



Evaluation of the Combined AERCOARE/AERMOD Modeling Approach for Offshore Sources

**Evaluation of the Combined AERCOARE/AERMOD
Modeling Approach for Offshore Sources**

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PREFACE

On 01 April 2011, the U.S. Environmental Protection Agency (EPA) Region 10 (R10) approved the use of the AERMOD dispersion program with output from an overwater meteorological data preprocessor program to estimate ambient air pollutant concentration impacts at outer continental shelf (OCS) locations in the Beaufort and Chukchi Seas of the Arctic Ocean. AERMOD was approved because it contains the necessary options, features and capabilities to estimate air pollutant concentration impacts from emission sources located in these two seas. The options and features include the PRIME downwash algorithm, Plume Volume Molar Ratio Method (PVMRM), and Ozone Limiting Method (OLM). Its capabilities consist of (1) estimating impacts from point, area and volume sources, (2) accounting for calm conditions, and (3) calculating design values based on deterministic and probabilistic standards. As an alternative to the AERMET preprocessor program designed for terrestrial application, the Coupled Ocean Atmosphere Response Experiment (COARE) air-sea flux algorithm was also approved to preprocess overwater meteorological data measurements. The COARE algorithm output was assembled with other meteorological variables in a spreadsheet to form the AERMOD overwater meteorological input files. EPA's guideline Offshore and Coastal Dispersion (OCD) model does not contain all these options, features, and capabilities, and the COARE algorithm to adequately predict ambient concentrations from emission sources proposed in marine environments.

Building upon its prior approval, R10 initiated two studies in late 2011. The first study modifies AERMOD to include the platform building downwash algorithm contained in the OCD model. The bases of the algorithm were wind tunnel experiments conducted by Ronald L. Peterson that employed scaled models of the Chevron U.S.A West Cameron 28A platform located near Cameron, LA. The second study that is the focus of this report, codes the COARE air-sea flux procedure into a meteorological data preprocessor program called AERCOARE. AERCOARE will read overwater measured hourly meteorological data or Weather Research and Forecasting (WRF) model predicted hourly meteorological data output from the Mesoscale Model Interface (MMIF) program. The output from AERCOARE can then be used by AERMOD in a marine environment.

The work was funded under a subcontract from the University of North Carolina at Chapel Hill with EPA Prime award EPD07102, Work Assignment 5-17. The EPA R10 Office of Environmental Assessment (OEA) Work Assignment Manager was Ms. Jennifer Crawford and the R10 Technical Lead was Mr. Herman Wong. Peer review of the draft document was provided by Dr. Sang-Mi Lee of the South Coast Air Quality Management District. Her review and comments are greatly appreciated.

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1.0 INTRODUCTION

ENVIRON conducted an evaluation of the combined AERCOARE/AERMOD (AERCOARE-MOD) modeling approach for offshore sources using tracer data from four field studies. AERCOARE processes overwater meteorological data for use by the AERMOD air quality dispersion model (EPA, 2004a). AERCOARE applies the Coupled Ocean Atmosphere Response Experiment (COARE) air-sea flux algorithm (Fairall, et. el., 2003) to estimate surface energy fluxes and assembles these estimates and overwater measurements for subsequent dispersion model simulations with AERMOD. AERCOARE would supplement AERMET (EPA, 2004b), the overland meteorological preprocessor for AERMOD, and allow AERMOD to be applied to offshore sources in a fashion similar to current new source review procedures over land.

The current study assesses the AERCOARE-MOD modeling approach using measurements from four offshore field studies. The remainder of this report presents: the evaluation datasets, techniques used to prepare data for AERCOARE, statistical model performance procedures and the results of the evaluation. The development of AERCOARE was sponsored by the U.S. Environmental Protection Agency (EPA) under Contract EP-D-7-102, Work Assignment 4-14 and Work Assignment 5-17.

2.0 BACKGROUND

The AERCOARE-MOD approach would update the current regulatory approach for offshore projects, the Offshore Coastal Dispersion (OCD) model (Chang and Hahn, 1997; DiCristofaro and Hanna, 1989). OCD has not been updated for many years and does not reflect the latest scientific advancements found in the AERMOD modeling system including:

- OCD does not contain internal routines for processing either missing data or hours of calm meteorology.
- OCD does not contain the regulatory PRIME downwash algorithms (Schulman, L. L. et al, 2000)
- The PVMRM¹ and OLM² methods for assessing the new 1-hour NO₂ ambient standard are not included in OCD.
- EPA methods recommended for estimating design concentrations associated with the new 24-hour PM_{2.5}, 1-hour NO₂, and 1-hour SO₂ ambient standards must be obtained by post-processing the OCD output files.
- OCD does not contain a volume source routine and the area source routine only considers circular areas without allowance for any initial vertical dispersion.
- 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 current regulatory 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 needed to AERMET-AERMOD for offshore applications include:

- The surface roughness over the ocean varies with wind speed and wave conditions, and is not a constant. The surface roughness for wind speed is also different than for temperature and specific humidity.
- AERMET uses the solar angle as an indication of the transition between daytime and nighttime boundary layer regimes. Over the ocean, the stability of the boundary layer does not respond as a strong function of solar heating, and especially in coastal waters, 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

¹ Plume Volume Molar Ratio Method, used to limit NO-to-NO₂ conversion based on available ozone.

² Ozone Limiting Method, used to limit NO-to-NO₂ conversion based on available ozone.

AERMET also do not incorporate moisture effects. The effect of surface moisture fluxes is typically stronger over the ocean than over land.

- The Bowen Ratio method for the latent heat flux in AERMET is overly simplistic. The ratio between the latent and sensible heat is not a constant.
- AERMOD does not contain routines for elevated platform downwash.
- AERMOD cannot simulate shoreline fumigation or dispersion affected by non-homogenous conditions either in space or time.

AERCOARE with the COARE air-sea flux method replaces AERMET by providing a meteorological input file that is technically more appropriate for marine applications. When AERCOARE provides the necessary meteorological data, AERMOD can be used to predict overwater concentration impacts in a manner consistent with new source review procedures over land. This allows the PVMRM, calms processing, volume source, and design concentration calculating procedures in AERMOD to be applied to sources located within the marine boundary layer.³

A similar AERMOD-COARE approach was recently approved by EPA Region 10 (R10) (EPA, 2011b) as an alternative model to OCD for application in an Arctic ice-free environment with concurrence from the EPA Model Clearinghouse (EPA, 2011a). In that application, the COARE algorithm was applied to overwater measurements and the results assembled in a spreadsheet. AERCOARE replaces the need for post-processing with a spreadsheet, provides support for missing data, adds options for the treatment of overwater mixing heights, and can consider many different input data formats (Richmond and Morris, 2012).

³ Note the current version of AERMOD does not contain routines for platform downwash or shoreline fumigation.

3.0 EVALUATION METHODS AND DATA SETS

The AERCOARE-MOD modeling approach was assessed by comparing predictions to the observations obtained from four offshore tracer studies: Pismo Beach, CA; Cameron, LA, Carpinteria, CA; and Ventura, CA. These studies are a subset of the data used to evaluate OCD (Chang and Hahn, 1997) and more recently, CALPUFF, the model preferred by the Minerals Management Service (MMS) (now Bureau of Ocean Energy Management (BOEM)) for permitting within their jurisdiction (Earth Tech, 2006). This section provides the rationale for the selection of these data sets, describes the data sets, outlines the procedures for the application of the AERCOARE algorithm, and presents the statistical methods used to compare AERCOARE-MOD predictions to measurements from the field programs.

3.1 Overwater Tracer Data Sets

The four model evaluation data sets used in the current study were provided by EPA R10 from the archives supporting development of the MMS (BOEM) version of CALPUFF and OCD Version 4 (DiCristofaro and Hanna, 1989). These studies occur under a wide range of overwater atmospheric stabilities that might be expected in coastal waters regardless of the latitude. The tracer measurements in Pismo Beach and Cameron occur in level terrain near the shoreline downwind of offshore tracer releases. These two studies provide tests of overwater dispersion without the complications due to air modification over the land or complex terrain. The Ventura study is similar; however the receptors are located 500 meters (m) to one kilometer (km) inland from the shoreline, so some air modification may have affected dispersion in this study. The Carpinteria complex terrain tracer study involved shoreline measurements observed on a bluff near plume level. The Carpinteria data set had much lighter winds and the transport distances were less than the other three studies.

3.1.1 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 CALPUFF evaluation archives. Tracer was released from a boat mast height of 13.1 m to 13.6 m above the water. Peak concentrations occurred near the shoreline at sampling distances from 6 km to 8 km away. The Pismo Beach evaluation database consists of 31 samples.

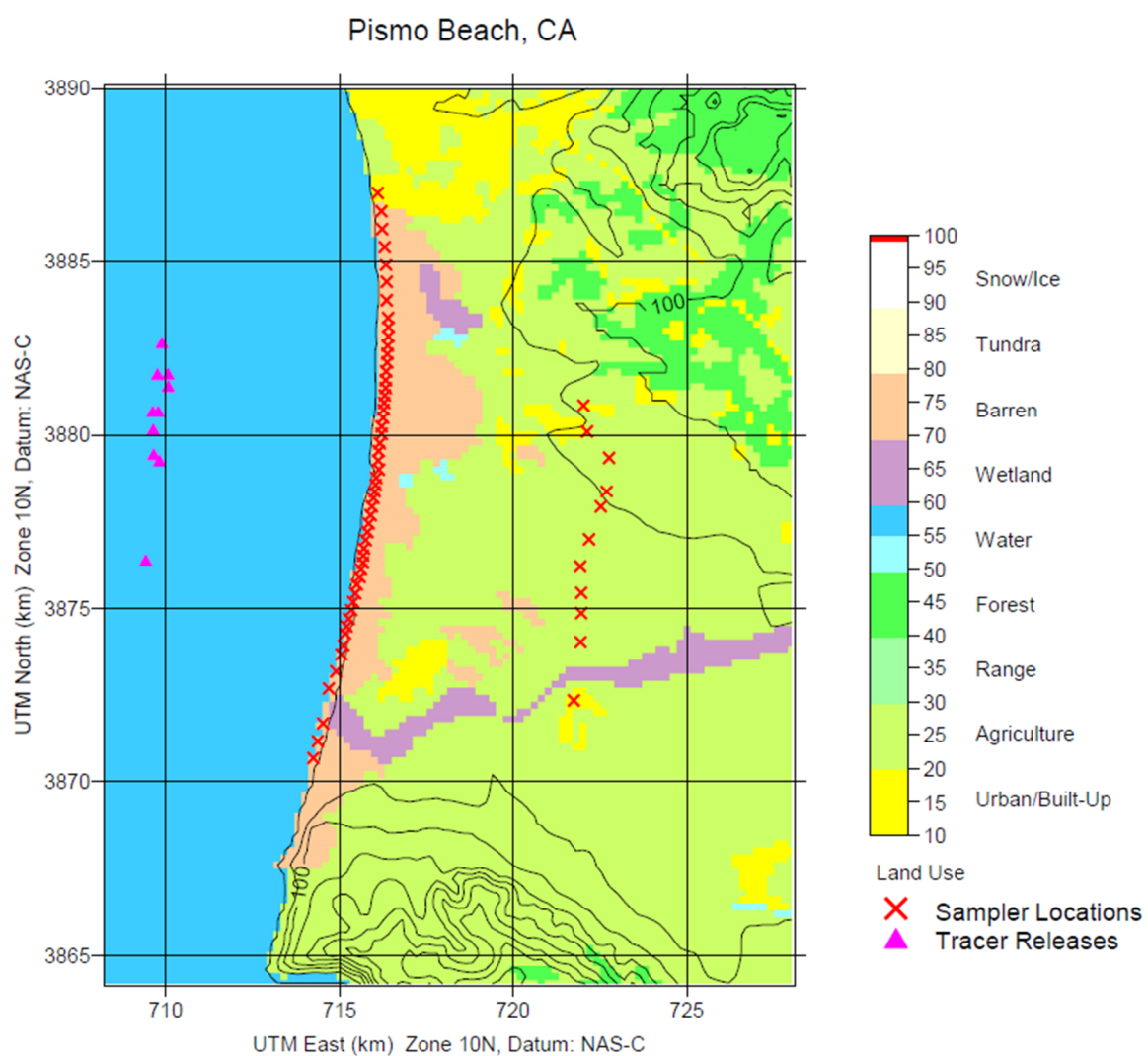


Figure 1. Pismo Beach

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 OCD and CALPUFF model evaluation reports with references to the original field studies.

Examination of the meteorological data in Table 1 reveals several inconsistencies between the air-sea temperature difference and the virtual potential temperature lapse rate. The virtual potential temperature lapse rate sometimes indicates a stable boundary layer (positive) when the air-sea temperature difference is unstable (negative).⁴ 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. We adjusted the air-sea temperature difference to be at least as stable as indicated by the virtual potential temperature lapse rate to address this inconsistency in our evaluation. In these instances, the sea temperature was adjusted so the air-sea temperature difference matched the measured potential 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 AERCOARE-MOD simulations. All simulations were 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 OCD contains a dispersion algorithm for very stable conditions that can only be triggered when the measured virtual potential temperature gradients exceeds 0.04 °C/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.

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 |
| 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

3.1.2 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 km to 10 km.

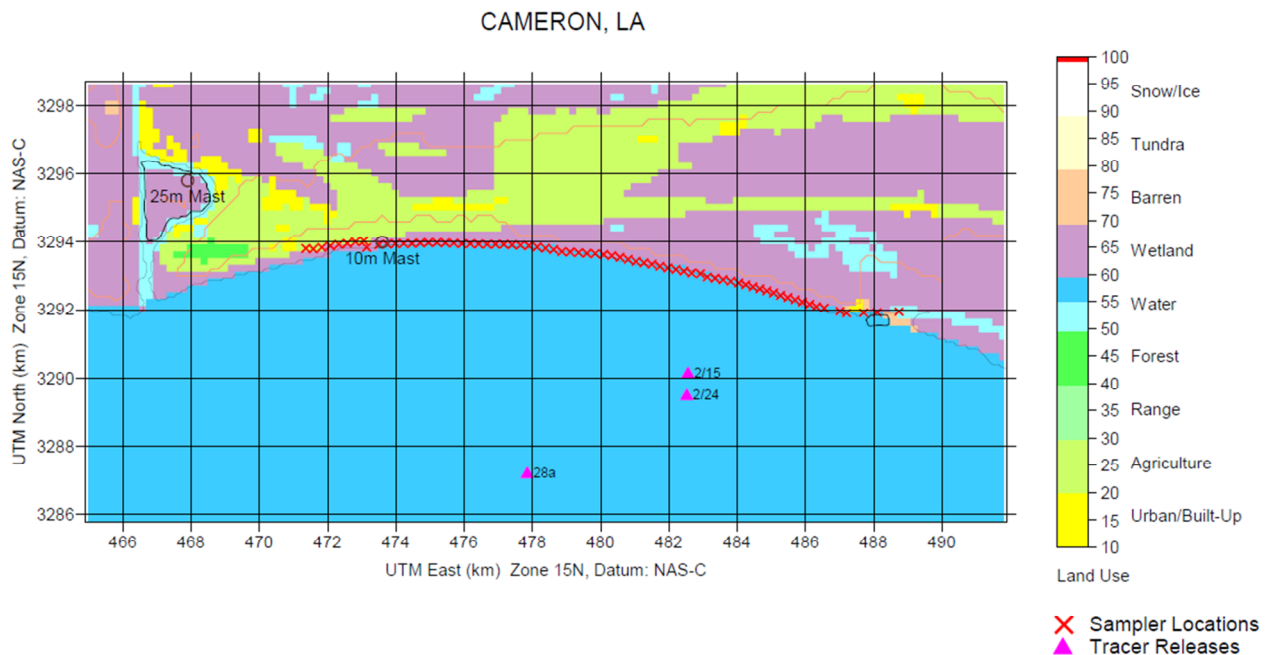


Figure 2. Cameron

The Cameron meteorological data used in the current analysis are shown in Table 3, and are based on the OCD and CALPUFF model evaluation data set. The data set contains both very stable and fairly unstable 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, 1982 hour 1700, the air-sea temperature difference is -0.8°C , while the virtual potential temperature lapse rate is 0.06°C/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 $+0.5^{\circ}\text{C}$. These contradictory data were resolved using the same methodology as in the Pismo Beach dataset.

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 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.

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.

3.1.3 Carpinteria

The Carpinteria tracer study was conducted in September and October 1985. Studies were conducted to examine offshore impacts caused by both interaction with complex terrain and shoreline fumigation. The current analysis only evaluated the complex terrain data set as the AERCOARE-MOD approach currently cannot simulate shoreline fumigation.

Figure 3 shows the land use and terrain for the Carpinteria field study. The shoreline receptors are located on a 20 m to 30 m high bluff within 0.8 km to 1.5 km of the offshore tethersonde release. 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.

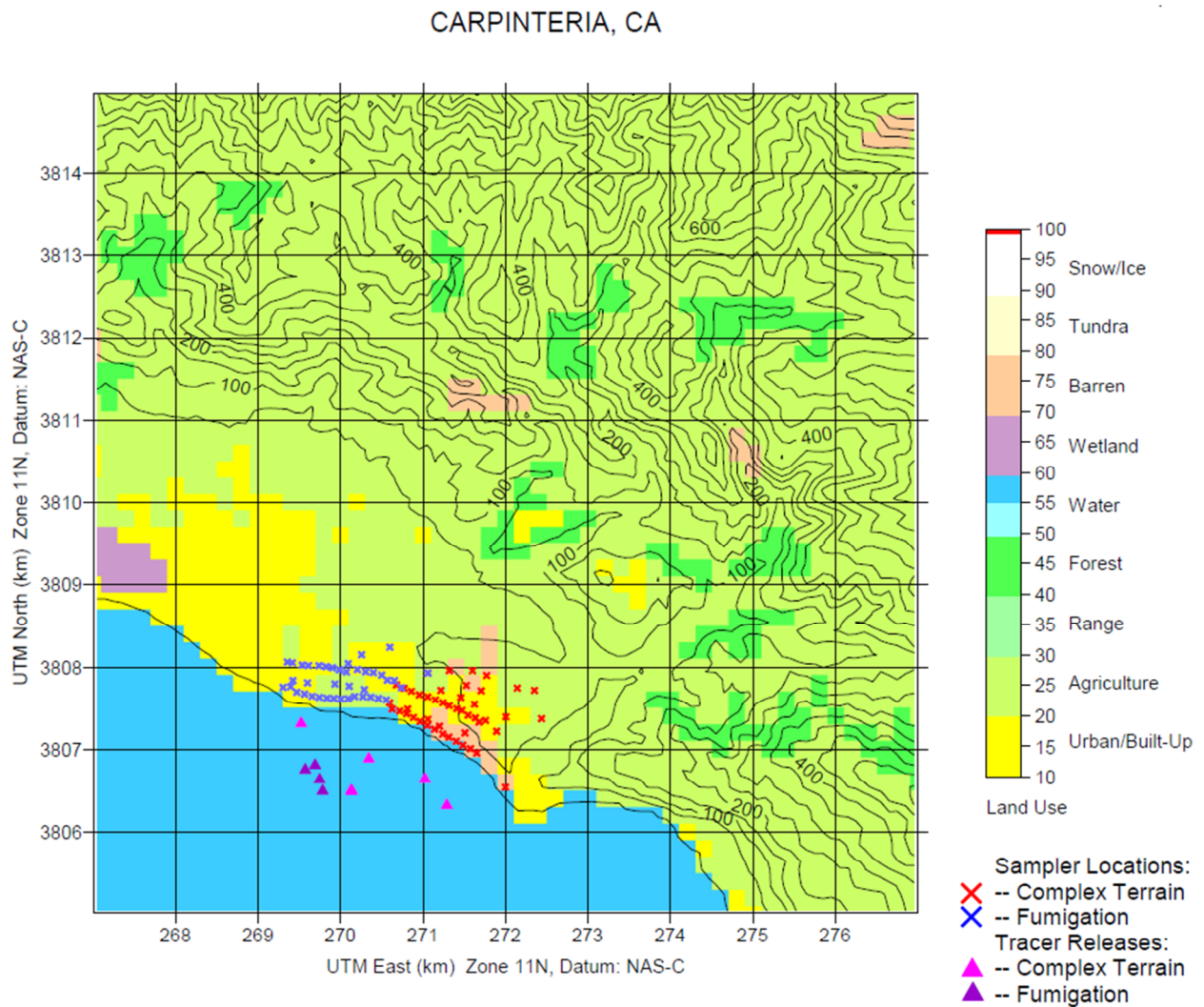


Figure 3. Carpinteria

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 AERCOARE-MOD 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 11103) (EPA, 2004c) 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.

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.

3.1.4 Ventura

The Ventura experiment was conducted during September 1980 and January 1981. Land use, release point locations and receptor sites are shown in Figure 4 based on the files from the CALPUFF evaluation archives. The tracer was released from a boat mast height of 8.1 m above the water. Peak concentrations occurred along the closet arc of receptors in Figure 4 at sampling distances from 7 km to 11 km away. The Ventura evaluation database consists of 17 samples.

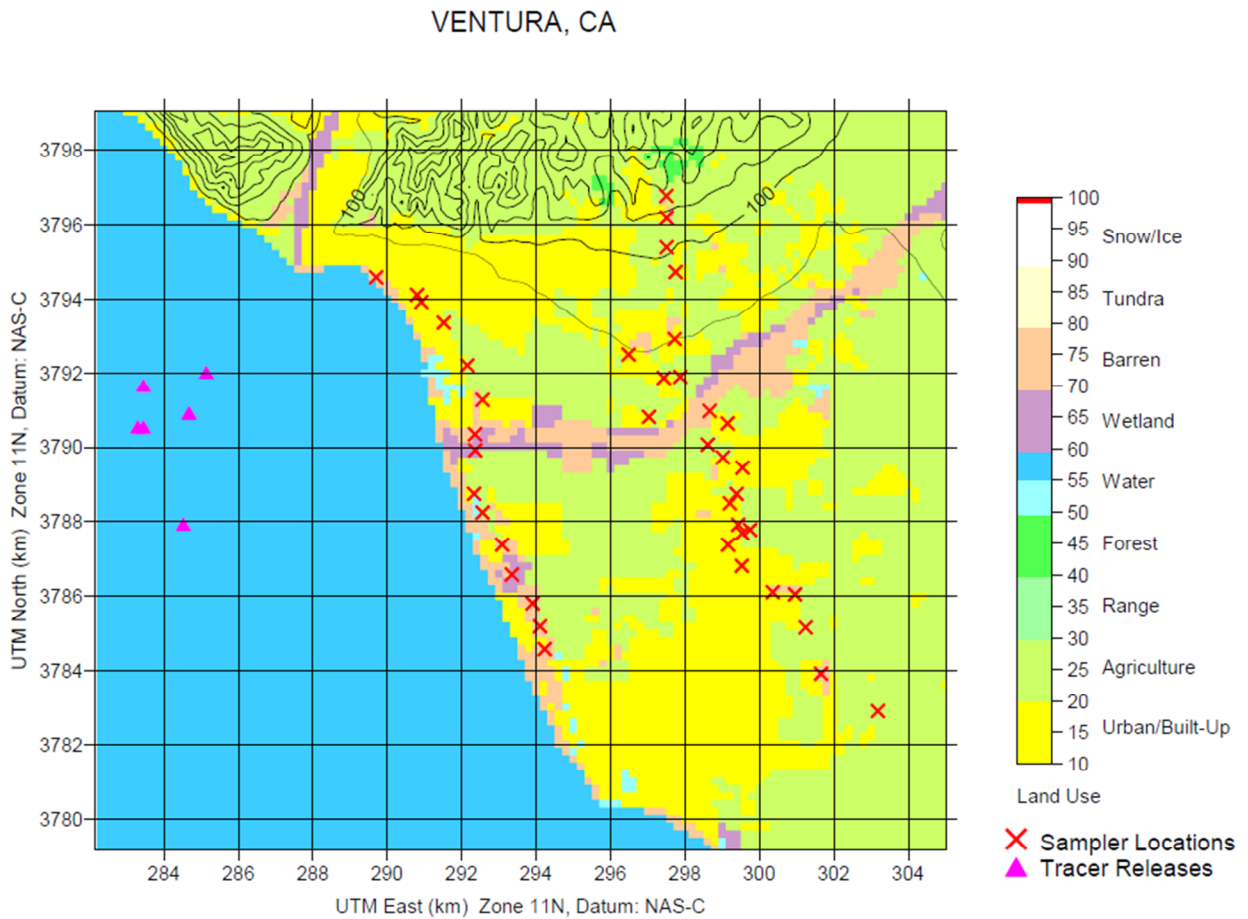


Figure 4. Ventura

The Ventura meteorological data used in the current analysis are shown in Table 7. The OCD and CALPUFF model evaluation data set stabilities ranged from moderately unstable to slightly stable. As with the Pismo Beach data, there are several hours of stable lapse rates accompanied by unstable air-sea temperature differences. For example, on September 29, 1980 hour 1400, the air-sea temperature difference is -0.8°C , while the virtual potential temperature lapse rate is 0.03°C/m . These contradictory data were resolved using the same methodology as in the Pismo Beach and Cameron datasets.

