines. Mixing heights were provided separately using several techniques based on the data from the OCD evaluation data sets. Further details are provided in the following discussion.

4.2.1 Data for COARE Algorithm

The COARE algorithm was applied to predict the surface energy fluxes from the overwater data sets briefly described above. The data necessary for the COARE algorithm depend on the options employed for estimating the surface roughness, for the treatment of a cool-skin, or heating of the upper layer of the ocean. The options selected for the evaluation and associated data are as follows:

- Several options are available to adjust the sea temperature to account for the difference between the skin temperature and the bulk temperature measurement taken at depth from a buoy or ship. The cool-skin and warm-layer options depend on solar radiation and downward longwave irradiance input data. Such data were not readily available for the current analysis and these options were not selected for the current evaluation. Model comparison tests have shown the COARE algorithm is not sensitive to these options for conditions in the Arctic Ocean.[3] CALPUFF also uses the COARE algorithm and previous studies concluded model performance was not sensitive to the cool-skin or warm-layer options for the Pismo Beach, Cameron, or Carpinteria data sets.[11]
- COARE also contains several methods for estimating the surface roughness length, and the routines can use wave height and period measurement data. The current simulations were conducted with the default option for a well-developed or deep sea. As with the warm-layer and cool-skin options, our sensitivity tests suggest the COARE algorithm is not very sensitive to surface roughness options, especially in the absence of wave measurement data.
- The air-sea temperature difference, overwater relative humidity and the wind velocity drive the energy fluxes and surface stability routines within the COARE routines. Air-sea temperature differences were based on the OCD data sets except for the cases discussed previously where the stable temperature lapse rate data contradicts such observations. In these instances the air-sea temperature difference was based on the lapse rate applied from the surface to the temperature measurement height.
- Wind speed, air temperature, and relative humidity were taken directly from the OCD data sets listed in Table 1, Table 3, and Table 5. The measurement heights are also listed in these tables.
- Surface pressure was assumed to be 1000 mb.
- The COARE algorithm has a small term that depends on rainfall. No precipitation was assumed for any of the hours of the evaluation.
- The COARE algorithm has a small term for "gustiness" that adds to the momentum fluxes during light winds caused by large scale eddies. The model evaluation used the COARE algorithm defaults for this parameter.

Surface energy flux estimates from the COARE algorithm were combined with measurements and reformatted according to the techniques discussed in the next section.

4.2.2 AERMOD Meteorological Data Assembly

The meteorological data for the AERMOD simulations were prepared from the COARE algorithm estimates of the energy fluxes using the data described above and other measurements from the Pismo Beach, Cameron, and Carpinteria field programs. Several different options were considered for preparation of the AERMOD data and were included as cases in the model evaluation. The assembly of the necessary input data was accomplished in a spreadsheet, where several options were applied and the input data reformatted to mimic the output from AERMET. The options selected for the evaluation and associated data are as follows:

- Wind speed, air temperature, and relative humidity data for each data set are shown in Table 1, Table 3, and Table 5. The PROFFILE input file used the actual measurement heights for each variable and there was no attempt to construct a vertical profile using other data that might be available from the field studies.
- Wind direction was assumed to be from the west for the Pismo Beach and Cameron data sets, as simulated receptors were located east of the release points with the downwind distances appropriate for the peak measurement sites. For Carpinteria, the wind directions shown in Table 5 were used in the simulations.
- The standard deviations of horizontal wind direction (sigma-theta or σ_Θ) for the simulations are based on the measurements shown in Table 1, Table 3, and Table 5. One case in the COARE-AERMOD simulations excluded such measurements to test the sensitivity of the predictions to the availability of these data compared to the internal AERMOD algorithm for prediction of sigma-theta.
- Standard deviations of the vertical wind velocity (sigma-w or σ_w) were not provided to AERMOD. Such data were not available for the Pismo Beach study and previous studies have cautioned against the use of such data from the Carpinteria and Cameron data sets. Sigma-w data were also not used in the previous OCD and MMS CALPUFF evaluation studies.
- Surface roughness lengths were estimated by the COARE algorithm using the default option for a well-developed sea based on friction velocity.[14]
- Monin-Obukhov length (L) and surface friction velocity (u_*) are from COARE algorithm estimates. AERMOD restricts the Monin-Obukhov length such that ABS (L) > 1. This restriction avoids unrealistic extremely stable and unstable conditions during light wind conditions. In the evaluation simulations we test further restricting the Monin-Obukhov length such that ABS (L) > 5, as is assumed by OCD. For consistency, the surface friction velocity output from COARE was adjusted to impose such restrictions.
- Convective boundary layer heights were assumed to be the same as the observed mixing heights from field studies when conditions where unstable as indicated by the Monin-Obukhov length ($L < 0$).

[14] AERMOD issues a warning when the roughness length is less than 0.001m and sets the length to 0.001m. This appears to be an arbitrary limit implemented to avoid “division by zero” errors, because AERMET writes out the surface roughness length to only three decimal places. The restriction within AERMOD that limits the surface roughness to 0.001m has little influence on downwind concentrations. Within AERMOD, the surface roughness length is used in the construction of the wind speed profiles and in the dry deposition velocity routines. For such smooth surfaces, almost all the wind shear occurs very close to the surface and when referenced to the measured wind speed at 10 m, the estimates for wind speeds at other levels are about the same for a surface roughness of 0.001m or 0.0001m.

- Convective velocity scales were calculated from the convective mixed layer height (z_{ic}), friction velocity (u_*), and Monin-Obukhov length (L):

$$w_* = u_* \left(\frac{-z_{ic}}{0.4L}\right)^{1/3}$$

- The vertical potential temperature gradient above the convective boundary layer was assumed to 0.01 ºC/m. This variable is used by AERMOD to estimate plume penetration for plume rise calculations and for the portion of the plume predicted to be above the convective mixed layer. Plume rise is not applicable and these conditions do not occur in the current evaluation.

- Mechanical mixing heights (z_{im}) were calculated from the surface friction velocity using the Venketram equation employed by AERMET:

$$z_{im} = 2300{u_*}^{3/2}$$

  The estimates were not temporally smoothed as in AERMET because the data in the field studies are not sequential. In addition, the smoothing does not significantly affect hour-to-hour variations when the heights are relatively small as they are over the water.

  For low winds and smooth surfaces the Venketram equation above results in very small mechanical mixing heights. The mechanical mixing height is an important variable in AERMOD and is used as a scaling parameter during the construction of several important meteorological profiles and the vertical dispersion term (σ_z). The mechanical mixing height is also in the denominator of the AERMOD equation used to calculate the lateral diffusion term (σ_y) during stable conditions. In order to avoid numerical problems and possible extrapolation of algorithms beyond their intended applications, the minimum mechanical mixing height was set at 25 m. This corresponds to a friction velocity of about 0.05 m/s.

  As an option in the evaluations, the mechanical mixing height was also assumed to be the same as the observed mixing heights in Table 1, Table 3, and Table 5.

- Miscellaneous variables used by the AERMOD deposition algorithm (not used in the simulations):
  - Sensible heat fluxes were set to the estimates from the COARE algorithm.
  - Bowen ratios were calculated from the COARE predicted sensible and latent heat fluxes.
  - Albedo was set to the COARE default of 0.055.
  - The cloud cover fraction was set to 0.
  - Precipitation amount and code were set as missing.
  - Surface pressure was set to 1000 mb.

Using the techniques and data discussed above, AERMOD meteorological data sets were prepared for each of the three field studies. Five cases were considered using various combinations of the many possible methods to assemble the data:

- Case 1: Require Abs (L) > 5, use measured σ_Θ measurements, and use the Venketram equation in AERMET for z_{im} and require z_{im} > 25 m.
- Case 2: Require Abs (L) > 5, use AERMOD predicted σ_Θ, and use the Venketram equation in AERMET for z_{im} and require z_{im} > 25 m.
- Case 3: Require Abs (L) > 1, use measured σ_Θ measurements, and observed mixing heights for the mechanical mixing height (z_{im}).
- Case 4: Require Abs (L) > 5, use measured σ_Θ measurements, and observed mixing heights for the mechanical mixing height (z_{im}).
- Case 5: Require Abs (L) > 5, use measured σ_Θ measurements, use the Venketram equation in AERMET for z_{im} and require z_{im} > 25 m, and modify AERMOD to use the Draxler equation for the ambient lateral dispersion parameter:

$$\sigma_y = \frac{\frac{\sigma_v}{u} x}{\left(1 + 0.9\sqrt{\frac{x}{1000u}}\right)}$$

where x is the downwind distance, u the effective wind speed, and σ_v is the effective standard deviation of the lateral wind speed calculated from σ_Θ. This equation is used both by OCD and CALPUFF. Case 5 was included to remove the sensitivity of the lateral dispersion term in AERMOD to the mixing height. The MMS CALPUFF evaluations found this equation performed better than several alternatives that are more similar to the formulation used by AERMOD.

Case 1 most resembles the options currently planned for permit applications in the Beaufort and Chukchi Seas. Case 3 is the combination that places the least restrictions on the preparation of the data and the use of the available observations. Case 5 was included after sensitivity tests indicated the lateral dispersion parameter seemed overly sensitive to assumptions concerning the mechanical mixing height. COARE-AERMOD predictions from the five cases above were obtained for the Pismo Beach, Cameron, and Carpinteria data sets. Peak predictions were compared to peak observations using the statistical model evaluation methods discussed in the following section.

4.3 Statistical Evaluation Procedures

Statistical procedures were applied to evaluate whether the COARE-AERMOD alternative modeling approach was biased towards underestimates using the Pismo Beach, Cameron, and Carpinteria overwater tracer studies. In addition the procedures were applied to examine which of the five cases for preparing the meteorological data performed statistically better within a regulatory modeling framework. The procedures are designed to evaluate how well the modeling approach explains the frequency distribution of the observed concentrations, especially the upper-end or highest observed concentrations. The analysis also measures the model’s ability to explain the temporal variability of the observations. Given two unbiased models, the approach with the least amount of scatter would generally be preferred.

The statistical methods and measures are similar to the techniques applied in the EPA evaluation of AERMOD[7] with a few changes as will be discussed below.

- Quantile-quantile (Q-Q) plots were prepared to test the ability of the model predictions to represent the frequency distribution of the observations. Q-Q plots are simple ranked pairings of predicted and observed concentration, such that any rank of the predicted concentration is plotted against the same ranking of the observed concentration. The Q-Q plots can be inspected to examine whether the models are biased towards underestimates at the important upper-end of the frequency distribution
- The robust highest concentration (*RHC*) has been used in most EPA model evaluation studies to measure the model's ability to characterize the upper end of the frequency distribution. Note that this can also be accomplished by visual inspection of the Q-Q plots. The RHC is calculated from:

$$RHC = c_n + (\bar{c} - c_n) ln\left(\frac{3n-1}{2}\right)$$

where c_n is the nth highest concentration and $\bar{c}$ is the average of the (*n*-1) highest concentrations. Following the suggestions from the EPA AERMOD evaluations, for the small sample data sets in the current analysis *n* was taken to be 11.

- Log-log scatter diagrams were prepared to test the ability of the model to explain the temporal variability in the observations. When the data from all studies are combined, the combined scatter diagrams can also be used to infer whether the model can explain the variability between the studies.

- Tables of statistical measures and "sigma" plots were prepared using the BOOT (Level 2/2/2007) statistical model evaluation package.[15] The BOOT program is an update of the package applied in the MMS CALPUFF evaluation.[11] The BOOT program was applied to provide information regarding bias of the mean, scatter or precision, and confidence limits using the bootstrap resampling method. The statistics were performed using the natural logarithm of the predictions and observations. Such geometric methods are more appropriate than linear statistics when the data exhibit a log-normal distribution and/or vary over several orders of magnitude. Bias of the geometric mean is measured from:

$$MG = e^{\left(\overline{\ln\left(\frac{c_o}{c_p}\right)}\right)}$$

where c_o and c_p are the observed and predicted concentrations, respectively. *MG* is a symmetric measure that is independent of the magnitude of the concentration where for a perfect model *MG* = 0 and a factor of two is bounded by $0.5 < MG < 2$. Note there are no zero observed or predicted concentrations in the evaluation data set. The scatter or precision is measured with the geometric variance:

[15] Chang, J.C., and S.R. Hanna, 2005. *Technical Descriptions and User's Guide for the BOOT Statistical Model Evaluation Software Package, Version 2.0.* July 10, 2005. Available from: http://www.harmo.org/Kit/Download.asp

$$V = \left(\overline{\left(\left(\frac{c}{c}\right)\right)^2}\right)$$

VG is similar to the normalized mean square error in linear statistics and measures scatter about a 1:1 observation-to-prediction ratio. A random scatter of a factor-of-two is equivalent to *VG* = 1.6, and *VG* = 12 would indicated a random scatter equivalent to a factor-of-five bias.

The BOOT program also provides other descriptive statistics, including the geometric correlation coefficient and the fraction within a factor-of-two. Importantly, bootstrap resampling methods are used by BOOT to test whether differences in *MG* or *VG* between the different cases are statistically significant.

The results of the performance evaluation using the methods outlined above are presented in the next section.

5 Results

COARE-AERMOD simulations were conducted to predict concentrations from the Pismo Beach, Cameron, and Carpinteria field studies using five different methods for the preparation of the meteorological data and for Case 5 the differences caused by an alternative lateral dispersion term. AERMOD was applied using default dispersion options for rural flat terrain for the Pismo Beach and Cameron simulations. Complex terrain was assumed from the Carpinteria data set. Peak predicted concentrations were compared to peak observed concentrations resulting in a total of 84 paired samples for statistical analysis with the techniques described in Section 4.3. In order to be independent of the tracer emission rate, the simulations were performed with a unit emission rate of 1 g/s and the observations were normalized by the tracer release rate providing concentrations in units of $\mu s/m^3$.

Figure 4 to Figure 8 show log-log scatter diagrams for the five cases. Each plot shows the 1:1 and factor-of-2 bounds for the prediction-to-observation ratio. The scatter diagrams for the five cases are similar with only subtle differences. Most of the differences occur at the upper end of the frequency distribution primarily populated by the Carpinteria complex terrain data set. In this region a couple of the cases over-predict the highest observations. There are also significant differences between the cases for the mid-range concentrations from the Pismo Beach data set, but these differences are difficult to pick out from the scatter diagrams.

Q-Q plots for the combined data set and each of the three individual data sets are shown in Figure 9 to Figure 12. Each plot shows the differences caused by the five different methods used to prepare the meteorological data, and for Case 5 the differences caused by an alternative lateral dispersion term. Figure 13 to Figure 17 show Q-Q plots for each of the five cases where the results from each field studies are compared to one another.

Comparing the Q-Q plots for the combined data set and each of the three field studies, the five COARE-AERMOD simulations generally predict the frequency distribution within a factor-of-two. The predictions tend to be biased towards over-prediction for the highest concentrations and under-prediction for the lower-end of the frequency distribution. This tendency is most apparent for the Pismo Beach data set (Figure 10), especially Case 3 where the higher concentrations are over-predicted using the AERMOD σ_Θ estimates. Importantly, COARE-AERMOD does not appear to be biased towards underestimates for the higher end of the frequency distribution, regardless of the options examined in this study.

Comparing the optional cases using the Q-Q plots, there is no clear choice for the best method to prepare the meteorological data. Case 3 using the AERMOD σ_Θ estimates seems to result in over-prediction for the combined data set and each individual data set. Depending on the data set, the method used to estimate the mechanical mixing height influenced the results. The observed mixing height seemed to perform the best for Pismo Beach, while the Venketram estimate worked the best overall. Removing the dependency of the lateral dispersion term on mixing height (Case 5) also seem to improve model performance in some instances, especially the Carpinteria data set where observed mixing heights appear to be the most uncertain.

The BOOT program statistics for each data set are summarized in Table 7 where the best performing modeling approach is highlighted for each statistic and data set. The full output of the BOOT program is attached. Table 7 also shows the *RHC* calculated for each data set and modeling case. For all the data sets and especially the Pismo Beach data set, the predicted concentrations are more variable than the observations. The Pismo Beach field study had the poorest paired-in-time model performance and the *RHC* is significantly over-predicted by each modeling alternative. Case 1, Case 3, and Case 5 had the least biased estimates for *RHC* for the combined, Cameron and Carpinteria data sets, respectively.

Sigma-plots prepared from the BOOT program output are shown in Figure 18 to Figure 20 for the combined data set and each individual data set. Sigma-plots display *MG* (bias) plotted against *VG* (scatter). The 95 percent confidence limits on MG are also shown based on the bootstrap resampling techniques applied by BOOT. For the combined data set, Case 2 (AERMOD σ_Θ estimates) significantly over-predicts observations and predicts significantly higher than the other cases. Examination of the attached BOOT output listing also suggests Case 5 (Draxler σ_y) has statistically less significant scatter than Case 1, Case 2, or Case 3. For Pismo Beach (Figure 19) this same trend is true, but all the cases have a significant amount of scatter and do not perform as well as for the Cameron or Carpinteria field studies. Comparing Case 3 to Case 4, restricting the Monin-Obukhov length such that Abs $(L) > 5$ seems to improve performance, but often not in a statistically significant manner.

The Cameron sigma-plot in Figure 20 again shows that Case 2 has the most scatter (highest *VG*) and the BOOT output suggests these differences are significant at the 95 percent confidence level. All the cases are biased towards over-prediction with Case 3 and Case 4 being the statistically least biased.

The complex terrain field study at Carpinteria is the exception to the trends from the other data sets as shown in Figure 21. Case 2 (AERMOD σ_Θ) predicts significantly higher than the cases with the observed σ_Θ data but in this instance these predictions more closely match observed concentrations. Case 1 is biased towards under-prediction for Carpinteria, but examination of the

Q-Q plot and scatter diagram in Figure 4 and Figure 12 shows this Case's performance is relatively good at the upper-end of the observed frequency distribution.

