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

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DISCLAIMER

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.

CONTENTS

TABLES

FIGURES

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 PVMRM[1] and OLM[2] methods for assessing the new 1-hour NO_2 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 NO_2, and 1-hour SO_2 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-NO_2 conversion based on available ozone.
[2] Ozone Limiting Method, used to limit NO-to-NO_2 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.

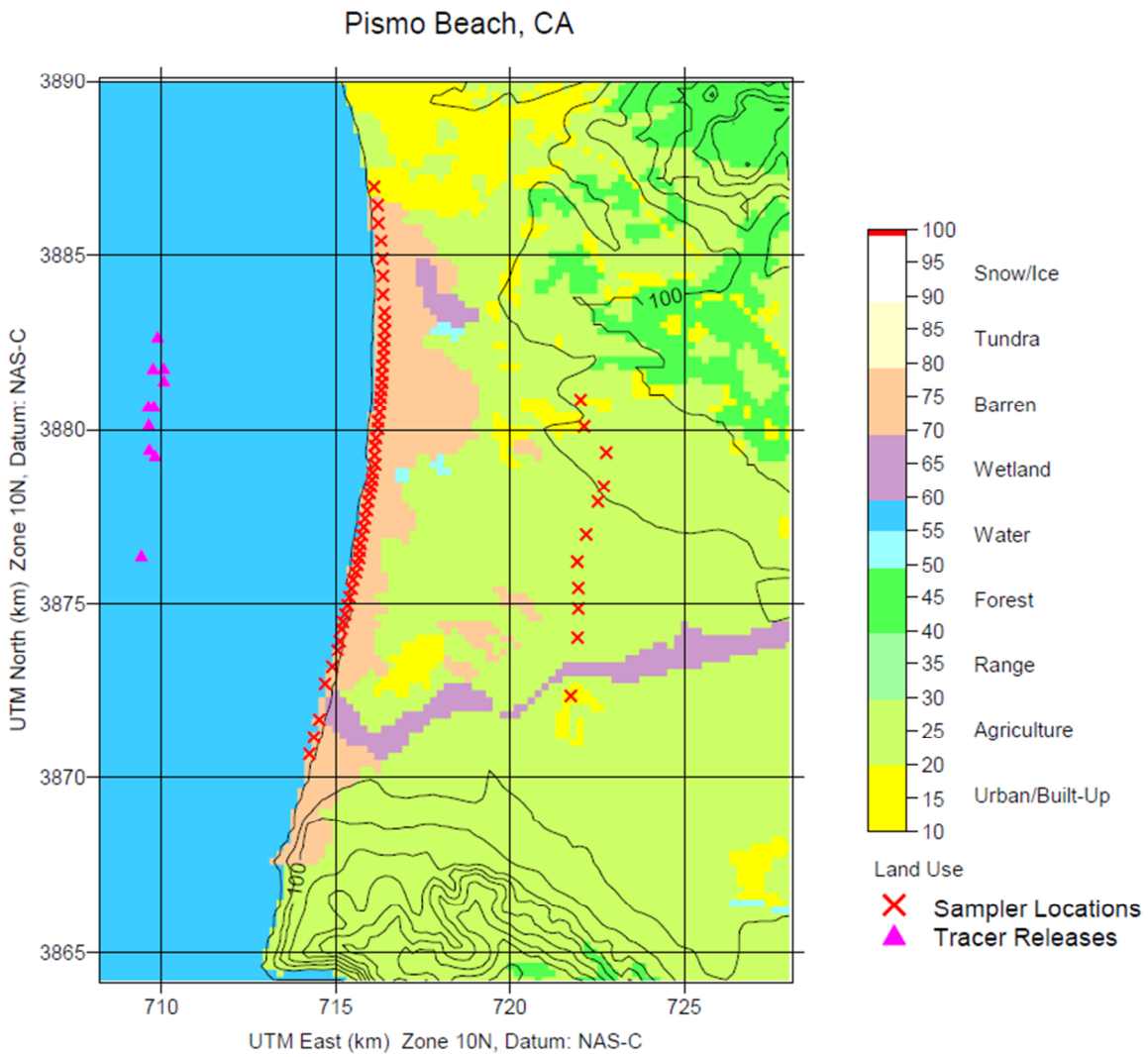

Figure 1. Pismo Beach

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

4 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

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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.

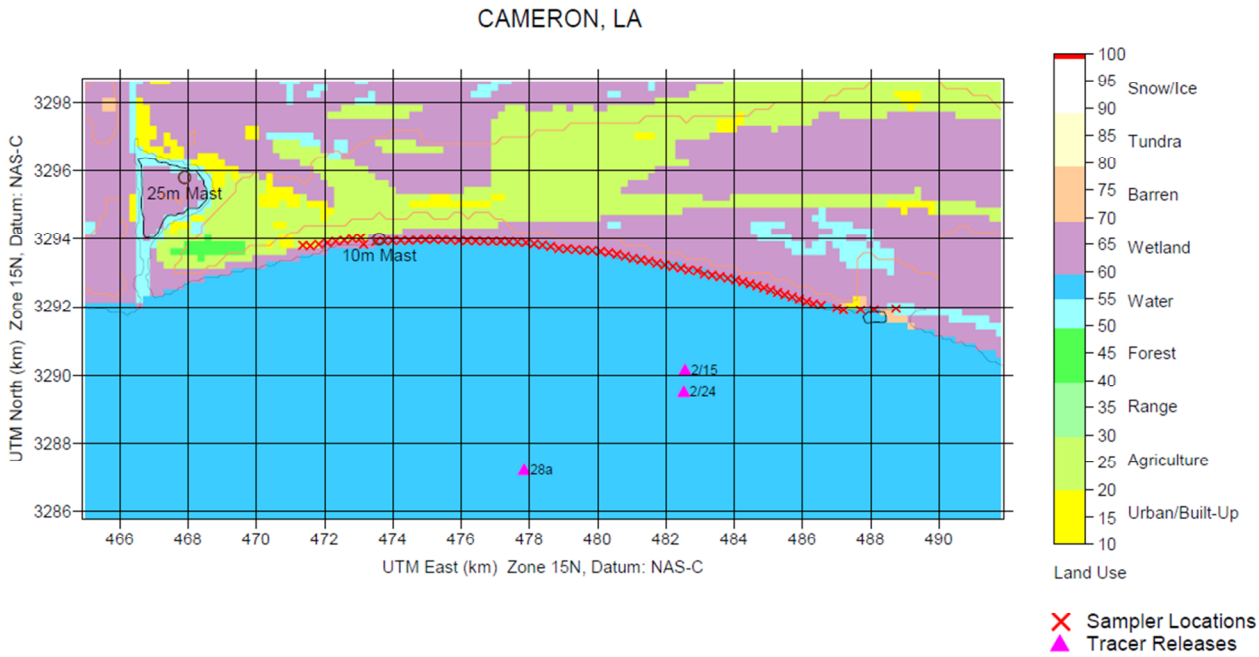

Figure 2. Cameron

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 °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.