Table 8 shows the source and receptor characteristics used in the Ventura tracer simulations. 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.

Table 7. Ventura 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) |
|---------------|-------------------|----------------------|-----------|------------------|-------------|-----------------|---------------|------------------|-----------------------------|-------------|--------------------------|
| 9/24/80 16:00 | 20.5 | 7.0 | 266 | 4.1 | 400 | 72 | 288.3 | -2.1 | 0.00 | 8.0 | -2.1 |
| 9/24/80 18:00 | 20.5 | 7.0 | 281 | 6.2 | 400 | 78 | 288.0 | -2.0 | 0.00 | 6.5 | -2.0 |
| 9/24/80 19:00 | 20.5 | 7.0 | 292 | 6.9 | 400 | 77 | 288.0 | -2.1 | 0.00 | 6.0 | -2.1 |
| 9/27/80 14:00 | 20.5 | 7.0 | 272 | 6.3 | 400 | 80 | 288.0 | -1.9 | 0.00 | 4.7 | -1.9 |
| 9/27/80 19:00 | 20.5 | 7.0 | 272 | 6.1 | 400 | 80 | 289.0 | -1.0 | 0.00 | 3.6 | -1.0 |
| 9/28/80 18:00 | 20.5 | 7.0 | 265 | 3.1 | 250 | 80 | 290.0 | -1.0 | 0.01 | 4.4 | 0.0 |
| 9/29/80 14:00 | 20.5 | 7.0 | 256 | 3.3 | 100 | 76 | 288.7 | -0.8 | 0.03 | 5.0 | 0.1 |
| 9/29/80 16:00 | 20.5 | 7.0 | 264 | 5.1 | 100 | 76 | 289.3 | 0.0 | 0.03 | 3.9 | 0.1 |
| 9/29/80 18:00 | 20.5 | 7.0 | 264 | 5.2 | 50 | 76 | 289.2 | -0.1 | 0.03 | 5.2 | 0.1 |
| 1/6/81 16:00 | 20.5 | 7.0 | 276 | 4.0 | 50 | 60 | 290.3 | 1.6 | 0.01 | 21.5 | 1.6 |
| 1/6/81 17:00 | 20.5 | 7.0 | 283 | 5.1 | 50 | 58 | 290.6 | 1.7 | 0.01 | 13.1 | 1.7 |
| 1/6/81 18:00 | 20.5 | 7.0 | 276 | 4.9 | 50 | 60 | 290.4 | 1.8 | 0.01 | 9.4 | 1.8 |
| 1/9/81 15:00 | 20.5 | 7.0 | 286 | 4.7 | 100 | 87 | 287.6 | -0.9 | 0.00 | 3.4 | -0.9 |
| 1/9/81 16:00 | 20.5 | 7.0 | 277 | 4.6 | 100 | 85 | 288.0 | -0.5 | 0.00 | 4.8 | -0.5 |
| 1/9/81 18:00 | 20.5 | 7.0 | 274 | 4.9 | 100 | 87 | 288.2 | -0.3 | 0.00 | 3.1 | -0.3 |
| 1/13/81 15:00 | 20.5 | 7.0 | 274 | 5.8 | 50 | 65 | 290.1 | 1.4 | 0.01 | 11.6 | 1.4 |
| 1/13/81 17:00 | 20.5 | 7.0 | 242 | 4.2 | 50 | 84 | 289.0 | 0.4 | 0.01 | 8.5 | 0.4 |

Table 8. Ventura Source and Receptor Data.

| Date/Time | Rel. Ht.(m) | Bldg. Ht. (m) | Bldg. Wid. (m) | Recep. Dist.(m) ¹ |
|---------------|-------------|---------------|----------------|------------------------------|
| 9/24/80 16:00 | 8.1 | 7.0 | 20.0 | 9291 |
| 9/24/80 18:00 | 8.1 | 7.0 | 20.0 | 9211 |
| 9/24/80 19:00 | 8.1 | 7.0 | 20.0 | 10799 |
| 9/27/80 14:00 | 8.1 | 7.0 | 20.0 | 9123 |
| 9/27/80 19:00 | 8.1 | 7.0 | 20.0 | 9123 |
| 9/28/80 18:00 | 8.1 | 7.0 | 20.0 | 9145 |
| 9/29/80 14:00 | 8.1 | 7.0 | 20.0 | 8085 |
| 9/29/80 16:00 | 8.1 | 7.0 | 20.0 | 7854 |
| 9/29/80 18:00 | 8.1 | 7.0 | 20.0 | 7854 |
| 1/6/81 16:00 | 8.1 | 7.0 | 20.0 | 7463 |
| 1/6/81 17:00 | 8.1 | 7.0 | 20.0 | 7416 |
| 1/6/81 18:00 | 8.1 | 7.0 | 20.0 | 7463 |
| 1/9/81 15:00 | 8.1 | 7.0 | 20.0 | 7956 |
| 1/9/81 16:00 | 8.1 | 7.0 | 20.0 | 7749 |
| 1/9/81 18:00 | 8.1 | 7.0 | 20.0 | 7704 |
| 1/13/81 15:00 | 8.1 | 7.0 | 20.0 | 7705 |
| 1/13/81 17:00 | 8.1 | 7.0 | 20.0 | 6914 |

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.

3.2 AERCOARE Overwater Data Set Procedures

AERCOARE Version 1.0 (12275) was applied to prepare the overwater meteorological data for the four offshore datasets. Several different options within AERCOARE were evaluated in the study including the estimation of mixing heights, the use of horizontal wind direction (sigma-theta data), and limitations on several important variables provided to AERMOD. Further details are provided in the following discussion.

3.2.1 Data for AERCOARE

AERCOARE uses the COARE algorithm 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. The warm-layer effects option also needs continuous data over the diurnal cycle that are not available for the tracer studies. 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, Ventura, or Carpinteria data sets (Earth Tech, 2006).

(AERCOARE variable $J_{warm} = J_{cool} = 0$).

- 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, sensitivity tests from previous studies suggest the COARE algorithm is not very sensitive to surface roughness options, especially in the absence of wave measurement data. (AERCOARE variable $J_{wave} = 0$).
- 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, Table 5, and Table 7. The measurement heights are also listed in these tables.
- Wind direction was assumed to be from the west for the Pismo Beach, Ventura 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.
- Surface pressure was assumed to be 1000 mb. This is the same pressure assumed for previous evaluation studies with these data sets and the COARE algorithm is not sensitive to the assumed atmospheric pressure.
- 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 default for this parameter. (AERCOARE variable $defzi = 600$ m).

AERCOARE combines surface energy flux estimates from the COARE algorithm with additional overwater measurements. Such techniques were evaluated using several options as discussed in the next section.

3.2.2 AERCOARE Meteorological Data Assembly Options

Several different AERCOARE options were considered for preparation of the AERMOD data and were included as cases in the model evaluation. The options selected for the evaluation and associated data are as follows:

- 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, Table 5 and Table 7. One case in the AERCOARE-MOD 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 Pismo Beach or Ventura 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 CALPUFF evaluation studies.
- AERMOD restricts the Monin-Obukhov length (L) such that $ABS(L) > 1$. This restriction avoids unrealistic extremely stable and unstable conditions during light wind conditions. In the evaluation simulations, we tested a Monin-Obukhov length of $ABS(L) > 5$, as is assumed by OCD and CALPUFF over water. (AERCOARE variable $dlmin = 5$ m).
- The virtual potential temperature gradient above the convective boundary layer was assumed to $0.01^\circ\text{C}/\text{m}$. 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 and plume penetration are not applicable to the passive tracer releases in the current evaluation. (AERCOARE variable $dvptg = 0.01^\circ\text{C}/\text{m}$).
- Convective boundary layer heights were assumed to be the same as the observed mixing heights from field studies when conditions were unstable as indicated by the Monin-Obukhov length ($L < 0$). Two options for mechanical mixing heights (z_{im}) were considered in the evaluation:
 - mechanical mixing heights were calculated from the surface friction velocity using the Venketram equation in AERMET (Venketram, 1980). The AERCOARE option for smoothing as in AERMET was not applied 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 in these studies. (AERCOARE variable $mixopt = 1$)
 - mechanical mixing heights were also assumed to be the same as the observed mixing heights in Table 1, Table 3, Table 5 and Table 7. (AERCOARE variable $mixopt = 0$)
- For low winds and smooth surfaces, the Venketram equation 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. AERMOD requires mixing heights be above 1 m. In this study we used a minimum mixing height of 25 m (AERCOARE variable $zimin = 25$ m). Appendix A provides further discussion on the sensitivity of the results to the assumed minimum mechanical mixing height.

Using the techniques and data discussed above, AERCOARE-MOD meteorological data sets were prepared for each of the four 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 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 σ_θ measurements, and observed mixing heights for the mechanical mixing height (z_{im}).
- Case 4: Require Abs (L) > 5, use σ_θ measurements, and observed mixing heights for the mechanical mixing height (z_{im}).
- Case 5: Require Abs (L) > 5, use 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 CALPUFF evaluations found this equation performed better than several alternatives that are more similar to the formulation used by AERMOD (Earth Tech, 2006).

AERCOARE-MOD predictions from the five cases above were obtained for the Pismo Beach, Cameron, Ventura, and Carpinteria data sets. The same five model option cases were evaluated in previous studies submitted to R10 and the EPA Modeling Clearinghouse (EPA 2011a; EPA 2011b). The current analysis adds the Ventura field study to the three data sets previously evaluated. Peak predictions were compared to peak observations using the statistical model evaluation methods discussed in the following section.

3.3 Statistical Evaluation Procedures

Statistical procedures were applied to evaluate whether the AERCOARE-MOD modeling approach was biased towards underestimates using the Pismo Beach, Cameron, Ventura, 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 (EPA, 2003) 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 predictions 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 n th highest concentration and \bar{c} is the average of the $(n-1)$ highest concentrations. For the small sample size data sets in the current analysis, n was taken to be 10.

- 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 (Chang and Hanna, 2005). The BOOT program is an update of the package applied in the CALPUFF evaluation (Earth Tech, 2006). 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, $MG = 1$ 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:

$$VG = e^{\left(\overline{\left(\ln\left(\frac{c_o}{c_p}\right)\right)^2}\right)}$$

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. Complete output listings from the BOOT program for each dataset and the combined dataset are attached.

4.0 RESULTS

AERCOARE-MOD simulations were conducted to predict concentrations from the Pismo Beach, Cameron, Ventura, and Carpinteria field studies using four different methods for the preparation of the meteorological data, and for Case 5, the differences caused by an alternative lateral dispersion term. AERMOD (Version 12060) was applied using default dispersion options for rural flat terrain for the Pismo Beach, Ventura and Cameron simulations. Complex terrain was assumed for the Carpinteria data set. Peak predicted concentrations were compared to peak observed concentrations resulting in a total of 101 paired samples for statistical analysis with the techniques described in Section 3.3. 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 $\mu\text{s}/\text{m}^3$.

Figure 5 to Figure 9 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 and Ventura data sets, but these differences are difficult to pick out from the scatter diagrams.

Q-Q plots for the combined data set and each of the four individual data sets are shown in Figure 10 to Figure 14. Each plot shows the differences caused by the four different methods used to prepare the meteorological data, and for Case 5 the differences caused by an alternative lateral dispersion term. Figure 15 to Figure 19 show Q-Q plots for each of the five cases where the results from each field study are compared to one another.