6 Summary

ENVIRON conducted this analysis to support alternative regulatory dispersion modeling practices applicable to Shell's proposed exploratory drilling sources in the Beaufort and Chukchi Seas following the EPA *Guideline of Air Quality Models, Section 3.2 Use of Alternative Models.* Currently, there is no regulatory dispersion modeling approach that can address all the issues associated with exploratory drilling sources and dispersive conditions in the Arctic Ocean. The proposed alternative approach bypasses the AERMET meteorological preprocessor using the COARE air-sea flux algorithm and overwater meteorological measurements. Per the *Guideline*, in order to fulfill EPA requirements for the application of an alternative modeling approach, ENVIRON conducted a model evaluation analysis using data from offshore tracer experiments. The conclusions from our analysis are as follows:

- The COARE-AERMOD alternative modeling approach was not biased towards underestimates at the high-end of the concentration frequency distribution
- The COARE-AERMOD approach performed better using the observed σ_Θ measurements. The internal AERMOD estimates of σ_Θ resulted in concentrations that were biased towards over-predictions and often caused statistically significant higher scatter as measured by the geometric variance (*VG*).
- COARE-AERMOD predictions were sensitive to the mixing height. An estimate of the mechanical mixing height based on the friction velocity, as in AERMET, was a better alternative than using the observed mixing height from the field studies. A portion of this sensitivity was due to the AERMOD equation for ambient lateral dispersion that depends on the mixing height. A replacement equation similar to OCD and CALPUFF reduced the scatter in some of the comparisons.
- The COARE-AERMOD approach was sensitive to assumptions during low wind speed conditions. Restricting the Monin-Obukhov length such that Abs $(L) > 5$ seems to improve performance by limiting the occurrence of extremely unstable or stable conditions.

Based on our analysis, ENVIRON believes the alternative COARE-AERMOD approach is a more suitable modeling technique than either AERMOD or OCD for regulatory simulations of exploratory drilling sources in offshore areas. The combination of surface fluxes predicted by the COARE algorithm and measured overwater meteorological data is preferred to the conventional application of AERMET. For the dispersion model, AERMOD is preferred over OCD because of the PRIME downwash algorithm, the ability to simulate volume sources, and the importance of the PVMRM algorithm for assessing the 1-hour NO2 ambient standard. COARE-AERMOD was not biased towards underestimates in the field studies examined in this study.

Tables

Table 1 Pismo Beach OCD Meteorological Data

Date/Time	Wind Obs. Ht. (m)	Temp RH Obs. Ht. (m)	Wind Dir.	Wind Speed (m/s)	Mix Ht. (m)	Rel. Humid. (%)	Air Temp. (K)	Air-Sea Temp (K)	Virt. Pot. Temp Grad. (K/m)	Sigma-Theta	Revised Air-Sea Temp (K)
12/8/81 15:00	20.5	7.0	261	2.2	100	67	287.7	1.3	0.030	9.43	1.30
12/8/81 16:00	20.5	7.0	284	1.6	100	75	287.5	1.2	0.030	12.90	1.20
12/11/81 14:00	20.5	7.0	275	4.5	600	74	285.6	-0.4	0.010	5.60	**0.00**
12/11/81 15:00	20.5	7.0	283	5.4	600	73	286.1	0.0	0.010	4.57	**0.00**
12/11/81 17:00	20.5	7.0	289	8.6	700	84	286.0	0.1	0.010	2.12	0.10
12/11/81 19:00	20.5	7.0	305	7.9	900	81	286.1	0.2	0.010	45.00	0.20
12/13/81 14:00	20.5	7.0	289	5.4	50	95	285.5	-0.8	0.000	0.92	-0.80
12/13/81 15:00	20.5	7.0	280	6.1	50	97	285.3	-0.8	0.000	2.41	-0.80
12/13/81 17:00	20.5	7.0	301	7.9	50	92	286.2	0.3	0.060	1.89	**0.35**
12/14/81 13:00	20.5	7.0	292	7.7	50	79	287.2	1.3	0.020	1.20	1.30
12/14/81 15:00	20.5	7.0	292	10.9	50	90	286.4	0.4	0.020	1.20	0.40
12/14/81 17:00	20.5	7.0	296	9.9	50	88	286.7	0.9	0.020	1.78	0.90
12/15/81 13:00	20.5	7.0	304	5.6	50	88	286.1	0.3	0.010	14.41	0.30
12/15/81 14:00	20.5	7.0	299	6.1	50	83	287.7	1.1	0.010	45.00	1.10
12/15/81 19:00	20.5	7.0	321	1.6	50	70	289.4	3.4	0.030	45.00	3.40
6/21/82 15:00	20.5	7.0	276	4.3	800	84	287.5	1.5	0.008	1.37	1.50
6/21/82 16:00	20.5	7.0	269	3.8	800	86	287.3	1.4	0.008	2.12	1.40
6/21/82 17:00	20.5	7.0	261	2.7	800	87	287.3	1.5	0.008	6.84	1.50
6/21/82 18:00	20.5	7.0	276	3.0	800	89	286.9	1.2	0.008	19.70	1.20
6/22/82 15:00	20.5	7.0	274	3.7	700	80	288.6	1.7	0.005	6.05	1.70
6/22/82 16:00	20.5	7.0	268	5.2	700	78	288.8	2.1	0.005	3.32	2.10
6/22/82 19:00	20.5	7.0	289	3.2	700	84	287.2	1.3	0.005	10.59	1.30
6/24/82 13:00	20.5	7.0	269	3.9	600	82	288.1	0.9	0.010	27.79	0.90
6/24/82 15:00	20.5	7.0	269	5.3	600	84	288.1	0.6	0.010	7.46	0.60
6/25/82 12:00	20.5	7.0	286	5.6	100	76	288.9	2.2	0.010	1.37	2.20
6/25/82 13:00	20.5	7.0	280	6.5	100	80	288.5	2.6	0.010	1.60	2.60

Table 1 Pismo Beach OCD Meteorological Data (Continued)

Date/Time	Wind Obs. Ht. (m)	Temp RH Obs. Ht. (m)	Wind Dir.	Wind Speed (m/s)	Mix Ht. (m)	Rel. Humid. (%)	Air Temp. (K)	Air-Sea Temp (K)	Virt. Pot. Temp Grad. (K/m)	Sigma-Theta	Revised Air-Sea Temp (K)
6/25/82 15:00	20.5	7.0	286	9.8	100	82	288.3	2.6	0.010	5.48	2.60
6/25/82 16:00	20.5	7.0	288	9.1	100	82	288.3	2.9	0.010	0.92	2.90
6/25/82 17:00	20.5	7.0	290	9.5	100	81	288.4	3.2	0.010	1.20	3.20
6/27/82 16:00	20.5	7.0	287	12.7	100	93	287.0	3.4	0.010	1.09	3.40
6/27/82 18:00	20.5	7.0	285	10.2	100	94	287.7	3.7	0.010	7.74	3.70

Table 2 Pismo Beach Source and Receptor Data

Date/Time	Rel. Ht.(m)	Bldg. Ht. (m)	Bldg. Wid. (m)	Recep. Dist.(m) [1]
12/8/81 15:00	13.1	7.0	20.0	6730
12/8/81 16:00	13.1	7.0	20.0	6506
12/11/81 14:00	13.1	7.0	20.0	6422
12/11/81 15:00	13.1	7.0	20.0	6509
12/11/81 17:00	13.1	7.0	20.0	6619
12/11/81 19:00	13.1	7.0	20.0	7316
12/13/81 14:00	13.1	7.0	20.0	6516
12/13/81 15:00	13.1	7.0	20.0	6372
12/13/81 17:00	13.1	7.0	20.0	6870
12/14/81 13:00	13.1	7.0	20.0	6378
12/14/81 15:00	13.1	7.0	20.0	6378
12/14/81 17:00	13.1	7.0	20.0	6526
12/15/81 13:00	13.1	7.0	20.0	6944
12/15/81 14:00	13.1	7.0	20.0	6697
12/15/81 19:00	13.1	7.0	20.0	8312
6/21/82 15:00	13.6	7.0	20.0	6532
6/21/82 16:00	13.6	7.0	20.0	6589
6/21/82 17:00	13.6	7.0	20.0	6748
6/21/82 18:00	13.6	7.0	20.0	6532
6/22/82 15:00	13.6	7.0	20.0	6125
6/22/82 16:00	13.6	7.0	20.0	6214
6/22/82 19:00	13.6	7.0	20.0	6054
6/24/82 13:00	13.6	7.0	20.0	6244
6/24/82 15:00	13.6	7.0	20.0	6244
6/25/82 12:00	13.6	7.0	20.0	6406
6/25/82 13:00	13.6	7.0	20.0	6377
6/25/82 15:00	13.6	7.0	20.0	6406
6/25/82 16:00	13.6	7.0	20.0	6435
6/25/82 17:00	13.6	7.0	20.0	6455
6/27/82 16:00	13.6	7.0	20.0	6630
6/27/82 18:00	13.6	7.0	20.0	6579

1. All releases were simulated with a 270 degree wind direction from a source at (0, 0) and a receptor at (X,0) where X is the downwind distance with the peak observed concentration. All receptors are in flat terrain with a 1.5m flag pole height.

Table 3 Cameron OCD Meteorological Data

Date/Time	Wind Obs. Ht. (m)	Temp RH Obs. Ht. (m)	Wind Dir.	Wind Speed (m/s)	Mix Ht. (m)	Rel. Humid. (%)	Air Temp. (K)	Air-Sea Temp (K)	Virt. Pot. Temp Grad. (K/m)	Sigma-Theta	Revised Air-Sea Temp (K)
7/20/81 14:00	10	10	202	4.6	800	63	302.4	-2.7	0.00	6.39	-2.7
7/20/81 15:00	10	10	210	4.8	800	64	302.6	-2.6	0.00	4.92	-2.6
7/23/81 17:00	10	18	232	4.3	225	73	303.6	-1.4	0.00	4.74	-1.4
7/23/81 18:00	10	18	229	5.1	225	74	303.7	-1.2	0.00	4.74	-1.2
7/27/81 20:00	10	18	176	2.1	400	82	300.2	-4.4	0.00	999.00	-4.4
7/27/81 22:00	10	18	151	4.5	450	82	300.0	-4.5	0.00	999.00	-4.5
7/29/81 16:00	10	18	218	4.6	420	69	303.0	-2.2	0.00	9.59	-2.2
7/29/81 17:00	10	18	240	5.0	430	68	303.0	-2.0	0.00	6.45	-2.0
7/29/81 19:00	10	18	241	5.0	450	68	303.1	-1.7	0.00	9.59	-1.7
2/15/82 16:00	10	10	142	5.7	200	89	287.4	0.0	0.06	999.00	**0.5**
2/15/82 17:00	10	10	134	5.6	200	88	287.1	-0.8	0.06	999.00	**0.5**
2/15/82 20:00	10	10	147	5.9	200	87	287.4	-0.4	0.06	999.00	**0.5**
2/17/82 14:00	10	10	178	3.3	200	93	288.8	2.1	0.03	2.46	2.1
2/17/82 15:00	18	18	195	3.7	200	93	288.1	0.9	0.03	7.63	0.9
2/17/82 16:00	18	18	210	4.3	200	93	288.0	0.6	0.03	3.89	**0.4**
2/17/82 17:00	18	18	206	3.5	200	93	287.7	-0.2	0.03	3.78	**0.4**
2/17/82 18:00	18	18	193	3.5	200	93	287.4	-0.7	0.03	2.06	**0.4**
2/22/82 14:00	18	18	171	5.2	100	75	290.6	1.3	0.03	2.69	1.3
2/22/82 16:00	18	18	172	4.7	100	76	290.6	0.9	0.03	2.41	0.9
2/22/82 17:00	18	18	182	4.5	100	76	290.9	0.8	0.03	2.81	0.8
2/23/82 14:00	18	18	152	4.8	50	84	291.5	3.7	0.03	0.63	3.7
2/23/82 17:00	18	18	165	6.2	80	88	291.2	2.3	0.03	3.21	2.3
2/24/82 15:00	18	18	143	3.7	50	49	293.1	5.0	0.05	2.75	5.0
2/24/82 16:00	18	18	143	3.7	50	50	292.9	4.6	0.05	3.21	4.6
2/24/82 17:00	18	18	140	3.5	50	50	292.9	4.7	0.05	3.26	4.7
2/24/82 19:00	18	18	156	4.1	50	52	290.7	2.7	0.05	2.63	2.7

Table 4 Cameron Source and Receptor Data

Date/Time	Rel. Ht.(m)	Bldg. Ht. (m)	Bldg. Wid. (m)	Recep. Dist.(m) [1]
7/20/81 14:00	13.0	0.0	0.0	7180
7/20/81 15:00	13.0	0.0	0.0	7400
7/23/81 17:00	13.0	0.0	0.0	8930
7/23/81 18:00	13.0	0.0	0.0	8710
7/27/81 20:00	13.0	0.0	0.0	7020
7/27/81 22:00	13.0	0.0	0.0	7859
7/29/81 16:00	13.0	0.0	0.0	7820
7/29/81 17:00	13.0	0.0	0.0	9780
7/29/81 19:00	13.0	0.0	0.0	9950
2/15/82 16:00	13.0	7.0	20.0	4834
2/15/82 17:00	13.0	7.0	20.0	5762
2/15/82 20:00	13.0	7.0	20.0	4526
2/17/82 14:00	13.0	0.0	0.0	7000
2/17/82 15:00	13.0	0.0	0.0	6985
2/17/82 16:00	13.0	0.0	0.0	7400
2/17/82 17:00	13.0	0.0	0.0	7260
2/17/82 18:00	13.0	0.0	0.0	6950
2/22/82 14:00	13.0	0.0	0.0	7095
2/22/82 16:00	13.0	0.0	0.0	7070
2/22/82 17:00	13.0	0.0	0.0	6955
2/23/82 14:00	13.0	0.0	0.0	7769
2/23/82 17:00	13.0	0.0	0.0	7245
2/24/82 15:00	13.0	7.0	20.0	5669
2/24/82 16:00	13.0	7.0	20.0	5669
2/24/82 17:00	13.0	7.0	20.0	6023
2/24/82 19:00	13.0	7.0	20.0	4786

1. All releases were simulated with a 270 degree wind direction from a source at (0, 0) and a receptor at (X,0) where X is the downwind distance with the peak observed concentration. All receptors are in flat terrain with a 1.5m flag pole height.

Table 5 Carpinteria OCD Meteorological Data

Date/Time	Wind Obs. Ht. (m)	Temp RH Obs. Ht. (m)	Wind Dir.	Wind Speed (m/s)	Mix Ht. (m)	Rel. Humid. (%)	Air Temp. (K)	Air-Sea Temp (K)	Virt. Pot. Temp Grad. (K/m)	Sigma-Theta	Revised Air-Sea Temp (K)
9/19/85 9:00	30	9	259.7	1.3	500	78.8	289.45	-1.1	0.00	26.84	-1.10
9/19/85 10:00	30	9	235.4	1.3	500	79.0	289.95	-0.8	0.00	28.41	-0.80
9/19/85 11:00	30	9	214.1	2.6	500	80.1	290.15	-0.7	0.00	24.42	-0.70
9/19/85 12:00	30	9	252.9	3.1	500	80.1	290.25	-0.7	0.00	32.86	-0.70
9/22/85 9:00	30	9	220.8	1.0	500	70.6	290.55	0.5	0.02	32.13	0.50
9/22/85 10:00	30	9	251.1	1.2	500	81.0	290.15	0.3	0.02	17.43	0.30
9/22/85 11:00	30	9	253.8	2.4	500	92.1	289.55	1.0	0.02	7.97	1.00
9/22/85 11:00	30	9	230.0	2.4	500	92.1	289.55	1.0	0.02	7.97	1.00
9/22/85 12:00	30	9	248.4	2.8	500	91.1	289.45	1.1	0.02	17.43	1.10
9/22/85 12:00	30	9	237.7	2.8	500	91.1	289.45	1.1	0.02	17.43	1.10
9/25/85 10:00	24	9	163.8	1.0	500	60.3	294.35	2.8	0.01	41.67	2.80
9/25/85 11:00	46	9	163.8	1.6	500	69.9	294.15	2.3	0.01	9.87	2.30
9/25/85 12:00	46	9	165.6	1.0	500	90.3	294.05	2.1	0.01	26.06	2.10
9/25/85 13:00	46	9	175.0	1.0	500	90.4	294.55	2.7	0.01	18.37	2.70
9/26/85 12:00	49	9	262.0	3.8	500	83.5	291.85	-0.7	0.00	10.87	-0.70
9/26/85 13:00	49	9	262.2	4.0	500	81.0	291.95	-1.0	0.00	11.80	-1.00
9/28/85 10:00	24	9	155.8	5.4	500	85.1	291.25	-0.6	0.00	8.92	-0.60
9/28/85 10:00	24	9	155.8	5.4	500	85.1	291.25	-0.6	0.00	8.92	-0.60
9/28/85 11:00	24	9	174.7	3.2	500	84.1	291.15	-0.8	0.00	10.87	-0.80
9/28/85 11:00	24	9	177.0	3.2	500	84.1	291.15	-0.8	0.00	10.87	-0.80
9/28/85 13:00	24	9	234.5	1.5	500	82.5	291.45	-0.6	0.00	10.87	-0.60
9/28/85 13:00	24	9	229.5	1.5	500	82.5	291.45	-0.6	0.00	10.87	-0.60
9/28/85 14:00	24	9	215.0	2.1	500	81.7	291.65	-0.3	0.00	11.80	-0.30
9/28/85 14:00	24	9	215.0	2.1	500	81.7	291.65	-0.3	0.00	11.80	-0.30
9/29/85 11:00	30	9	243.7	3.4	500	86.0	291.35	-0.3	0.00	18.37	-0.30
9/29/85 12:00	30	9	238.9	3.1	500	87.8	291.25	-0.4	0.00	4.97	-0.40
9/29/85 12:00	30	9	232.7	3.1	500	87.8	291.25	-0.4	0.00	4.97	-0.40