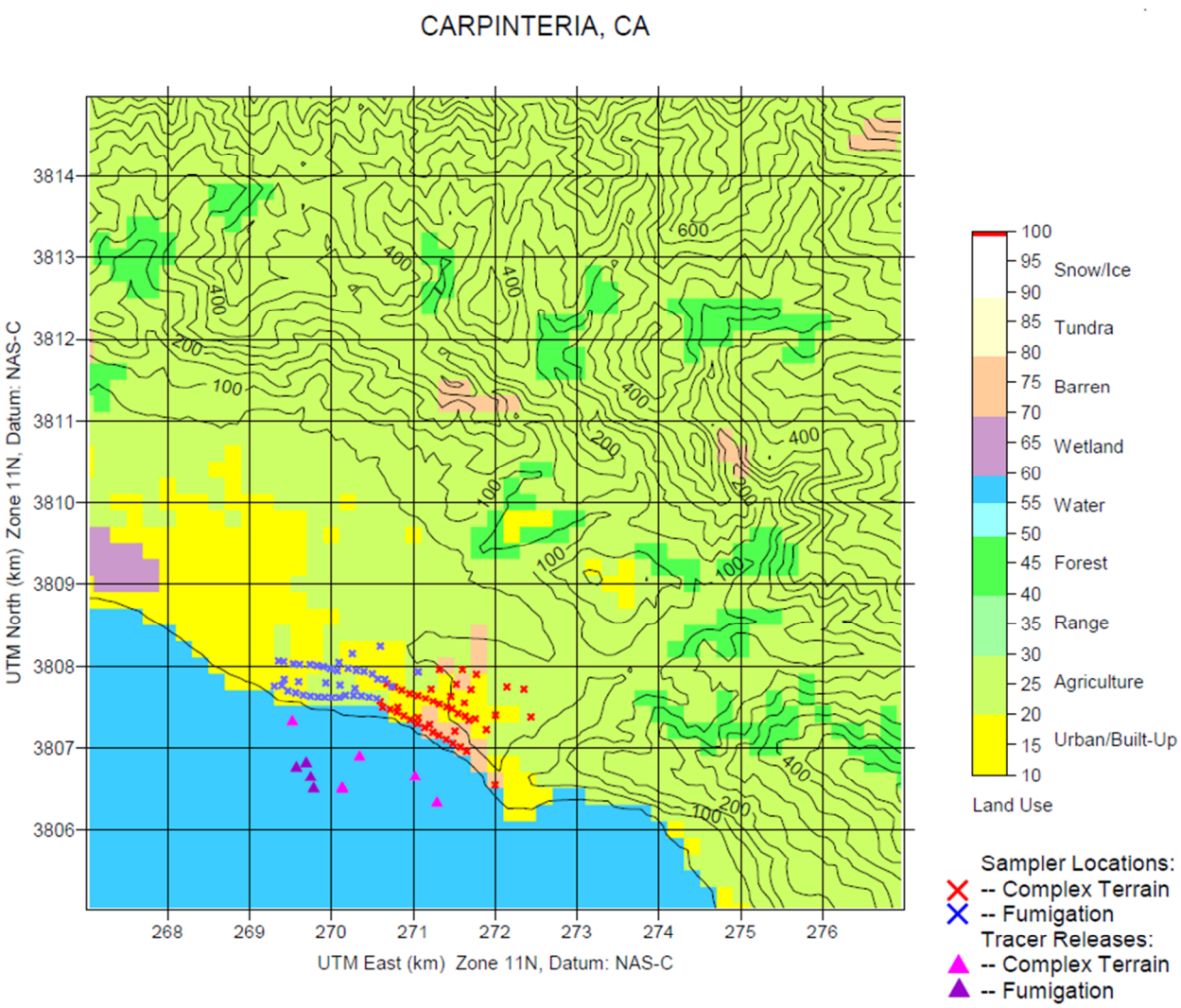

Figure 3. Carpinteria

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.

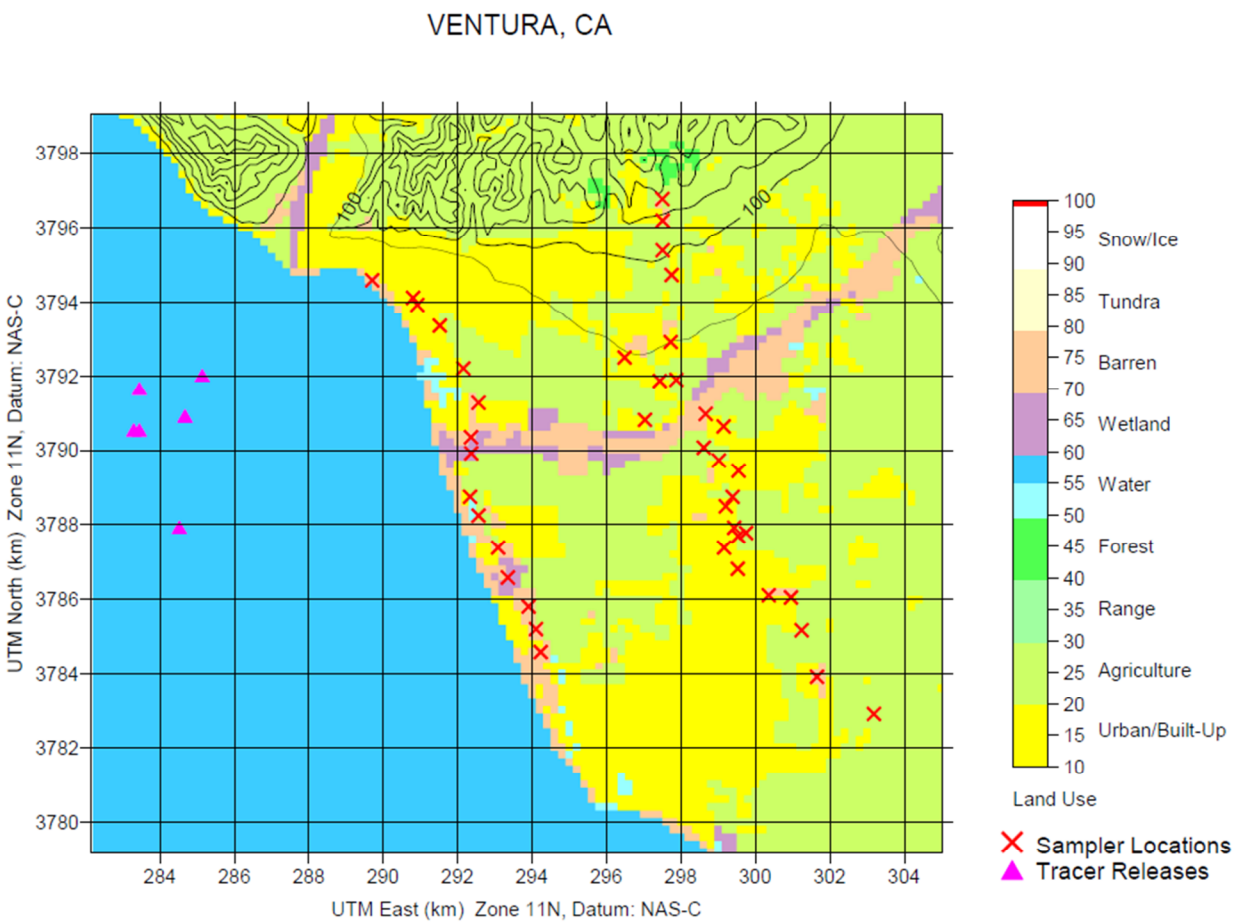

Figure 4. Ventura

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 Jwarm = Jcool = 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 Jwave = 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 °C/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 °C/m).
- Convective boundary layer heights were assumed to be the same as the observed mixing heights from field studies when conditions where unstable as indicated by the Monin-Obukhov length (L < 0). 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:

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

  where c_n is the nth highest concentration and $\overline{c}$ 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 µs/m3.

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.