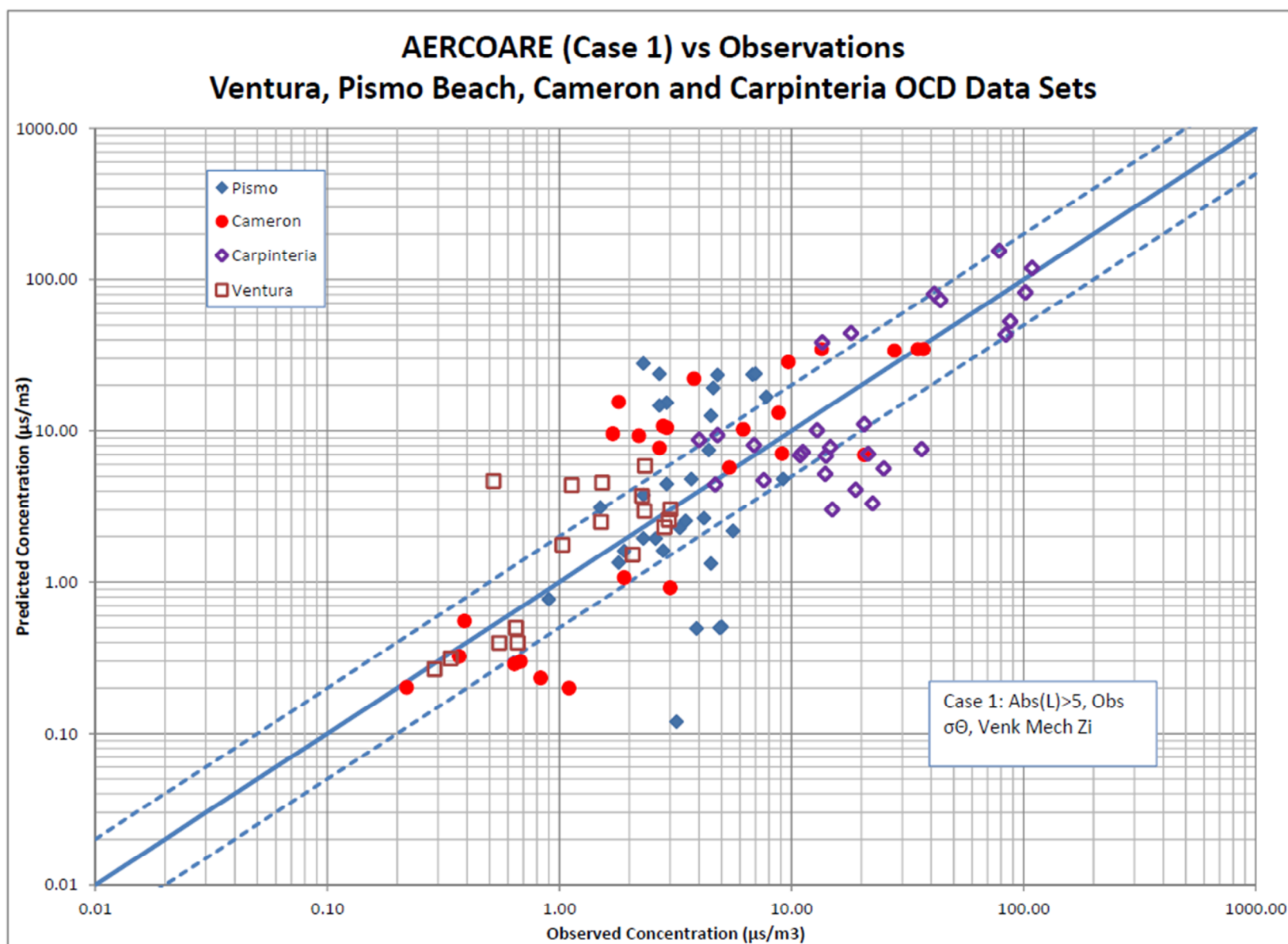


Figure 5. Scatter Plot of AERCOARE Case 1 versus Observations

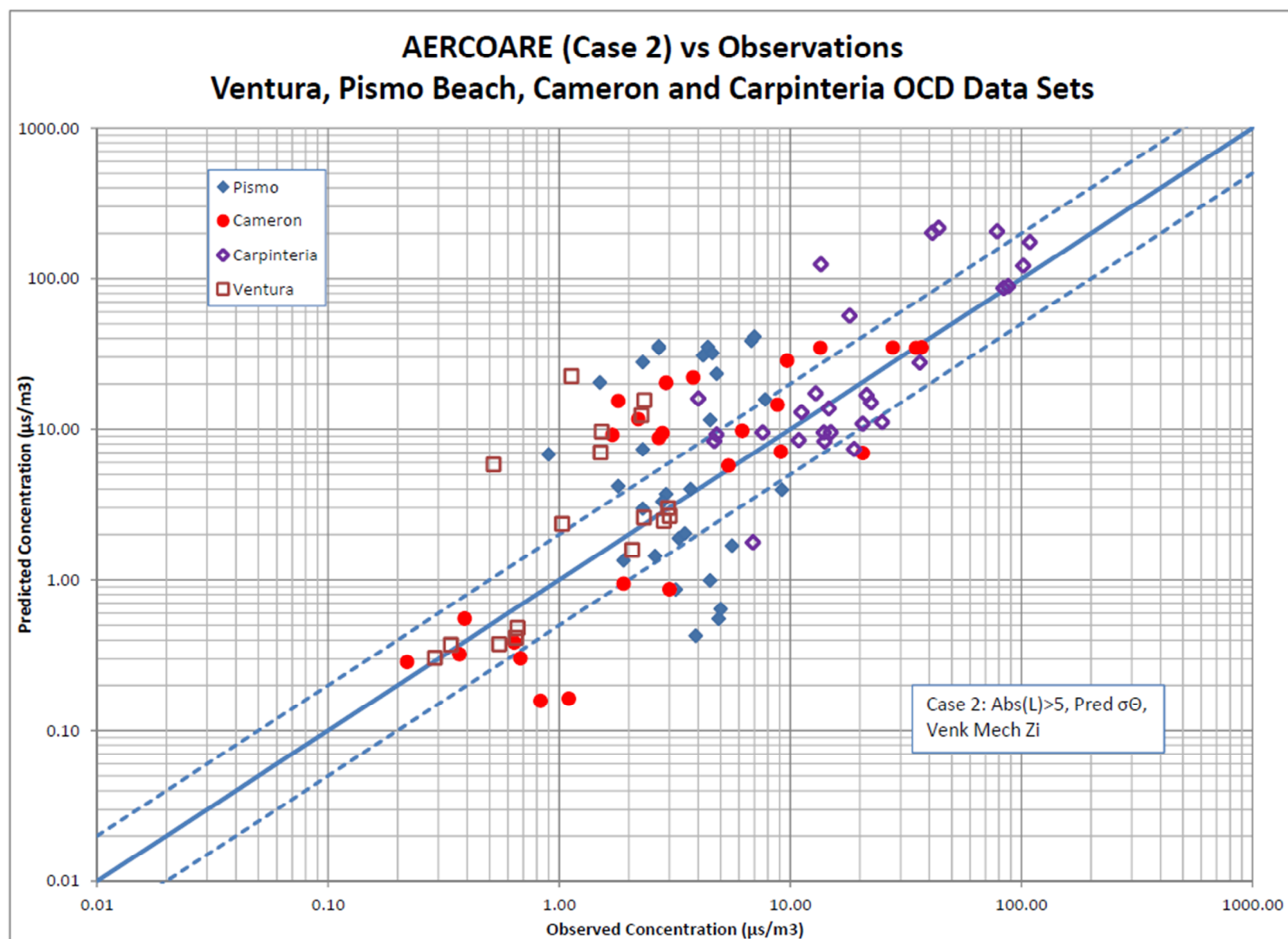


Figure 6. Scatter Plot of AERCOARE Case 2 versus Observations

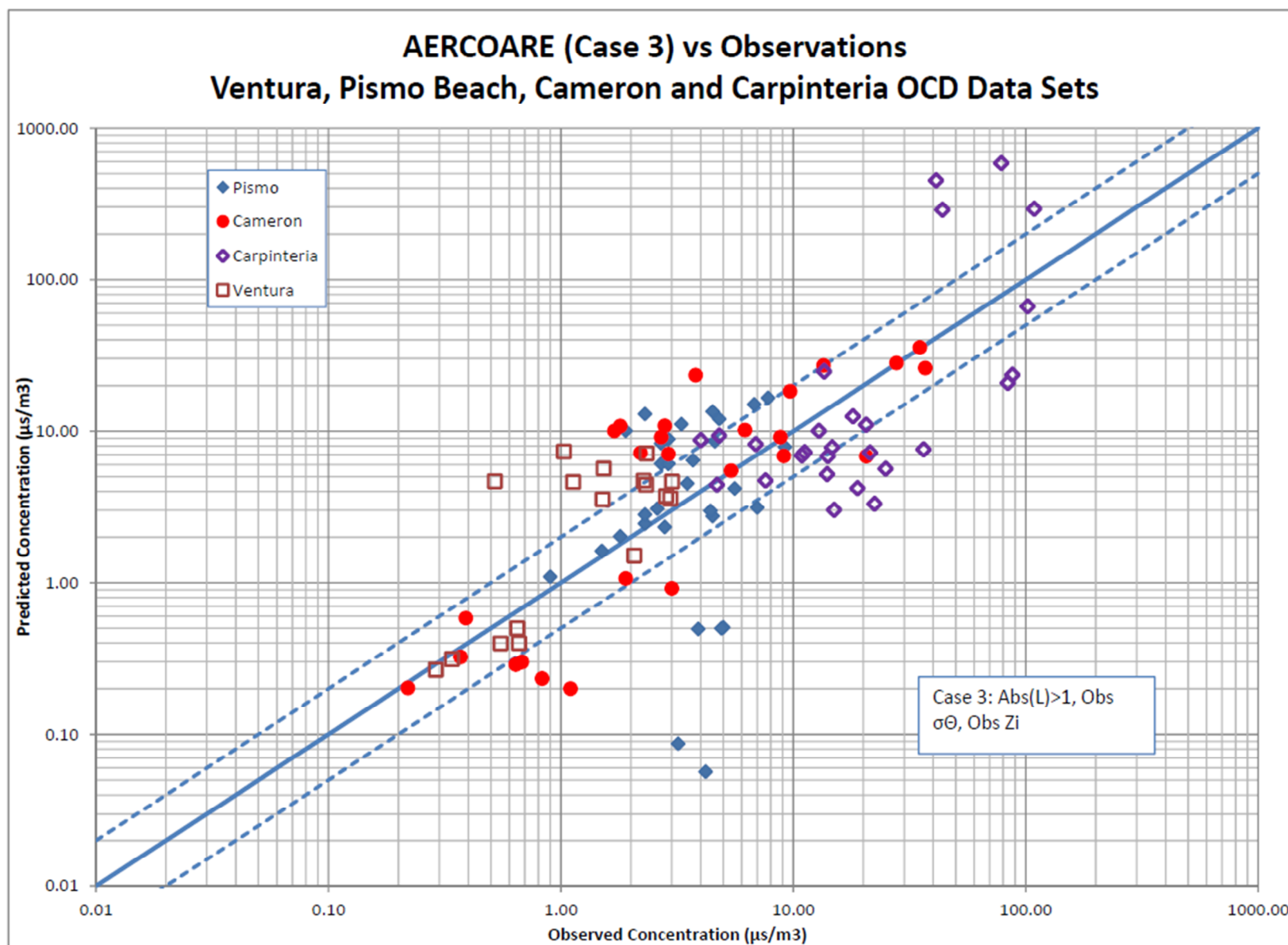


Figure 7. Scatter Plot of AERCOARE Case 3 versus Observations

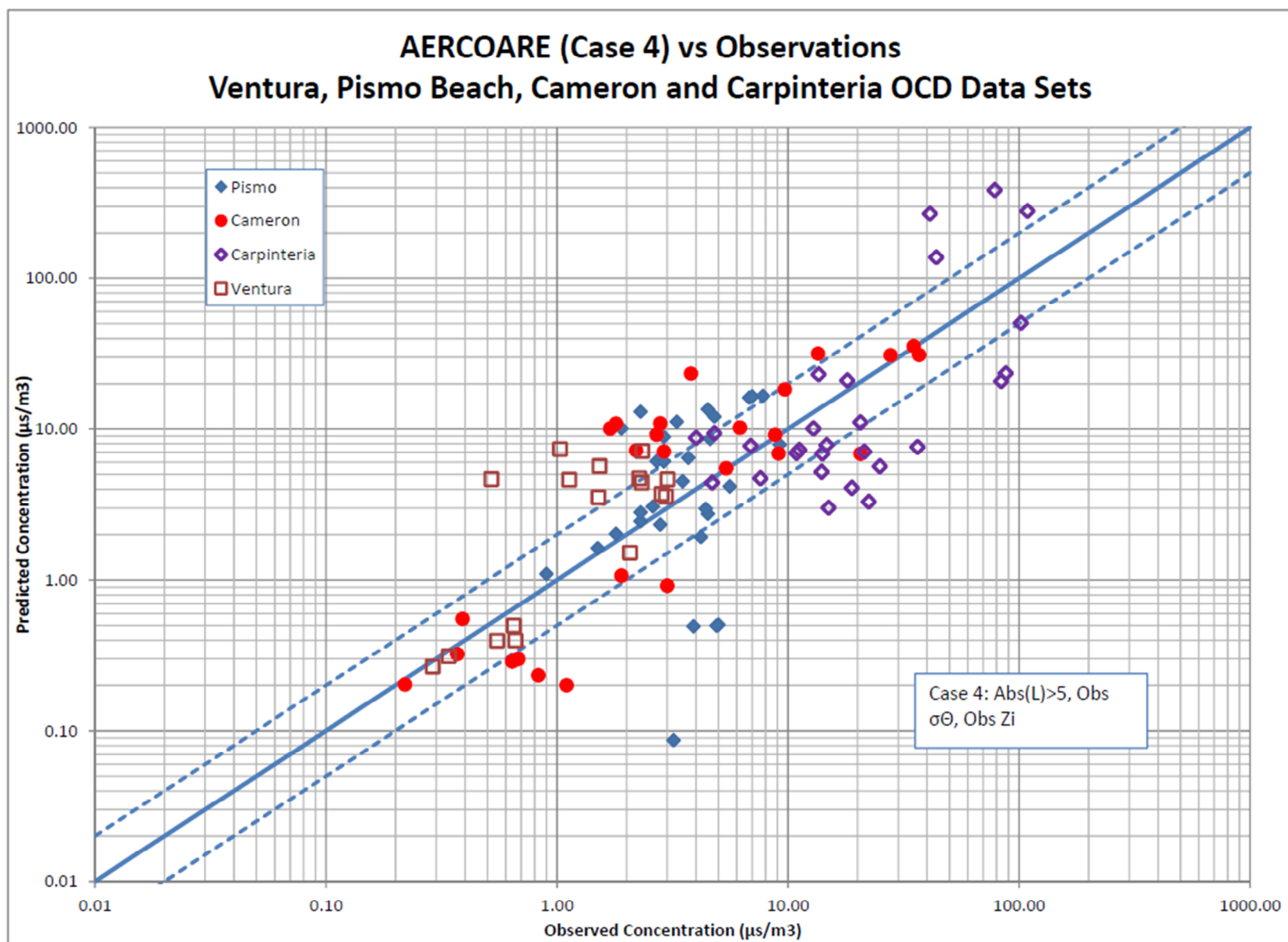


Figure 8. Scatter Plot of AERCOARE Case 4 versus Observations

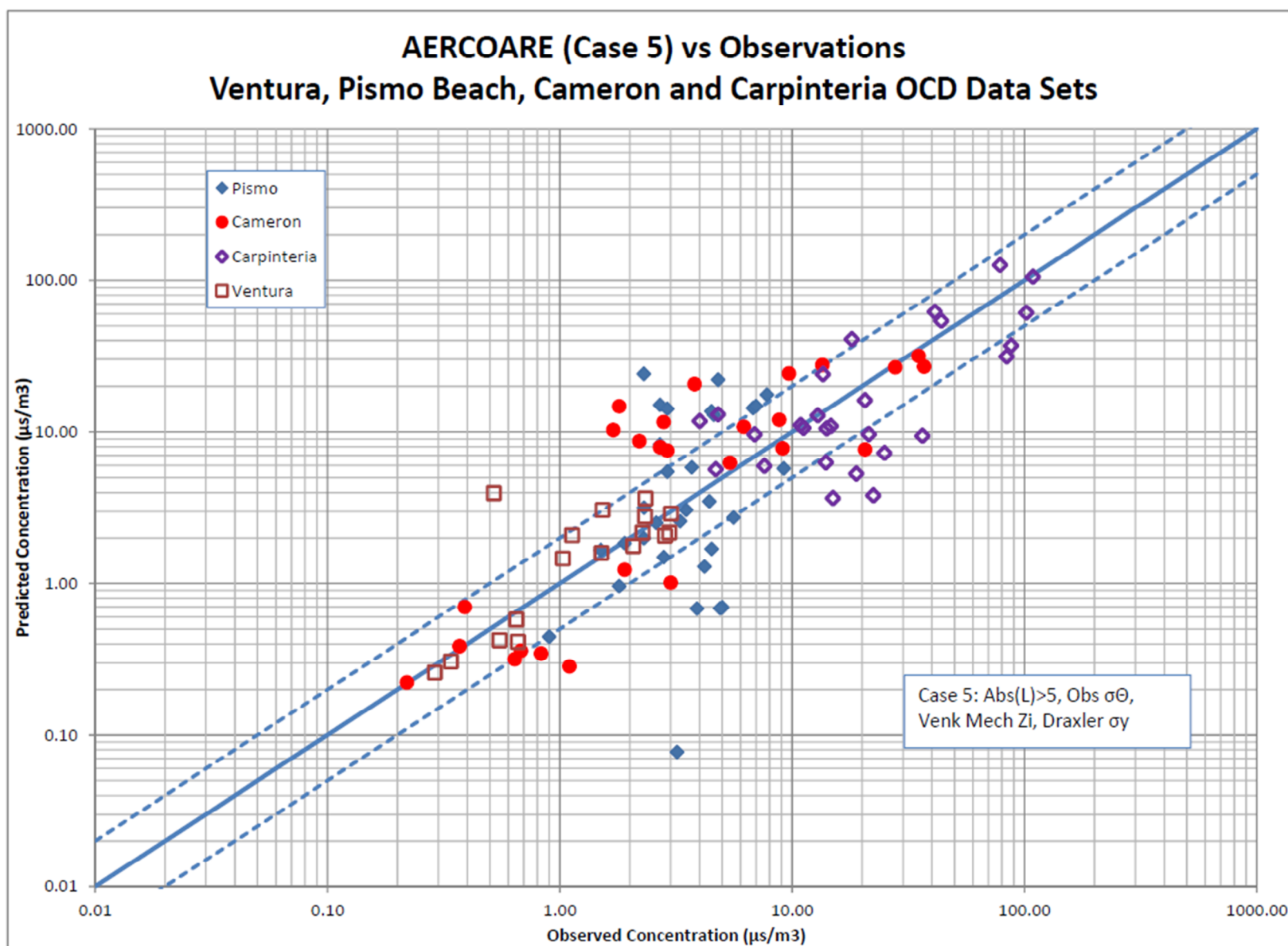


Figure 9. Scatter Plot of AERCOARE Case 5 versus Observations

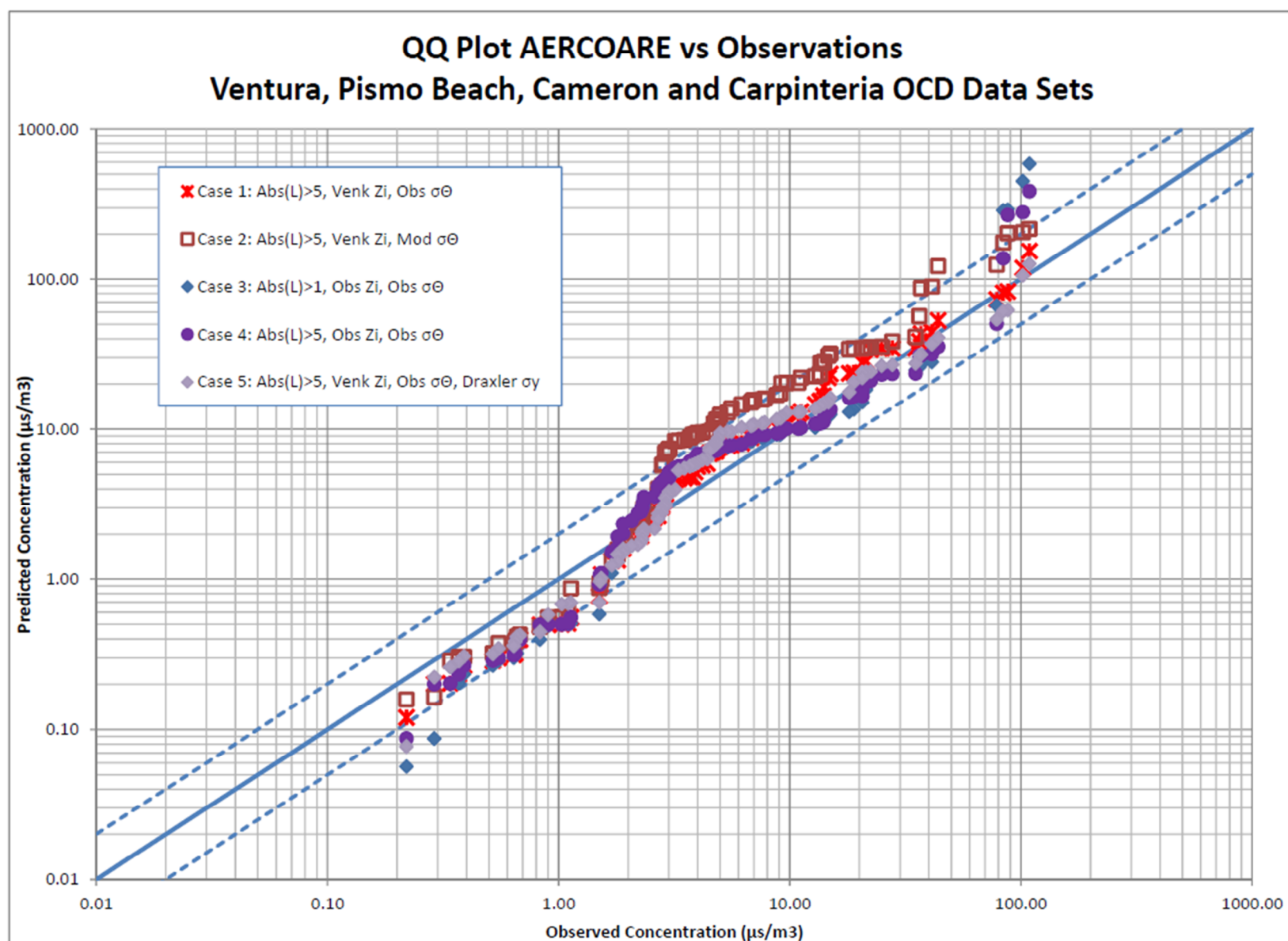


Figure 10. QQ Plot of AERCOARE versus All Observations

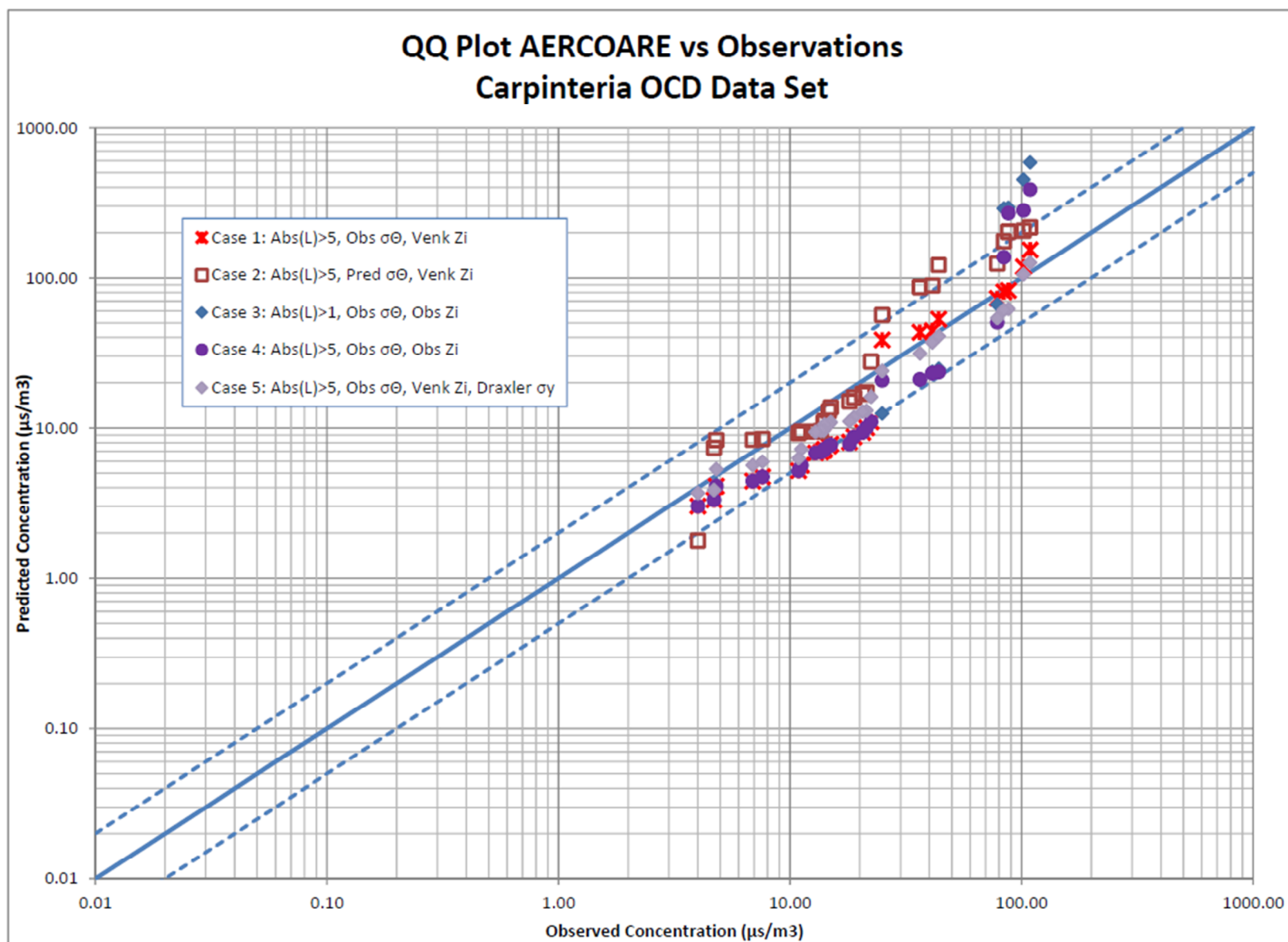


Figure 11. QQ Plot of AERCOARE versus Carpinteria Observations

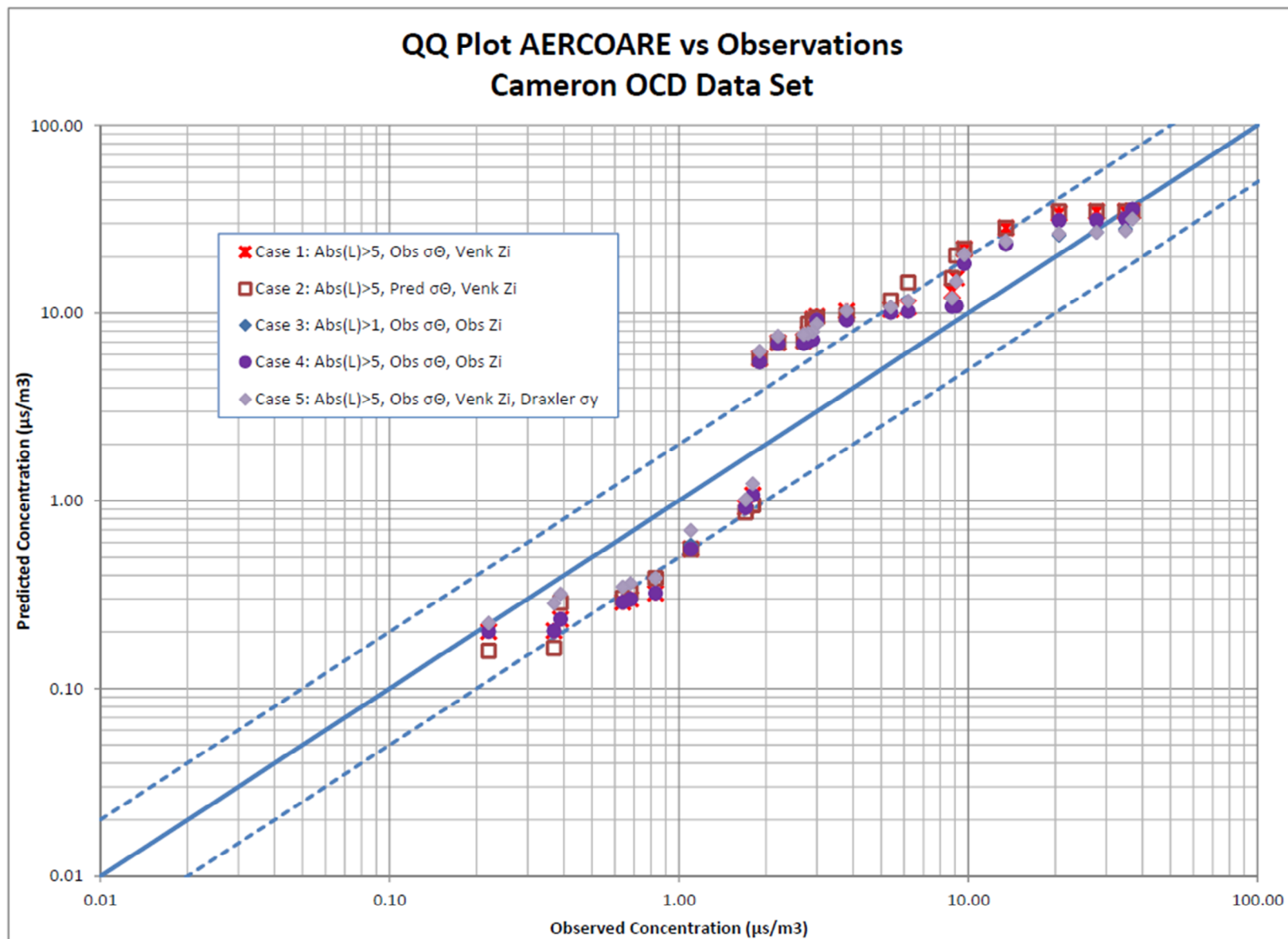


Figure 12. QQ Plot of AERCOARE versus Cameron Observations

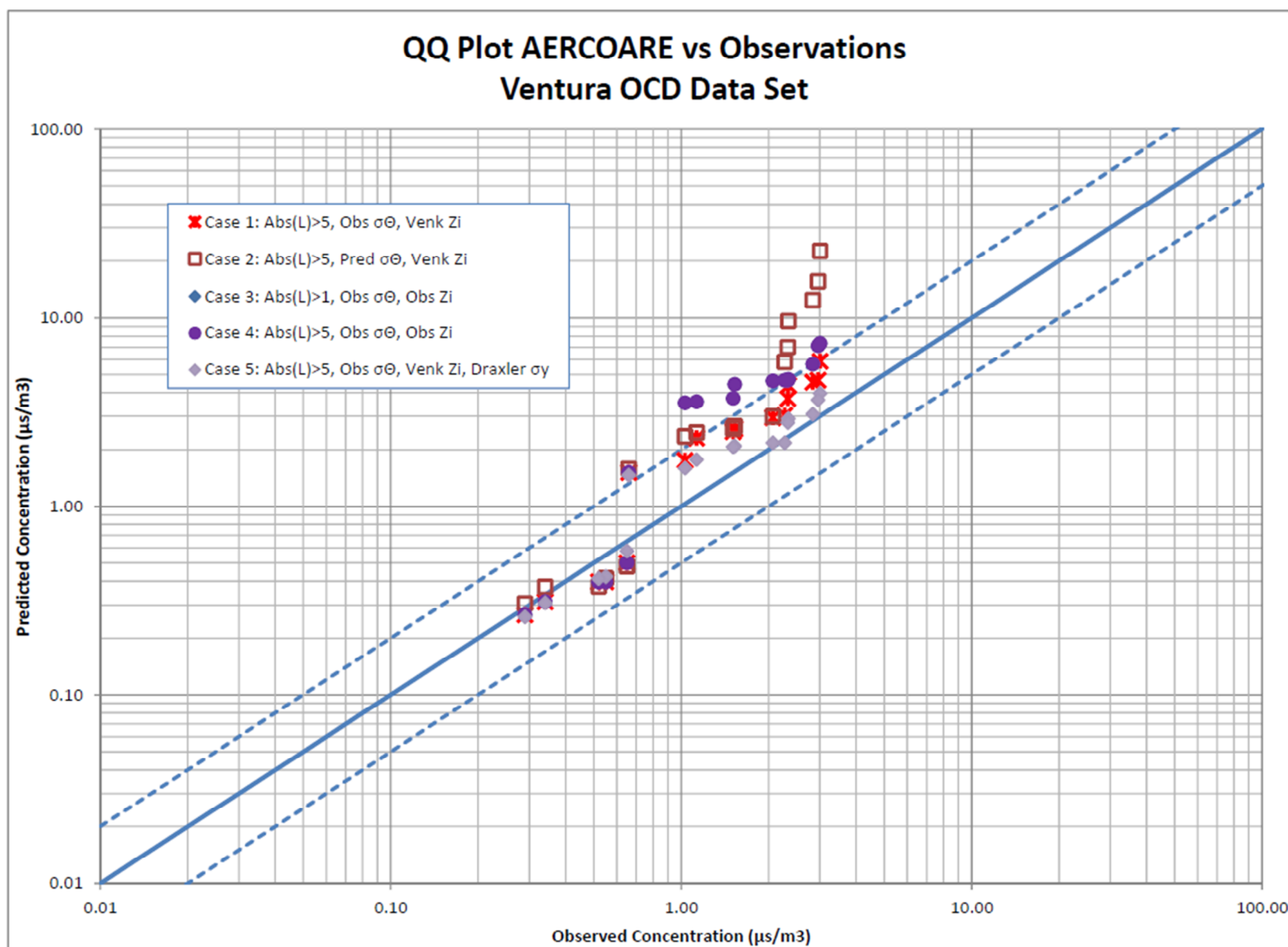


Figure 13. QQ Plot of AERCOARE versus Ventura Observations

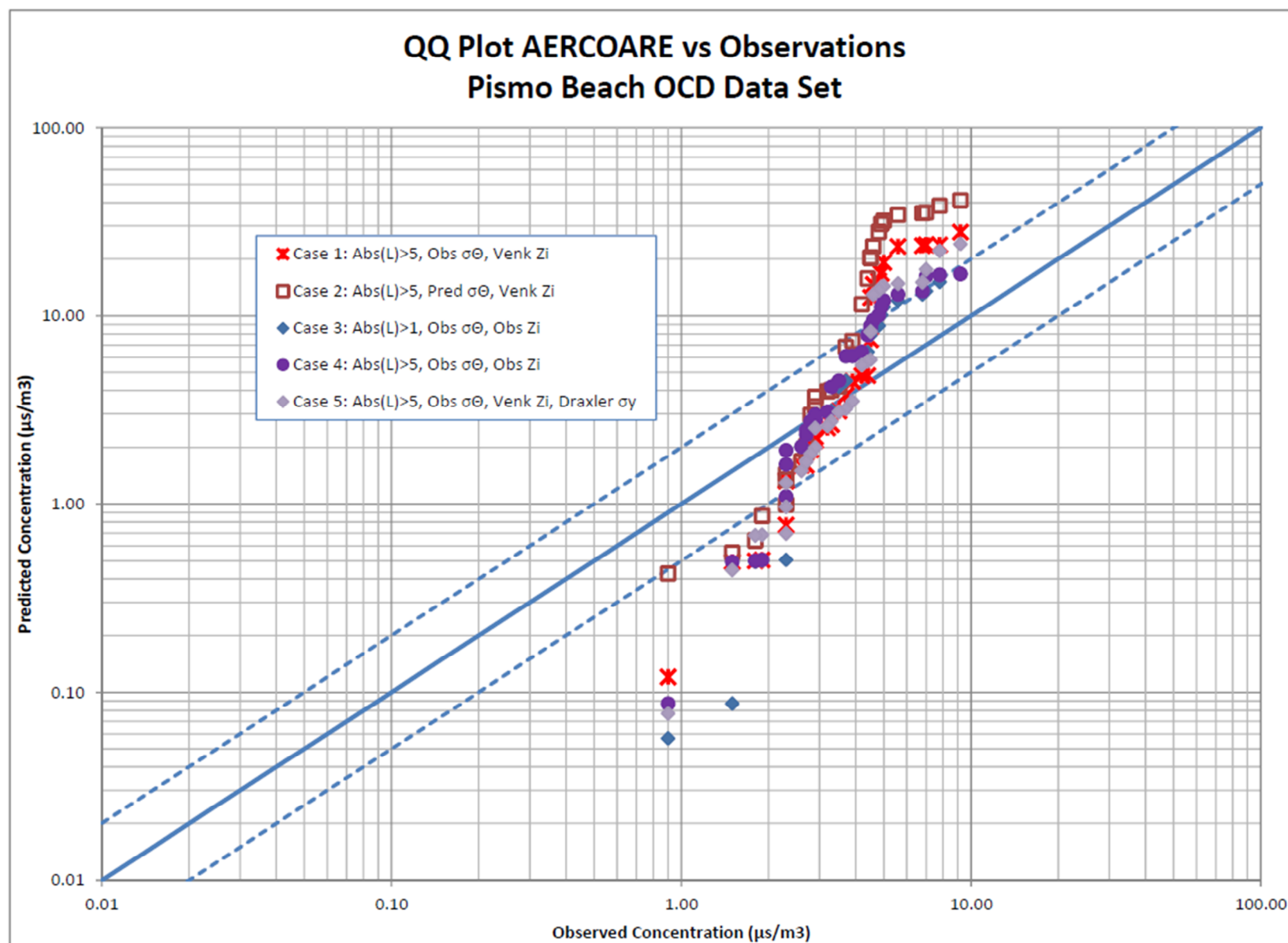


Figure 14. QQ Plot of AERCOARE versus Pismo Beach Observations

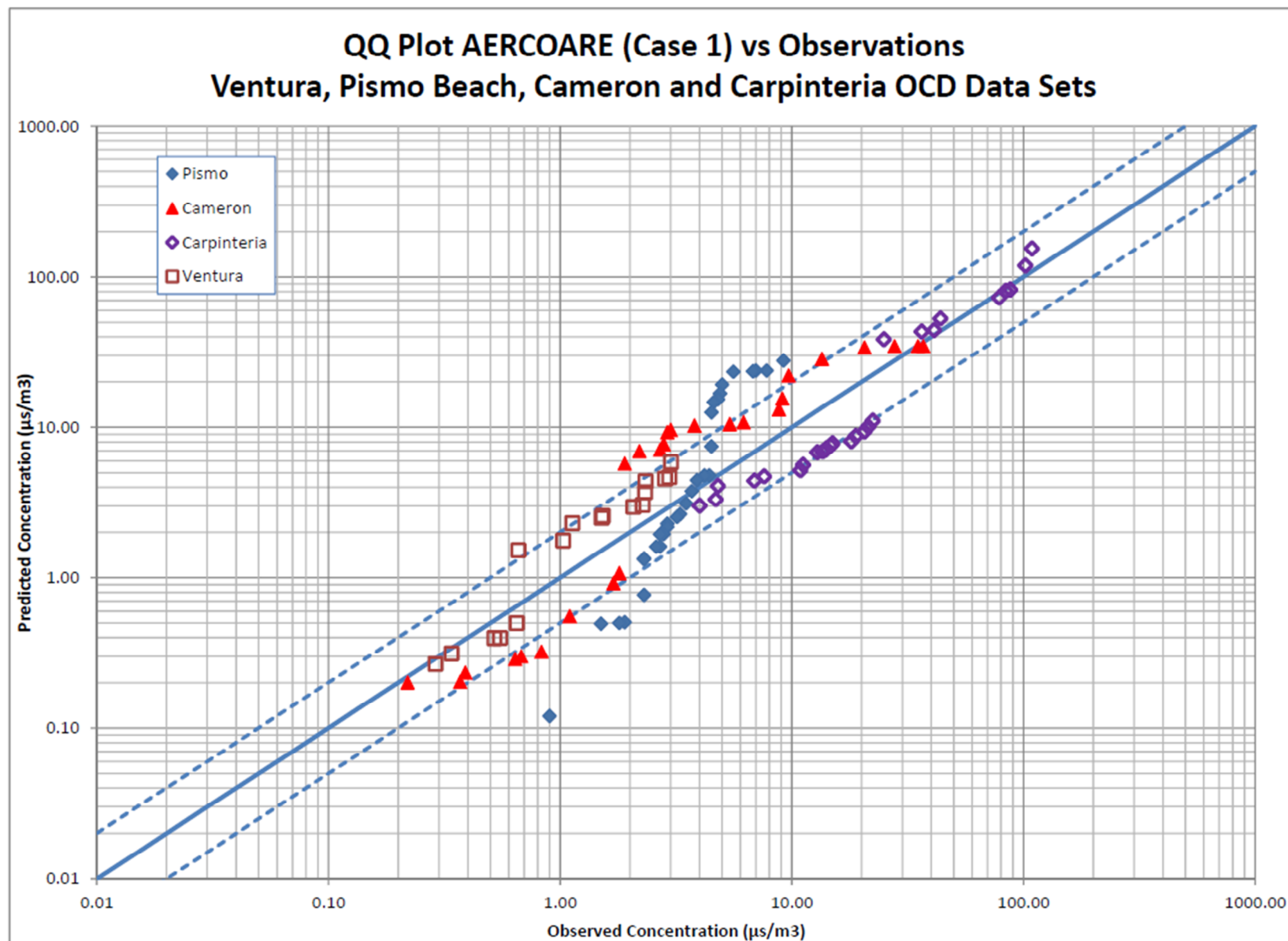


Figure 15. QQ Plot of AERCOARE Case 1 versus Observations

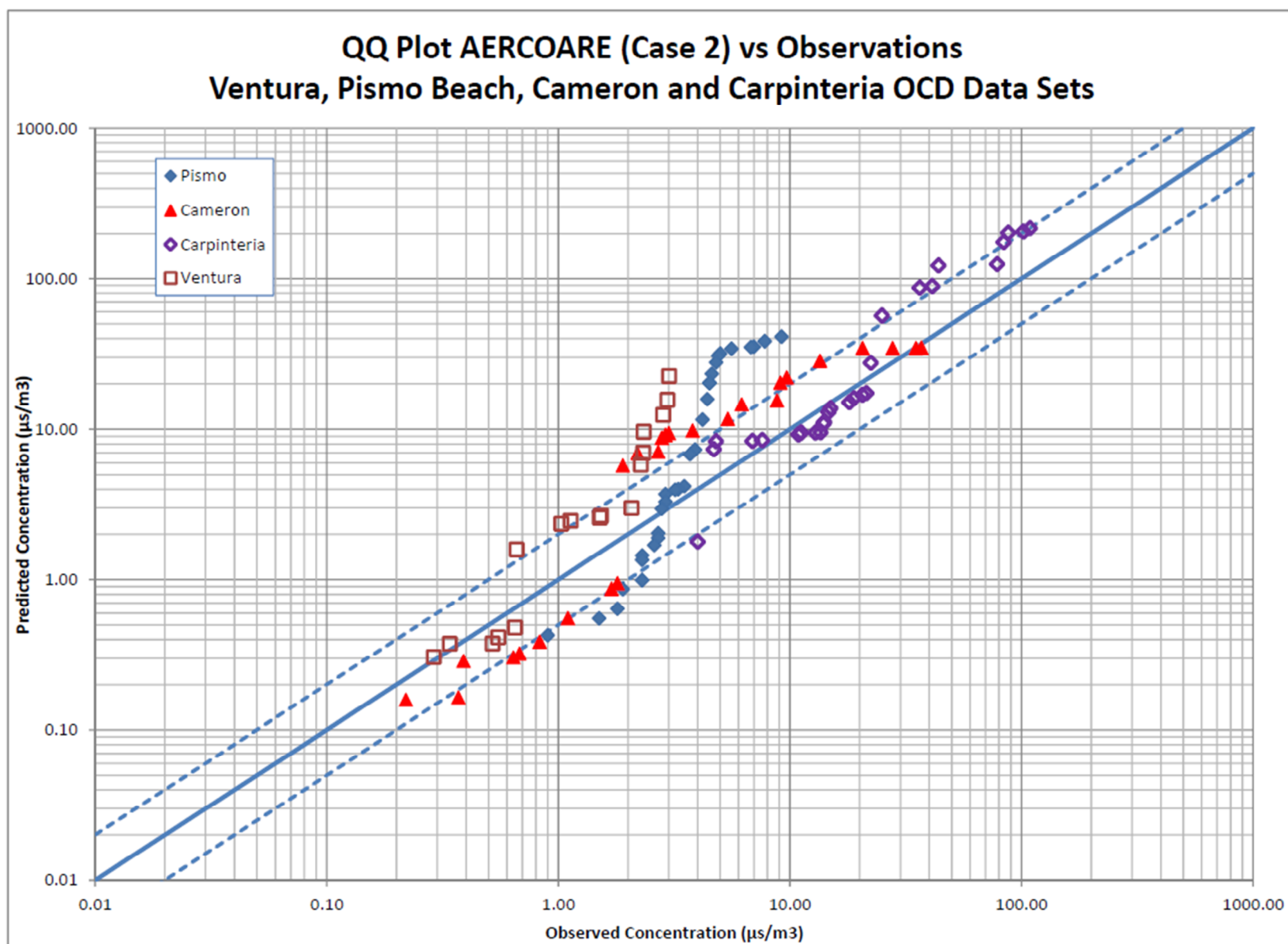
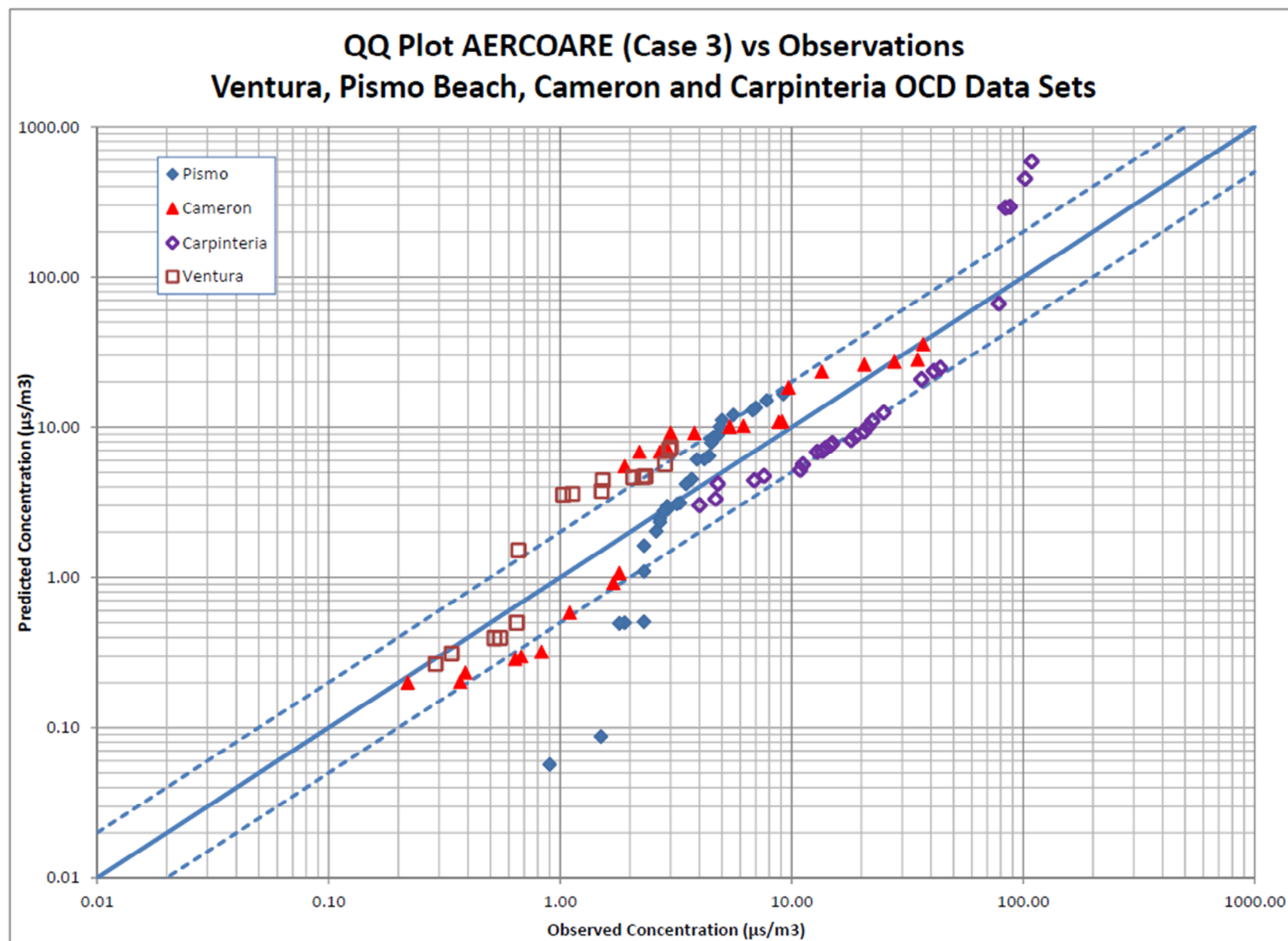


Figure 16. QQ Plot of AERCOARE Case 2 versus Observations



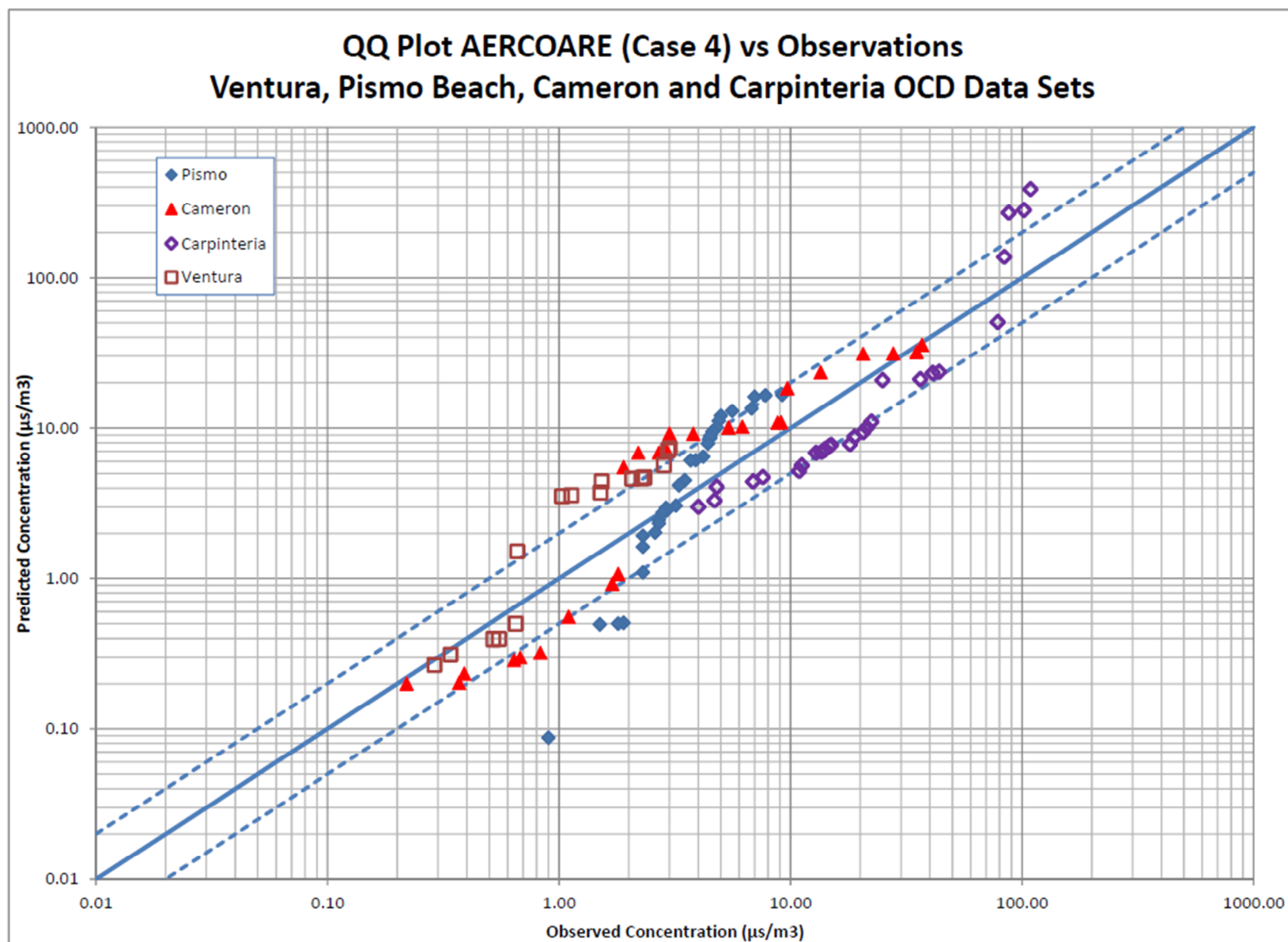