Table 6 Carpinteria Source Parameters

Date/Time	Release Type [1]	Rel. Ht. (m)	UTM East (m)	UTM North (m)
9/19/85 9:00	SF6	30.5	270,343	3,806,910
9/19/85 10:00	SF6	30.5	270,343	3,806,910
9/19/85 11:00	SF6	30.5	270,343	3,806,910
9/19/85 12:00	SF6	30.5	270,343	3,806,910
9/22/85 9:00	SF6	18.3	270,133	3,806,520
9/22/85 10:00	SF6	18.3	270,133	3,806,520
9/22/85 11:00	SF6	18.3	270,133	3,806,520
9/22/85 11:00	Freon	36.6	270,133	3,806,520
9/22/85 12:00	SF6	18.3	270,133	3,806,520
9/22/85 12:00	Freon	36.6	270,133	3,806,520
9/25/85 10:00	SF6	24.4	271,024	3,806,660
9/25/85 11:00	SF6	24.4	271,024	3,806,660
9/25/85 12:00	SF6	24.4	271,024	3,806,660
9/25/85 13:00	SF6	24.4	271,024	3,806,660
9/26/85 12:00	Freon	24.4	269,524	3,807,330
9/26/85 13:00	Freon	24.4	269,524	3,807,330
9/28/85 10:00	SF6	24.4	271,289	3,806,340
9/28/85 10:00	Freon	42.7	271,289	3,806,340
9/28/85 11:00	SF6	24.4	271,289	3,806,340
9/28/85 11:00	Freon	42.7	271,289	3,806,340
9/28/85 13:00	SF6	24.4	270,133	3,806,520
9/28/85 13:00	Freon	39.6	270,133	3,806,520
9/28/85 14:00	SF6	24.4	270,133	3,806,520
9/28/85 14:00	Freon	39.6	270,133	3,806,520
9/29/85 11:00	SF6	30.5	270,133	3,806,520
9/29/85 12:00	SF6	30.5	270,133	3,806,520
9/29/85 12:00	Freon	61.0	270,133	3,806,520

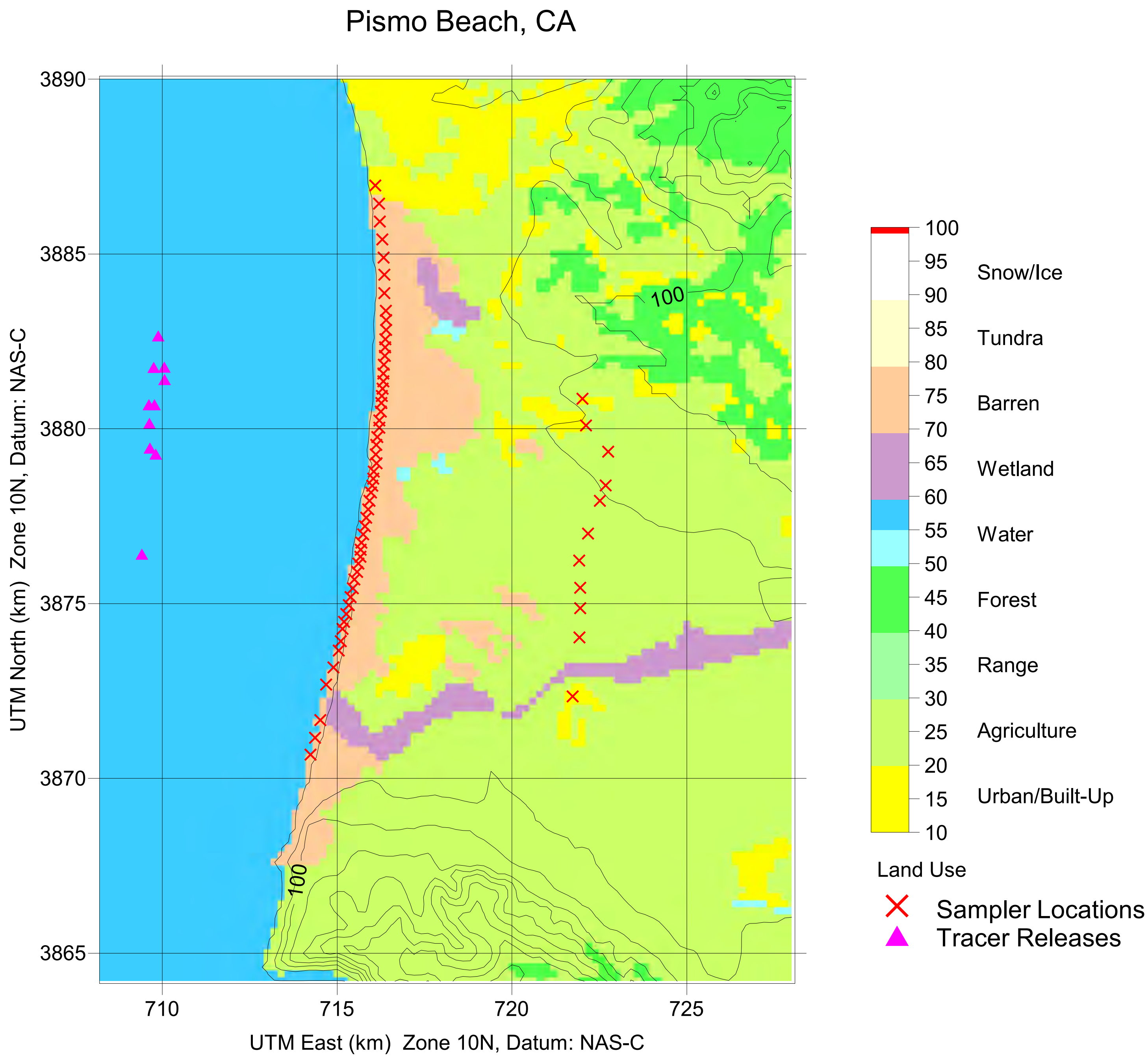
1. For some hours releases were from two different heights using different tracer gases. Actual source and receptor locations were used in the simulations where receptor heights and scale heights were calculated with AERMAP. There was no building downwash assumed for these simulations.

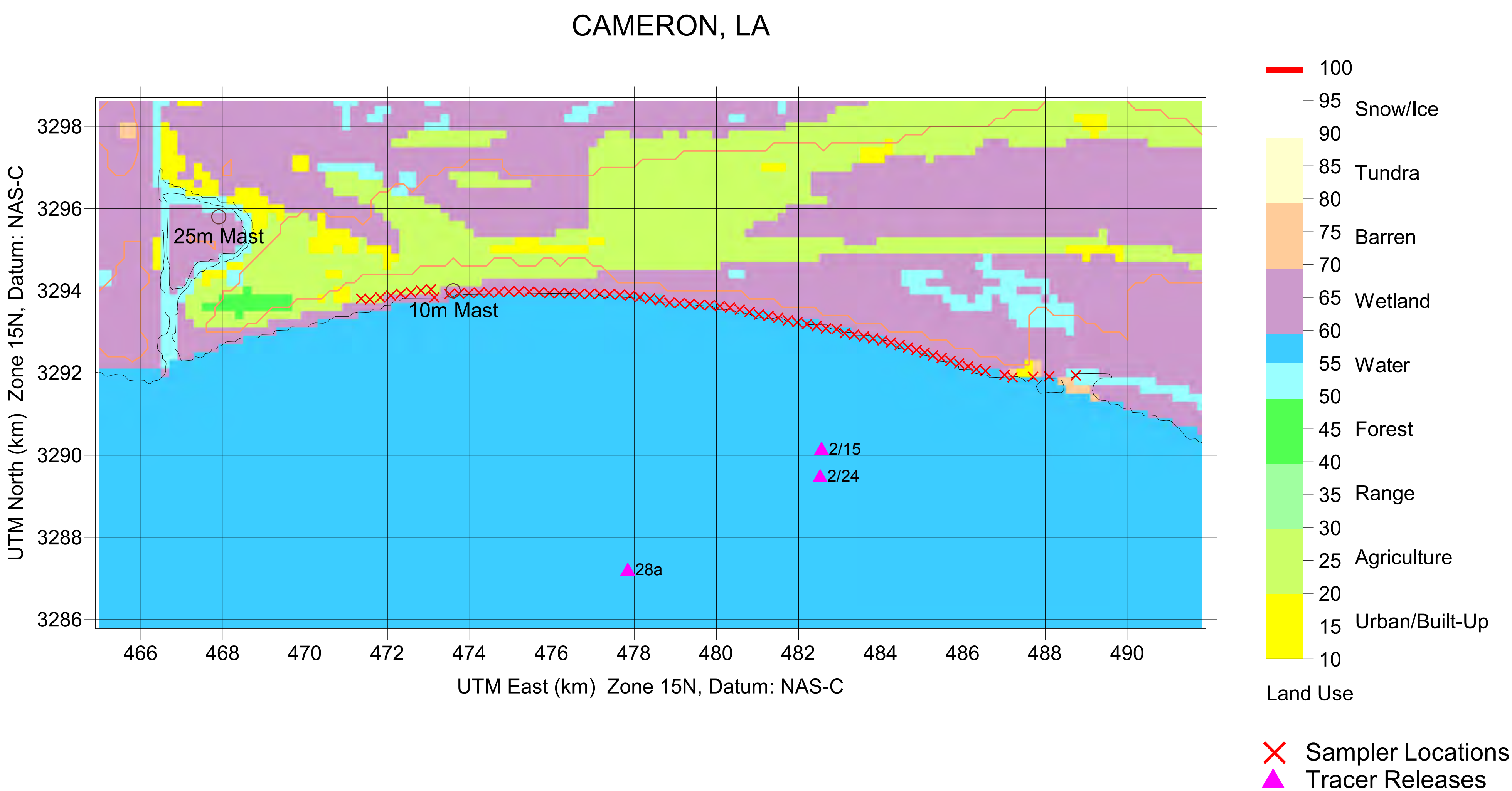
Table 7 Performance Evaluation Statistical Results by Data Set and COARE-AERMOD Case

Data Set	Case	Description	Geom. Mean (µs/m3)	Geom. Std.	MG	VG	Geom. Correl. Coef.	Frac. Factor of 2	RHC (µs/m3)
All Data (84 samples)	0	Observations	5.9	1.30	1.00	1.00	1.00	1.00	128
	1	Abs(L)>5, Obs σΘ, Venk Zi	5.8	1.61	1.02	3.59	0.72	**0.49**	**130**
	2	Abs(L)>5, Pred σΘ, Venk Zi	8.2	1.72	0.72	4.89	0.71	0.45	286
	3	Abs(L)>1, Obs σΘ, Obs Zi	5.5	1.71	1.08	4.45	0.70	0.45	446
	4	Abs(L)>5, Obs σΘ, Obs Zi	5.8	1.59	1.03	3.36	0.73	0.45	310
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	**5.9**	**1.52**	**1.01**	**2.93**	**0.74**	0.48	111
Pismo Beach, CA (31 samples)	0	Observations	3.5	0.50	1.00	1.00	1.00	1.00	9
	1	Abs(L)>5, Obs σΘ, Venk Zi	3.7	1.40	0.93	6.20	0.28	**0.48**	43
	2	Abs(L)>5, Pred σΘ, Venk Zi	5.8	1.46	0.59	13.10	0.05	0.29	55
	3	Abs(L)>1, Obs σΘ, Obs Zi	3.2	1.41	1.09	7.70	0.15	0.45	**19**
	4	Abs(L)>5, Obs σΘ, Obs Zi	3.8	**1.23**	0.91	**4.27**	0.27	**0.48**	20
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	**3.4**	1.33	**1.04**	4.75	**0.35**	0.42	30
Cameron, LA (26 samples)	0	Observations	3.2	1.41	1.00	1.00	1.00	1.00	41
	1	Abs(L)>5, Obs σΘ, Venk Zi	4.0	1.84	0.79	2.99	0.84	0.42	49
	2	Abs(L)>5, Pred σΘ, Venk Zi	4.1	1.87	0.77	3.55	0.81	0.42	53
	3	Abs(L)>1, Obs σΘ, Obs Zi	**3.7**	1.77	**0.86**	2.64	0.84	**0.46**	**40**
	4	Abs(L)>5, Obs σΘ, Obs Zi	3.7	1.79	0.85	2.65	**0.84**	**0.46**	44
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	4.1	**1.70**	0.76	**2.58**	0.84	**0.46**	36
Carpinteria, CA (27 samples)	0	Observations	20.1	0.93	1.00	1.00	1.00	1.00	137
	1	Abs(L)>5, Obs σΘ, Venk Zi	13.9	1.18	1.45	2.29	0.71	0.56	172
	2	Abs(L)>5, Pred σΘ, Venk Zi	**24.3**	1.30	**0.83**	2.15	**0.76**	**0.67**	330
	3	Abs(L)>1, Obs σΘ, Obs Zi	15.0	1.50	1.34	3.93	0.66	0.44	470
	4	Abs(L)>5, Obs σΘ, Obs Zi	14.2	1.37	1.42	3.21	0.67	0.41	329
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	15.5	**0.97**	1.30	**1.90**	0.69	0.56	**129**

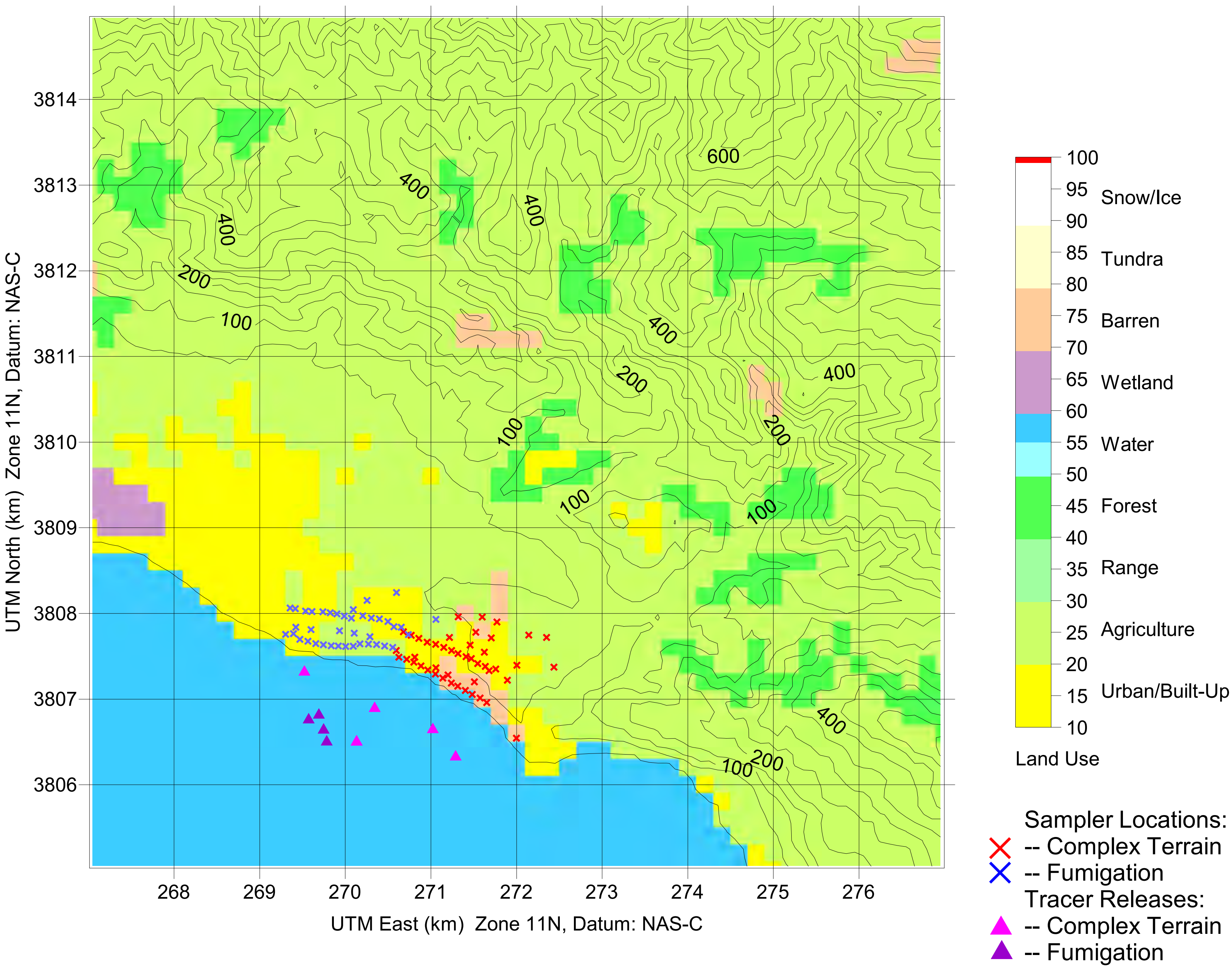
VG is a measure of geometric variance or scatter, VG = exp(average(ln(Co/Cp)))
MG is a measure of bias about the geometric mean, MG = exp(average((ln(Co/Cp))^2))
RHC = "Robust Highest Concentration" based on top 11 samples
Best performing modeling approach or Case is highlighted in **red**