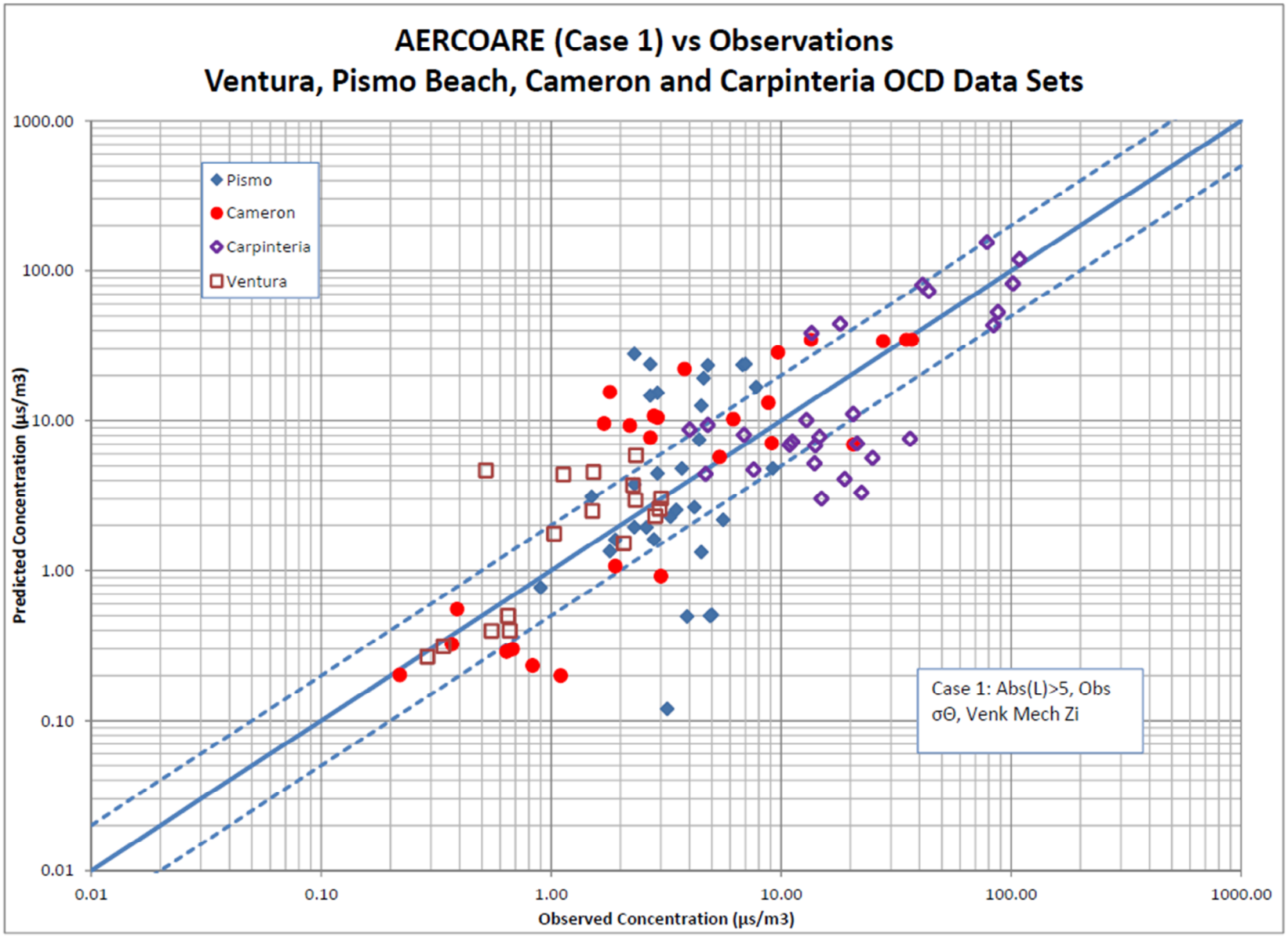

Figure 5. Scatter Plot of AERCOARE Case 1 versus Observations

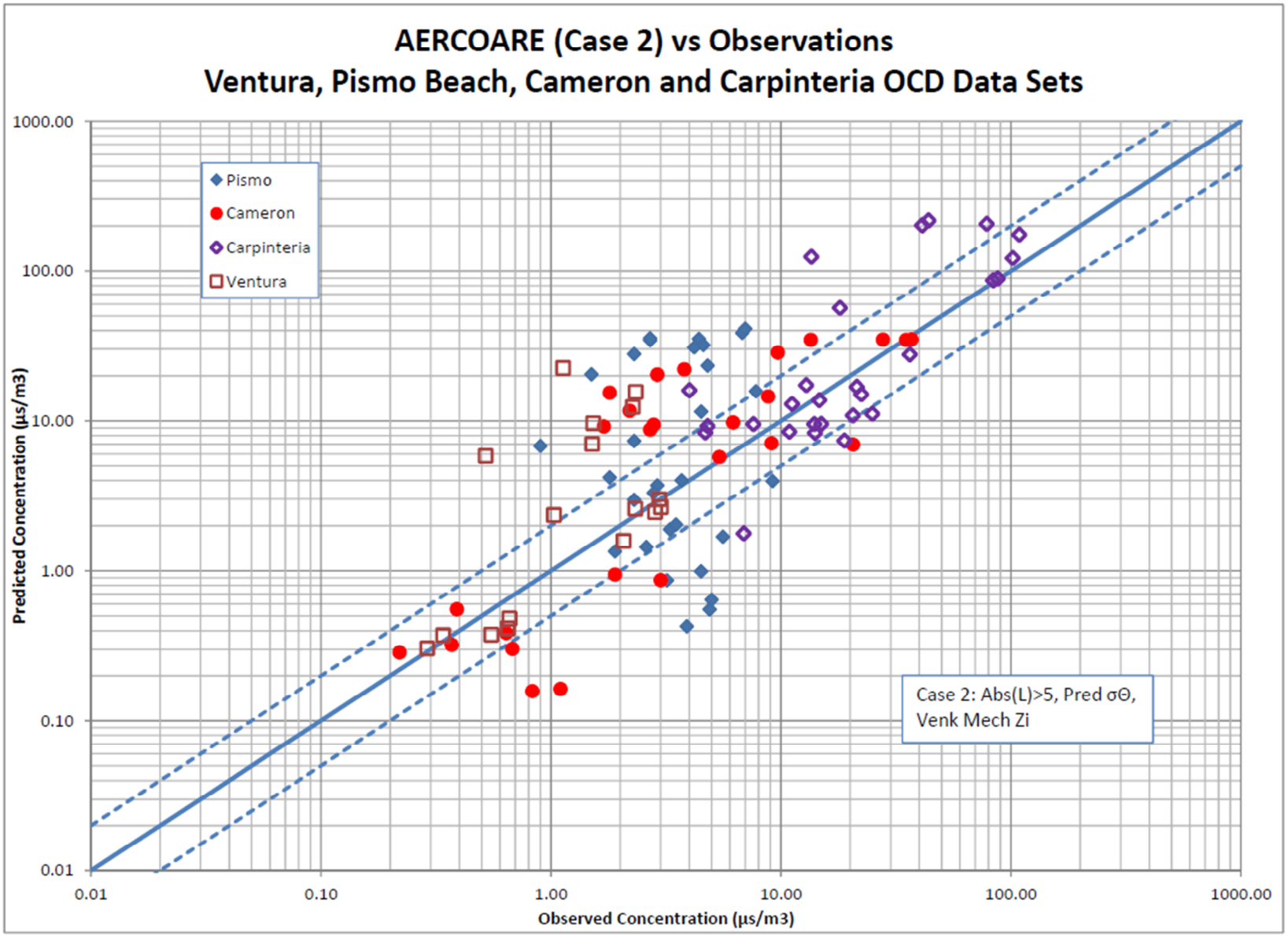

Figure 6. Scatter Plot of AERCOARE Case 2 versus Observations

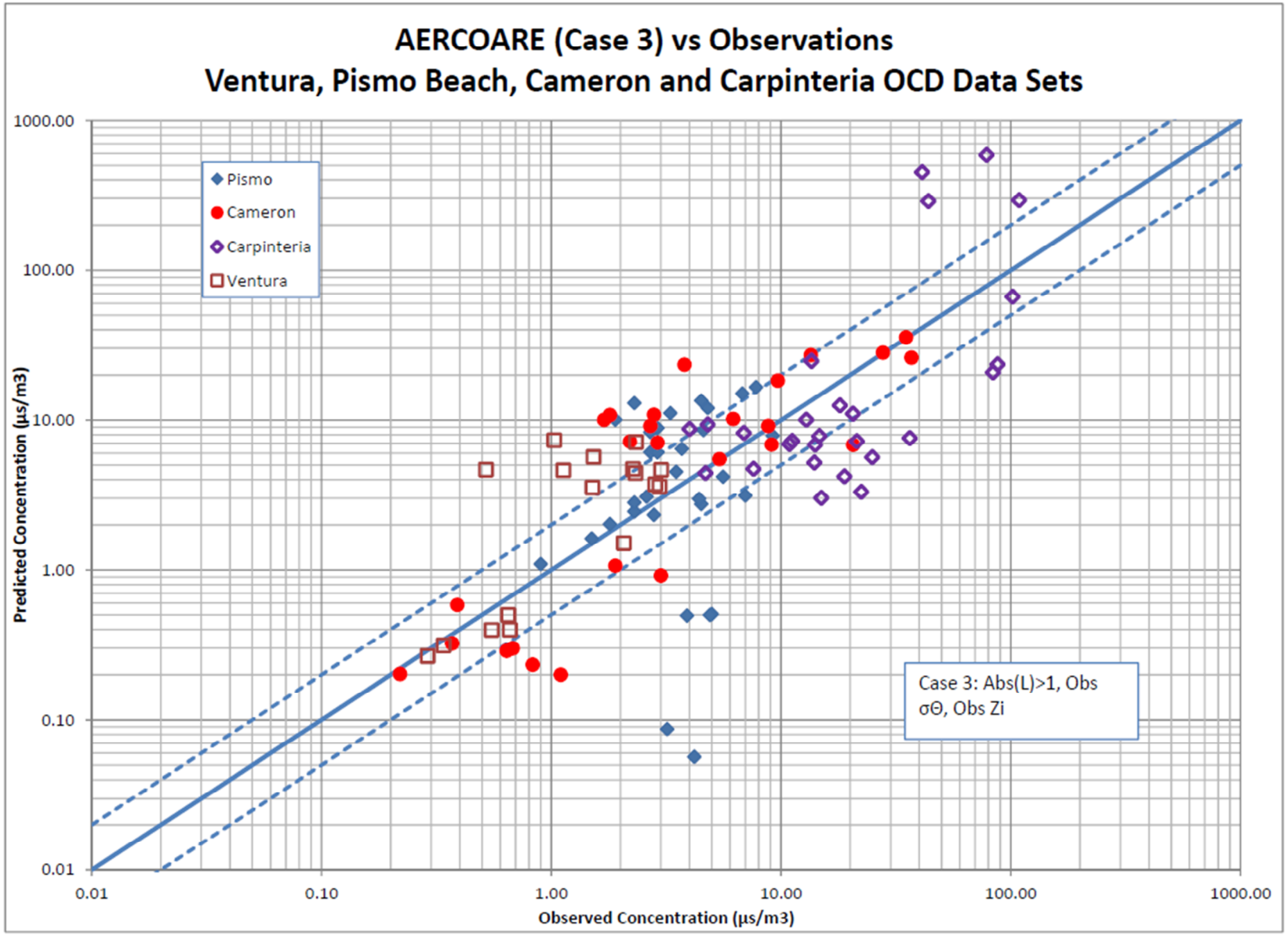