Figure 18. QQ Plot of AERCOARE Case 4 versus Observations

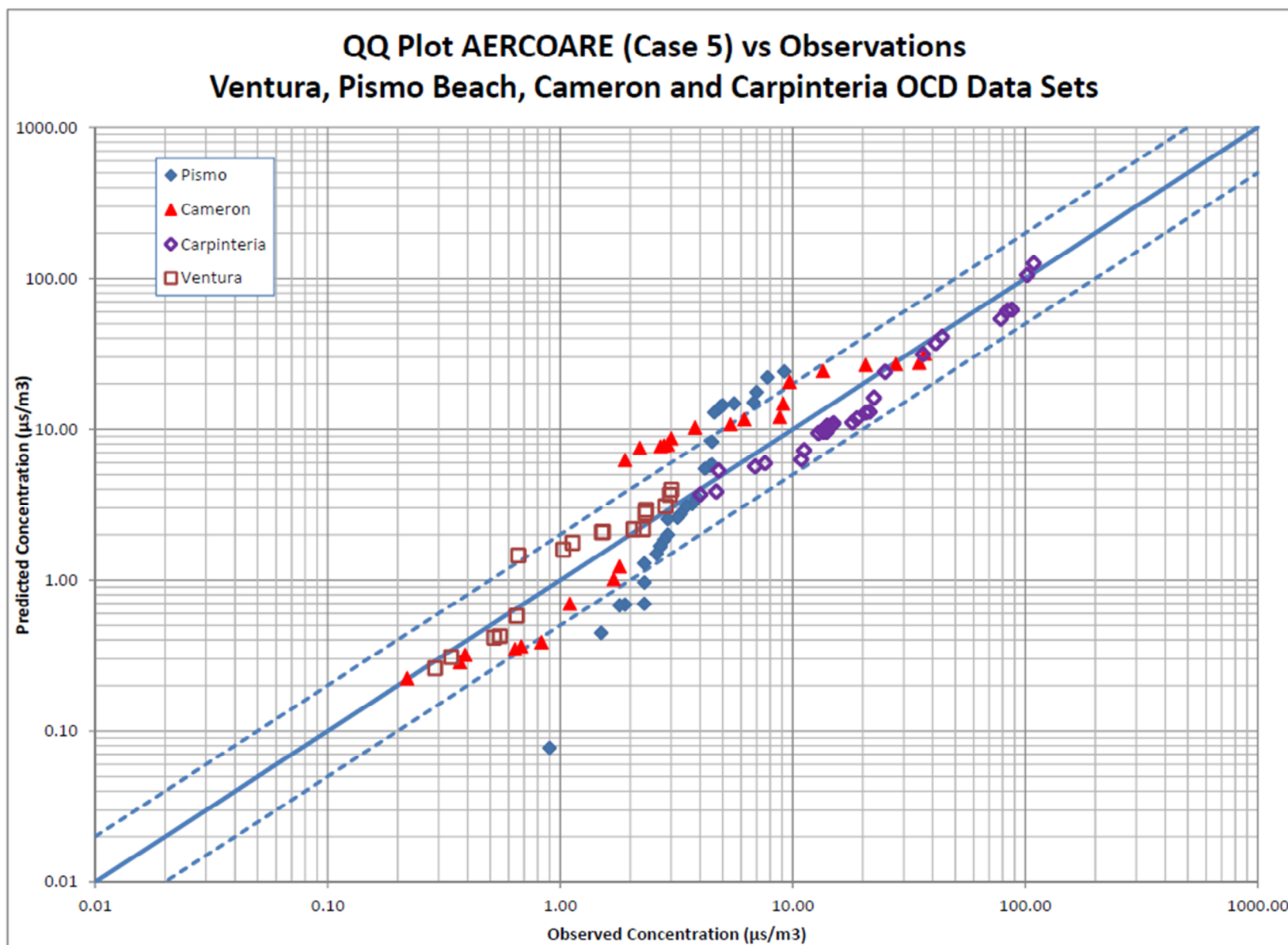


Figure 19. QQ Plot of AERCOARE Case 5 versus Observations

Comparing the Q-Q plots for the combined data set and each of the four field studies, the five AERCOARE-MOD 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 Ventura (Figure 13) and Pismo Beach (Figure 14) data sets. In most instances higher concentrations are over-predicted using the AERMOD σ_θ estimates (Case 2). Importantly, AERCOARE-MOD 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 2 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. Allowing the Monin-Obukhov length to become very stable (Case 3) also resulted in severe over-predictions in some instances. Removing the dependency of the lateral dispersion term on mixing height (Case 5) also improved 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 9 where the best performing modeling approach is highlighted for each statistic and data set. The full output of the BOOT program is attached in Appendix B. Table 9 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. Overall, the performance statistics tend to be the best for Case 5 with the modified lateral dispersion term followed by Case 1. The poorest performance usually was associated with using predicted AERMOD σ_θ estimates (Case 2).