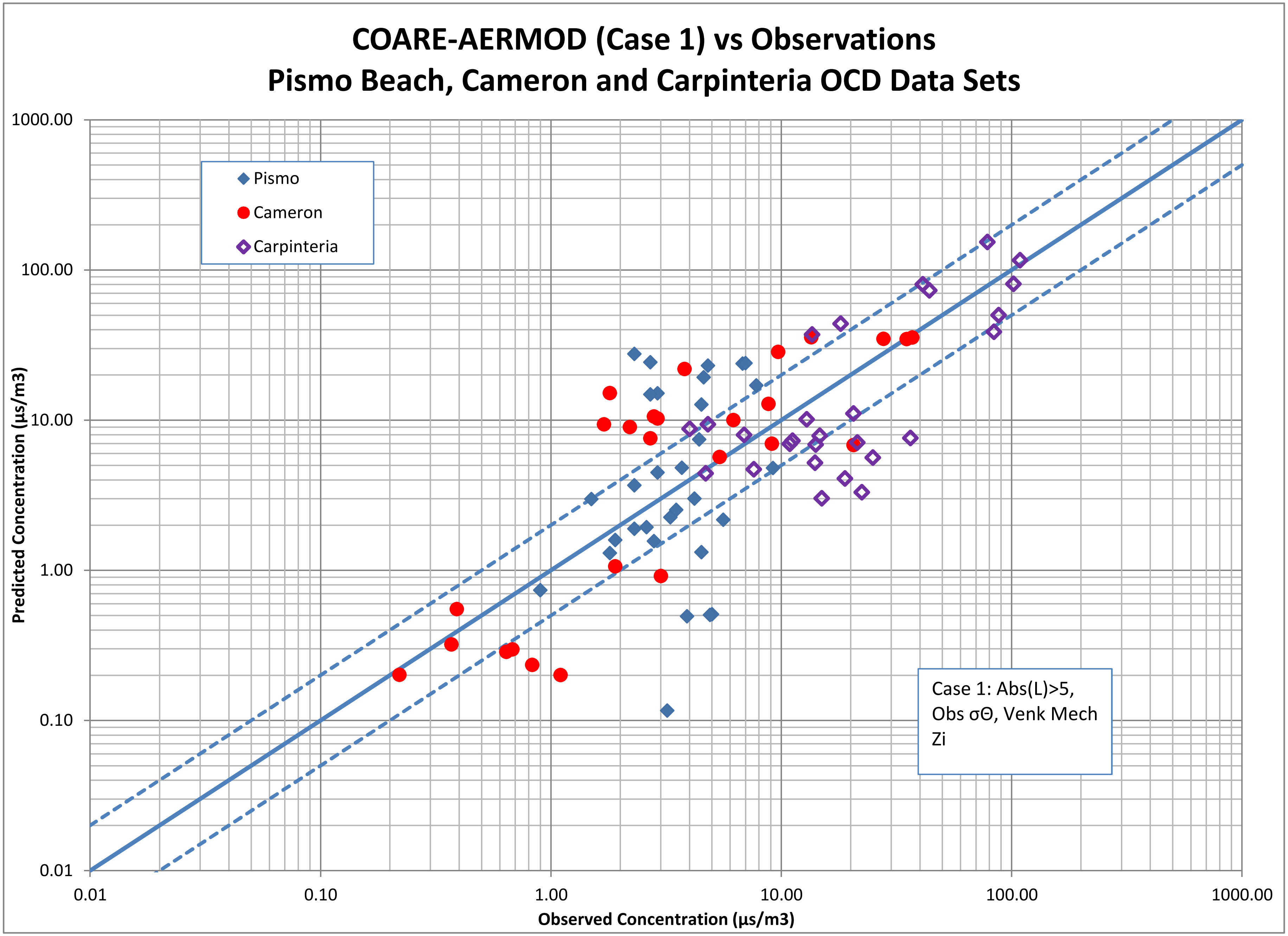
Figures

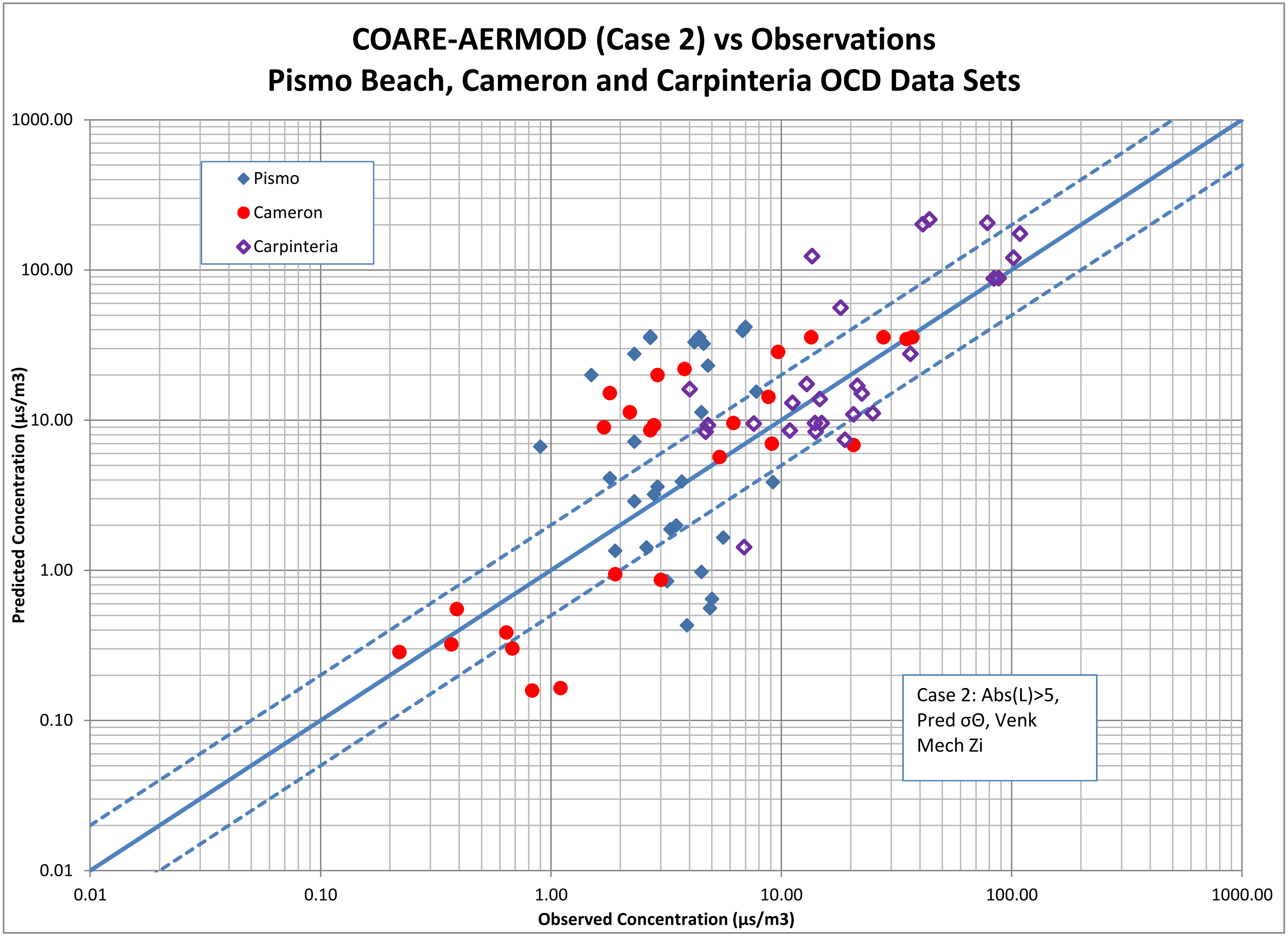

Pismo Beach, CA
3890
3885
3880
3875
3870
3865
710
715
720
725
UTM North (km) Zone 10N, Datum: NAS-C
UTM East (km) Zone 10N, Datum: NAS-C
100
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
Snow/Ice
Tundra
Barren
Wetland
Water
Forest
Range
Agriculture
Urban/Built-Up
Land Use
Sampler Locations
Tracer Releases

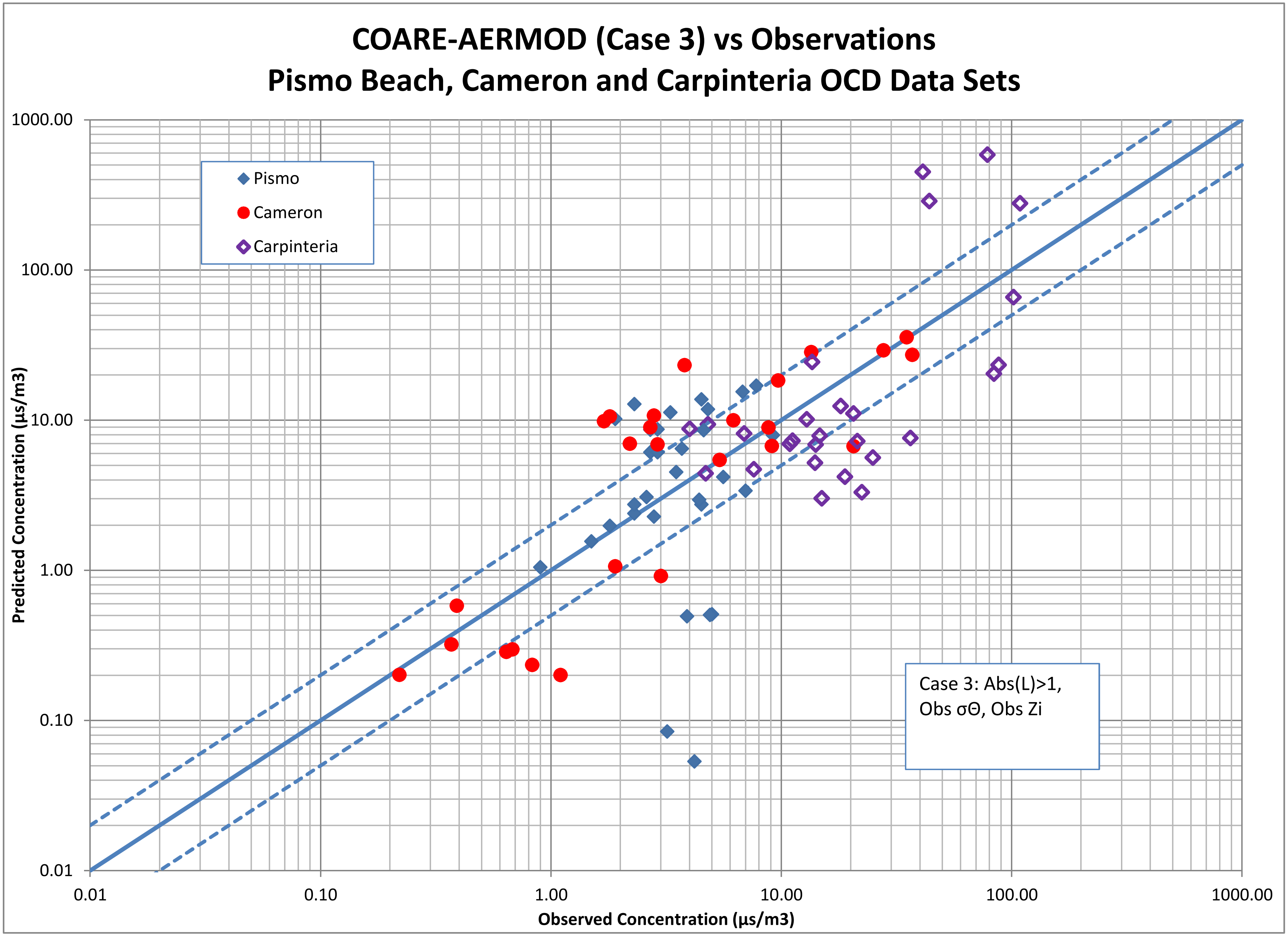

CAMERON, LA
25m Mast
10m Mast
2/15
2/24
28a
UTM North (km) Zone 15N, Datum: NAS-C
UTM East (km) Zone 15N, Datum: NAS-C
3298
3296
3294
3292
3290
3288
3286
466
468
470
472
474
476
478
480
482
484
486
488
490
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
Snow/Ice
Tundra
Barren
Wetland
Water
Forest
Range
Agriculture
Urban/Built-Up
Land Use
Sampler Locations
Tracer Releases