Figure 7. Scatter Plot of AERCOARE Case 3 versus Observations

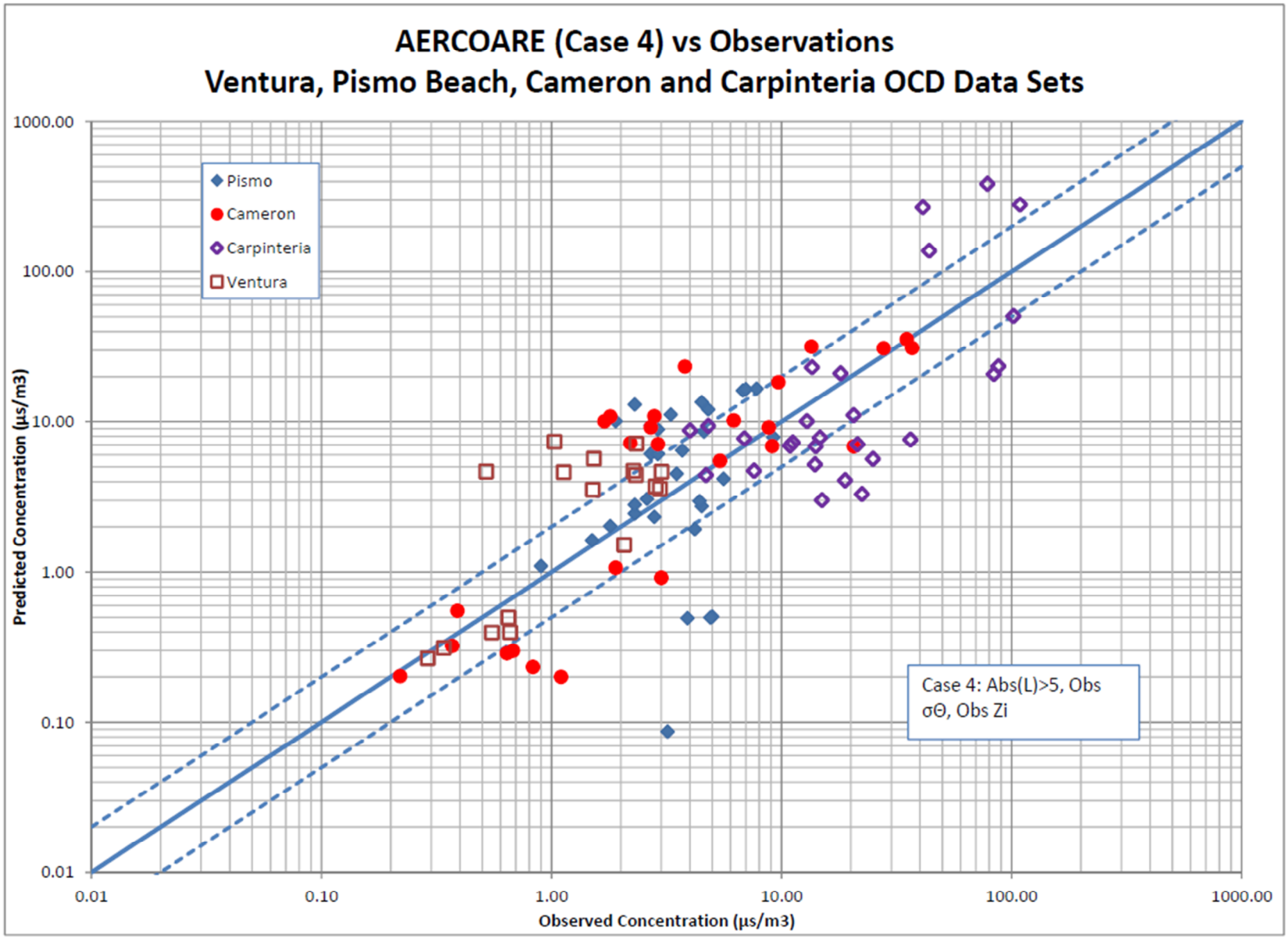

Figure 8. Scatter Plot of AERCOARE Case 4 versus Observations

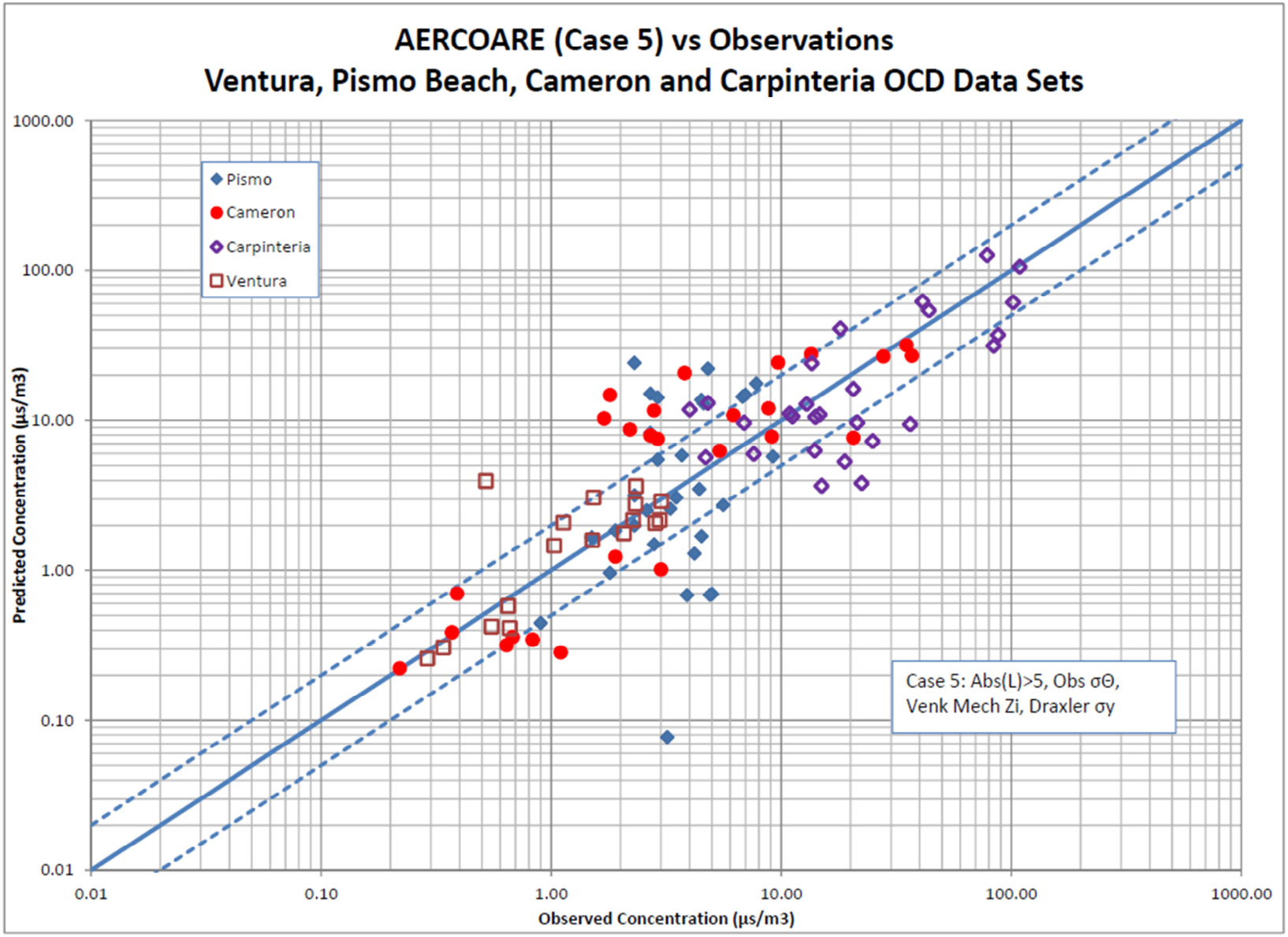