Table 9. Performance Evaluation Statistical Results by Data Set and AERCOARE-MOD Case.

| Data Set | Case | Description | Geom. Mean ($\mu\text{s}/\text{m}^3$) | Geom. Std. | MG | VG | Geom. Correl. Coef. | Frac. Factor of 2 | RHC ($\mu\text{s}/\text{m}^3$) |
|--|------|--|---|---------------|-------------|-------------|---------------------------|-------------------------|-------------------------------------|
| All Data (101 samples) | 0 | Observations | 4.5 | 1.36 | 1.00 | 1.00 | 1.00 | 1.00 | 125 |
| | 1 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi | 4.7 | 1.60 | 0.96 | 3.21 | 0.75 | 0.54 | 146 |
| | 2 | Abs(L)>5, Pred $\sigma\theta$, Venk Zi | 6.8 | 1.73 | 0.67 | 4.93 | 0.72 | 0.47 | 311 |
| | 3 | Abs(L)>1, Obs $\sigma\theta$, Obs Zi | 4.7 | 1.67 | 0.97 | 4.05 | 0.71 | 0.48 | 493 |
| | 4 | Abs(L)>5, Obs $\sigma\theta$, Obs Zi | 4.9 | 1.57 | 0.93 | 3.23 | 0.74 | 0.47 | 333 |
| | 5 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi, Draxler $\sigma\gamma$ | 4.6 | 1.53 | 0.99 | 2.60 | 0.78 | 0.55 | 117 |
| Ventura, CA (17 samples) | 0 | Observations | 1.2 | 0.76 | 1.00 | 1.00 | 1.00 | 1.00 | 4 |
| | 1 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi | 1.6 | 1.03 | 0.73 | 1.81 | 0.73 | 0.77 | 6 |
| | 2 | Abs(L)>5, Pred $\sigma\theta$, Venk Zi | 2.4 | 1.37 | 0.50 | 5.28 | 0.62 | 0.59 | 20 |
| | 3 | Abs(L)>1, Obs $\sigma\theta$, Obs Zi | 2.1 | 1.18 | 0.57 | 2.58 | 0.75 | 0.59 | 8 |
| | 4 | Abs(L)>5, Obs $\sigma\theta$, Obs Zi | 2.1 | 1.18 | 0.57 | 2.58 | 0.75 | 0.59 | 8 |
| | 5 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi, Draxler $\sigma\gamma$ | 1.4 | 0.88 | 0.87 | 1.41 | 0.77 | 0.88 | 4 |
| 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 $\sigma\theta$, Venk Zi | 3.7 | 1.39 | 0.93 | 6.17 | 0.27 | 0.45 | 43 |
| | 2 | Abs(L)>5, Pred $\sigma\theta$, Venk Zi | 5.9 | 1.45 | 0.59 | 12.90 | 0.04 | 0.26 | 55 |
| | 3 | Abs(L)>1, Obs $\sigma\theta$, Obs Zi | 3.2 | 1.40 | 1.09 | 7.53 | 0.14 | 0.45 | 19 |
| | 4 | Abs(L)>5, Obs $\sigma\theta$, Obs Zi | 3.8 | 1.23 | 0.91 | 4.30 | 0.26 | 0.45 | 20 |
| | 5 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi, Draxler $\sigma\gamma$ | 3.3 | 1.33 | 1.04 | 4.80 | 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 $\sigma\theta$, Venk Zi | 4.1 | 1.84 | 0.78 | 3.03 | 0.83 | 0.42 | 49 |
| | 2 | Abs(L)>5, Pred $\sigma\theta$, Venk Zi | 4.2 | 1.87 | 0.76 | 3.60 | 0.81 | 0.42 | 53 |
| | 3 | Abs(L)>1, Obs $\sigma\theta$, Obs Zi | 3.7 | 1.77 | 0.86 | 2.67 | 0.83 | 0.46 | 40 |
| | 4 | Abs(L)>5, Obs $\sigma\theta$, Obs Zi | 3.7 | 1.79 | 0.84 | 2.68 | 0.84 | 0.46 | 44 |
| | 5 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi, Draxler $\sigma\gamma$ | 4.1 | 1.70 | 0.76 | 2.58 | 0.84 | 0.46 | 36 |
| VG is a measure of geometric variance or scatter, $\text{VG} = \exp(\text{average}(\ln(\text{Co}/\text{Cp})))$ MG is a measure of bias about the geometric mean, $\text{MG} = \exp(\text{average}((\ln(\text{Co}/\text{Cp}))^2))$ RHC = "Robust Highest Concentration" based on top 10 samples Best performing modeling approach or Case is highlighted in red | | | | | | | | | |

Table 9. Performance Evaluation Statistical Results by Data Set and AERCOARE-MOD Case (Continued).

| Data Set | Case | Description | Geom. Mean ($\mu\text{s}/\text{m}^3$) | Geom. Std. | MG | VG | Geom. Correl. Coef. | Frac. Factor of 2 | RHC ($\mu\text{s}/\text{m}^3$) |
|--|------|--|---|---------------|-------------|-------------|---------------------------|-------------------------|-------------------------------------|
| Carpinteria, CA (27 samples) | 0 | Observations | 20.1 | 0.93 | 1.00 | 1.00 | 1.00 | 1.00 | 137 |
| | 1 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi | 14.0 | 1.19 | 1.44 | 2.29 | 0.72 | 0.59 | 172 |
| | 2 | Abs(L)>5, Pred $\sigma\theta$, Venk Zi | 24.3 | 1.29 | 0.83 | 2.10 | 0.76 | 0.67 | 330 |
| | 3 | Abs(L)>1, Obs $\sigma\theta$, Obs Zi | 15.0 | 1.50 | 1.34 | 3.95 | 0.66 | 0.44 | 470 |
| | 4 | Abs(L)>5, Obs $\sigma\theta$, Obs Zi | 14.2 | 1.36 | 1.42 | 3.19 | 0.67 | 0.41 | 329 |
| | 5 | Abs(L)>5, Obs $\sigma\theta$, Venk Zi, Draxler $\sigma\gamma$ | 15.5 | 0.97 | 1.30 | 1.90 | 0.69 | 0.56 | 129 |
| VG is a measure of geometric variance or scatter, $\text{VG} = \exp(\text{average}(\ln(\text{Co}/\text{Cp})))$ MG is a measure of bias about the geometric mean, $\text{MG} = \exp(\text{average}((\ln(\text{Co}/\text{Cp}))^2))$ RHC = "Robust Highest Concentration" based on top 10 samples Best performing modeling approach or Case is highlighted in red | | | | | | | | | |

Sigma-plots prepared from the BOOT program output are shown in Figure 20 to Figure 24 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, has more scatter, and predicts significantly higher concentrations than the other cases. Examination of the attached BOOT output listing suggests Case 5 (Draxler σ_y) has statistically less significant scatter than all the other cases.

The Cameron sigma-plot in Figure 21 again shows 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.

All the Pismo Beach cases in Figure 23 have a significant amount of scatter and do not perform as well as for the Cameron, Ventura or Carpinteria field studies. Based on a comparison between Case 3 and Case 4, restricting the Monin-Obukhov length such that $Abs(L) > 5$ seems to improve performance, but often not in a statistically significant manner. This restriction appears to help for the other sites as well when extremely stable conditions occurred.

The Ventura sigma-plot in Figure 24 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 except Case 5 are biased towards over-prediction. Some over-prediction may be the result of not accounting for enhanced dispersion caused by air modification as the plumes travel over land since the receptors are located 500 m to 1 km inland.

The complex terrain field study at Carpinteria is the exception to the trends from the other data sets as shown in Figure 22. Case 2 (AERMOD σ_θ) predicts significantly higher than the cases with the observed σ_θ data but in this instance these predictions are less biased overall. Case 1 is biased towards under-prediction for Carpinteria, but examination of the Q-Q plot and scatter diagram in Figure 5 and Figure 14 shows this Case's performance is relatively good at the upper-end of the observed frequency distribution.

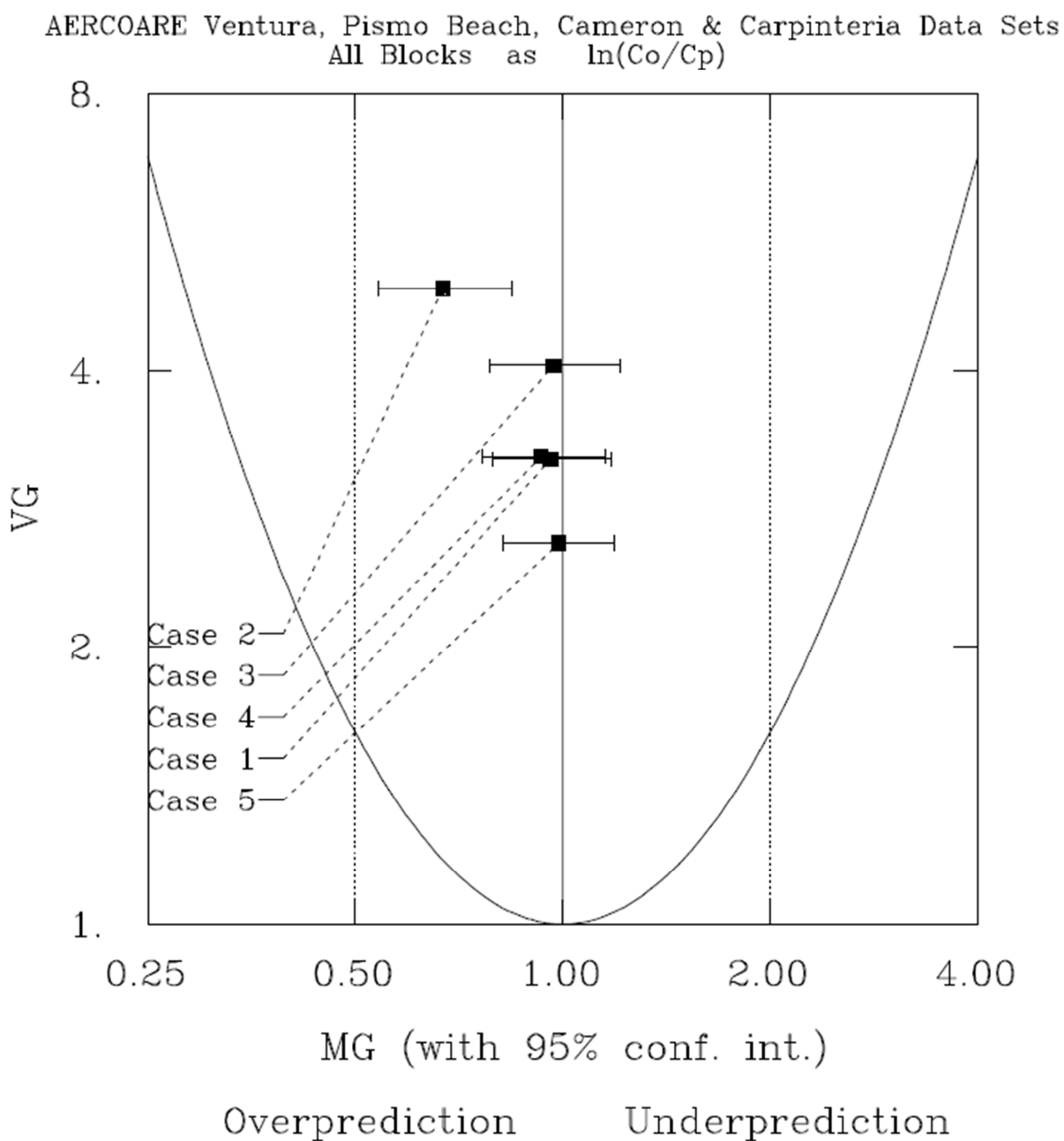


Figure 20. Sigma Plot for All Sites

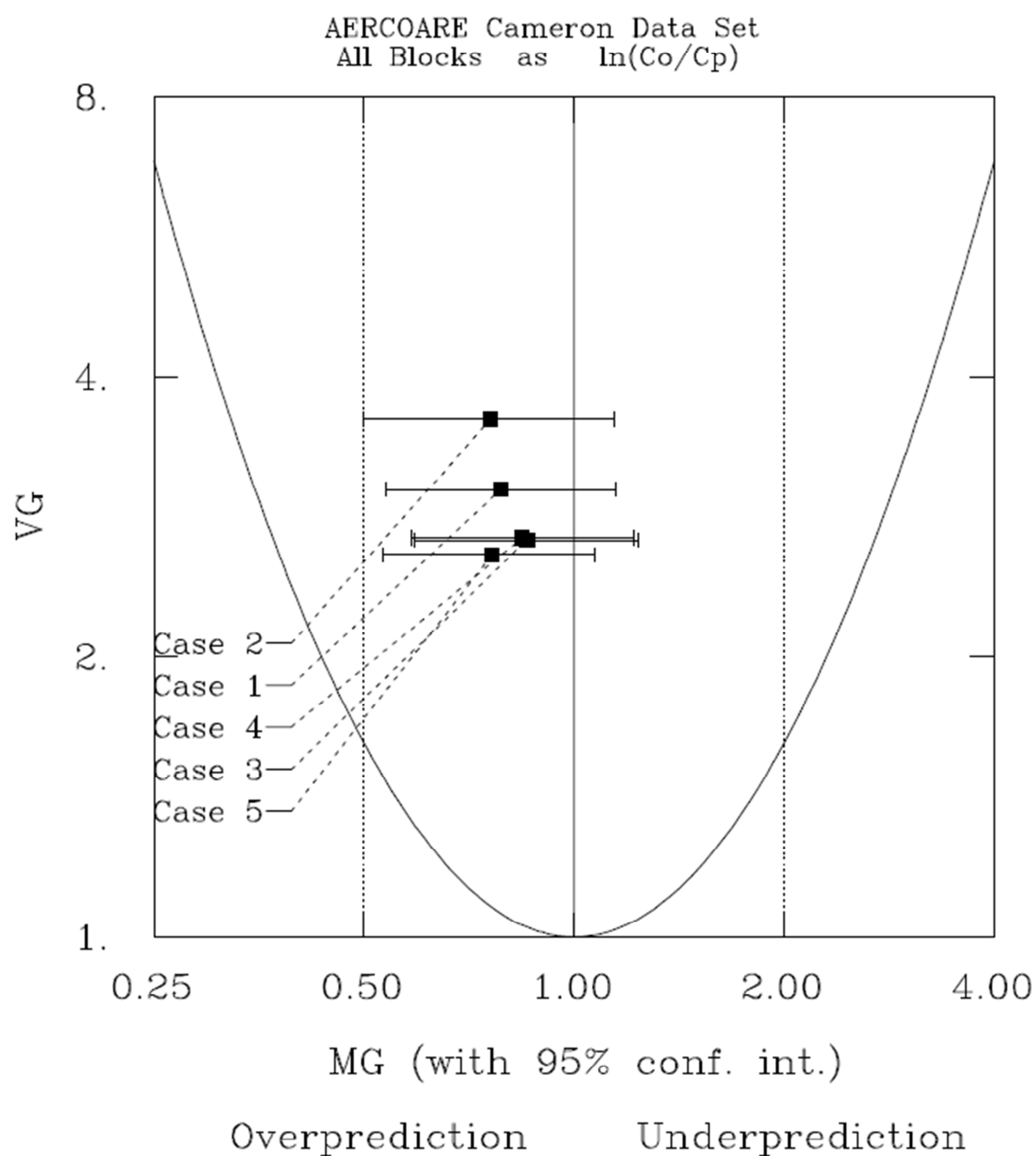


Figure 21. Sigma Plot for Cameron

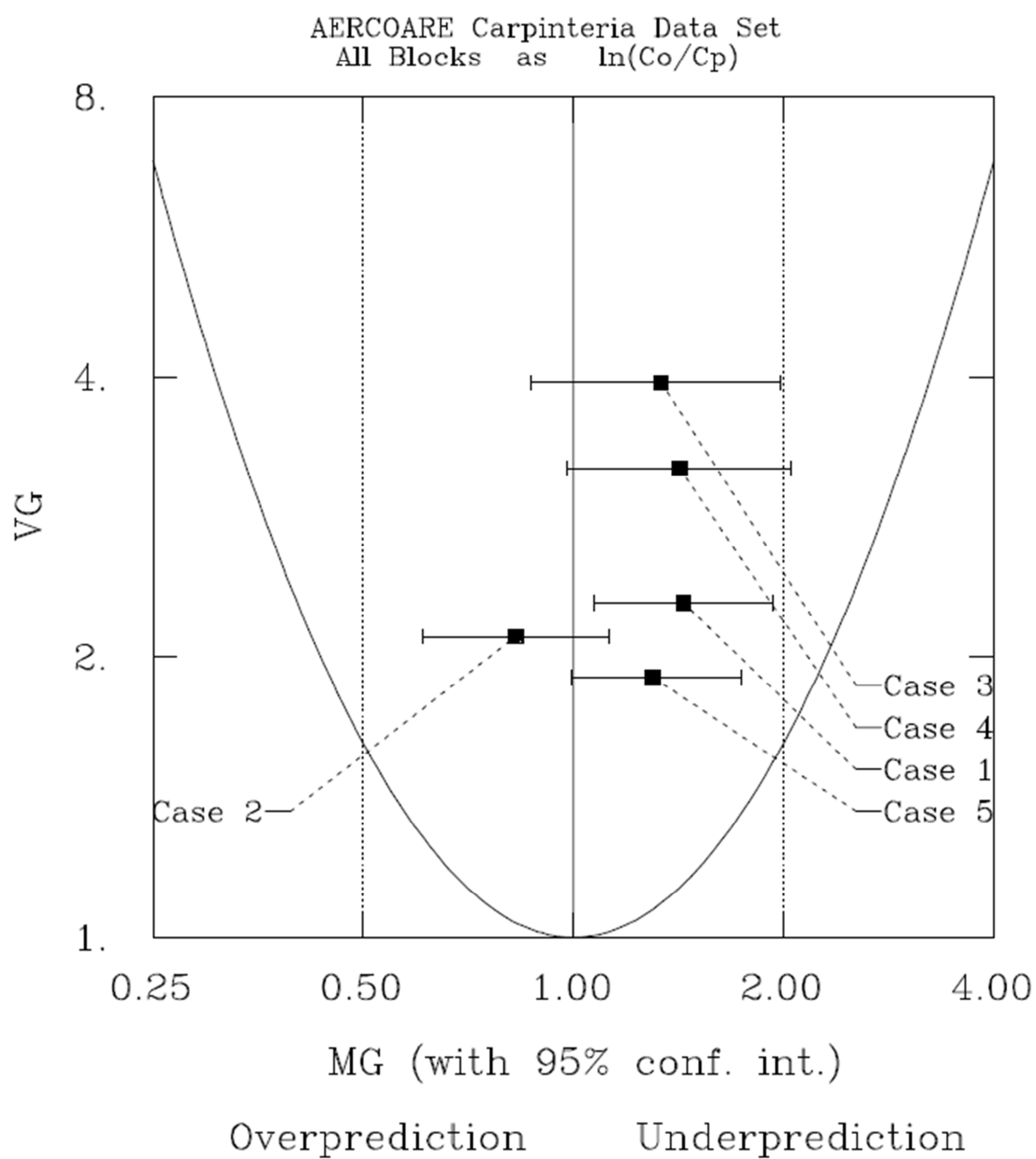


Figure 22. Sigma Plot for Carpinteria

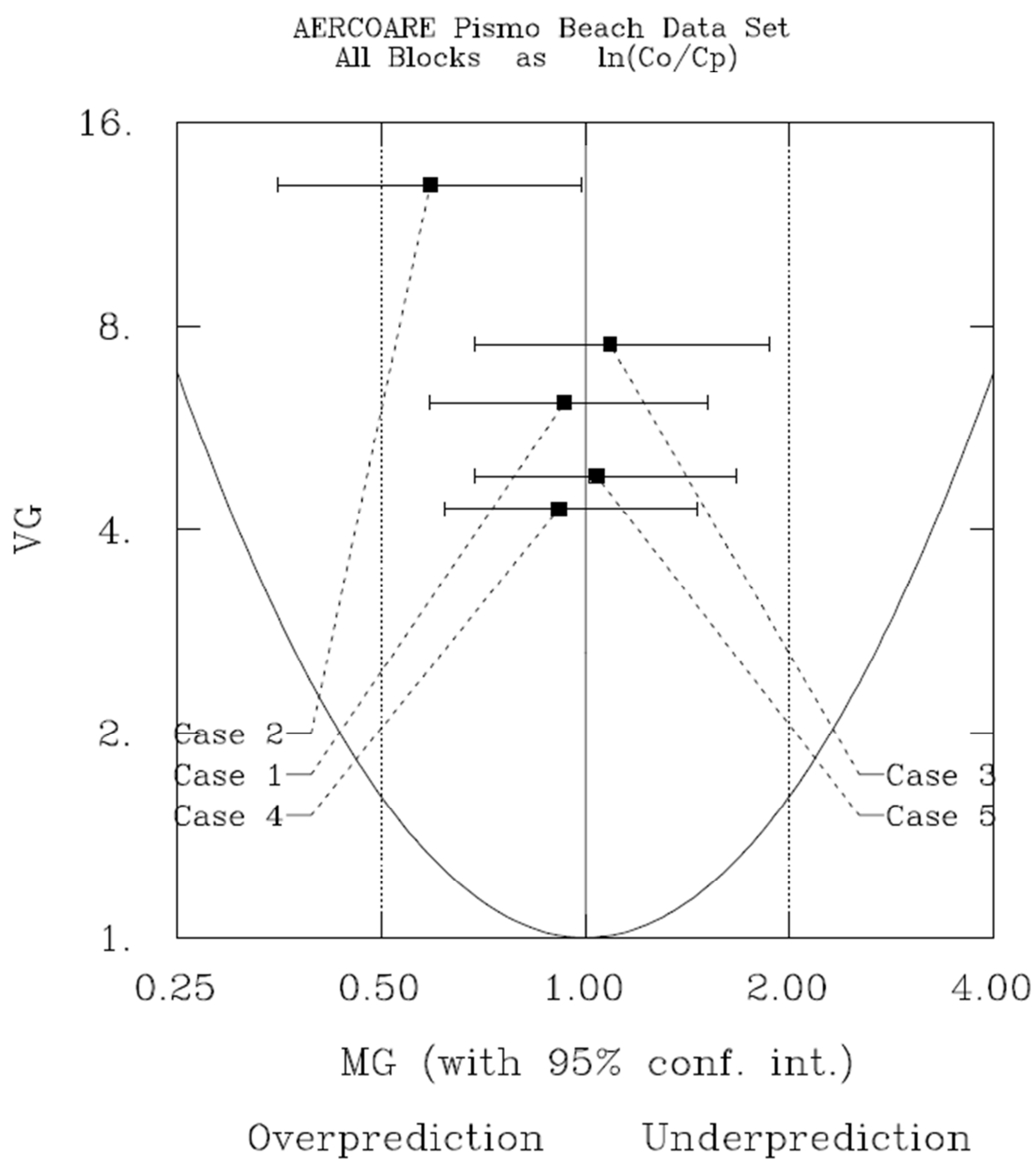


Figure 23. Sigma Plot for Pismo Beach

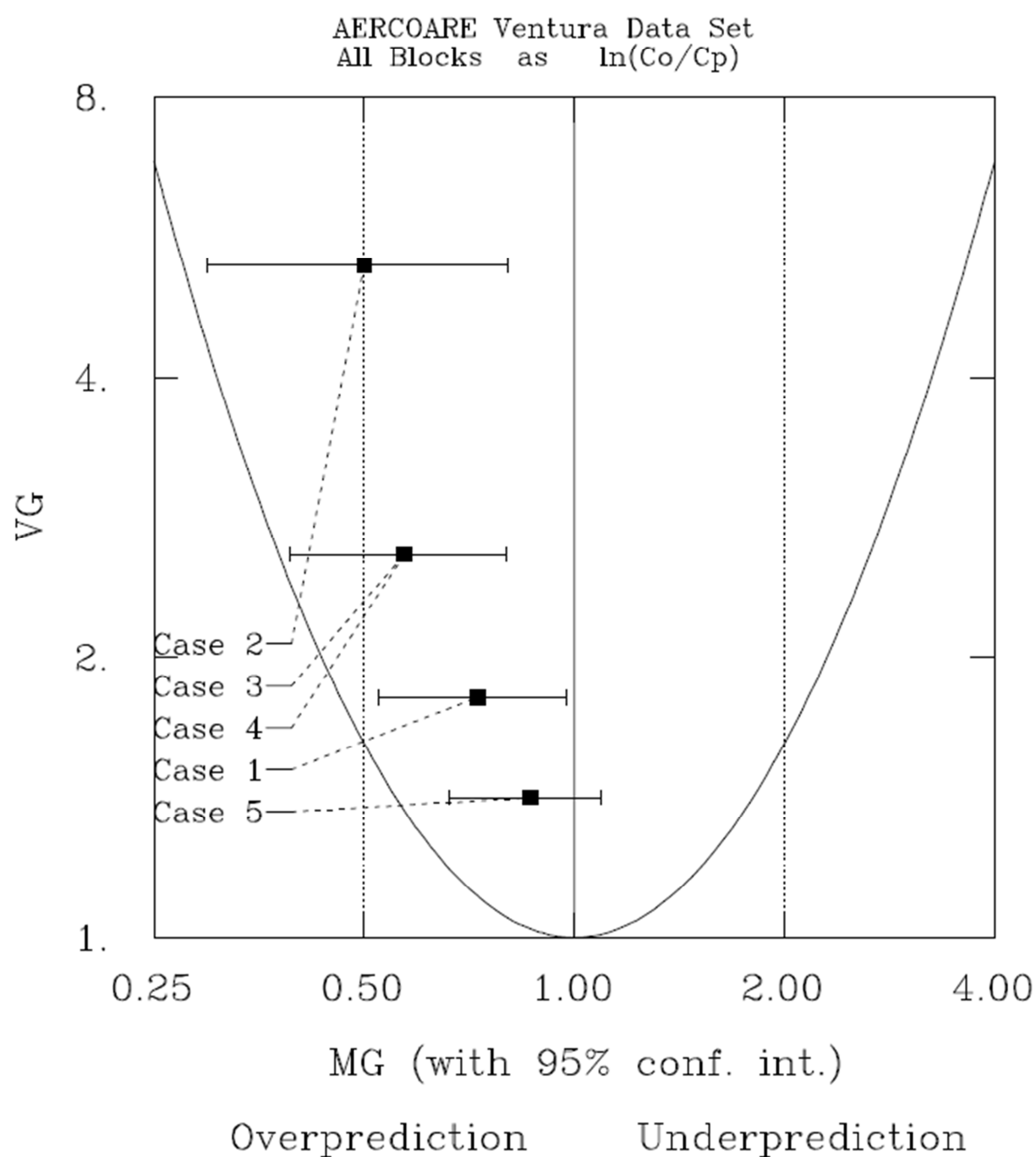


Figure 24. Sigma Plot for Ventura

5.0 SUMMARY

ENVIRON conducted this analysis to evaluate the combination of AERCOARE/AERMOD as a viable regulatory dispersion modeling approach for offshore sources. The proposed alternative approach bypasses the AERMET meteorological preprocessor using AERCOARE and overwater meteorological measurements. ENVIRON conducted a model evaluation analysis using data from four offshore tracer experiments. The conclusions from our analysis are as follows:

- The AERCOARE-MOD modeling approach was not biased towards underestimates at the high-end of the concentration frequency distribution.
- The AERCOARE-MOD 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).
- AERCOARE-MOD 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 AERCOARE-MOD 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.
- The results of current study where data from the Ventura field study was added to the analysis are consistent with the model evaluation results previously submitted to R10 and the EPA Model Clearinghouse (EPA 2011a; EPA 2011b).