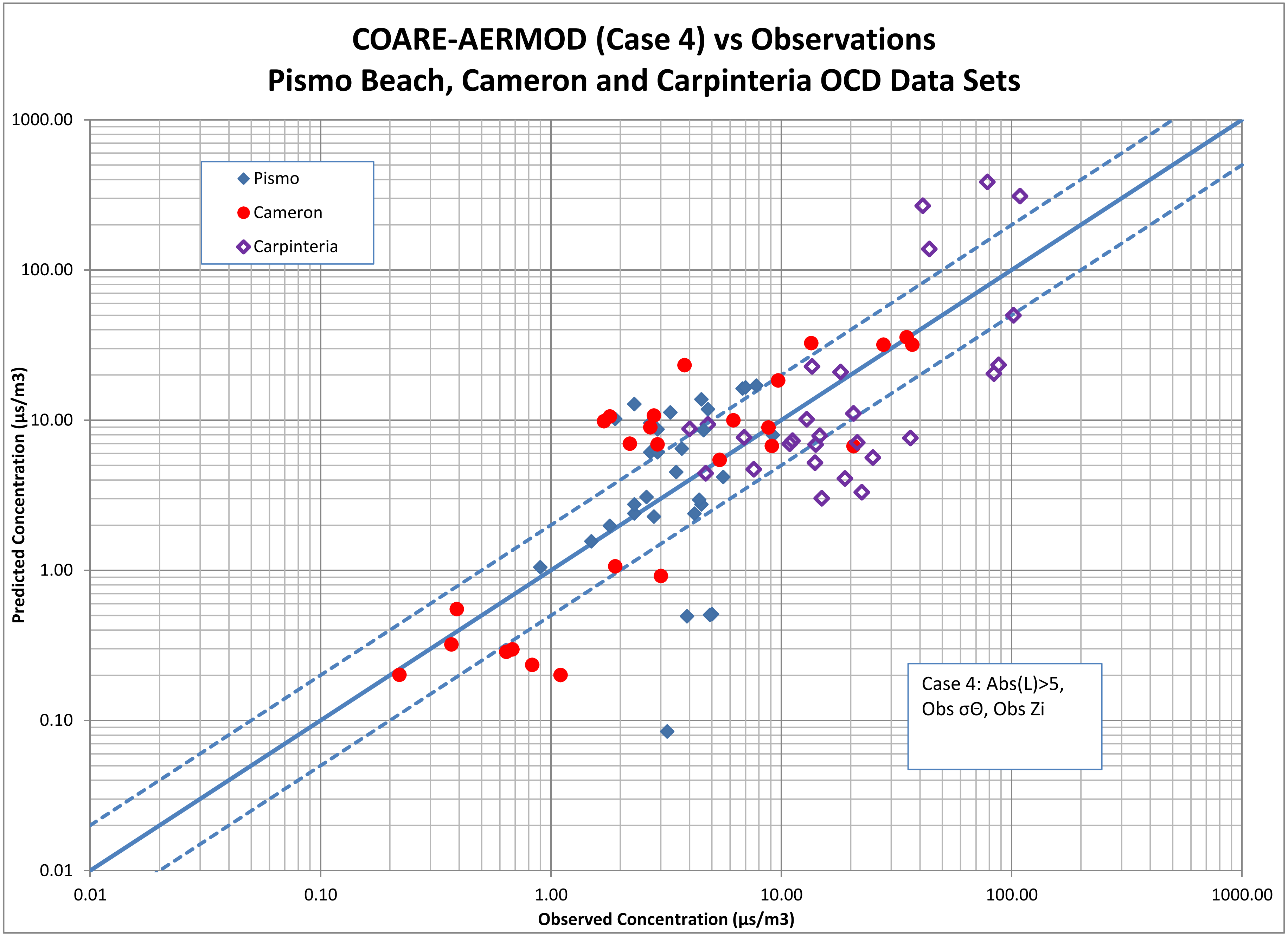
CARPINTERIA, CA

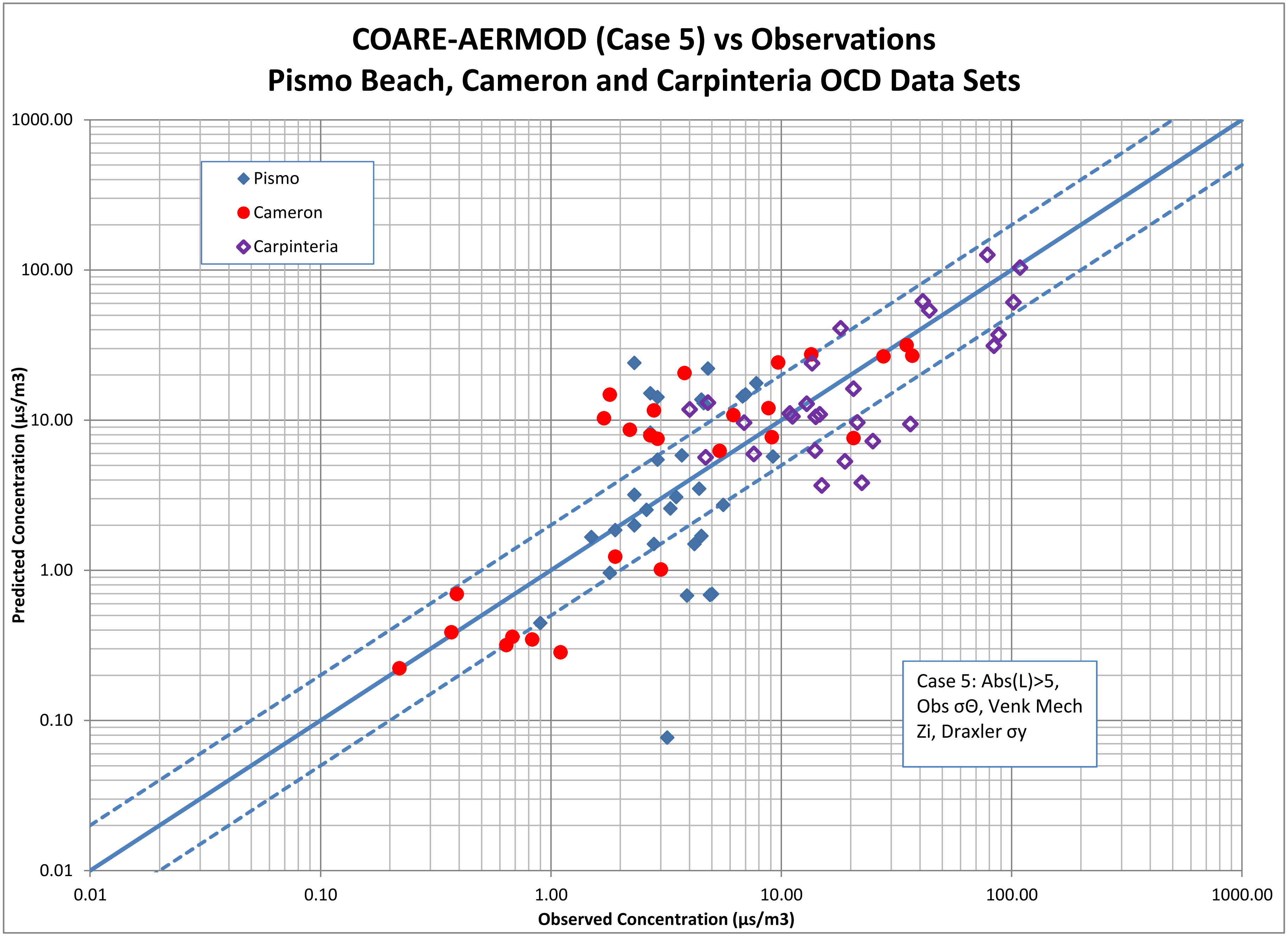


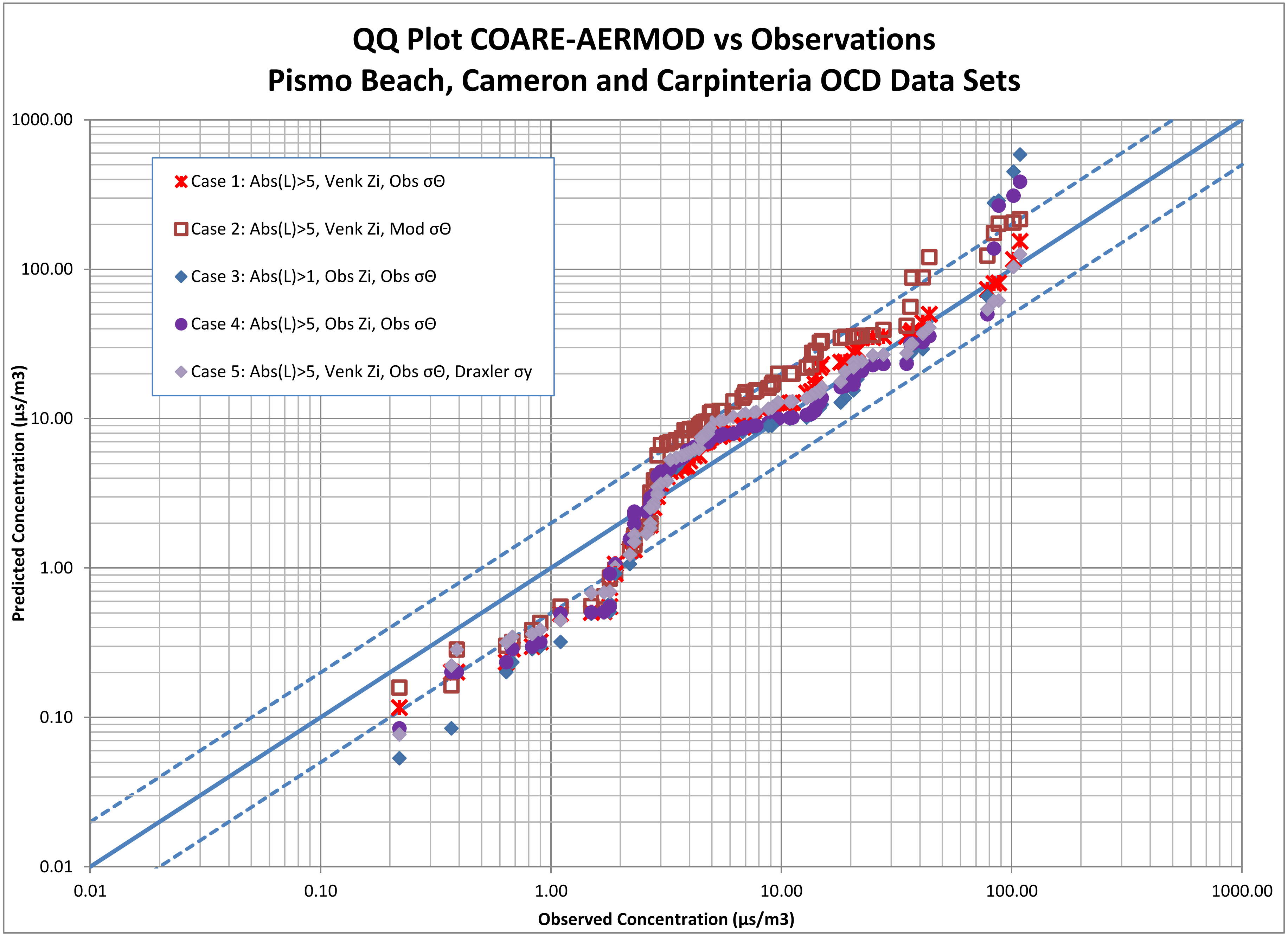

COARE-AERMOD (Case 1) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Case 1: Abs(L)>5, Obs σΘ, Venk Mech Zi
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00

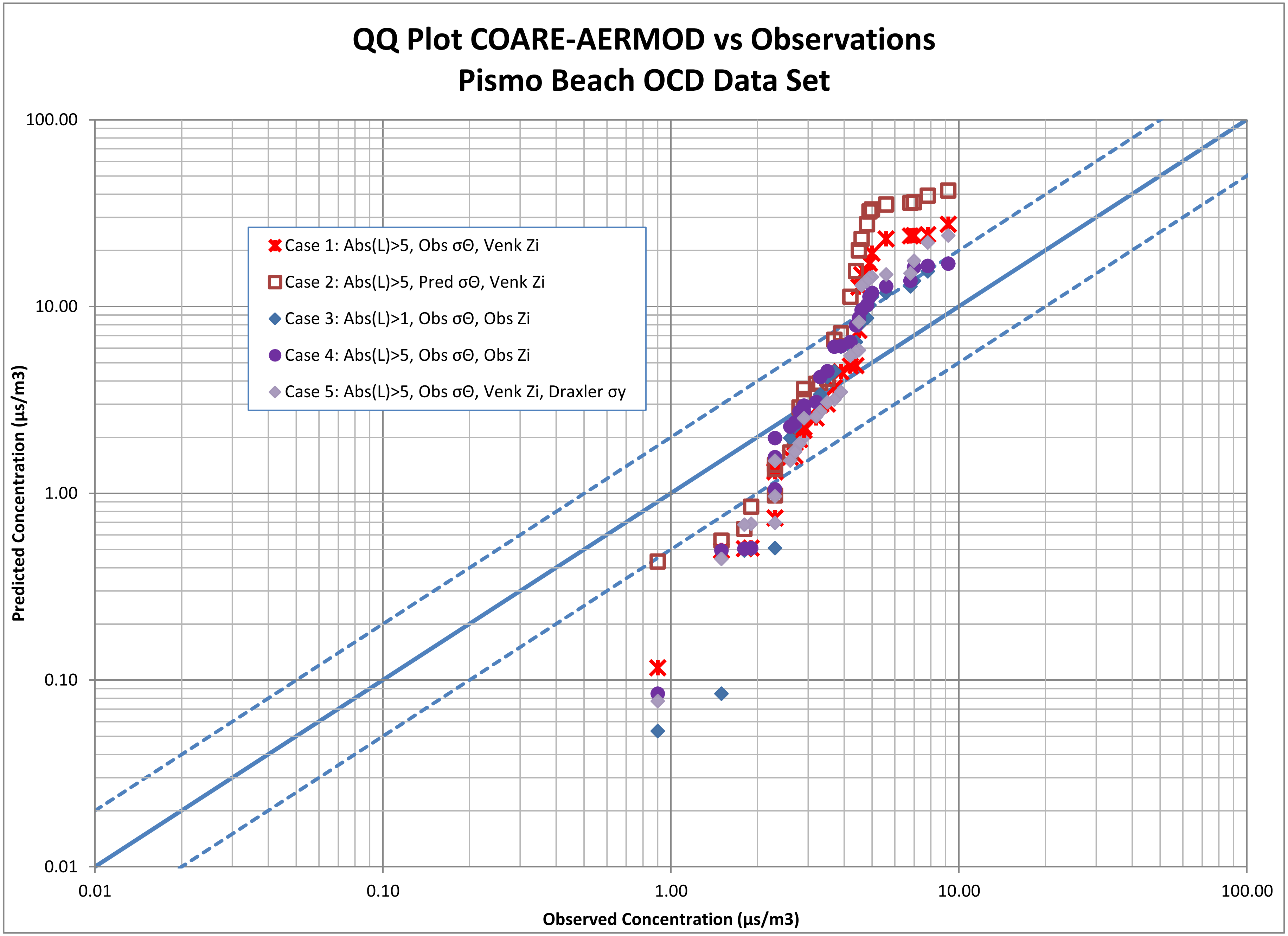

COARE-AERMOD (Case 2) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Case 2: Abs(L)>5, Pred σΘ, Venk Mech Zi
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00

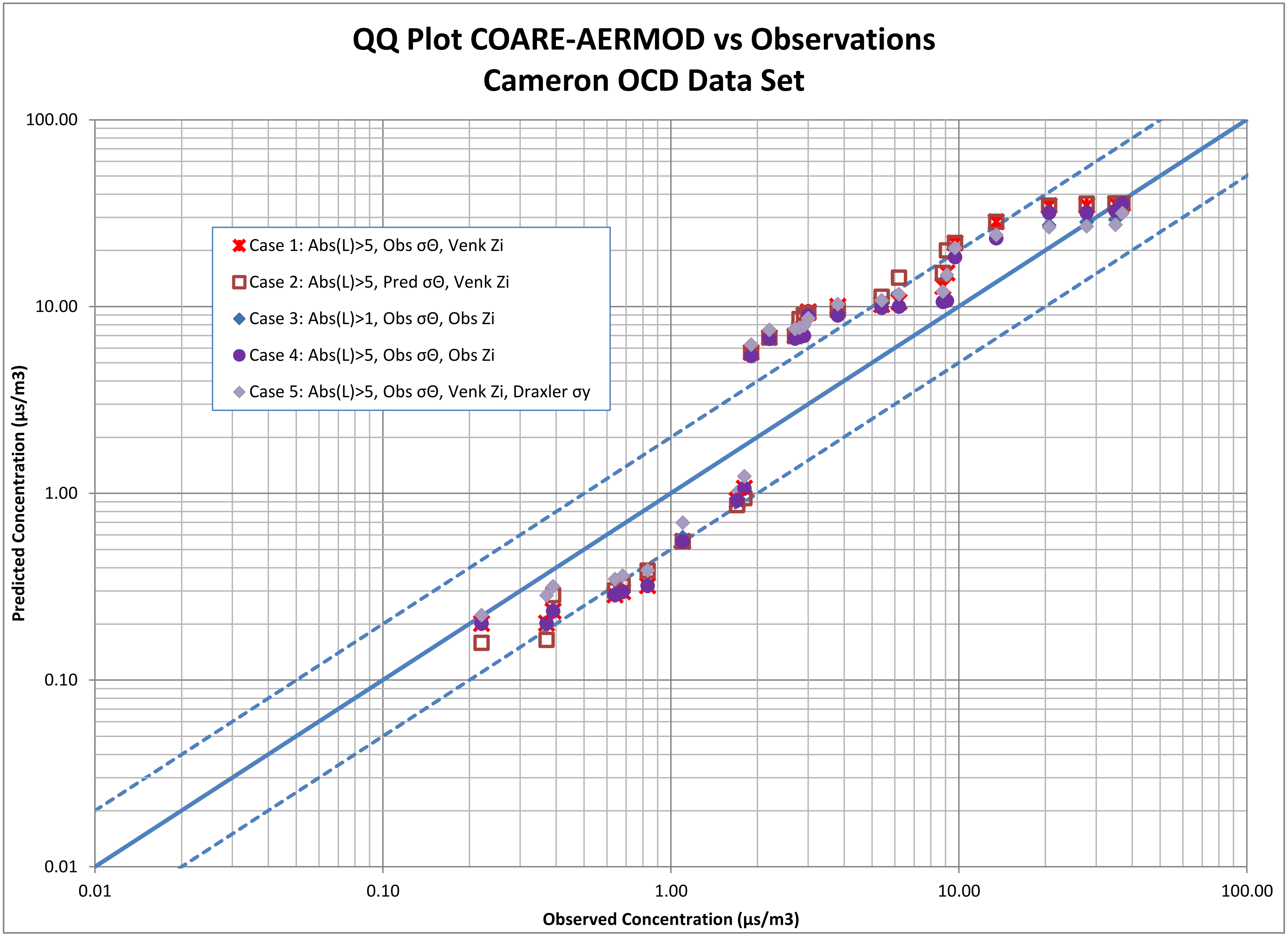

COARE-AERMOD (Case 3) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Case 3: Abs(L)>1,
Obs σΘ, Obs Zi
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00

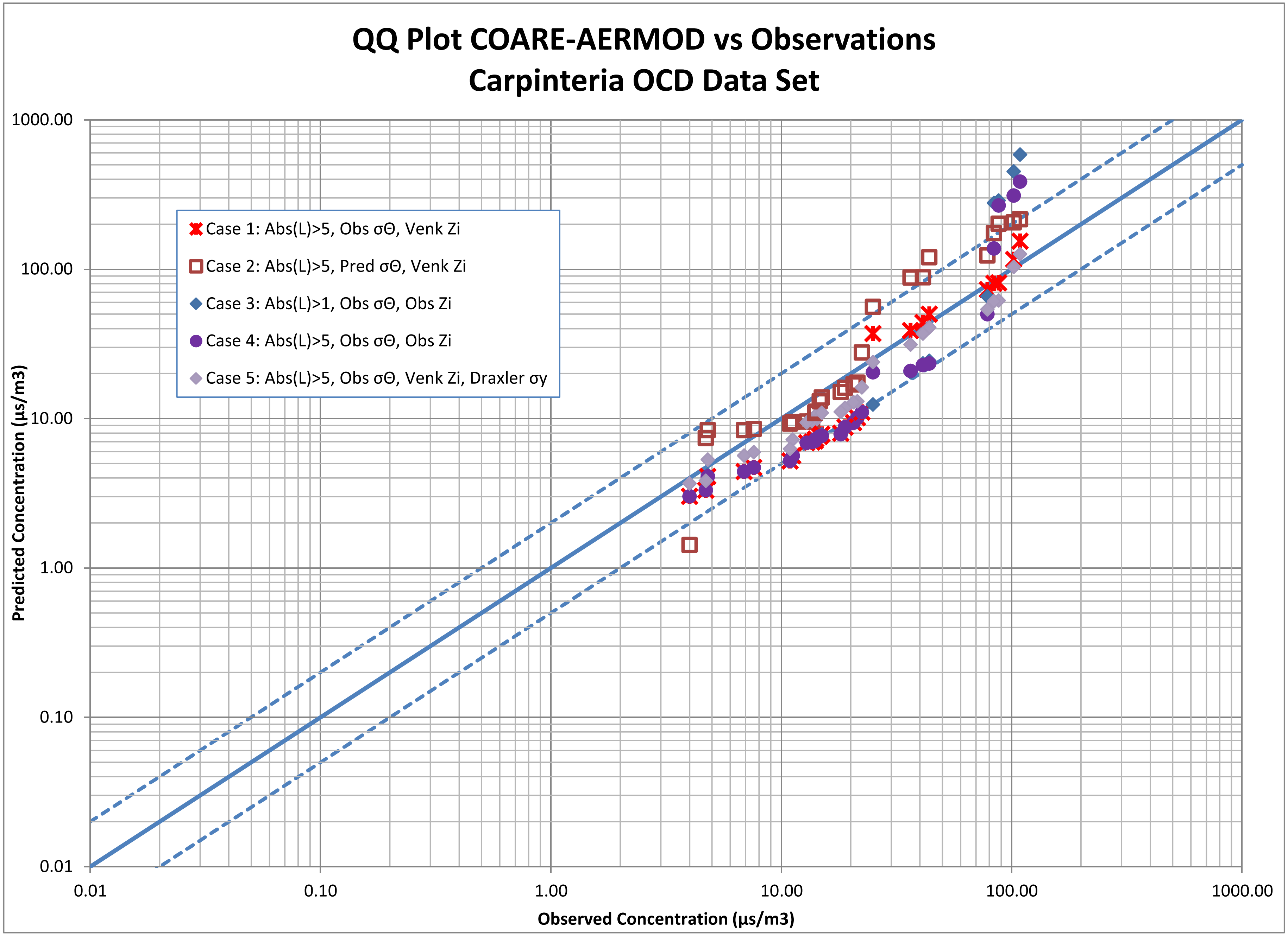

COARE-AERMOD (Case 4) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Case 4: Abs(L)>5,
Obs σΘ, Obs Zi
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00