Figure 9. Scatter Plot of AERCOARE Case 5 versus Observations

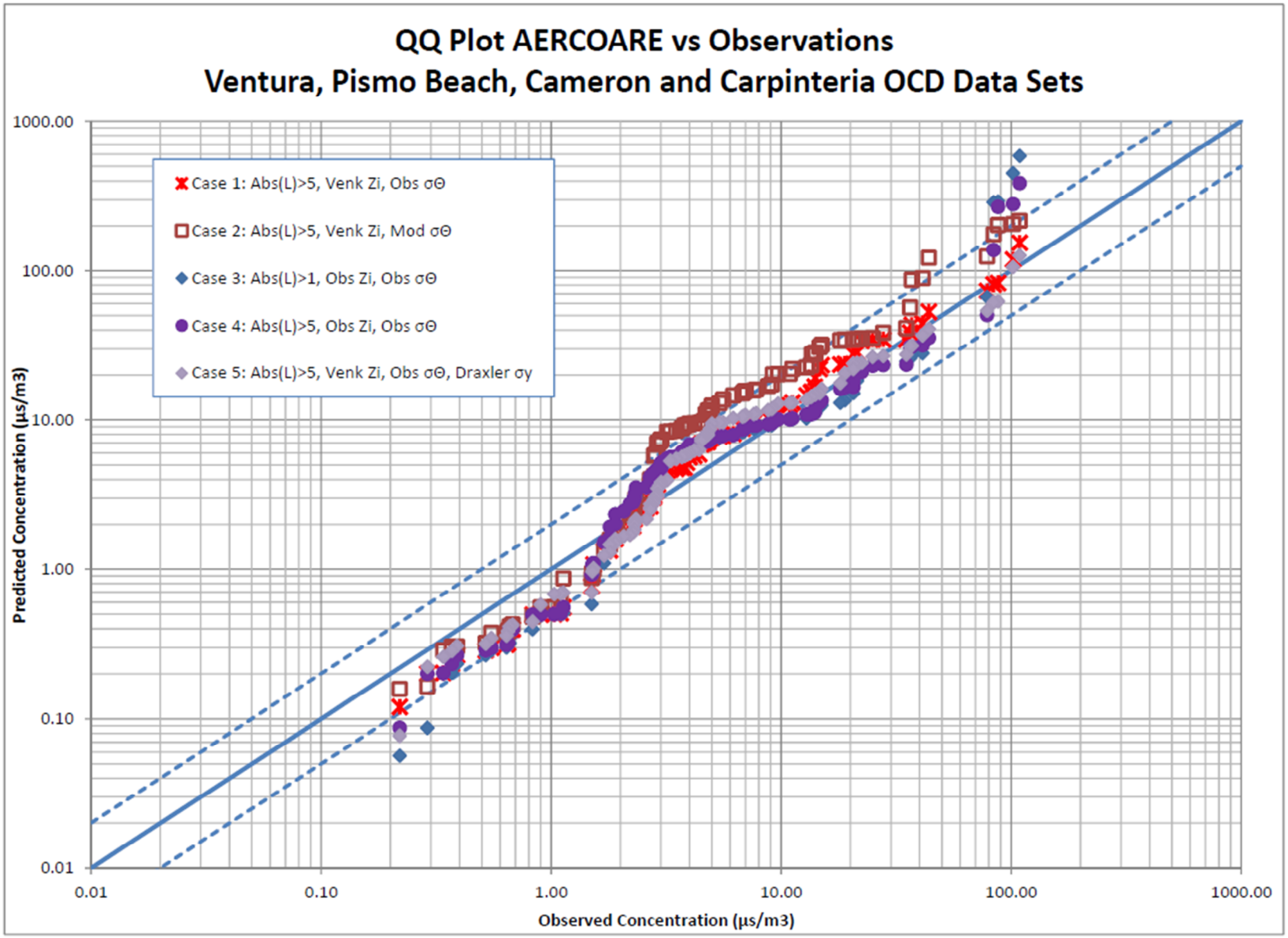

Figure 10. QQ Plot of AERCOARE versus All Observations

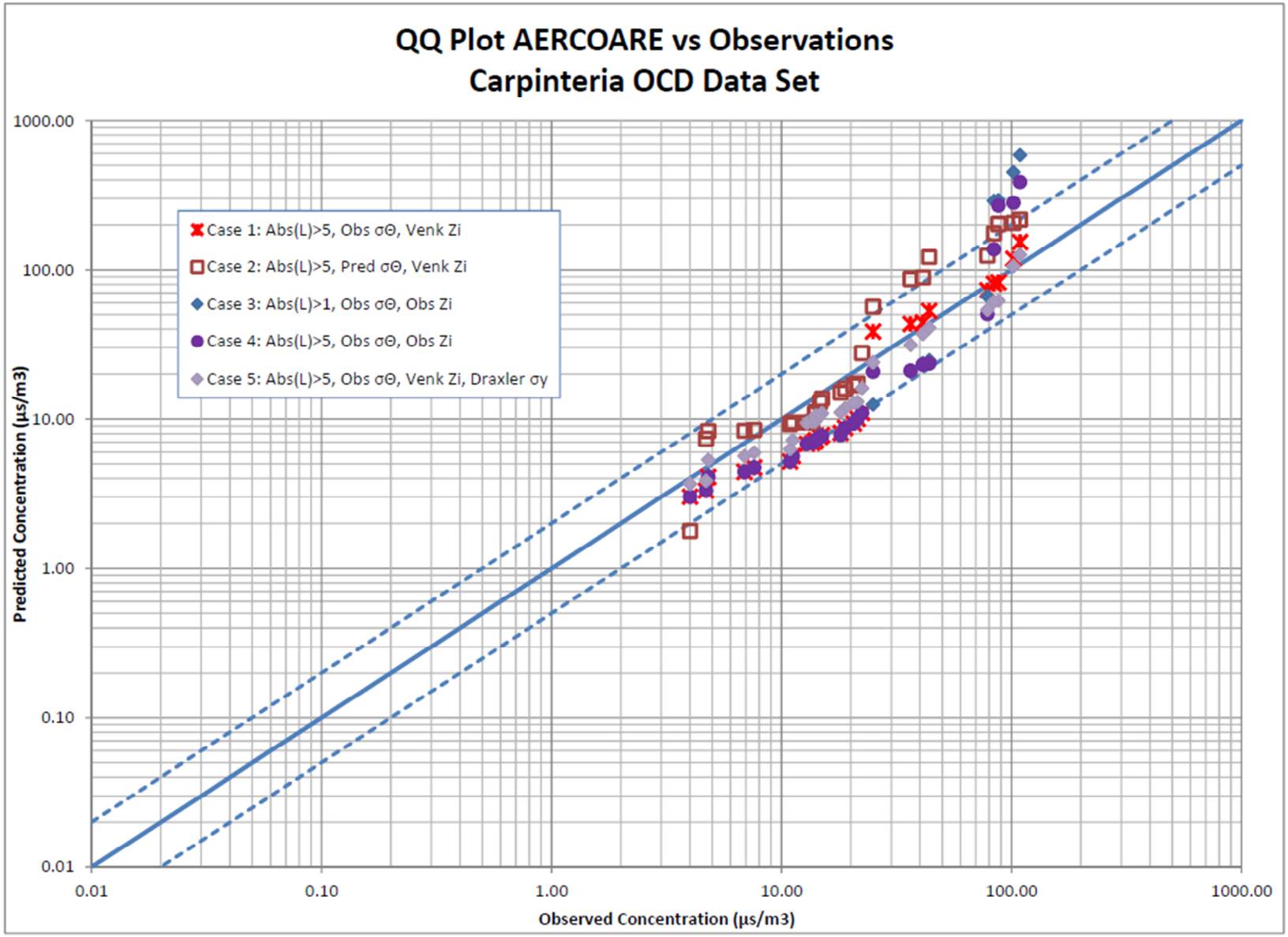

Figure 11. QQ Plot of AERCOARE versus Carpinteria Observations