Based on our analysis, we believe that the AERCOARE-MOD approach is a more suitable modeling technique than either AERMET/AERMOD or OCD for regulatory simulations of 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 NO_2 ambient standard. AERCOARE-MOD was not biased towards underestimates in the field studies examined in this study.

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APPENDIX A: SENSITIVITY TO ASSUMED MINIMUM MIXING HEIGHTS

APPENDIX A: SENSITIVITY TO ASSUMED MINIMUM MIXING HEIGHTS

This appendix examines the sensitivity of model evaluation results to the minimum mixing height allowed by AERCOARE. The mixing height is an important scaling variable in many different AERMOD algorithms. In Case 1, Case 2, and Case 5, the mechanical mixing height is calculated using the same Venketram algorithm as employed by the AERMET meteorological preprocessor. AERMET calculates the mechanical mixing height (z_{im}) from the friction velocity (u_s) according to:

$$z_{im} = 2300u_s^{3/2}$$

In AERMET, and optionally in AERCOARE, the initial estimate is smoothed based on the previous estimate to allow for residual turbulence from the previous hour. The mechanical mixing height trends towards zero as the friction velocity or wind speed approach zero. Over water very low friction velocities occur during light winds. For example for the Carpinteria field study, the COARE predicted friction velocities during several hours are less than 0.005 m/s, resulting in mechanical mixing heights less than 1 m. Out of the 36 hours of data, 50 percent are less than 25 m for the light winds observed during this study.

There are both numerical and practical reasons for specifying a minimum mixing height. A minimum mixing height must be used with the AERMOD model since the variable is used in the denominator of several equations. For example the AERMOD horizontal dispersion parameter for ambient turbulence (σ_y) is calculated from:

$$\sigma_y = \frac{\sigma_v x}{u \left(1 + 78 \left(\frac{0.46}{\max(z, 0.46)} \right) \left(\frac{\sigma_v x}{u z_i} \right)^{0.3} \right)}$$

where z_i is the mixing height, z is the height of the plume centerline, x is the downwind distance, σ_v is plume average standard deviation of the crosswind velocity, and u the plume average wind velocity. As the mixing height goes to zero, very small plume widths are predicted and the mixing height must be limited to some small value to keep the equation from becoming indeterminate. Currently, AERMOD restricts the mixing height to be greater than 1 m.

The above equation and the equation used by AERMOD for the vertical dispersion from sources near the surface differ from simpler expressions used by CALPUFF, OCD and many other models, because the authors cited poor performance for the Prairie Grass field experiment.⁵ The equation above is an empirical fit to the Prairie Grass data set and should be applied with caution when the variables are well outside those used for the fit. The Prairie Grass field study is the sole experiment (out of 17) that examined dispersion from a near surface release. In the other datasets used in the AERMOD model evaluation study, plumes were influenced by

⁵ Cimorelli, A.J., Perry, S.G., Venketram, A., Weil, J.C., Paine, R.J., Wilson, R.B., Lee, R.F., Peters, W.D., and R.W. Brode, 2005. "AERMOD: A Dispersion Model for Industrial Source Applications. Part I: General Model Formulation and Boundary Layer Characterization." J. Applied Meteorology, 44, 683-693.

downwash or were sufficiently high that the surface dispersion algorithms in AERMOD are not that important. The minimum mixing height used in the Prairie Grass experiment simulations was 67 m based on the input files from EPA's website.⁶ Mixing heights of 1 m to 10 m are well outside the range used to develop the near surface dispersion algorithms in AERMOD.

In order to test the sensitivity of the model evaluation results to the assumed minimum mixing height, ENVIRON reran Case 1 with minimum mixing heights of 1 m, 5 m, and 15 m to compare with the simulations in the main body of this report where 25 m was assumed. This assumption affects the results from the evaluation of the Pismo Beach and Carpinteria data sets. Winds during the Ventura and Cameron studies were sufficient to keep predicted mechanical mixing heights above 25 m for all hours.

Figure A-1 shows a scatter diagram where predictions for each assumed minimum mixing height are compared to the observed normalized concentrations for Pismo Beach and Carpinteria. Q-Q plots for Carpinteria and Pismo Beach are shown in Figure A-2 and Figure A-3, respectively. The predictions for Pismo Beach were only slightly affected when mixing heights were allowed to be lower than 25 m. However, the predictions for Carpinteria were up to three times higher when the AERMOD default of 1 m was allowed resulting in severe over prediction at the upper end of the frequency distribution.

ENVIRON recommends a default minimum of 25 m be used to limit mixing heights when the Venketram algorithm is used for the mechanical mixing height. The AERMOD default limit of 1 m potentially results in very high predictions that are not supported by the tracer data in the Carpinteria study and is outside the limits used to develop the empirical algorithm AERMOD employs for the horizontal dispersion parameter.

⁶ The Prairie Grass AERMOD files can be found at <http://www.epa.gov/ttn/scram/7thconf/aermod/pgrass.zip>. The meteorological file used is "PGRSURF.222"