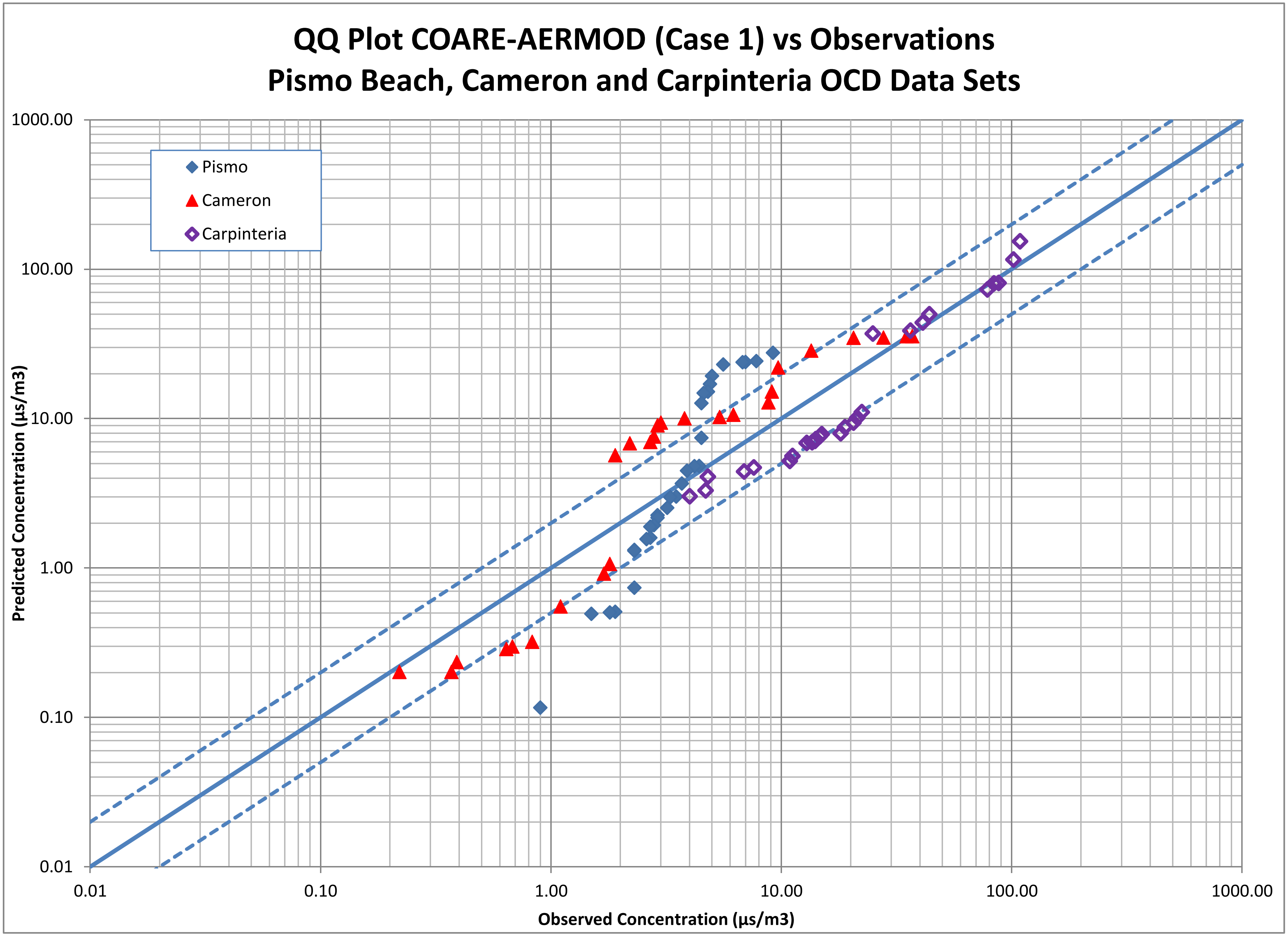

COARE-AERMOD (Case 5) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Case 5: Abs(L)>5, Obs σΘ, Venk Mech Zi, Draxler σy
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00

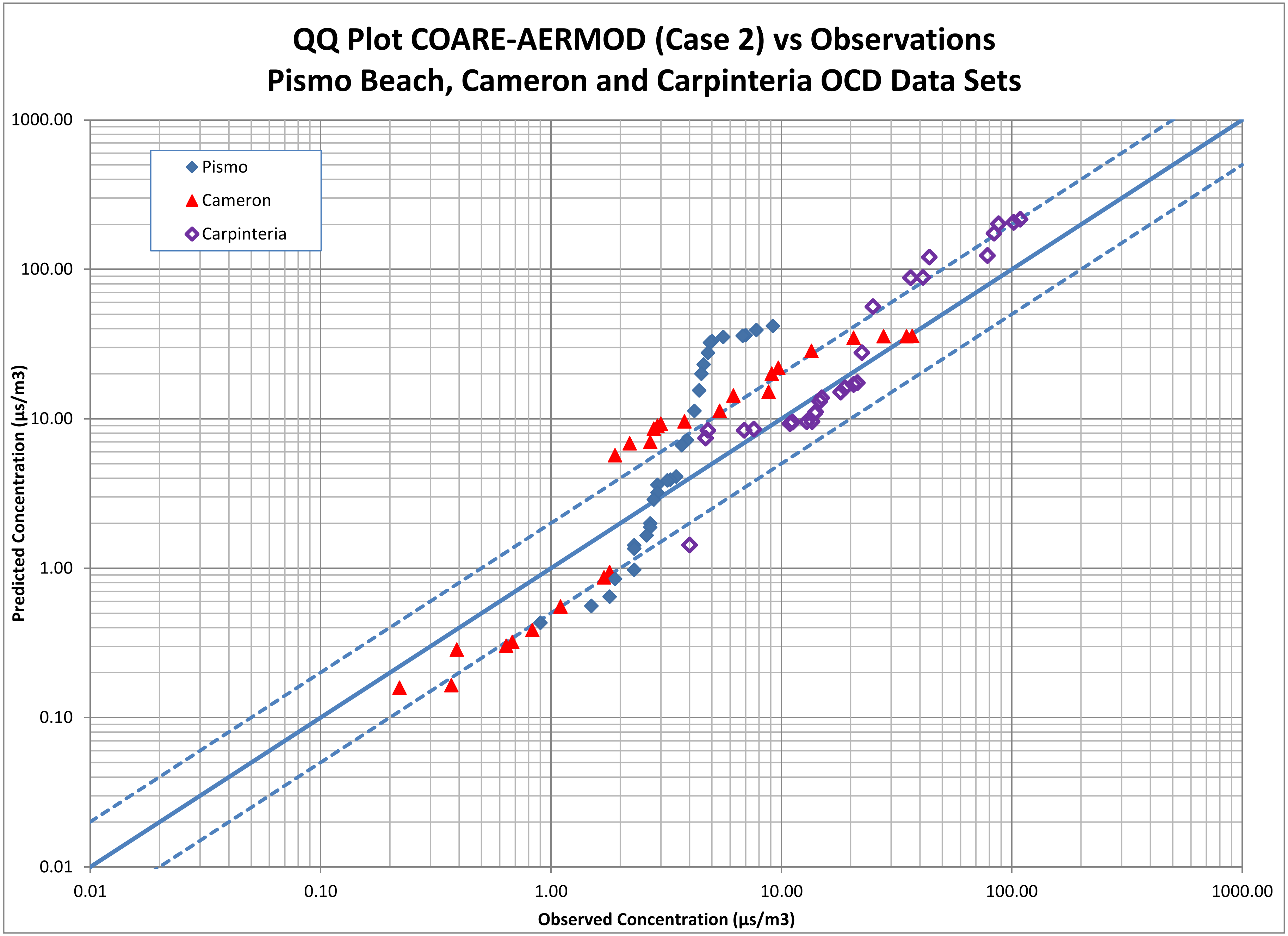

QQ Plot COARE-AERMOD vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Case 1: Abs(L)>5, Venk Zi, Obs σΘ
Case 2: Abs(L)>5, Venk Zi, Mod σΘ
Case 3: Abs(L)>1, Obs Zi, Obs σΘ
Case 4: Abs(L)>5, Obs Zi, Obs σΘ
Case 5: Abs(L)>5, Venk Zi, Obs σΘ, Draxler σy
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
0.01
0.10
1.00
10.00
100.00
1000.00

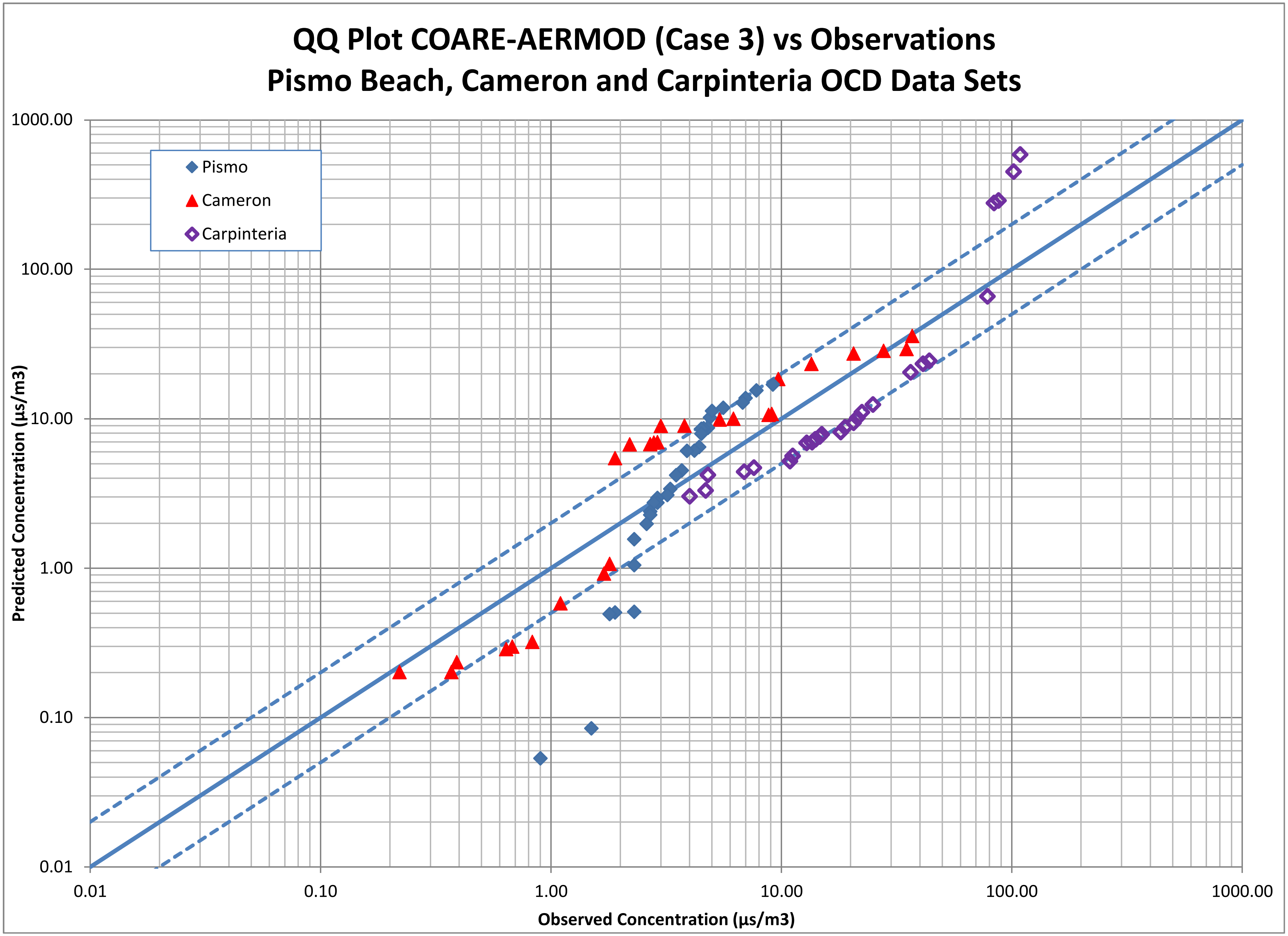

QQ Plot COARE-AERMOD vs Observations
Pismo Beach OCD Data Set
Case 1: Abs(L)>5, Obs σΘ, Venk Zi
Case 2: Abs(L)>5, Pred σΘ, Venk Zi
Case 3: Abs(L)>1, Obs σΘ, Obs Zi
Case 4: Abs(L)>5, Obs σΘ, Obs Zi
Case 5: Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00

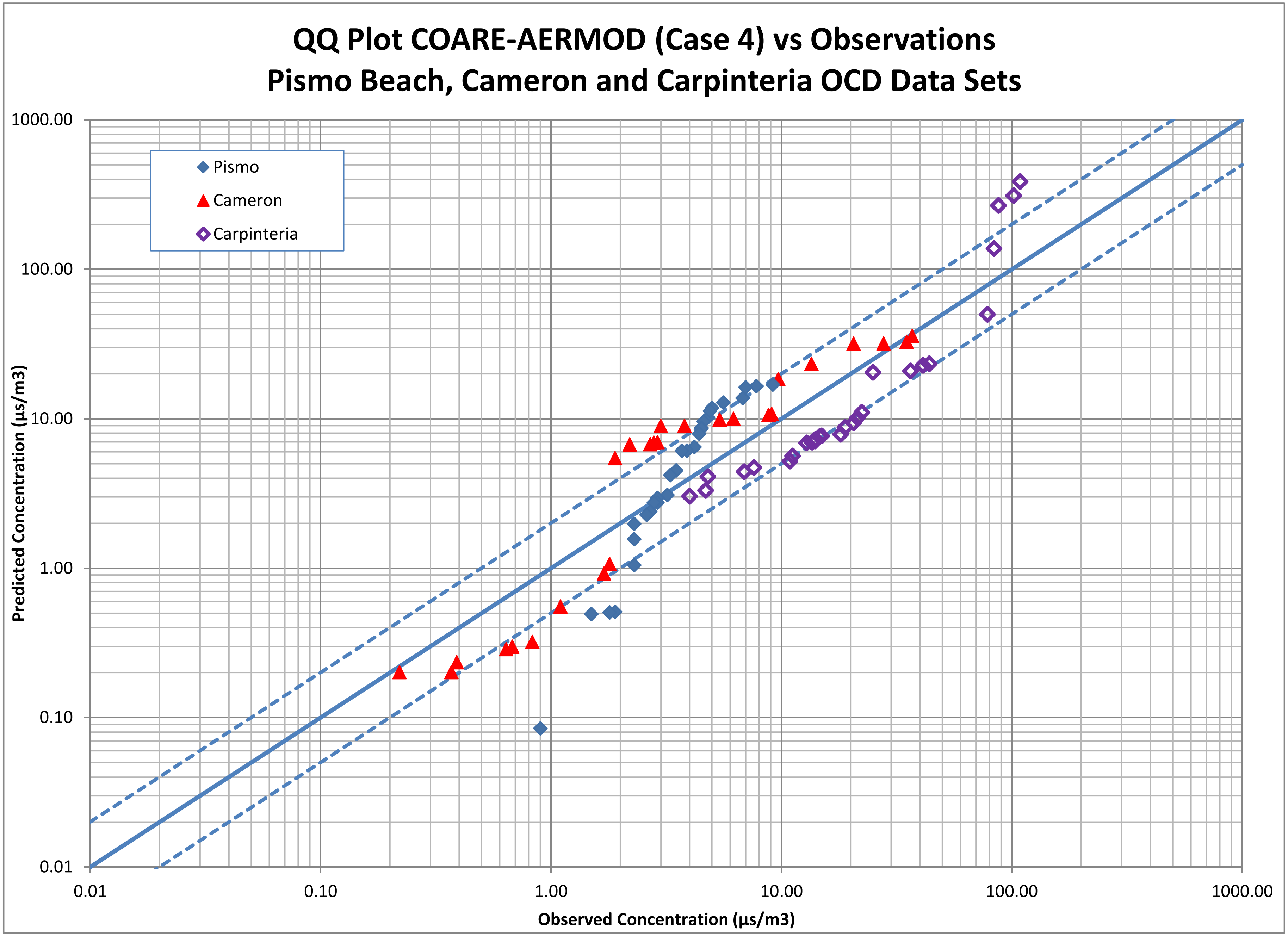

QQ Plot COARE-AERMOD vs Observations
Cameron OCD Data Set
Case 1: Abs(L)>5, Obs σΘ, Venk Zi
Case 2: Abs(L)>5, Pred σΘ, Venk Zi
Case 3: Abs(L)>1, Obs σΘ, Obs Zi
Case 4: Abs(L)>5, Obs σΘ, Obs Zi
Case 5: Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00

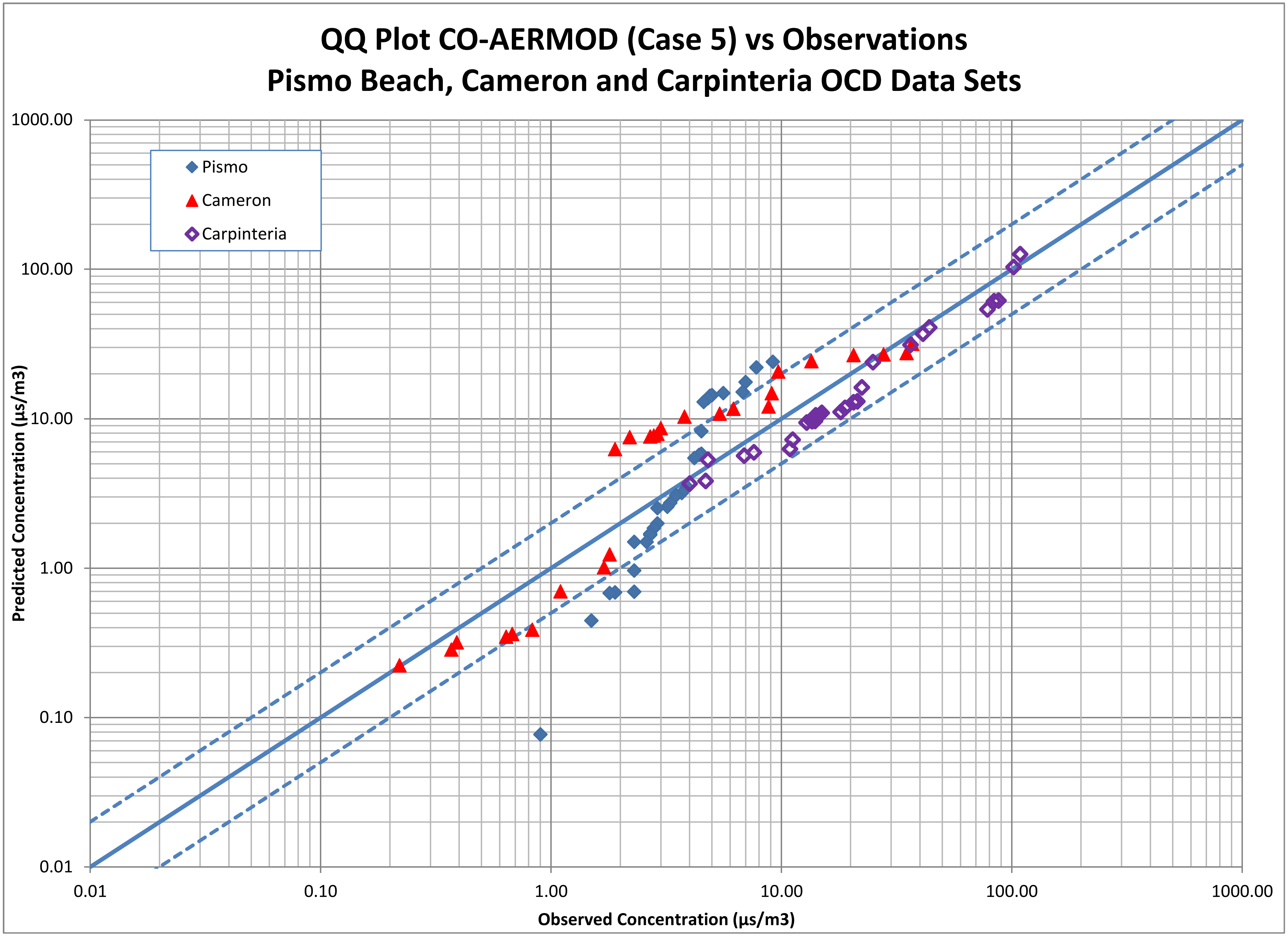

QQ Plot COARE-AERMOD vs Observations
Carpinteria OCD Data Set
Case 1: Abs(L)>5, Obs σΘ, Venk Zi
Case 2: Abs(L)>5, Pred σΘ, Venk Zi
Case 3: Abs(L)>1, Obs σΘ, Obs Zi
Case 4: Abs(L)>5, Obs σΘ, Obs Zi
Case 5: Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy
Predicted Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00
Observed Concentration (µs/m3)