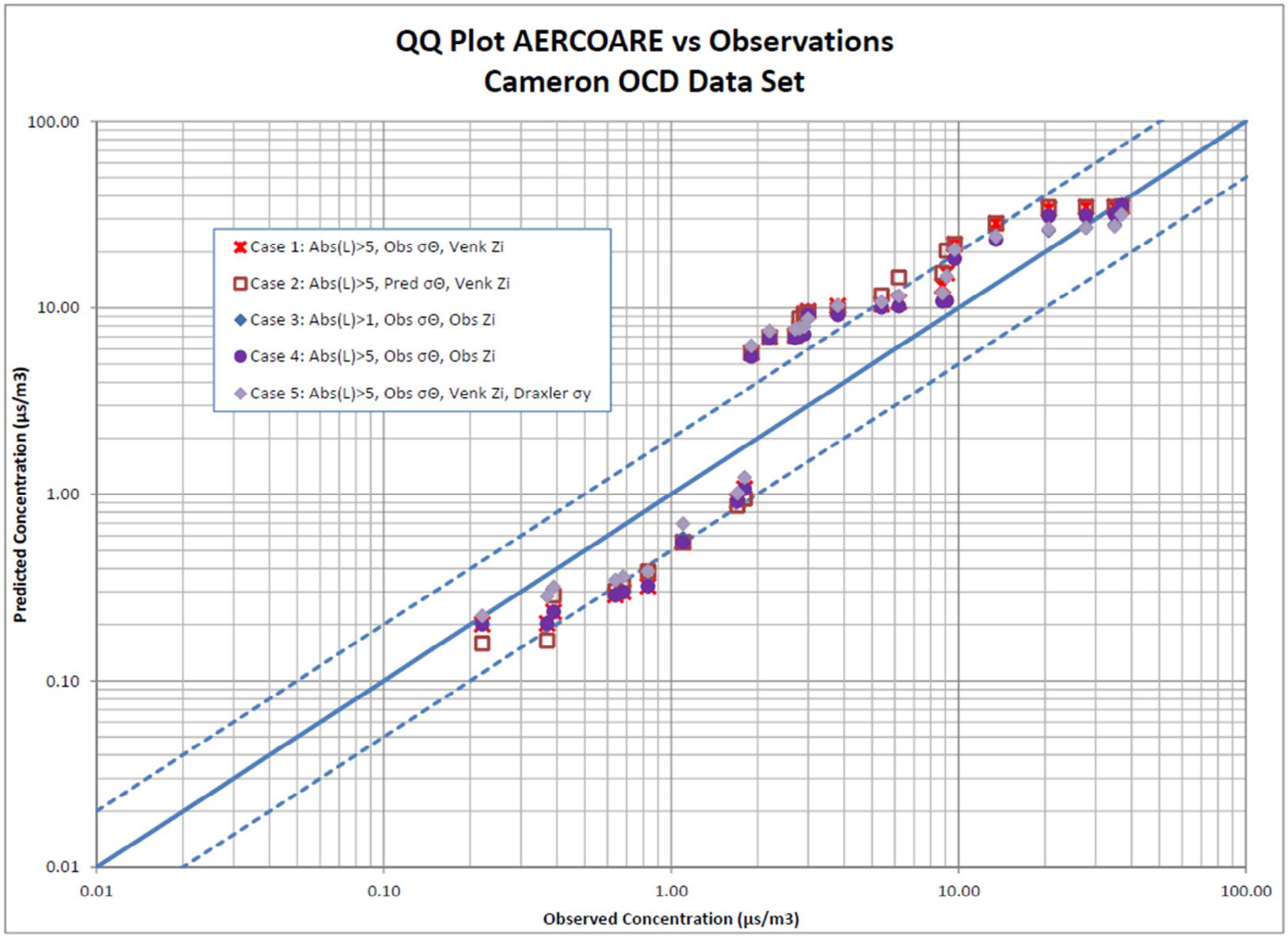

Figure 12. QQ Plot of AERCOARE versus Cameron Observations

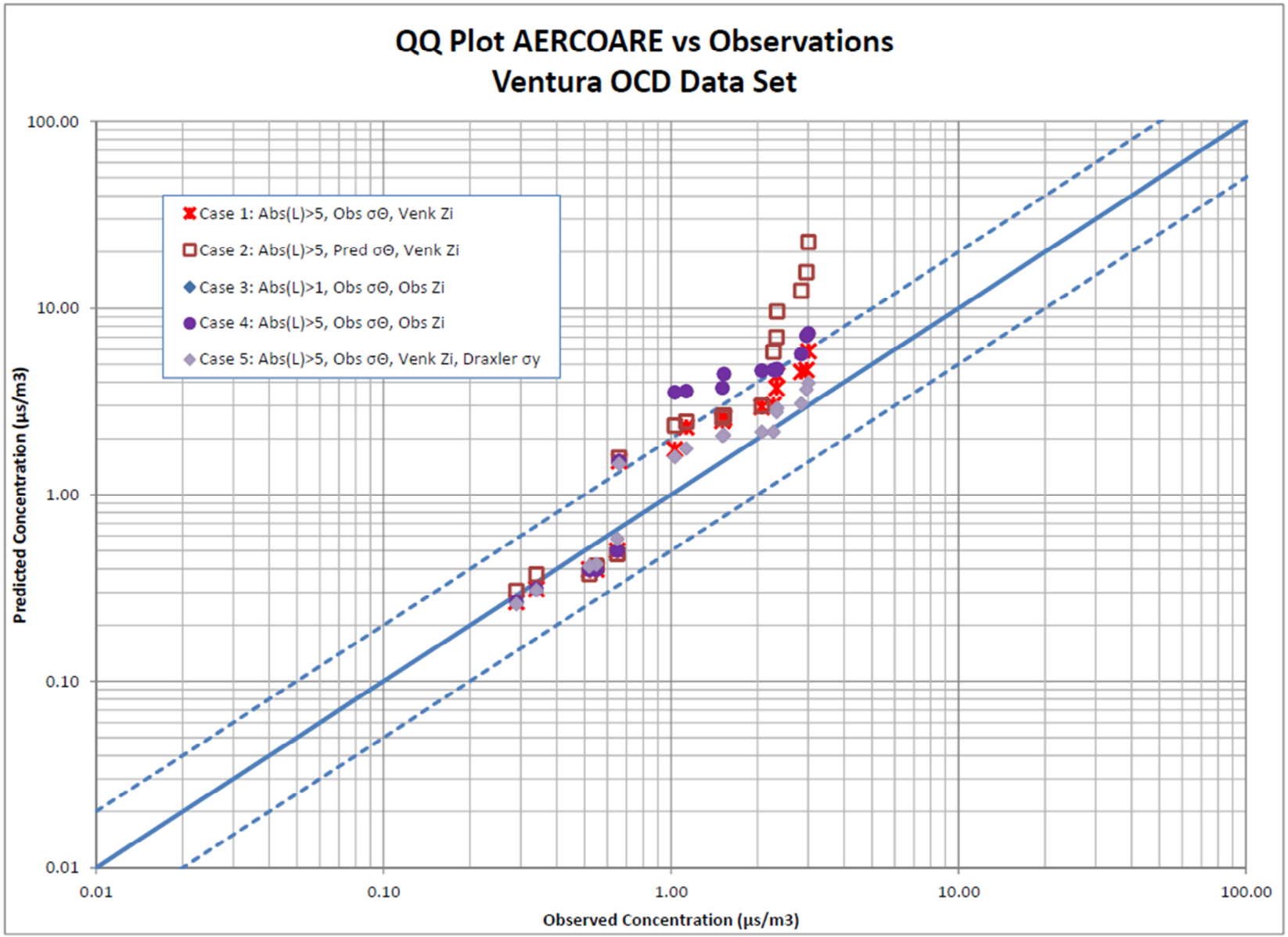

Figure 13. QQ Plot of AERCOARE versus Ventura Observations

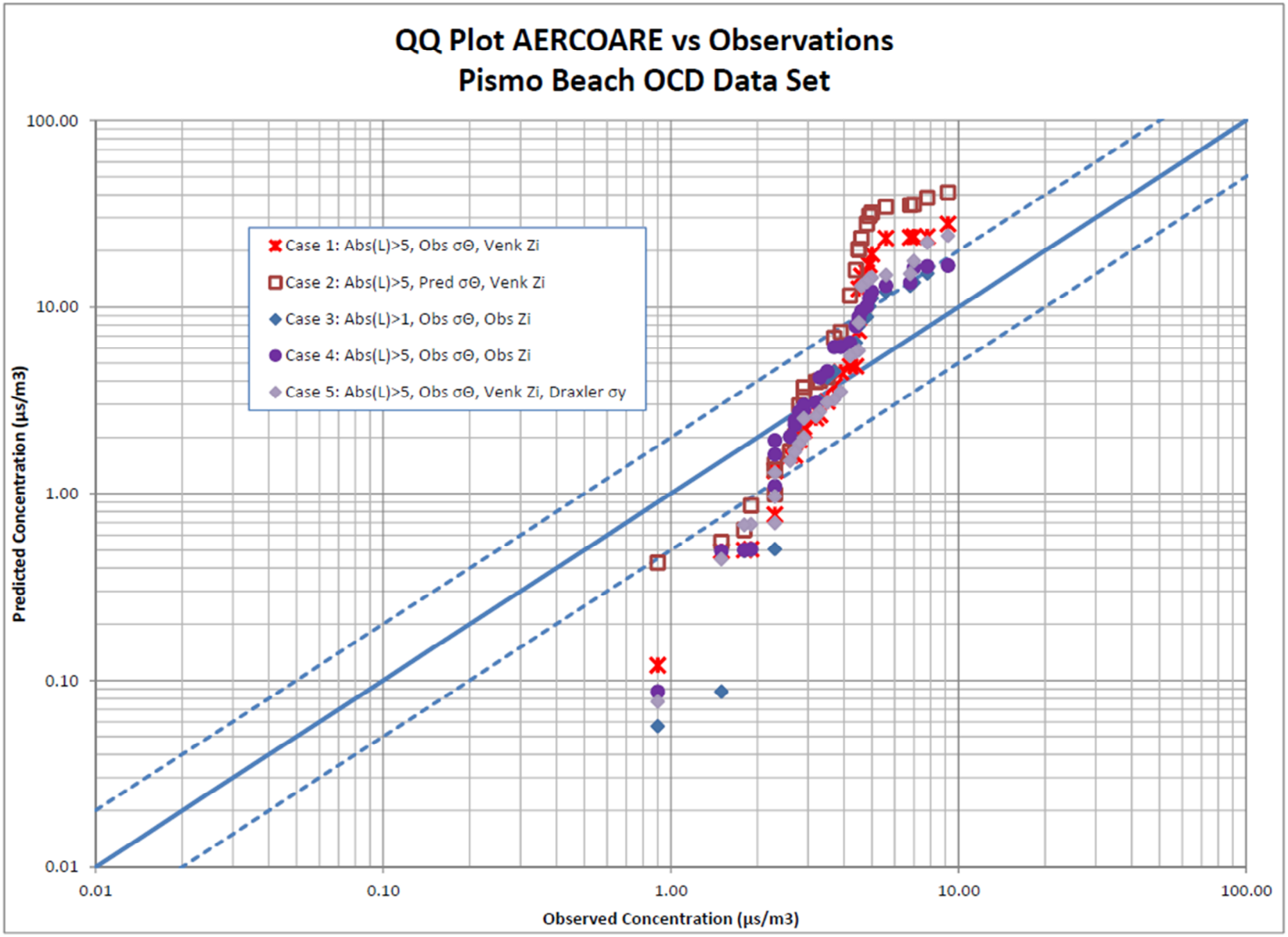