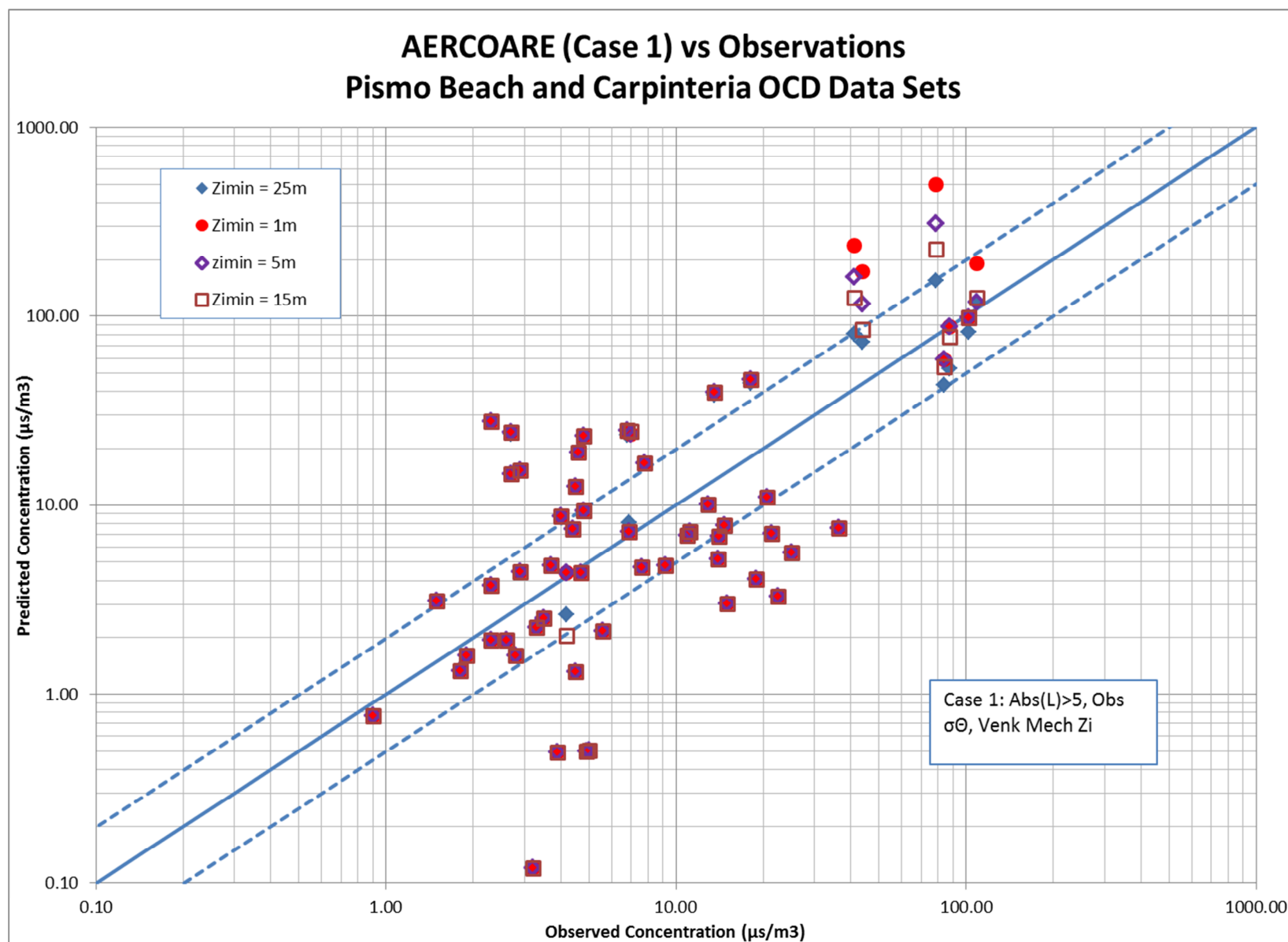


Figure A-1. Scatter Plot of Case 1 for Several Minimum Mixing Heights

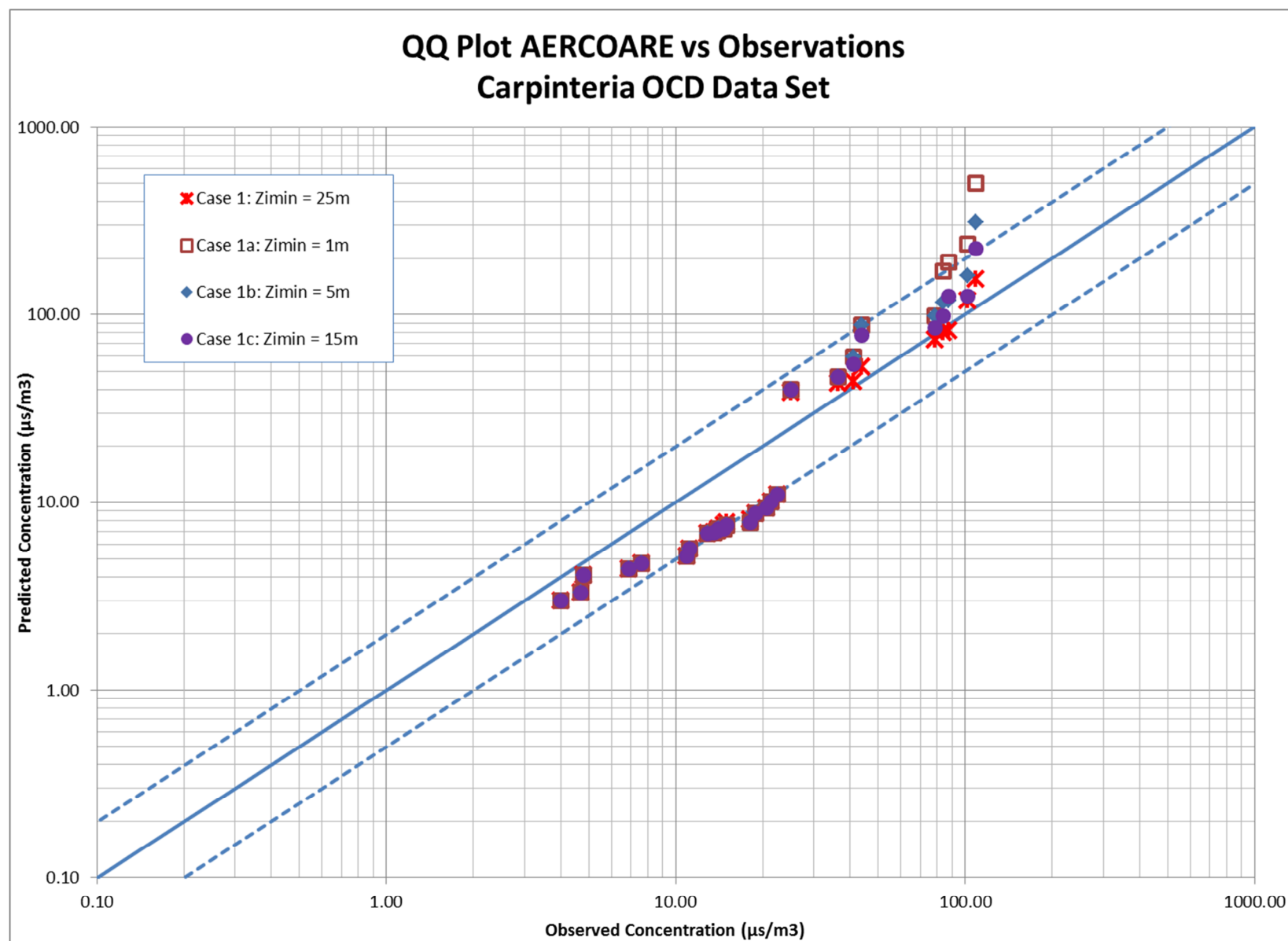


Figure A-2. QQ Plot for Case 1 Carpinteria for Several Minimum Mixing Heights

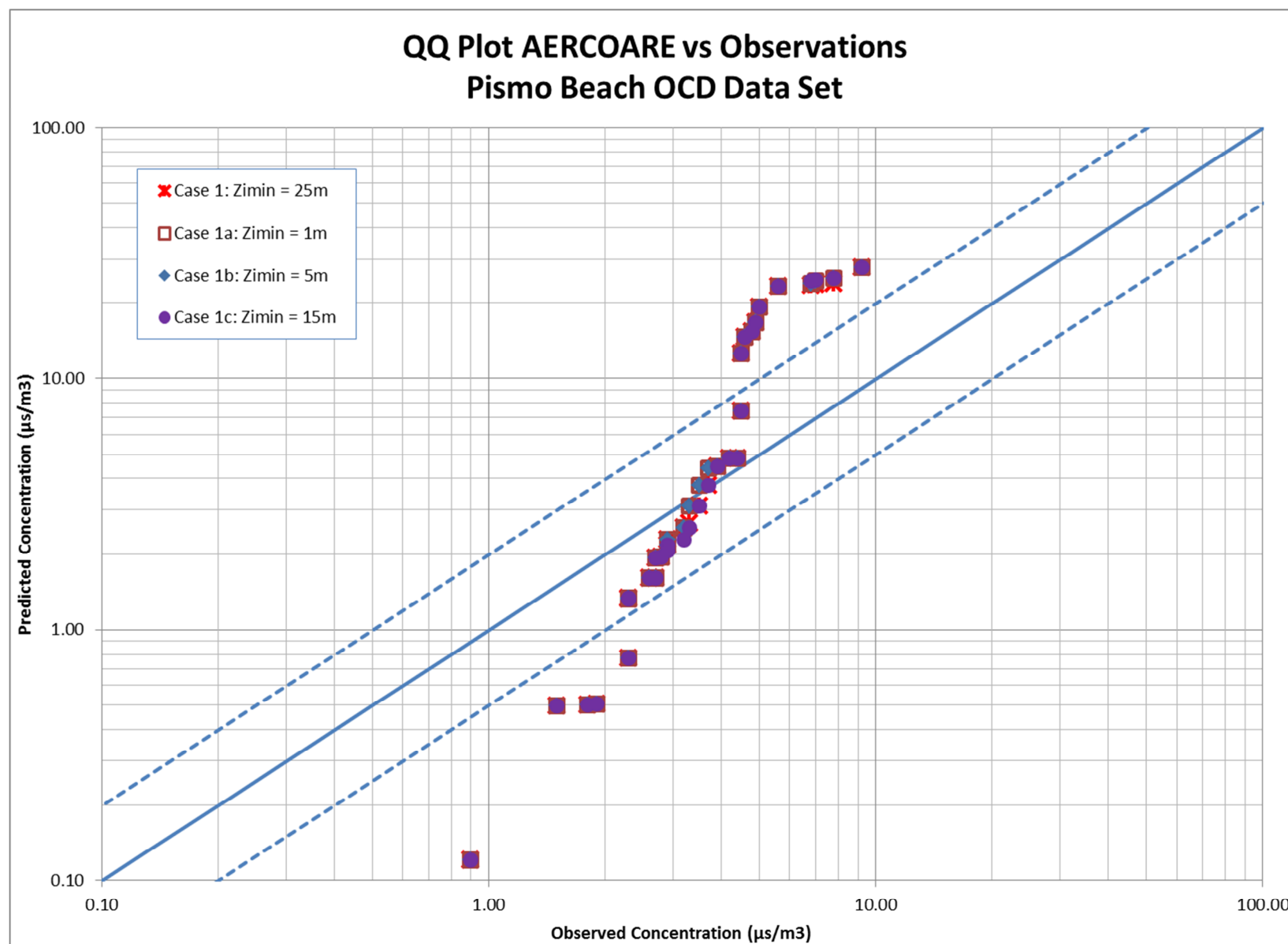


Figure A-3. QQ Plot for Case 1 Pismo Beach for Several Minimum Mixing Heights

APPENDIX B: BOOT PROGRAM OUTPUT

APPENDIX B: BOOT PROGRAM OUTPUT

Boot Program Output for All Data Sets Combined

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

```

No. of experiments          = 101
No. of models               = 6
(with the observed data counted as one)
No. of observations         = 101
(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
paired sampling             = 98
(there might be odd number of observations in each block)
No. of blocks (regimes)     = 4
No. of experiments in each block (regime)
  17  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 = 4) | | | | | | |
|--------------------------|------------------------------------|-------|----------------------|------|--------|--------|-------|--------|----------|
| MODEL | MEAN | SIGMA | BIAS | VG | CORR | FA2 | MG | HIGH | 2nd HIGH |
| PCOR | | | | | | | | | |
| | <----- (logarithmic values) -----> | | (arithmetic values) | | | | | | |
| OBS. | 1.51 | 1.36 | 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 | 1.55 | 1.60 | -0.04 | 3.21 | 0.746 | 0.535 | 0.96 | 154 | 118 |
| n/a | | | | | | | | | |
| | | | | | (MGfn= | 1.497, | MGfp= | 1.559, | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 2 | 1.91 | 1.73 | -0.40 | 4.93 | 0.724 | 0.465 | 0.67 | 217 | 206 |
| n/a | | | | | | | | | |
| | | | | | (MGfn= | 1.342, | MGfp= | 2.002, | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 3 | 1.54 | 1.67 | -0.03 | 4.05 | 0.712 | 0.475 | 0.97 | 586 | 451 |
| n/a | | | | | | | | | |
| | | | | | (MGfn= | 1.547, | MGfp= | 1.596, | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 4 | 1.58 | 1.57 | -0.07 | 3.23 | 0.739 | 0.465 | 0.93 | 386 | 280 |
| n/a | | | | | | | | | |
| | | | | | (MGfn= | 1.479, | MGfp= | 1.590, | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 5 | 1.52 | 1.53 | -0.01 | 2.60 | 0.778 | 0.545 | 0.99 | 126 | 106 |
| n/a | | | | | | | | | |
| | | | | | (MGfn= | 1.432, | MGfp= | 1.449, | |
| MG=MGfn/MGfp) | | | | | | | | | |

| Block 1: Ventura, Ca (N= 17) | | | | | | | | | |
|----------------------------------|------------------------------------|-------|-------|------|---------------------|-------|----------------------------|------|----------|
| MODEL | MEAN | SIGMA | BIAS | VG | CORR | FA2 | MG | HIGH | 2nd HIGH |
| PCOR | <----- (logarithmic values) -----> | | | | (arithmetic values) | | | | |
| OBS. | 0.18 | 0.76 | 0.00 | 1.00 | 1.000 | 1.000 | 1.00 | 3 | 3 |
| n/a | | | | | | | | | |
| | | | | | | | (MGfn= 1.000, MGfp= 1.000, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 1 | 0.50 | 1.03 | -0.32 | 1.81 | 0.732 | 0.765 | 0.73 | 6 | 5 |
| n/a | | | | | | | (MGfn= 1.120, MGfp= 1.539, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 2 | 0.87 | 1.37 | -0.69 | 5.28 | 0.615 | 0.588 | 0.50 | 23 | 16 |
| n/a | | | | | | | (MGfn= 1.104, MGfp= 2.208, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 3 | 0.74 | 1.18 | -0.56 | 2.58 | 0.745 | 0.588 | 0.57 | 7 | 7 |
| n/a | | | | | | | (MGfn= 1.097, MGfp= 1.923, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 4 | 0.74 | 1.18 | -0.56 | 2.58 | 0.745 | 0.588 | 0.57 | 7 | 7 |
| n/a | | | | | | | (MGfn= 1.097, MGfp= 1.923, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 5 | 0.32 | 0.88 | -0.14 | 1.41 | 0.768 | 0.882 | 0.87 | 4 | 4 |
| n/a | | | | | | | (MGfn= 1.119, MGfp= 1.293, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Block 2: 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 | 1.39 | -0.07 | 6.17 | 0.270 | 0.452 | 0.93 | 28 | 24 |
| n/a | | | | | | | (MGfn= 1.651, MGfp= 1.771, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 2 | 1.77 | 1.45 | -0.53 | 12.9 | 0.044 | 0.258 | 0.59 | 41 | 39 |
| n/a | | | | | | | (MGfn= 1.538, MGfp= 2.605, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 3 | 1.16 | 1.40 | 0.08 | 7.53 | 0.138 | 0.452 | 1.09 | 17 | 15 |
| n/a | | | | | | | (MGfn= 1.723, MGfp= 1.584, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 4 | 1.33 | 1.23 | -0.09 | 4.30 | 0.255 | 0.452 | 0.91 | 17 | 16 |
| n/a | | | | | | | (MGfn= 1.498, MGfp= 1.639, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 5 | 1.20 | 1.33 | 0.04 | 4.80 | 0.345 | 0.419 | 1.04 | 24 | 22 |
| n/a | | | | | | | (MGfn= 1.649, MGfp= 1.586, | | |
| MG=MGfn/MGfp) | | | | | | | | | |

| Block | 3: 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 | 1.40 | 1.84 | -0.24 | 3.03 | 0.833 | 0.423 | 0.78 | 35 | 35 | |
| n/a | | | | | | | (MGfn= 1.360, MGfp= 1.732, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 2 | 1.43 | 1.87 | -0.27 | 3.60 | 0.811 | 0.423 | 0.76 | 35 | 35 | |
| n/a | | | | | | | (MGfn= 1.379, MGfp= 1.814, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 3 | 1.31 | 1.77 | -0.16 | 2.67 | 0.833 | 0.462 | 0.86 | 36 | 28 | |
| n/a | | | | | | | (MGfn= 1.377, MGfp= 1.609, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 4 | 1.32 | 1.79 | -0.17 | 2.68 | 0.838 | 0.462 | 0.84 | 36 | 32 | |
| n/a | | | | | | | (MGfn= 1.367, MGfp= 1.622, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 5 | 1.42 | 1.70 | -0.27 | 2.58 | 0.835 | 0.462 | 0.76 | 32 | 27 | |
| n/a | | | | | | | (MGfn= 1.293, MGfp= 1.694, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Block | 4: 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 | 2.64 | 1.19 | 0.36 | 2.29 | 0.717 | 0.593 | 1.44 | 154 | 118 | |
| n/a | | | | | | | (MGfn= 1.760, MGfp= 1.225, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 2 | 3.19 | 1.29 | -0.19 | 2.10 | 0.759 | 0.667 | 0.83 | 217 | 206 | |
| n/a | | | | | | | (MGfn= 1.265, MGfp= 1.530, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 3 | 2.71 | 1.50 | 0.29 | 3.95 | 0.657 | 0.444 | 1.34 | 586 | 451 | |
| n/a | | | | | | | (MGfn= 1.901, MGfp= 1.421, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 4 | 2.65 | 1.36 | 0.35 | 3.19 | 0.666 | 0.407 | 1.42 | 386 | 280 | |
| n/a | | | | | | | (MGfn= 1.897, MGfp= 1.335, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |
| Case 5 | 2.74 | 0.97 | 0.26 | 1.90 | 0.685 | 0.556 | 1.30 | 126 | 106 | |
| n/a | | | | | | | (MGfn= 1.569, MGfp= 1.207, | | | |
| MG=MGfn/MGfp) | | | | | | | | | | |

Note: The Percentile 95% Confidence Limits are based on the 2.5th and 97.5th percentiles of the cumulative distribution function.
The Student's t 95% Confidence Limits are based on calculated mean and standard deviation.

| Model(s) | | Student's t | | Student t | Mean | S.D. | Percentile | |
|----------|------|--------------|-------|-----------|--------|-------|--------------|-------|
| | | 95% | | | | | 95% | |
| | | Conf. limits | | | | | Conf. limits | |
| Case 1 | VG | 2.3 | 4.4 | 7.299 | 1.170 | 0.160 | 2. | 4. |
| | MG | 0.781 | 1.179 | -0.398 | -0.041 | 0.104 | 0.793 | 1.178 |
| | MGfn | 1.327 | 1.691 | 6.622 | 0.404 | 0.061 | 1.348 | 1.701 |
| | MGfp | 1.385 | 1.761 | 7.359 | 0.446 | 0.061 | 1.389 | 1.761 |
| Case 2 | VG | 3.4 | 7.1 | 8.713 | 1.591 | 0.183 | 4. | 7. |
| | MG | 0.531 | 0.846 | -3.414 | -0.400 | 0.117 | 0.540 | 0.845 |
| | MGfn | 1.208 | 1.490 | 5.549 | 0.294 | 0.053 | 1.222 | 1.495 |
| | MGfp | 1.702 | 2.353 | 8.497 | 0.694 | 0.082 | 1.707 | 2.332 |
| Case 3 | VG | 2.6 | 6.5 | 5.978 | 1.405 | 0.235 | 3. | 7. |
| | MG | 0.776 | 1.214 | -0.266 | -0.030 | 0.113 | 0.783 | 1.211 |
| | MGfn | 1.342 | 1.791 | 6.018 | 0.438 | 0.073 | 1.358 | 1.819 |
| | MGfp | 1.417 | 1.800 | 7.764 | 0.468 | 0.060 | 1.431 | 1.805 |
| Case 4 | VG | 2.3 | 4.5 | 6.943 | 1.172 | 0.169 | 2. | 5. |
| | MG | 0.760 | 1.138 | -0.711 | -0.072 | 0.102 | 0.765 | 1.153 |
| | MGfn | 1.305 | 1.679 | 6.180 | 0.392 | 0.063 | 1.324 | 1.684 |
| | MGfp | 1.422 | 1.780 | 8.217 | 0.464 | 0.057 | 1.432 | 1.791 |
| Case 5 | VG | 1.9 | 3.6 | 5.855 | 0.959 | 0.164 | 2. | 4. |
| | MG | 0.816 | 1.193 | -0.141 | -0.013 | 0.096 | 0.818 | 1.190 |
| | MGfn | 1.278 | 1.606 | 6.259 | 0.360 | 0.057 | 1.294 | 1.619 |
| | MGfp | 1.301 | 1.621 | 6.725 | 0.373 | 0.055 | 1.313 | 1.631 |

| Model(s) | | Student's t | | Student t | Mean | S.D. | Percentile | |
|-----------------|------|--------------|-------|-----------|--------|-------|--------------|-------|
| | | 95% | | | | | 95% | |
| | | Conf. limits | | | | | Conf. limits | |
| Case 1 - Case 2 | VG | 0.467 | 0.921 | -2.462 | -0.421 | 0.171 | 0.471 | 0.910 |
| | MG | 1.279 | 1.602 | 6.330 | 0.359 | 0.057 | 1.283 | 1.599 |
| | MGfn | 1.040 | 1.199 | 3.071 | 0.110 | 0.036 | 1.044 | 1.199 |
| | MGfp | 0.714 | 0.853 | -5.532 | -0.248 | 0.045 | 0.711 | 0.846 |
| Case 1 - Case 3 | VG | 0.524 | 1.191 | -1.139 | -0.235 | 0.207 | 0.491 | 1.099 |
| | MG | 0.867 | 1.128 | -0.171 | -0.011 | 0.066 | 0.861 | 1.114 |
| | MGfn | 0.887 | 1.053 | -0.791 | -0.034 | 0.043 | 0.879 | 1.031 |
| | MGfp | 0.895 | 1.068 | -0.510 | -0.023 | 0.045 | 0.893 | 1.065 |
| Case 1 - Case 4 | VG | 0.836 | 1.191 | -0.026 | -0.002 | 0.089 | 0.834 | 1.183 |
| | MG | 0.942 | 1.129 | 0.674 | 0.031 | 0.046 | 0.943 | 1.132 |
| | MGfn | 0.977 | 1.048 | 0.681 | 0.012 | 0.018 | 0.976 | 1.046 |
| | MGfp | 0.909 | 1.060 | -0.485 | -0.019 | 0.039 | 0.909 | 1.058 |
| Case 1 - Case 5 | VG | 1.101 | 1.386 | 3.633 | 0.211 | 0.058 | 1.101 | 1.387 |
| | MG | 0.921 | 1.027 | -1.024 | -0.028 | 0.027 | 0.922 | 1.024 |
| | MGfn | 1.007 | 1.086 | 2.329 | 0.045 | 0.019 | 1.006 | 1.083 |
| | MGfp | 1.037 | 1.115 | 3.951 | 0.072 | 0.018 | 1.039 | 1.118 |
| Case 2 - Case 3 | VG | 0.730 | 1.987 | 0.737 | 0.186 | 0.252 | 0.733 | 1.947 |
| | MG | 0.565 | 0.844 | -3.662 | -0.370 | 0.101 | 0.563 | 0.832 |
| | MGfn | 0.768 | 0.975 | -2.399 | -0.145 | 0.060 | 0.757 | 0.961 |
| | MGfp | 1.100 | 1.427 | 3.429 | 0.225 | 0.066 | 1.115 | 1.435 |
| Case 2 - Case 4 | VG | 1.003 | 2.306 | 1.997 | 0.419 | 0.210 | 0.987 | 2.272 |
| | MG | 0.613 | 0.847 | -4.023 | -0.328 | 0.081 | 0.618 | 0.838 |
| | MGfn | 0.831 | 0.989 | -2.236 | -0.098 | 0.044 | 0.828 | 0.984 |
| | MGfp | 1.110 | 1.426 | 3.630 | 0.229 | 0.063 | 1.124 | 1.431 |
| Case 2 - Case 5 | VG | 1.258 | 2.815 | 3.117 | 0.632 | 0.203 | 1.261 | 2.780 |
| | MG | 0.582 | 0.793 | -4.974 | -0.387 | 0.078 | 0.581 | 0.784 |
| | MGfn | 0.857 | 1.022 | -1.485 | -0.066 | 0.044 | 0.855 | 1.016 |
| | MGfp | 1.228 | 1.547 | 5.510 | 0.321 | 0.058 | 1.240 | 1.558 |
| Case 3 - Case 4 | VG | 0.886 | 1.800 | 1.304 | 0.233 | 0.179 | 1.010 | 1.841 |
| | MG | 0.965 | 1.128 | 1.076 | 0.042 | 0.039 | 0.980 | 1.135 |
| | MGfn | 0.976 | 1.124 | 1.298 | 0.046 | 0.036 | 0.999 | 1.131 |
| | MGfp | 0.979 | 1.029 | 0.315 | 0.004 | 0.012 | 0.982 | 1.029 |
| Case 3 - Case 5 | VG | 1.067 | 2.290 | 2.319 | 0.447 | 0.193 | 1.139 | 2.377 |
| | MG | 0.871 | 1.111 | -0.270 | -0.017 | 0.061 | 0.876 | 1.105 |
| | MGfn | 1.006 | 1.163 | 2.149 | 0.079 | 0.037 | 1.020 | 1.169 |

| | | | | | | | | |
|-----------------|------|-------|-------|--------|--------|-------|-------|-------|
| Case 4 - Case 5 | MGfp | 1.009 | 1.199 | 2.192 | 0.095 | 0.043 | 1.014 | 1.200 |
| | VG | 1.049 | 1.460 | 2.564 | 0.213 | 0.083 | 1.051 | 1.458 |
| | MG | 0.864 | 1.029 | -1.342 | -0.059 | 0.044 | 0.863 | 1.026 |
| | MGfn | 0.996 | 1.071 | 1.778 | 0.032 | 0.018 | 0.997 | 1.072 |
| | MGfp | 1.017 | 1.180 | 2.429 | 0.091 | 0.038 | 1.020 | 1.183 |

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 |
| Case 3 | | | | X | 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 | | | |
| 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 | | | | | |

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 | | | | | | 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 |
| ----- | | | | |
| | 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
paired 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 | 1.39 | -0.07 | 6.17 | 0.270 | 0.452 | 0.93 | 28 | 24 |
| n/a | | | | | | | (MGfn= 1.651, MGfp= 1.771, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 2 | 1.77 | 1.45 | -0.53 | 12.9 | 0.044 | 0.258 | 0.59 | 41 | 39 |
| n/a | | | | | | | (MGfn= 1.538, MGfp= 2.605, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 3 | 1.16 | 1.40 | 0.08 | 7.53 | 0.138 | 0.452 | 1.09 | 17 | 15 |
| n/a | | | | | | | (MGfn= 1.723, MGfp= 1.584, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 4 | 1.33 | 1.23 | -0.09 | 4.30 | 0.255 | 0.452 | 0.91 | 17 | 16 |
| n/a | | | | | | | (MGfn= 1.498, MGfp= 1.639, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 5 | 1.20 | 1.33 | 0.04 | 4.80 | 0.345 | 0.419 | 1.04 | 24 | 22 |
| n/a | | | | | | | (MGfn= 1.649, MGfp= 1.586, | | |
| MG=MGfn/MGfp) | | | | | | | | | |

Note: The Percentile 95% Confidence Limits are based on the 2.5th and 97.5th percentiles of the cumulative distribution function.
The Student's t 95% Confidence Limits are based on calculated mean and standard deviation.

| Model(s) | | Student's t | | | | Percentile | | | |
|-----------------|------|--------------|-------|--------------|--------|------------|--------------|---------|--|
| | | 95% | | Student t | Mean | S.D. | 95% | | |
| | | Conf. limits | | | | | Conf. limits | | |
| Case 1 | VG | 2.6 | 15. | 4.254 | 1.835 | 0.431 | 3. | 0.1E+02 | |
| | MG | 0.570 | 1.532 | -0.280 | -0.068 | 0.242 | 0.588 | 1.514 | |
| | MGfn | 1.222 | 2.244 | 3.388 | 0.504 | 0.149 | 1.287 | 2.243 | |
| | MGfp | 1.351 | 2.324 | 4.307 | 0.572 | 0.133 | 1.397 | 2.356 | |
| Case 2 | VG | 5.6 | 30. | 6.250 | 2.558 | 0.409 | 6. | 0.3E+02 | |
| | MG | 0.336 | 1.038 | -1.907 | -0.526 | 0.276 | 0.351 | 0.985 | |
| | MGfn | 1.186 | 1.993 | 3.386 | 0.430 | 0.127 | 1.240 | 2.002 | |
| | MGfp | 1.798 | 3.766 | 5.283 | 0.956 | 0.181 | 1.862 | 3.723 | |
| Case 3 | VG | 1.7 | 34. | 2.802 | 2.045 | 0.730 | 2. | 0.4E+02 | |
| | MG | 0.645 | 1.861 | 0.351 | 0.091 | 0.259 | 0.687 | 1.870 | |
| | MGfn | 1.147 | 2.625 | 2.719 | 0.551 | 0.203 | 1.222 | 2.615 | |
| | MGfp | 1.295 | 1.939 | 4.657 | 0.460 | 0.099 | 1.324 | 1.926 | |
| Case 4 | VG | 1.7 | 11. | 3.236 | 1.480 | 0.457 | 2. | 0.1E+02 | |
| | MG | 0.588 | 1.436 | -0.387 | -0.084 | 0.218 | 0.621 | 1.463 | |
| | MGfn | 1.095 | 2.075 | 2.622 | 0.410 | 0.157 | 1.157 | 2.096 | |
| | MGfp | 1.340 | 2.007 | 5.003 | 0.495 | 0.099 | 1.361 | 1.991 | |
| Case 5 | VG | 1.9 | 13. | 3.345 | 1.589 | 0.475 | 2. | 0.1E+02 | |
| | MG | 0.661 | 1.645 | 0.187 | 0.042 | 0.223 | 0.687 | 1.669 | |
| | MGfn | 1.222 | 2.241 | 3.392 | 0.504 | 0.148 | 1.287 | 2.273 | |
| | MGfp | 1.255 | 2.007 | 4.023 | 0.462 | 0.115 | 1.280 | 2.018 | |
| Model(s) | | Student's t | | | | Percentile | | | |
| | | 95% | | Student t | Mean | S.D. | 95% | | |
| | | Conf. limits | | | | | Conf. limits | | |
| Case 1 - Case 2 | VG | 0.195 | 1.205 | -1.624 | -0.723 | 0.445 | 0.211 | 1.169 | |
| | MG | 1.179 | 2.121 | 3.189 | 0.458 | 0.144 | 1.216 | 2.073 | |
| | MGfn | 0.931 | 1.245 | 1.040 | 0.074 | 0.071 | 0.960 | 1.263 | |
| | MGfp | 0.535 | 0.866 | -3.258 | -0.384 | 0.118 | 0.537 | 0.843 | |
| Case 1 - Case 3 | VG | 0.219 | 3.004 | -0.327 | -0.210 | 0.641 | 0.160 | 2.088 | |
| | MG | 0.581 | 1.252 | -0.845 | -0.159 | 0.188 | 0.578 | 1.222 | |
| | MGfn | 0.721 | 1.262 | -0.342 | -0.047 | 0.137 | 0.690 | 1.167 | |
| | MGfp | 0.899 | 1.392 | 1.044 | 0.112 | 0.107 | 0.902 | 1.367 | |
| Case 1 - Case 4 | VG | 0.914 | 2.225 | 1.631 | 0.355 | 0.218 | 0.939 | 2.228 | |
| | MG | 0.791 | 1.308 | 0.135 | 0.017 | 0.123 | 0.802 | 1.313 | |
| | MGfn | 1.003 | 1.203 | 2.120 | 0.094 | 0.044 | 1.006 | 1.200 | |
| | MGfp | 0.882 | 1.324 | 0.779 | 0.077 | 0.099 | 0.889 | 1.311 | |
| Case 1 - Case 5 | VG | 0.919 | 1.780 | 1.523 | 0.246 | 0.162 | 0.926 | 1.691 | |
| | MG | 0.788 | 1.019 | -1.737 | -0.109 | 0.063 | 0.794 | 1.014 | |
| | MGfn | 0.916 | 1.094 | 0.016 | 0.001 | 0.044 | 0.919 | 1.082 | |
| | MGfp | 1.024 | 1.217 | 2.616 | 0.110 | 0.042 | 1.031 | 1.214 | |
| Case 2 - Case 3 | VG | 0.354 | 7.899 | 0.675 | 0.513 | 0.761 | 0.325 | 6.670 | |
| | MG | 0.296 | 0.982 | -2.104 | -0.617 | 0.293 | 0.299 | 0.923 | |
| | MGfn | 0.625 | 1.256 | -0.708 | -0.121 | 0.171 | 0.598 | 1.156 | |
| | MGfp | 1.129 | 2.390 | 2.701 | 0.496 | 0.184 | 1.142 | 2.258 | |
| Case 2 - Case 4 | VG | 0.914 | 9.458 | 1.885 | 1.079 | 0.572 | 0.921 | 8.171 | |
| | MG | 0.405 | 1.020 | -1.954 | -0.442 | 0.226 | 0.422 | 1.013 | |
| | MGfn | 0.834 | 1.248 | 0.203 | 0.020 | 0.099 | 0.831 | 1.211 | |
| | MGfp | 1.103 | 2.282 | 2.594 | 0.462 | 0.178 | 1.117 | 2.189 | |
| Case 2 - Case 5 | VG | 0.862 | 8.065 | 1.771 | 0.970 | 0.547 | 0.884 | 6.932 | |
| | MG | 0.377 | 0.852 | -2.847 | -0.568 | 0.199 | 0.387 | 0.826 | |
| | MGfn | 0.753 | 1.147 | -0.713 | -0.073 | 0.103 | 0.751 | 1.102 | |
| | MGfp | 1.220 | 2.203 | 3.418 | 0.494 | 0.145 | 1.240 | 2.165 | |
| Case 3 - Case 4 | VG | 0.529 | 5.857 | 0.960 | 0.565 | 0.589 | 0.968 | 9.773 | |
| | MG | 0.924 | 1.537 | 1.408 | 0.175 | 0.125 | 1.002 | 1.582 | |
| | MGfn | 0.906 | 1.463 | 1.202 | 0.141 | 0.117 | 1.000 | 1.576 | |
| | MGfp | 0.913 | 1.022 | -1.247 | -0.034 | 0.028 | 0.911 | 1.000 | |
| Case 3 - Case 5 | VG | 0.477 | 5.216 | 0.779 | 0.456 | 0.585 | 0.685 | 6.732 | |
| | MG | 0.766 | 1.440 | 0.319 | 0.049 | 0.155 | 0.790 | 1.450 | |
| | MGfn | 0.826 | 1.332 | 0.406 | 0.048 | 0.117 | 0.875 | 1.368 | |
| | MGfp | 0.843 | 1.183 | -0.021 | -0.002 | 0.083 | 0.856 | 1.183 | |
| Case 4 - Case 5 | VG | 0.625 | 1.288 | -0.615 | -0.109 | 0.177 | 0.637 | 1.273 | |
| | MG | 0.722 | 1.076 | -1.293 | -0.126 | 0.098 | 0.721 | 1.058 | |
| | MGfn | 0.830 | 0.999 | -2.064 | -0.093 | 0.045 | 0.833 | 0.993 | |
| | MGfp | 0.880 | 1.213 | 0.418 | 0.033 | 0.078 | 0.896 | 1.203 | |

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 |

| | | |
|---|---|----|
| 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 | | |
| paired 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 | | |

[illegible]

70

| Model(s) | | Student's t | | Student t | Mean | S.D. | Percentile | |
|-----------------|------|--------------|-------|-----------|--------|-------|--------------|-------|
| | | 95% | | | | | 95% | |
| | | Conf. limits | | | | | Conf. limits | |
| Case 1 | VG | 1.9 | 4.9 | 4.704 | 1.108 | 0.236 | 2. | 5. |
| | MG | 0.525 | 1.172 | -1.244 | -0.243 | 0.195 | 0.538 | 1.148 |
| | MGfn | 1.114 | 1.660 | 3.174 | 0.307 | 0.097 | 1.132 | 1.650 |
| | MGfp | 1.326 | 2.268 | 4.223 | 0.550 | 0.130 | 1.357 | 2.242 |
| Case 2 | VG | 2.1 | 6.3 | 4.730 | 1.284 | 0.271 | 2. | 6. |
| | MG | 0.493 | 1.170 | -1.312 | -0.275 | 0.210 | 0.499 | 1.141 |
| | MGfn | 1.106 | 1.719 | 3.003 | 0.321 | 0.107 | 1.131 | 1.720 |
| | MGfp | 1.367 | 2.414 | 4.323 | 0.597 | 0.138 | 1.405 | 2.418 |
| Case 3 | VG | 1.7 | 4.2 | 4.579 | 0.983 | 0.215 | 2. | 4. |
| | MG | 0.585 | 1.254 | -0.838 | -0.155 | 0.185 | 0.590 | 1.235 |
| | MGfn | 1.130 | 1.681 | 3.323 | 0.321 | 0.096 | 1.151 | 1.673 |
| | MGfp | 1.253 | 2.067 | 3.915 | 0.476 | 0.122 | 1.280 | 2.054 |
| Case 4 | VG | 1.7 | 4.2 | 4.610 | 0.988 | 0.214 | 2. | 4. |
| | MG | 0.576 | 1.234 | -0.923 | -0.171 | 0.185 | 0.584 | 1.218 |
| | MGfn | 1.121 | 1.670 | 3.240 | 0.313 | 0.097 | 1.142 | 1.666 |
| | MGfp | 1.264 | 2.084 | 3.990 | 0.484 | 0.121 | 1.293 | 2.072 |
| Case 5 | VG | 1.6 | 4.1 | 4.272 | 0.945 | 0.221 | 2. | 4. |
| | MG | 0.529 | 1.103 | -1.511 | -0.269 | 0.178 | 0.533 | 1.072 |
| | MGfn | 1.100 | 1.524 | 3.260 | 0.258 | 0.079 | 1.113 | 1.519 |
| | MGfp | 1.305 | 2.200 | 4.155 | 0.527 | 0.127 | 1.331 | 2.187 |
| Model(s) | | Student's t | | Student t | Mean | S.D. | Percentile | |
| | | 95% | | | | | 95% | |
| | | Conf. limits | | | | | Conf. limits | |
| Case 1 - Case 2 | VG | 0.684 | 1.029 | -1.771 | -0.175 | 0.099 | 0.671 | 0.985 |
| | MG | 0.954 | 1.118 | 0.847 | 0.033 | 0.038 | 0.968 | 1.118 |
| | MGfn | 0.944 | 1.030 | -0.665 | -0.014 | 0.021 | 0.945 | 1.026 |
| | MGfp | 0.898 | 1.014 | -1.580 | -0.046 | 0.029 | 0.894 | 1.000 |
| Case 1 - Case 3 | VG | 0.966 | 1.331 | 1.611 | 0.126 | 0.078 | 0.993 | 1.347 |
| | MG | 0.855 | 0.981 | -2.623 | -0.088 | 0.033 | 0.856 | 0.971 |
| | MGfn | 0.965 | 1.010 | -1.174 | -0.013 | 0.011 | 0.964 | 1.000 |
| | MGfp | 1.007 | 1.153 | 2.261 | 0.075 | 0.033 | 1.018 | 1.153 |
| Case 1 - Case 4 | VG | 0.963 | 1.321 | 1.571 | 0.120 | 0.077 | 0.987 | 1.334 |
| | MG | 0.872 | 0.992 | -2.306 | -0.072 | 0.031 | 0.874 | 0.982 |
| | MGfn | 0.985 | 1.003 | -1.371 | -0.006 | 0.004 | 0.984 | 1.000 |
| | MGfp | 1.001 | 1.140 | 2.101 | 0.066 | 0.031 | 1.012 | 1.139 |
| Case 1 - Case 5 | VG | 1.039 | 1.334 | 2.687 | 0.163 | 0.061 | 1.055 | 1.333 |
| | MG | 0.955 | 1.104 | 0.753 | 0.026 | 0.035 | 0.956 | 1.095 |
| | MGfn | 0.998 | 1.107 | 1.968 | 0.049 | 0.025 | 1.001 | 1.105 |
| | MGfp | 0.977 | 1.072 | 1.026 | 0.023 | 0.022 | 0.982 | 1.071 |
| Case 2 - Case 3 | VG | 0.998 | 1.830 | 2.045 | 0.301 | 0.147 | 1.061 | 1.856 |
| | MG | 0.784 | 1.003 | -2.016 | -0.120 | 0.060 | 0.777 | 0.981 |
| | MGfn | 0.952 | 1.052 | 0.037 | 0.001 | 0.024 | 0.953 | 1.050 |
| | MGfp | 1.011 | 1.259 | 2.274 | 0.121 | 0.053 | 1.031 | 1.267 |
| Case 2 - Case 4 | VG | 0.994 | 1.818 | 2.017 | 0.296 | 0.147 | 1.052 | 1.844 |
| | MG | 0.799 | 1.015 | -1.797 | -0.105 | 0.058 | 0.793 | 0.998 |
| | MGfn | 0.964 | 1.054 | 0.373 | 0.008 | 0.022 | 0.965 | 1.053 |
| | MGfp | 1.005 | 1.246 | 2.159 | 0.113 | 0.052 | 1.024 | 1.254 |
| Case 2 - Case 5 | VG | 1.035 | 1.902 | 2.292 | 0.339 | 0.148 | 1.100 | 1.913 |
| | MG | 0.869 | 1.137 | -0.093 | -0.006 | 0.065 | 0.872 | 1.120 |
| | MGfn | 0.981 | 1.158 | 1.578 | 0.063 | 0.040 | 0.992 | 1.161 |
| | MGfp | 0.974 | 1.180 | 1.488 | 0.070 | 0.047 | 0.992 | 1.191 |
| Case 3 - Case 4 | VG | 0.973 | 1.017 | -0.486 | -0.005 | 0.011 | 0.972 | 1.012 |
| | MG | 0.996 | 1.036 | 1.632 | 0.016 | 0.010 | 1.000 | 1.036 |
| | MGfn | 0.993 | 1.022 | 1.024 | 0.007 | 0.007 | 1.000 | 1.021 |
| | MGfp | 0.977 | 1.007 | -1.129 | -0.008 | 0.007 | 0.976 | 1.004 |
| Case 3 - Case 5 | VG | 0.878 | 1.228 | 0.463 | 0.038 | 0.081 | 0.881 | 1.200 |
| | MG | 1.060 | 1.184 | 4.248 | 0.114 | 0.027 | 1.065 | 1.179 |
| | MGfn | 1.018 | 1.114 | 2.859 | 0.063 | 0.022 | 1.022 | 1.113 |
| | MGfp | 0.907 | 0.995 | -2.307 | -0.051 | 0.022 | 0.906 | 0.988 |
| Case 4 - Case 5 | VG | 0.882 | 1.236 | 0.524 | 0.043 | 0.082 | 0.883 | 1.209 |
| | MG | 1.036 | 1.176 | 3.195 | 0.098 | 0.031 | 1.042 | 1.171 |
| | MGfn | 1.007 | 1.110 | 2.347 | 0.055 | 0.024 | 1.012 | 1.108 |
| | MGfp | 0.911 | 1.007 | -1.758 | -0.043 | 0.025 | 0.910 | 1.001 |

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 | | | | | | X |
| 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 | | | | | | |

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
paired 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 | 2.64 | 1.19 | 0.36 | 2.29 | 0.717 | 0.593 | 1.44 | 154 | 118 |
| n/a | | | | | | | (MGfn= 1.760, MGfp= 1.225, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 2 | 3.19 | 1.29 | -0.19 | 2.10 | 0.759 | 0.667 | 0.83 | 217 | 206 |
| n/a | | | | | | | (MGfn= 1.265, MGfp= 1.530, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 3 | 2.71 | 1.50 | 0.29 | 3.95 | 0.657 | 0.444 | 1.34 | 586 | 451 |
| n/a | | | | | | | (MGfn= 1.901, MGfp= 1.421, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 4 | 2.65 | 1.36 | 0.35 | 3.19 | 0.666 | 0.407 | 1.42 | 386 | 280 |
| n/a | | | | | | | (MGfn= 1.897, MGfp= 1.335, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 5 | 2.74 | 0.97 | 0.26 | 1.90 | 0.685 | 0.556 | 1.30 | 126 | 106 |
| n/a | | | | | | | (MGfn= 1.569, MGfp= 1.207, | | |
| MG=MGfn/MGfp) | | | | | | | | | |

Note: The Percentile 95% Confidence Limits are based on the 2.5th and 97.5th percentiles of the cumulative distribution function.
The Student's t 95% Confidence Limits are based on calculated mean and standard deviation.

| Model(s) | | Student's t | | Student t | Mean | S.D. | Percentile | |
|----------|------|------------------|-------|-----------|--------|-------|------------------|-------|
| | | 95% Conf. limits | | | | | 95% Conf. limits | |
| Case 1 | VG | 1.6 | 3.4 | 4.502 | 0.833 | 0.185 | 2. | 3. |
| | MG | 1.043 | 2.018 | 2.318 | 0.372 | 0.161 | 1.073 | 1.929 |
| | MGfn | 1.395 | 2.247 | 4.926 | 0.571 | 0.116 | 1.441 | 2.223 |
| | MGfp | 1.074 | 1.387 | 3.196 | 0.199 | 0.062 | 1.093 | 1.375 |
| Case 2 | VG | 1.4 | 3.2 | 3.548 | 0.731 | 0.206 | 1. | 3. |
| | MG | 0.601 | 1.164 | -1.111 | -0.178 | 0.161 | 0.609 | 1.126 |
| | MGfn | 1.097 | 1.467 | 3.367 | 0.238 | 0.071 | 1.123 | 1.465 |
| | MGfp | 1.198 | 1.919 | 3.634 | 0.416 | 0.115 | 1.242 | 1.893 |
| Case 3 | VG | 2.2 | 7.3 | 4.719 | 1.380 | 0.292 | 2. | 7. |
| | MG | 0.862 | 2.122 | 1.376 | 0.302 | 0.219 | 0.869 | 1.980 |
| | MGfn | 1.498 | 2.448 | 5.435 | 0.650 | 0.120 | 1.535 | 2.398 |
| | MGfp | 1.080 | 1.856 | 2.642 | 0.348 | 0.132 | 1.129 | 1.880 |
| Case 4 | VG | 2.1 | 5.0 | 5.413 | 1.170 | 0.216 | 2. | 5. |
| | MG | 0.957 | 2.153 | 1.835 | 0.362 | 0.197 | 0.978 | 2.047 |
| | MGfn | 1.489 | 2.455 | 5.330 | 0.648 | 0.122 | 1.530 | 2.417 |
| | MGfp | 1.080 | 1.642 | 2.816 | 0.287 | 0.102 | 1.119 | 1.667 |
| Case 5 | VG | 1.4 | 2.6 | 4.334 | 0.647 | 0.149 | 1. | 3. |
| | MG | 0.970 | 1.773 | 1.848 | 0.271 | 0.147 | 0.994 | 1.740 |
| | MGfn | 1.265 | 1.968 | 4.244 | 0.456 | 0.107 | 1.291 | 1.958 |
| | MGfp | 1.063 | 1.361 | 3.075 | 0.185 | 0.060 | 1.080 | 1.361 |

| Model(s) | | Student's t | | Student t | Mean | S.D. | Percentile | |
|-----------------|------|------------------|-------|-----------|--------|-------|------------------|-------|
| | | 95% Conf. limits | | | | | 95% Conf. limits | |
| Case 1 - Case 2 | VG | 0.620 | 1.975 | 0.361 | 0.102 | 0.282 | 0.641 | 1.852 |
| | MG | 1.396 | 2.155 | 5.215 | 0.551 | 0.106 | 1.416 | 2.083 |
| | MGfn | 1.130 | 1.723 | 3.253 | 0.333 | 0.102 | 1.148 | 1.684 |
| | MGfp | 0.705 | 0.918 | -3.383 | -0.217 | 0.064 | 0.706 | 0.902 |
| Case 1 - Case 3 | VG | 0.330 | 1.015 | -2.003 | -0.547 | 0.273 | 0.322 | 0.925 |
| | MG | 0.836 | 1.376 | 0.581 | 0.070 | 0.121 | 0.862 | 1.393 |
| | MGfn | 0.849 | 1.006 | -1.900 | -0.078 | 0.041 | 0.849 | 0.993 |
| | MGfp | 0.692 | 1.074 | -1.392 | -0.149 | 0.107 | 0.684 | 1.033 |
| Case 1 - Case 4 | VG | 0.508 | 1.004 | -2.030 | -0.337 | 0.166 | 0.510 | 0.957 |
| | MG | 0.841 | 1.215 | 0.118 | 0.011 | 0.090 | 0.857 | 1.212 |
| | MGfn | 0.850 | 1.009 | -1.836 | -0.077 | 0.042 | 0.847 | 1.000 |
| | MGfp | 0.783 | 1.072 | -1.145 | -0.088 | 0.076 | 0.779 | 1.046 |
| Case 1 - Case 5 | VG | 1.035 | 1.403 | 2.514 | 0.186 | 0.074 | 1.053 | 1.385 |
| | MG | 0.992 | 1.234 | 1.907 | 0.101 | 0.053 | 1.002 | 1.225 |
| | MGfn | 1.031 | 1.222 | 2.790 | 0.115 | 0.041 | 1.035 | 1.215 |
| | MGfp | 0.954 | 1.079 | 0.476 | 0.014 | 0.030 | 0.955 | 1.075 |
| Case 2 - Case 3 | VG | 0.268 | 1.021 | -1.992 | -0.648 | 0.326 | 0.283 | 0.996 |
| | MG | 0.454 | 0.844 | -3.182 | -0.480 | 0.151 | 0.468 | 0.840 |
| | MGfn | 0.525 | 0.836 | -3.634 | -0.412 | 0.113 | 0.537 | 0.827 |
| | MGfp | 0.878 | 1.306 | 0.709 | 0.069 | 0.097 | 0.893 | 1.298 |
| Case 2 - Case 4 | VG | 0.351 | 1.184 | -1.484 | -0.438 | 0.295 | 0.371 | 1.175 |
| | MG | 0.444 | 0.766 | -4.066 | -0.540 | 0.133 | 0.458 | 0.762 |
| | MGfn | 0.525 | 0.839 | -3.586 | -0.410 | 0.114 | 0.535 | 0.825 |
| | MGfp | 0.965 | 1.343 | 1.612 | 0.130 | 0.080 | 0.988 | 1.333 |
| Case 2 - Case 5 | VG | 0.626 | 1.891 | 0.314 | 0.085 | 0.269 | 0.665 | 1.894 |
| | MG | 0.491 | 0.829 | -3.520 | -0.450 | 0.128 | 0.508 | 0.815 |
| | MGfn | 0.652 | 0.992 | -2.132 | -0.218 | 0.102 | 0.662 | 0.990 |
| | MGfp | 1.058 | 1.502 | 2.720 | 0.232 | 0.085 | 1.081 | 1.491 |
| Case 3 - Case 4 | VG | 0.957 | 1.591 | 1.698 | 0.210 | 0.124 | 0.992 | 1.624 |
| | MG | 0.863 | 1.028 | -1.412 | -0.060 | 0.042 | 0.864 | 1.019 |
| | MGfn | 0.967 | 1.037 | 0.085 | 0.001 | 0.017 | 0.969 | 1.041 |
| | MGfp | 0.988 | 1.144 | 1.723 | 0.061 | 0.036 | 1.000 | 1.147 |
| Case 3 - Case 5 | VG | 1.197 | 3.619 | 2.723 | 0.733 | 0.269 | 1.311 | 3.655 |
| | MG | 0.775 | 1.371 | 0.221 | 0.031 | 0.139 | 0.769 | 1.316 |
| | MGfn | 1.134 | 1.299 | 5.849 | 0.194 | 0.033 | 1.137 | 1.295 |
| | MGfp | 0.917 | 1.510 | 1.345 | 0.163 | 0.121 | 0.949 | 1.522 |
| Case 4 - Case 5 | VG | 1.214 | 2.343 | 3.272 | 0.523 | 0.160 | 1.293 | 2.355 |
| | MG | 0.885 | 1.354 | 0.875 | 0.090 | 0.103 | 0.878 | 1.314 |
| | MGfn | 1.137 | 1.291 | 6.219 | 0.192 | 0.031 | 1.142 | 1.287 |
| | MGfp | 0.921 | 1.331 | 1.136 | 0.102 | 0.090 | 0.943 | 1.343 |

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 | | | | X | | |
| 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 | 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 | | | | | X | |
| 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 Ventura

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