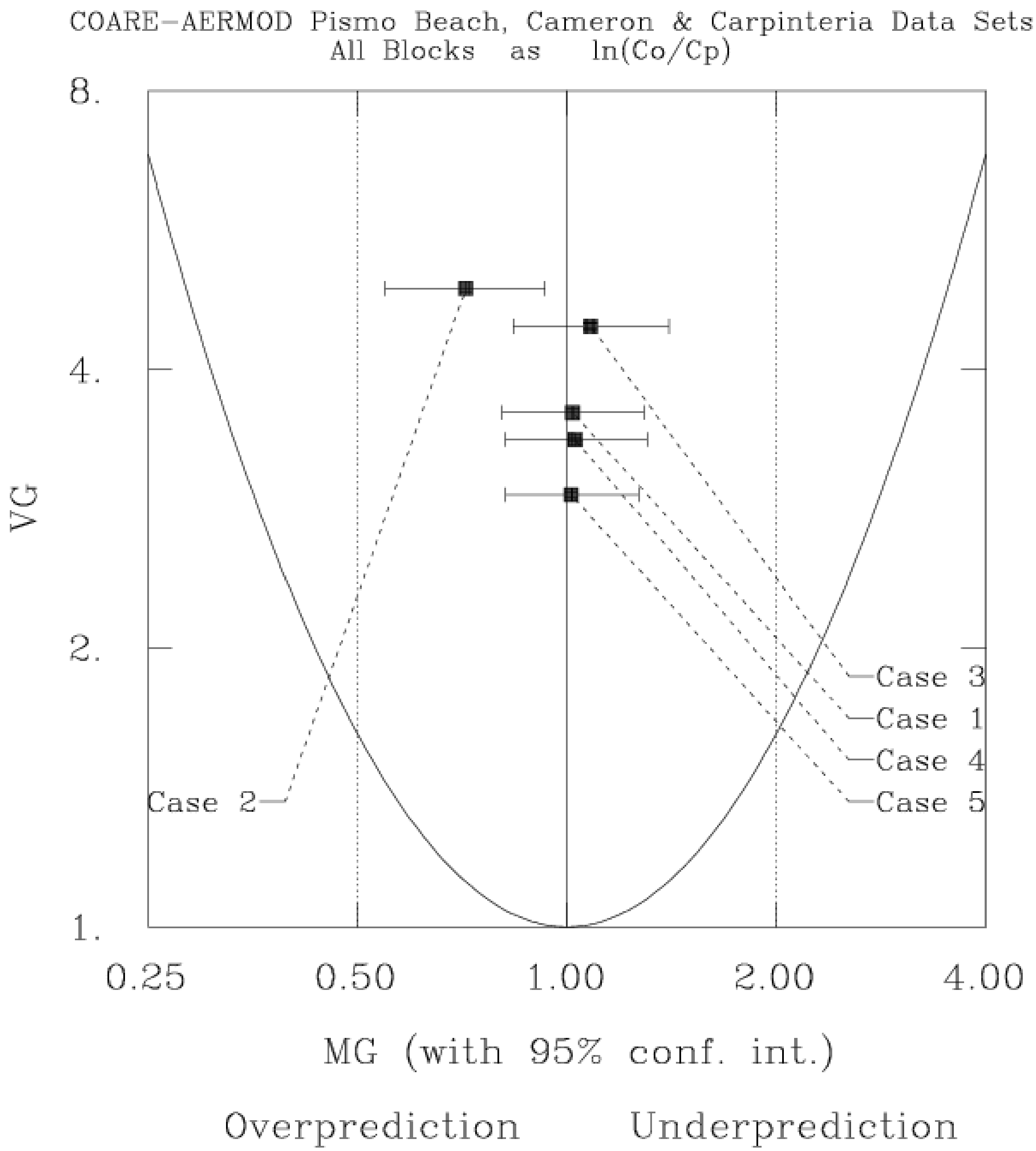

QQ Plot COARE-AERMOD (Case 1) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00

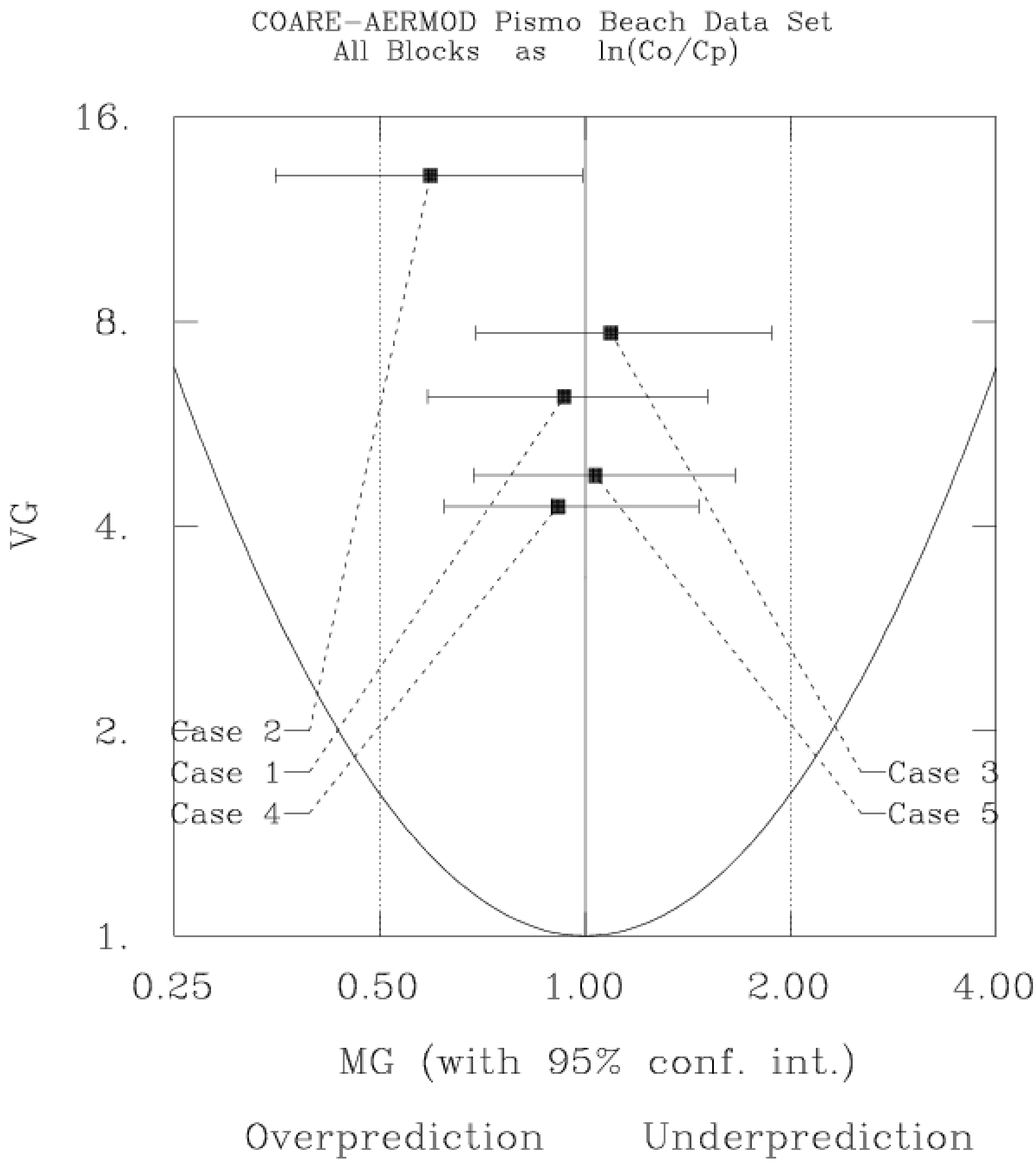

QQ Plot COARE-AERMOD (Case 2) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00

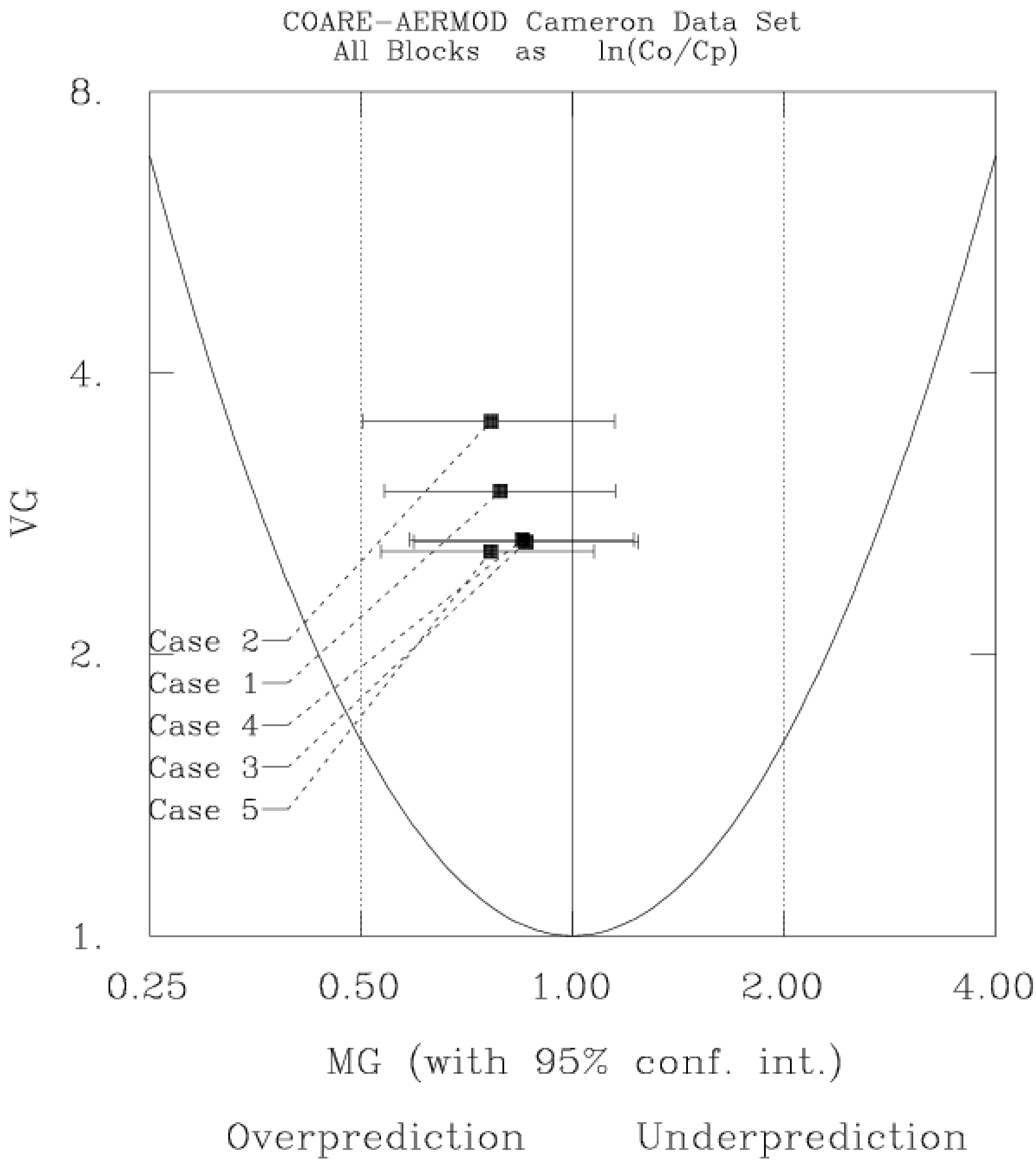

QQ Plot COARE-AERMOD (Case 3) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)

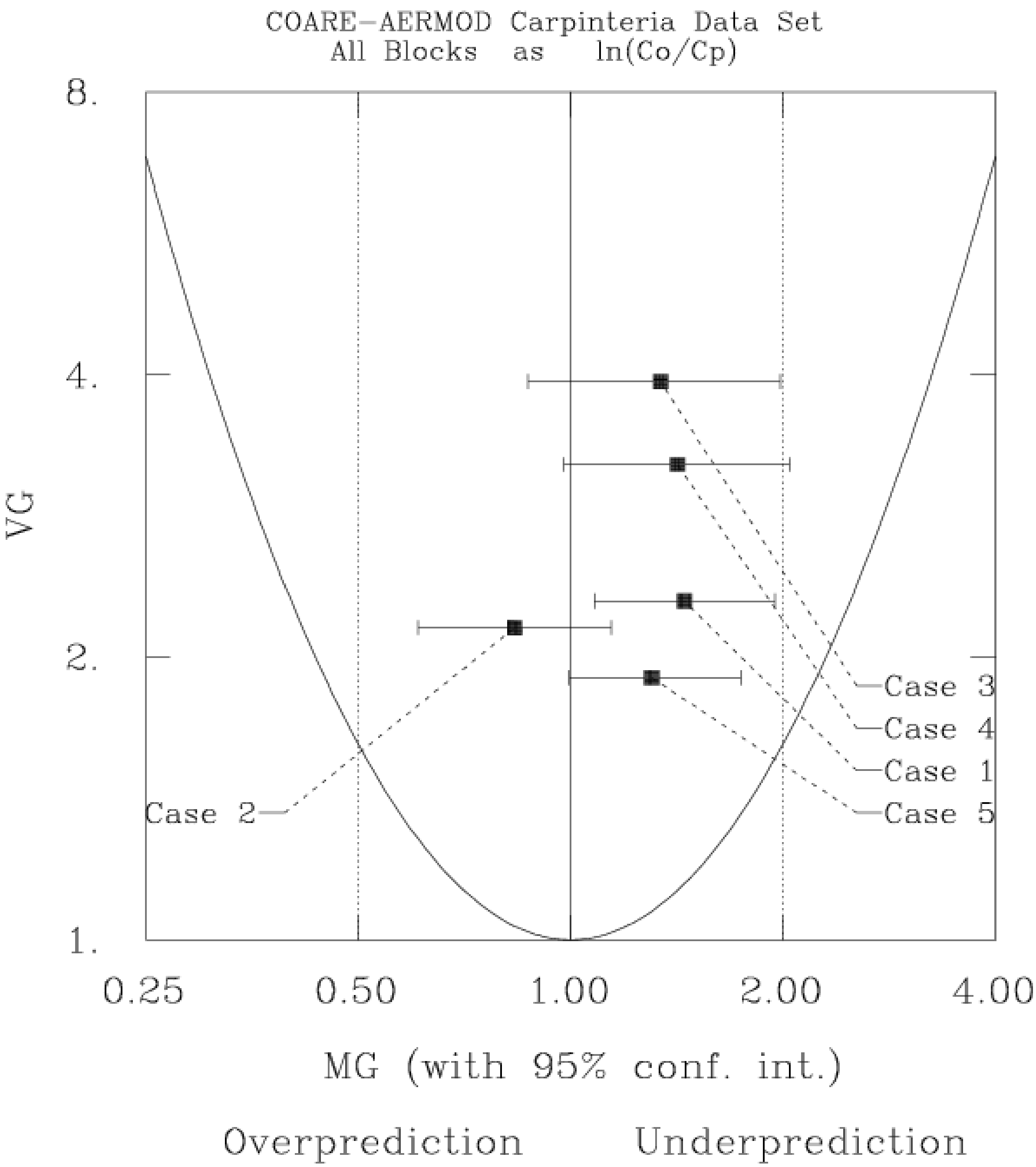

QQ Plot COARE-AERMOD (Case 4) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00


QQ Plot CO-AERMOD (Case 5) vs Observations
Pismo Beach, Cameron and Carpinteria OCD Data Sets
Pismo
Cameron
Carpinteria
Predicted Concentration (µs/m3)
Observed Concentration (µs/m3)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
1000.00


COARE-AERMOD Pismo Beach, Cameron & Carpinteria Data Sets
All Blocks as ln(Co/Cp)
8.
4.
2.
1.
VG
0.25
0.50
1.00
2.00
4.00
MG (with 95% conf. int.)
Overprediction
Underprediction
Case 2
Case 3
Case 1
Case 4
Case 5


COARE−AERMOD Pismo Beach Data Set
All Blocks as ln(Co/Cp)
16.
8.
4.
2.
1.
VG
Case 2
Case 1
Case 4
Case 3
Case 5
0.25
0.50
1.00
2.00
4.00
MG (with 95% conf. int.)
Overprediction
Underprediction


COARE-AERMOD Cameron Data Set
All Blocks as ln(Co/Cp)
8.
4.
2.
1.
VG
Case 2
Case 1
Case 4
Case 3
Case 5
0.25
0.50
1.00
2.00
4.00
MG (with 95% conf. int.)
Overprediction
Underprediction


COARE-AERMOD Carpinteria Data Set
All Blocks as ln(Co/Cp)
8.
4.
2.
1.
VG
0.25
0.50
1.00
2.00
4.00
MG (with 95% conf. int.)
Overprediction
Underprediction
Case 3
Case 4
Case 1
Case 5
Case 2