Figure 14. QQ Plot of AERCOARE versus Pismo Beach Observations

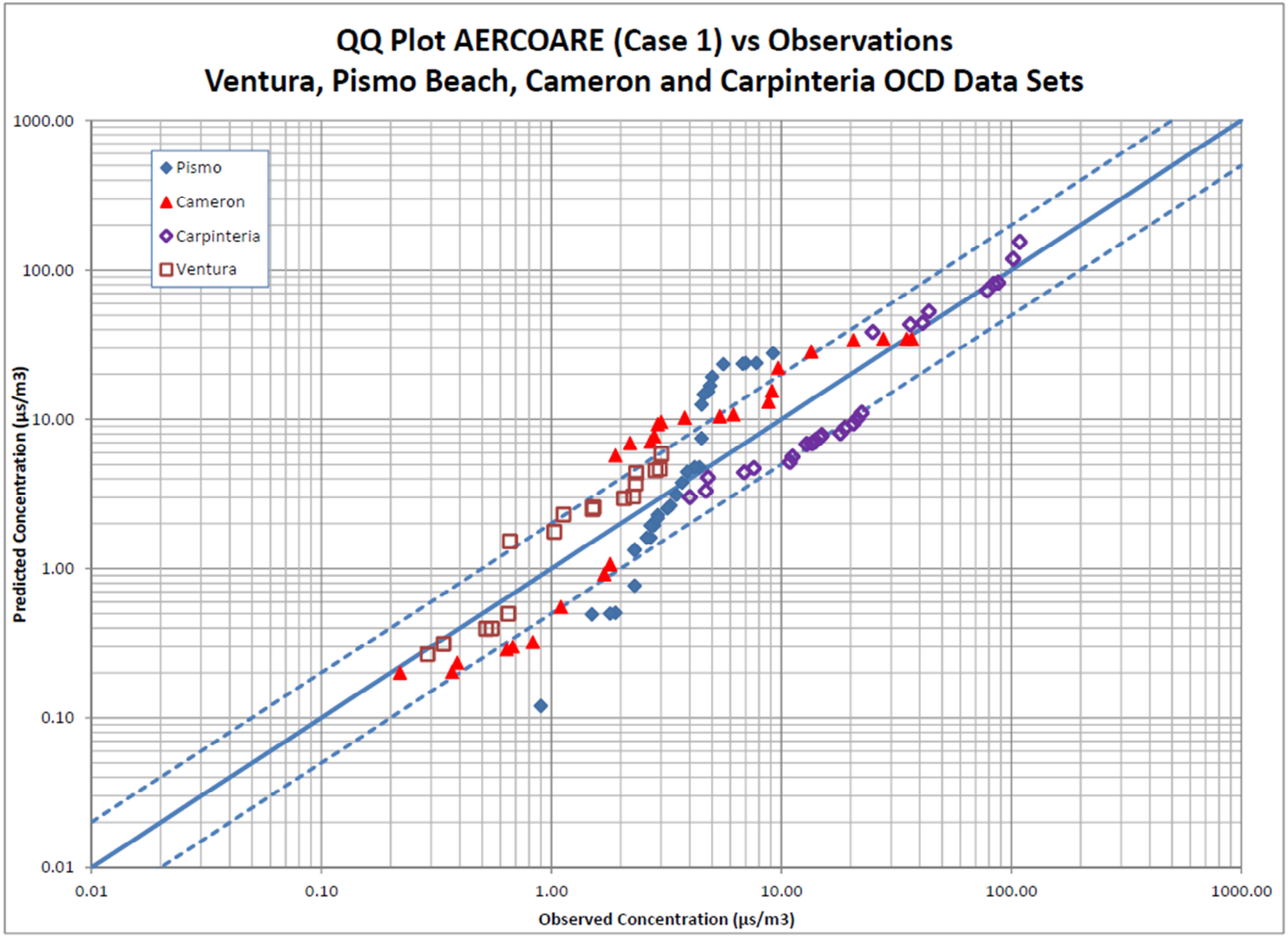

Figure 15. QQ Plot of AERCOARE Case 1 versus Observations

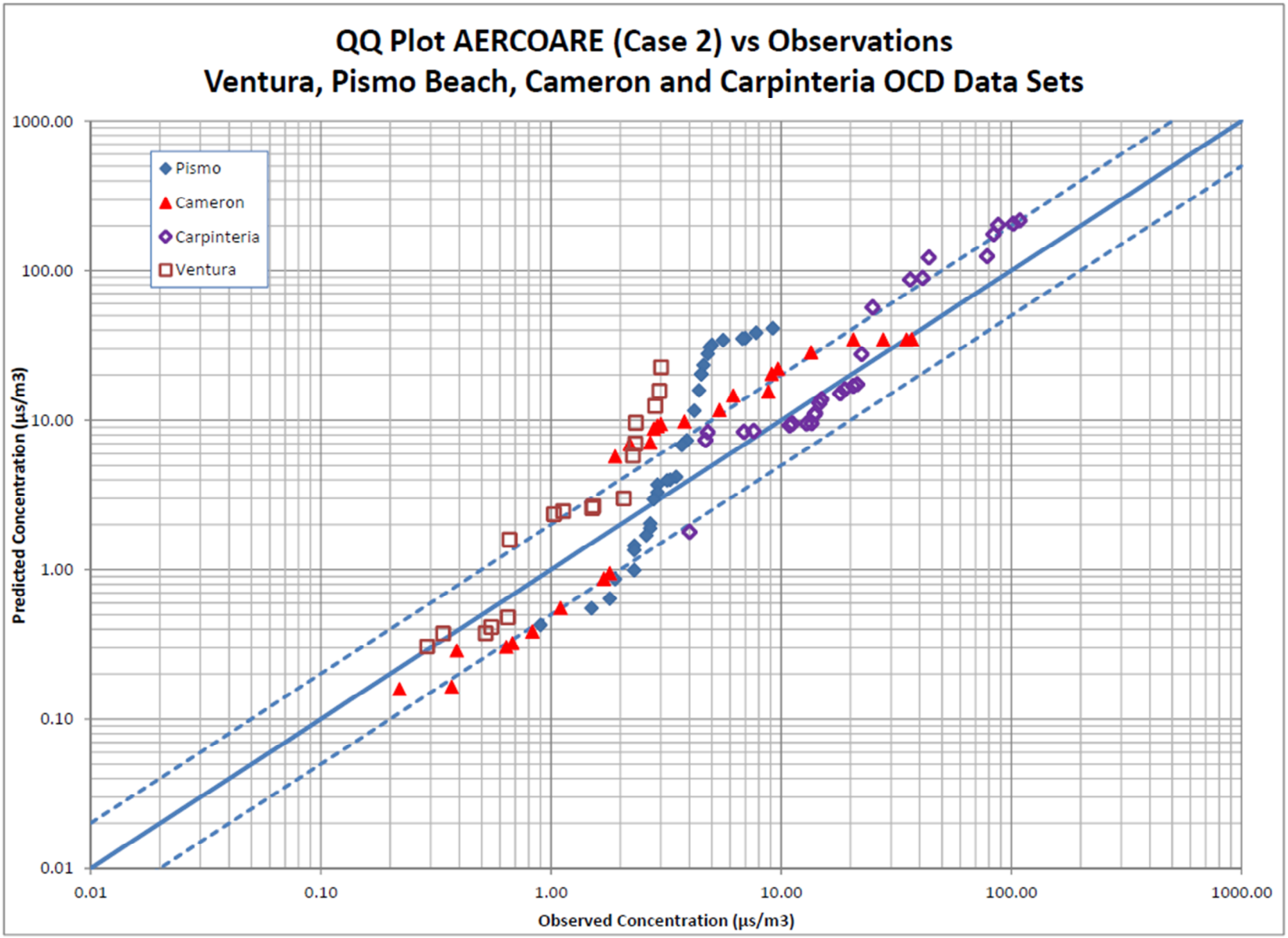