```

No. of experiments          = 17
No. of models               = 6
(with the observed data counted as one)
No. of observations         = 17
(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
paired sampling             = 16
(there might be odd number of observations in each block)
No. of blocks (regimes)     = 1
No. of experiments in each block (regime)
17

```

```

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. | 0.18 | 0.76 | 0.00 | 1.00 | 1.000 | 1.000 | 1.00 | 3 | 3 |
| n/a | | | | | | | | | |
| | | | | | | | (MGfn= 1.000, MGfp= 1.000, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 1 | 0.50 | 1.03 | -0.32 | 1.81 | 0.732 | 0.765 | 0.73 | 6 | 5 |
| n/a | | | | | | | (MGfn= 1.120, MGfp= 1.539, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 2 | 0.87 | 1.37 | -0.69 | 5.28 | 0.615 | 0.588 | 0.50 | 23 | 16 |
| n/a | | | | | | | (MGfn= 1.104, MGfp= 2.208, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 3 | 0.74 | 1.18 | -0.56 | 2.58 | 0.745 | 0.588 | 0.57 | 7 | 7 |
| n/a | | | | | | | (MGfn= 1.097, MGfp= 1.923, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 4 | 0.74 | 1.18 | -0.56 | 2.58 | 0.745 | 0.588 | 0.57 | 7 | 7 |
| n/a | | | | | | | (MGfn= 1.097, MGfp= 1.923, | | |
| MG=MGfn/MGfp) | | | | | | | | | |
| Case 5 | 0.32 | 0.88 | -0.14 | 1.41 | 0.768 | 0.882 | 0.87 | 4 | 4 |
| n/a | | | | | | | (MGfn= 1.119, MGfp= 1.293, | | |
| MG=MGfn/MGfp) | | | | | | | | | |

Note: The Percentile 95% Confidence Limits are based on the 2.5th and 97.5th percentiles of the cumulative distribution function.
The Student's t 95% Confidence Limits are based on calculated mean and standard deviation.

| | | Student's t | | | | | Percentile | |
|----------|------|--------------|-------|---------|--------|-------|--------------|---------|
| | | 95% | | Student | | | 95% | |
| Model(s) | | Conf. limits | | t | Mean | S.D. | Conf. limits | |
| Case 1 | VG | 1.0 | 3.2 | 2.133 | 0.583 | 0.273 | 1. | 3. |
| | MG | 0.513 | 1.043 | -1.867 | -0.312 | 0.167 | 0.525 | 0.974 |
| | MGfn | 1.034 | 1.214 | 2.995 | 0.114 | 0.038 | 1.047 | 1.210 |
| | MGfp | 1.125 | 2.082 | 2.931 | 0.426 | 0.145 | 1.196 | 2.070 |
| Case 2 | VG | 1.4 | 19. | 2.692 | 1.643 | 0.610 | 2. | 0.2E+02 |
| | MG | 0.286 | 0.883 | -2.588 | -0.688 | 0.266 | 0.298 | 0.803 |
| | MGfn | 1.018 | 1.197 | 2.600 | 0.099 | 0.038 | 1.034 | 1.194 |
| | MGfp | 1.308 | 3.688 | 3.218 | 0.787 | 0.244 | 1.412 | 3.534 |
| Case 3 | VG | 1.3 | 5.2 | 2.800 | 0.939 | 0.336 | 1. | 5. |
| | MG | 0.380 | 0.865 | -2.869 | -0.557 | 0.194 | 0.392 | 0.800 |
| | MGfn | 1.012 | 1.191 | 2.427 | 0.093 | 0.038 | 1.030 | 1.182 |
| | MGfp | 1.334 | 2.749 | 3.811 | 0.650 | 0.171 | 1.427 | 2.698 |
| Case 4 | VG | 1.3 | 5.2 | 2.800 | 0.939 | 0.336 | 1. | 5. |
| | MG | 0.380 | 0.865 | -2.869 | -0.557 | 0.194 | 0.392 | 0.800 |
| | MGfn | 1.012 | 1.191 | 2.427 | 0.093 | 0.038 | 1.030 | 1.182 |
| | MGfp | 1.334 | 2.749 | 3.811 | 0.650 | 0.171 | 1.427 | 2.698 |
| Case 5 | VG | 0.87 | 2.2 | 1.507 | 0.337 | 0.223 | 1. | 2. |
| | MG | 0.656 | 1.153 | -1.050 | -0.140 | 0.133 | 0.662 | 1.091 |
| | MGfn | 1.040 | 1.205 | 3.238 | 0.113 | 0.035 | 1.052 | 1.204 |
| | MGfp | 1.005 | 1.649 | 2.162 | 0.252 | 0.117 | 1.075 | 1.643 |

| | | Student's t | | | | | Percentile | |
|-----------------|------|--------------|--------|---------|--------|-------|--------------|--------|
| | | 95% | | Student | | | 95% | |
| Model(s) | | Conf. limits | | t | Mean | S.D. | Conf. limits | |
| Case 1 - Case 2 | VG | 0.133 | 0.901 | -2.352 | -1.060 | 0.451 | 0.130 | 0.715 |
| | MG | 1.105 | 1.918 | 2.886 | 0.375 | 0.130 | 1.151 | 1.912 |
| | MGfn | 0.969 | 1.062 | 0.656 | 0.014 | 0.022 | 0.974 | 1.055 |
| | MGfp | 0.528 | 0.919 | -2.764 | -0.361 | 0.131 | 0.534 | 0.876 |
| Case 1 - Case 3 | VG | 0.443 | 1.105 | -1.655 | -0.357 | 0.216 | 0.438 | 0.914 |
| | MG | 1.061 | 1.537 | 2.797 | 0.244 | 0.087 | 1.118 | 1.541 |
| | MGfn | 0.989 | 1.053 | 1.388 | 0.020 | 0.015 | 1.000 | 1.055 |
| | MGfp | 0.665 | 0.960 | -2.588 | -0.224 | 0.087 | 0.662 | 0.907 |
| Case 1 - Case 4 | VG | 0.443 | 1.105 | -1.655 | -0.357 | 0.216 | 0.438 | 0.914 |
| | MG | 1.061 | 1.537 | 2.797 | 0.244 | 0.087 | 1.118 | 1.541 |
| | MGfn | 0.989 | 1.053 | 1.388 | 0.020 | 0.015 | 1.000 | 1.055 |
| | MGfp | 0.665 | 0.960 | -2.588 | -0.224 | 0.087 | 0.662 | 0.907 |
| Case 1 - Case 5 | VG | 1.043 | 1.569 | 2.555 | 0.246 | 0.096 | 1.096 | 1.560 |
| | MG | 0.738 | 0.960 | -2.786 | -0.172 | 0.062 | 0.745 | 0.942 |
| | MGfn | 0.962 | 1.041 | 0.040 | 0.001 | 0.019 | 0.965 | 1.035 |
| | MGfp | 1.052 | 1.344 | 3.003 | 0.173 | 0.058 | 1.077 | 1.331 |
| Case 2 - Case 3 | VG | 0.698 | 5.850 | 1.404 | 0.704 | 0.501 | 0.839 | 5.822 |
| | MG | 0.627 | 1.228 | -0.826 | -0.131 | 0.159 | 0.646 | 1.169 |
| | MGfn | 0.962 | 1.052 | 0.283 | 0.006 | 0.021 | 0.967 | 1.047 |
| | MGfp | 0.827 | 1.590 | 0.889 | 0.137 | 0.154 | 0.854 | 1.531 |
| Case 2 - Case 4 | VG | 0.698 | 5.850 | 1.404 | 0.704 | 0.501 | 0.839 | 5.822 |
| | MG | 0.627 | 1.228 | -0.826 | -0.131 | 0.159 | 0.646 | 1.169 |
| | MGfn | 0.962 | 1.052 | 0.283 | 0.006 | 0.021 | 0.967 | 1.047 |
| | MGfp | 0.827 | 1.590 | 0.889 | 0.137 | 0.154 | 0.854 | 1.531 |
| Case 2 - Case 5 | VG | 1.174 | 11.618 | 2.417 | 1.306 | 0.541 | 1.547 | 11.887 |
| | MG | 0.387 | 0.865 | -2.885 | -0.548 | 0.190 | 0.389 | 0.807 |
| | MGfn | 0.917 | 1.061 | -0.393 | -0.014 | 0.034 | 0.923 | 1.054 |
| | MGfp | 1.146 | 2.541 | 2.846 | 0.534 | 0.188 | 1.228 | 2.494 |
| Case 3 - Case 4 | VG | 1.000 | 1.000 | 0.580 | 0.000 | 0.000 | 1.000 | 1.000 |
| | MG | 1.000 | 1.000 | 3.425 | 0.000 | 0.000 | 1.000 | 1.000 |
| | MGfn | 1.000 | 1.000 | 2.740 | 0.000 | 0.000 | 1.000 | 1.000 |
| | MGfp | 1.000 | 1.000 | -2.637 | 0.000 | 0.000 | 1.000 | 1.000 |
| Case 3 - Case 5 | VG | 1.105 | 3.021 | 2.542 | 0.603 | 0.237 | 1.278 | 3.073 |
| | MG | 0.518 | 0.838 | -3.684 | -0.417 | 0.113 | 0.521 | 0.803 |
| | MGfn | 0.920 | 1.045 | -0.651 | -0.020 | 0.030 | 0.921 | 1.031 |
| | MGfp | 1.182 | 1.873 | 3.657 | 0.397 | 0.109 | 1.235 | 1.872 |
| Case 4 - Case 5 | VG | 1.105 | 3.021 | 2.542 | 0.603 | 0.237 | 1.278 | 3.073 |
| | MG | 0.518 | 0.838 | -3.684 | -0.417 | 0.113 | 0.521 | 0.803 |
| | MGfn | 0.920 | 1.045 | -0.651 | -0.020 | 0.030 | 0.921 | 1.031 |
| | MGfp | 1.182 | 1.873 | 3.657 | 0.397 | 0.109 | 1.235 | 1.872 |

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 | X |
| Case 2 | | | | | | X |
| 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 | X | X |
| Case 2 | | | | | | X |
| Case 3 | | | | | X | 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 | | | | | X | |
| Case 2 | | | | | | |
| Case 3 | | | | | X | |
| Case 4 | | | | | | |

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 | X | X |
| Case 2 | | | | | | X |
| Case 3 | | | | | X | 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 |
| ----- | | | | |
| X | X | X | 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 |