Boot Program Output for All Data Sets Combined

```
  OUTPUT OF THE BOOT PROGRAM, LEVEL 2/2/2007


No. of experiments                    =   84
No. of models                         =    6
(with the observed data counted as one)
No. of observations                   =   84
(there might be multiple observations in each experiment, if the ASTM option is chosen)
(there is only one prediction in each experiment)
No. of observations available for
paried sampling                       =   82
(there might be odd number of observations in each block)
No. of blocks (regimes)               =    3
No. of experiments in each block (regime)
  31  26  27


Out of the following options:
(1) straight Co and Cp comparison
(4) consider ln(Co) and ln(Cp)
 4 was selected




Nominal (median) results          (No. of regimes =    3)
MODEL      MEAN      SIGMA       BIAS        VG    CORR   FA2     MG       HIGH   2nd HIGH   PCOR
           |<--------------- (logarithmic values) ----------------->|    (arithmetic values)
OBS.       1.78       1.30       0.00   1.00      1.000  1.000   1.00       109       102    n/a
                                                      (MGfn=  1.000, MGfp=  1.000, MG=MGfn/MGfp)

Case 1     1.76       1.61       0.02   3.59      0.716  0.488   1.02       154       116    n/a
                                                      (MGfn=  1.590, MGfp=  1.559, MG=MGfn/MGfp)

Case 2     2.11       1.72      -0.33   4.89      0.711  0.452   0.72       217       206    n/a
                                                      (MGfn=  1.401, MGfp=  1.958, MG=MGfn/MGfp)

Case 3     1.70       1.71       0.08   4.45      0.702  0.452   1.08       586       451    n/a
                                                      (MGfn=  1.659, MGfp=  1.533, MG=MGfn/MGfp)

Case 4     1.75       1.59       0.03   3.36      0.728  0.452   1.03       386       311    n/a
                                                      (MGfn=  1.568, MGfp=  1.526, MG=MGfn/MGfp)

Case 5     1.77       1.52       0.01   2.93      0.740  0.476   1.01       126       104    n/a
                                                      (MGfn=  1.503, MGfp=  1.482, MG=MGfn/MGfp)
```

```
Block   1: Pismo Beach, Ca                (N=   31)
MODEL      MEAN      SIGMA       BIAS       VG    CORR   FA2     MG       HIGH   2nd HIGH   PCOR
           |<--------------- (logarithmic values) ---------------->|    (arithmetic values)
OBS.       1.24       0.50       0.00   1.00      1.000  1.000   1.00          9          8    n/a
                                                      (MGfn=  1.000, MGfp=  1.000, MG=MGfn/MGfp)

Case 1     1.31       1.40      -0.07   6.20      0.278  0.484   0.93         28         24    n/a
                                                      (MGfn=  1.651, MGfp=  1.772, MG=MGfn/MGfp)

Case 2     1.76       1.46      -0.52   13.1      0.048  0.290   0.59         42         39    n/a
                                                      (MGfn=  1.542, MGfp=  2.599, MG=MGfn/MGfp)

Case 3     1.15       1.41       0.09   7.70      0.146  0.452   1.09         17         15    n/a
                                                      (MGfn=  1.724, MGfp=  1.580, MG=MGfn/MGfp)

Case 4     1.33       1.23      -0.09   4.27      0.265  0.484   0.91         17         17    n/a
                                                      (MGfn=  1.489, MGfp=  1.633, MG=MGfn/MGfp)

Case 5     1.21       1.33       0.03   4.75      0.347  0.419   1.04         24         22    n/a
                                                      (MGfn=  1.641, MGfp=  1.586, MG=MGfn/MGfp)


Block   2: Cameron, La                    (N=   26)
MODEL      MEAN      SIGMA       BIAS       VG    CORR   FA2     MG       HIGH   2nd HIGH   PCOR
           |<--------------- (logarithmic values) ---------------->|    (arithmetic values)
OBS.       1.15       1.41       0.00   1.00      1.000  1.000   1.00         37         35    n/a
                                                      (MGfn=  1.000, MGfp=  1.000, MG=MGfn/MGfp)

Case 1     1.39       1.84      -0.24   2.99      0.835  0.423   0.79         36         36    n/a
                                                      (MGfn=  1.360, MGfp=  1.724, MG=MGfn/MGfp)

Case 2     1.42       1.87      -0.27   3.55      0.813  0.423   0.77         36         36    n/a
                                                      (MGfn=  1.380, MGfp=  1.804, MG=MGfn/MGfp)

Case 3     1.31       1.77      -0.15   2.64      0.836  0.462   0.86         36         29    n/a
                                                      (MGfn=  1.376, MGfp=  1.603, MG=MGfn/MGfp)

Case 4     1.32       1.79      -0.16   2.65      0.840  0.462   0.85         36         33    n/a
                                                      (MGfn=  1.368, MGfp=  1.614, MG=MGfn/MGfp)

Case 5     1.42       1.70      -0.27   2.58      0.835  0.462   0.76         32         27    n/a
                                                      (MGfn=  1.294, MGfp=  1.694, MG=MGfn/MGfp)


Block   3: Carpinteria, Ca                (N=   27)
MODEL      MEAN      SIGMA       BIAS       VG    CORR   FA2     MG       HIGH   2nd HIGH   PCOR
           |<--------------- (logarithmic values) ---------------->|    (arithmetic values)
OBS.       3.00       0.93       0.00   1.00      1.000  1.000   1.00        109        102    n/a
                                                      (MGfn=  1.000, MGfp=  1.000, MG=MGfn/MGfp)

Case 1     2.63       1.18       0.37   2.29      0.714  0.556   1.45        154        116    n/a
                                                      (MGfn=  1.768, MGfp=  1.222, MG=MGfn/MGfp)

Case 2     3.19       1.30      -0.18   2.15      0.756  0.667   0.83        217        206    n/a
                                                      (MGfn=  1.273, MGfp=  1.530, MG=MGfn/MGfp)

Case 3     2.71       1.50       0.29   3.93      0.655  0.444   1.34        586        451    n/a
                                                      (MGfn=  1.900, MGfp=  1.418, MG=MGfn/MGfp)

Case 4     2.65       1.37       0.35   3.21      0.666  0.407   1.42        386        311    n/a
                                                      (MGfn=  1.896, MGfp=  1.339, MG=MGfn/MGfp)

Case 5     2.74       0.97       0.26   1.90      0.685  0.556   1.30        126        104    n/a
                                                      (MGfn=  1.570, MGfp=  1.207, MG=MGfn/MGfp)
```

```
SUMMARY OF CONFIDENCE LIMITS ANALYSES BASED ON PERCENTILE CONFIDENCE LIMITS
 ---------------------------------------------------------------------------


   D(ln(VG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

              C   C   C   C   C
              a   a   a   a   a
              s   s   s   s   s
              e   e   e   e   e

              1   2   3   4   5
             --------------------
  Case 1  |                   X
  Case 2  |                   X
  Case 3  |                   X
  Case 4  |

   D(ln(MG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

              C   C   C   C   C
              a   a   a   a   a
              s   s   s   s   s
              e   e   e   e   e

              1   2   3   4   5
             --------------------
  Case 1  |       X
  Case 2  |           X   X   X
  Case 3  |
  Case 4  |

   D(ln(MGfn)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

              C   C   C   C   C
              a   a   a   a   a
              s   s   s   s   s
              e   e   e   e   e

              1   2   3   4   5
             --------------------
  Case 1  |       X           X
  Case 2  |           X   X
  Case 3  |                   X
  Case 4  |                   X

   D(ln(MGfp)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

              C   C   C   C   C
              a   a   a   a   a
              s   s   s   s   s
              e   e   e   e   e

              1   2   3   4   5
             --------------------
  Case 1  |       X           X
  Case 2  |           X   X   X
  Case 3  |
  Case 4  |

   ln(MG) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

              C   C   C   C   C
              a   a   a   a   a
              s   s   s   s   s
              e   e   e   e   e

              1   2   3   4   5
             --------------------
                  X
```

ln(MGfn) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
 C   C   C   C   C
 a   a   a   a   a
 s   s   s   s   s
 e   e   e   e   e

 1   2   3   4   5
--------------------
 X   X   X   X   X
```

ln(MGfp) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
 C   C   C   C   C
 a   a   a   a   a
 s   s   s   s   s
 e   e   e   e   e

 1   2   3   4   5
--------------------
 X   X   X   X   X
```

Boot Program Output for Pismo Beach

```
OUTPUT OF THE BOOT PROGRAM, LEVEL 2/2/2007


No. of experiments                    =   31
No. of models                         =    6
(with the observed data counted as one)
No. of observations                   =   31
(there might be multiple observations in each experiment, if the ASTM option is chosen)
(there is only one prediction in each experiment)
No. of observations available for
paried sampling                       =   30
(there might be odd number of observations in each block)
No. of blocks (regimes)               =    1
No. of experiments in each block (regime)
  31


Out of the following options:
(1) straight Co and Cp comparison
(4) consider ln(Co) and ln(Cp)
 4 was selected




Nominal (median) results           (No. of regimes =    1)
MODEL      MEAN      SIGMA       BIAS        VG    CORR   FA2     MG       HIGH   2nd HIGH   PCOR
           |<--------------- (logarithmic values) ---------------->|    (arithmetic values)
OBS.       1.24       0.50       0.00   1.00      1.000  1.000   1.00         9         8    n/a
                                                      (MGfn=  1.000, MGfp=  1.000, MG=MGfn/MGfp)

Case 1     1.31       1.40      -0.07   6.20      0.278  0.484   0.93        28        24    n/a
                                                      (MGfn=  1.651, MGfp=  1.772, MG=MGfn/MGfp)

Case 2     1.76       1.46      -0.52   13.1      0.048  0.290   0.59        42        39    n/a
                                                      (MGfn=  1.542, MGfp=  2.599, MG=MGfn/MGfp)

Case 3     1.15       1.41       0.09   7.70      0.146  0.452   1.09        17        15    n/a
                                                      (MGfn=  1.724, MGfp=  1.580, MG=MGfn/MGfp)

Case 4     1.33       1.23      -0.09   4.27      0.265  0.484   0.91        17        17    n/a
                                                      (MGfn=  1.489, MGfp=  1.633, MG=MGfn/MGfp)

Case 5     1.21       1.33       0.03   4.75      0.347  0.419   1.04        24        22    n/a
                                                      (MGfn=  1.641, MGfp=  1.586, MG=MGfn/MGfp)
```

```
SUMMARY OF CONFIDENCE LIMITS ANALYSES BASED ON PERCENTILE CONFIDENCE LIMITS
---------------------------------------------------------------------------


  D(ln(VG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |
 Case 2  |
 Case 3  |
 Case 4  |

  D(ln(MG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |       X
 Case 2  |           X       X
 Case 3  |               X
 Case 4  |

  D(ln(MGfn)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |               X
 Case 2  |
 Case 3  |
 Case 4  |                   X

  D(ln(MGfp)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |       X           X
 Case 2  |           X   X   X
 Case 3  |
 Case 4  |

  ln(MG) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
                 X
```

ln(MGfn) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
 C   C   C   C   C
 a   a   a   a   a
 s   s   s   s   s
 e   e   e   e   e

 1   2   3   4   5
--------------------
 X   X   X   X   X
```

ln(MGfp) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
 C   C   C   C   C
 a   a   a   a   a
 s   s   s   s   s
 e   e   e   e   e

 1   2   3   4   5
--------------------
 X   X   X   X   X
```

Boot Program Output for Cameron

```
   OUTPUT OF THE BOOT PROGRAM, LEVEL 2/2/2007


No. of experiments                     =   26
No. of models                          =    6
(with the observed data counted as one)
No. of observations                    =   26
(there might be multiple observations in each experiment, if the ASTM option is chosen)
(there is only one prediction in each experiment)
No. of observations available for
paried sampling                        =   26
(there might be odd number of observations in each block)
No. of blocks (regimes)                =    1
No. of experiments in each block (regime)
  26


Out of the following options:
(1) straight Co and Cp comparison
(4) consider ln(Co) and ln(Cp)
 4 was selected




Nominal (median) results           (No. of regimes =    1)
MODEL      MEAN      SIGMA       BIAS        VG    CORR   FA2     MG       HIGH   2nd HIGH   PCOR
           |<--------------- (logarithmic values) ---------------->|    (arithmetic values)
OBS.       1.15       1.41       0.00   1.00      1.000  1.000   1.00        37         35    n/a
                                                      (MGfn=  1.000, MGfp=  1.000, MG=MGfn/MGfp)

Case 1     1.39       1.84      -0.24   2.99      0.835  0.423   0.79        36         36    n/a
                                                      (MGfn=  1.360, MGfp=  1.724, MG=MGfn/MGfp)

Case 2     1.42       1.87      -0.27   3.55      0.813  0.423   0.77        36         36    n/a
                                                      (MGfn=  1.380, MGfp=  1.804, MG=MGfn/MGfp)

Case 3     1.31       1.77      -0.15   2.64      0.836  0.462   0.86        36         29    n/a
                                                      (MGfn=  1.376, MGfp=  1.603, MG=MGfn/MGfp)

Case 4     1.32       1.79      -0.16   2.65      0.840  0.462   0.85        36         33    n/a
                                                      (MGfn=  1.368, MGfp=  1.614, MG=MGfn/MGfp)

Case 5     1.42       1.70      -0.27   2.58      0.835  0.462   0.76        32         27    n/a
                                                      (MGfn=  1.294, MGfp=  1.694, MG=MGfn/MGfp)
```

```
SUMMARY OF CONFIDENCE LIMITS ANALYSES BASED ON PERCENTILE CONFIDENCE LIMITS
---------------------------------------------------------------------------


  D(ln(VG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |       X           X
 Case 2  |           X   X   X
 Case 3  |
 Case 4  |

  D(ln(MG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |           X   X
 Case 2  |           X   X
 Case 3  |                   X
 Case 4  |                   X

  D(ln(MGfn)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |
 Case 2  |
 Case 3  |                   X
 Case 4  |                   X

  D(ln(MGfp)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |           X   X
 Case 2  |           X   X
 Case 3  |                   X
 Case 4  |                   X

  ln(MG) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
```

ln(MGfn) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
 C   C   C   C   C
 a   a   a   a   a
 s   s   s   s   s
 e   e   e   e   e

 1   2   3   4   5
--------------------
 X   X   X   X   X
```

ln(MGfp) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
 C   C   C   C   C
 a   a   a   a   a
 s   s   s   s   s
 e   e   e   e   e

 1   2   3   4   5
--------------------
 X   X   X   X   X
```

Boot Program Output for Carpinteria

```
   OUTPUT OF THE BOOT PROGRAM, LEVEL 2/2/2007


 No. of experiments                     =   27
 No. of models                          =    6
 (with the observed data counted as one)
 No. of observations                    =   27
 (there might be multiple observations in each experiment, if the ASTM option is chosen)
 (there is only one prediction in each experiment)
 No. of observations available for
 paried sampling                        =   26
 (there might be odd number of observations in each block)
 No. of blocks (regimes)                =    1
 No. of experiments in each block (regime)
   27


 Out of the following options:
 (1) straight Co and Cp comparison
 (4) consider ln(Co) and ln(Cp)
  4 was selected




 Nominal (median) results           (No. of regimes =    1)
 MODEL      MEAN      SIGMA       BIAS        VG    CORR   FA2     MG       HIGH   2nd HIGH   PCOR
            |<---------------- (logarithmic values) ---------------->|    (arithmetic values)
 OBS.       3.00       0.93       0.00   1.00      1.000  1.000   1.00       109       102    n/a
                                                       (MGfn=  1.000, MGfp=  1.000, MG=MGfn/MGfp)

 Case 1     2.63       1.18       0.37   2.29      0.714  0.556   1.45       154       116    n/a
                                                       (MGfn=  1.768, MGfp=  1.222, MG=MGfn/MGfp)

 Case 2     3.19       1.30      -0.18   2.15      0.756  0.667   0.83       217       206    n/a
                                                       (MGfn=  1.273, MGfp=  1.530, MG=MGfn/MGfp)

 Case 3     2.71       1.50       0.29   3.93      0.655  0.444   1.34       586       451    n/a
                                                       (MGfn=  1.900, MGfp=  1.418, MG=MGfn/MGfp)

 Case 4     2.65       1.37       0.35   3.21      0.666  0.407   1.42       386       311    n/a
                                                       (MGfn=  1.896, MGfp=  1.339, MG=MGfn/MGfp)

 Case 5     2.74       0.97       0.26   1.90      0.685  0.556   1.30       126       104    n/a
                                                       (MGfn=  1.570, MGfp=  1.207, MG=MGfn/MGfp)
```

```
SUMMARY OF CONFIDENCE LIMITS ANALYSES BASED ON PERCENTILE CONFIDENCE LIMITS
---------------------------------------------------------------------------


  D(ln(VG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |           X   X   X
 Case 2  |
 Case 3  |                   X
 Case 4  |                   X

  D(ln(MG)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |       X           X
 Case 2  |           X   X   X
 Case 3  |
 Case 4  |

  D(ln(MGfn)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |       X   X       X
 Case 2  |           X   X
 Case 3  |                   X
 Case 4  |                   X

  D(ln(MGfp)) among models: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
 Case 1  |       X
 Case 2  |                   X
 Case 3  |
 Case 4  |

  ln(MG) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

             C   C   C   C   C
             a   a   a   a   a
             s   s   s   s   s
             e   e   e   e   e

             1   2   3   4   5
            --------------------
             X
```

ln(MGfn) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
           C   C   C   C   C
           a   a   a   a   a
           s   s   s   s   s
           e   e   e   e   e

           1   2   3   4   5
          --------------------
           X   X   X   X   X
```

ln(MGfp) for each model: an 'X' indicates significantly different from zero at 95% confidence limits

```
           C   C   C   C   C
           a   a   a   a   a
           s   s   s   s   s
           e   e   e   e   e

           1   2   3   4   5
          --------------------
           X   X   X   X   X
```