Figure 16. QQ Plot of AERCOARE Case 2 versus Observations

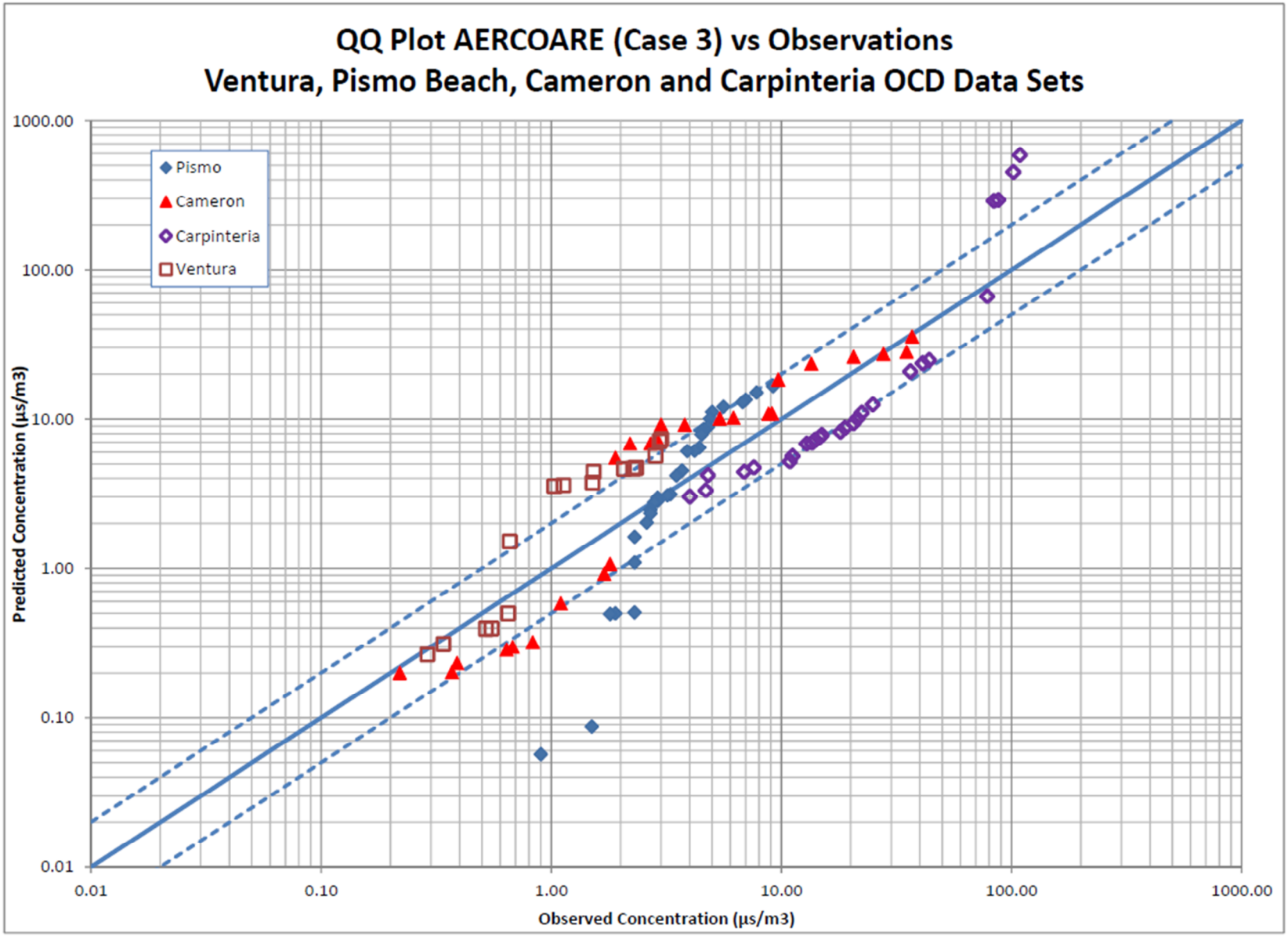

Figure 17. QQ Plot of AERCOARE Case 3 versus Observations

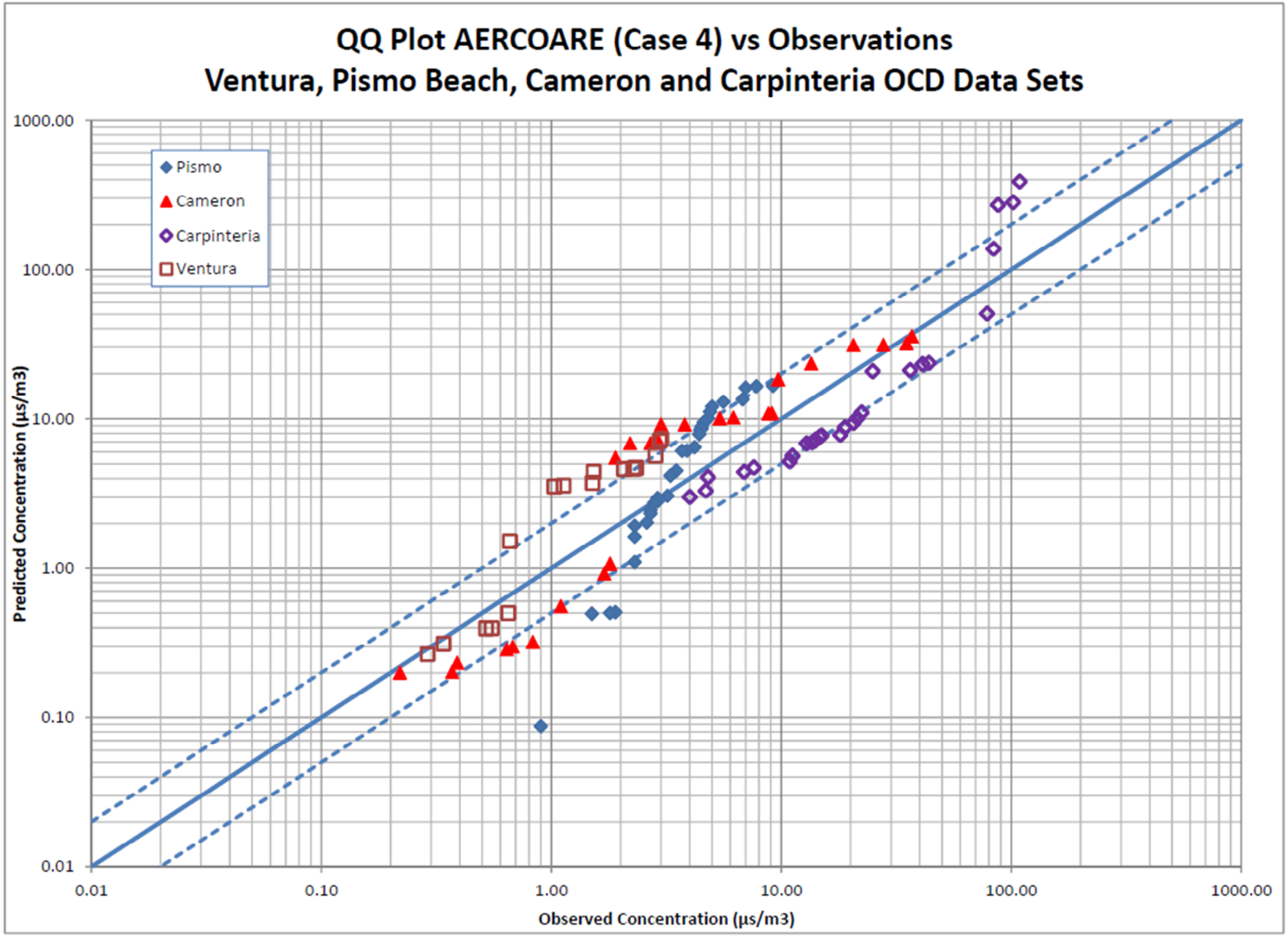

Figure 18. QQ Plot of AERCOARE Case 4 versus Observations

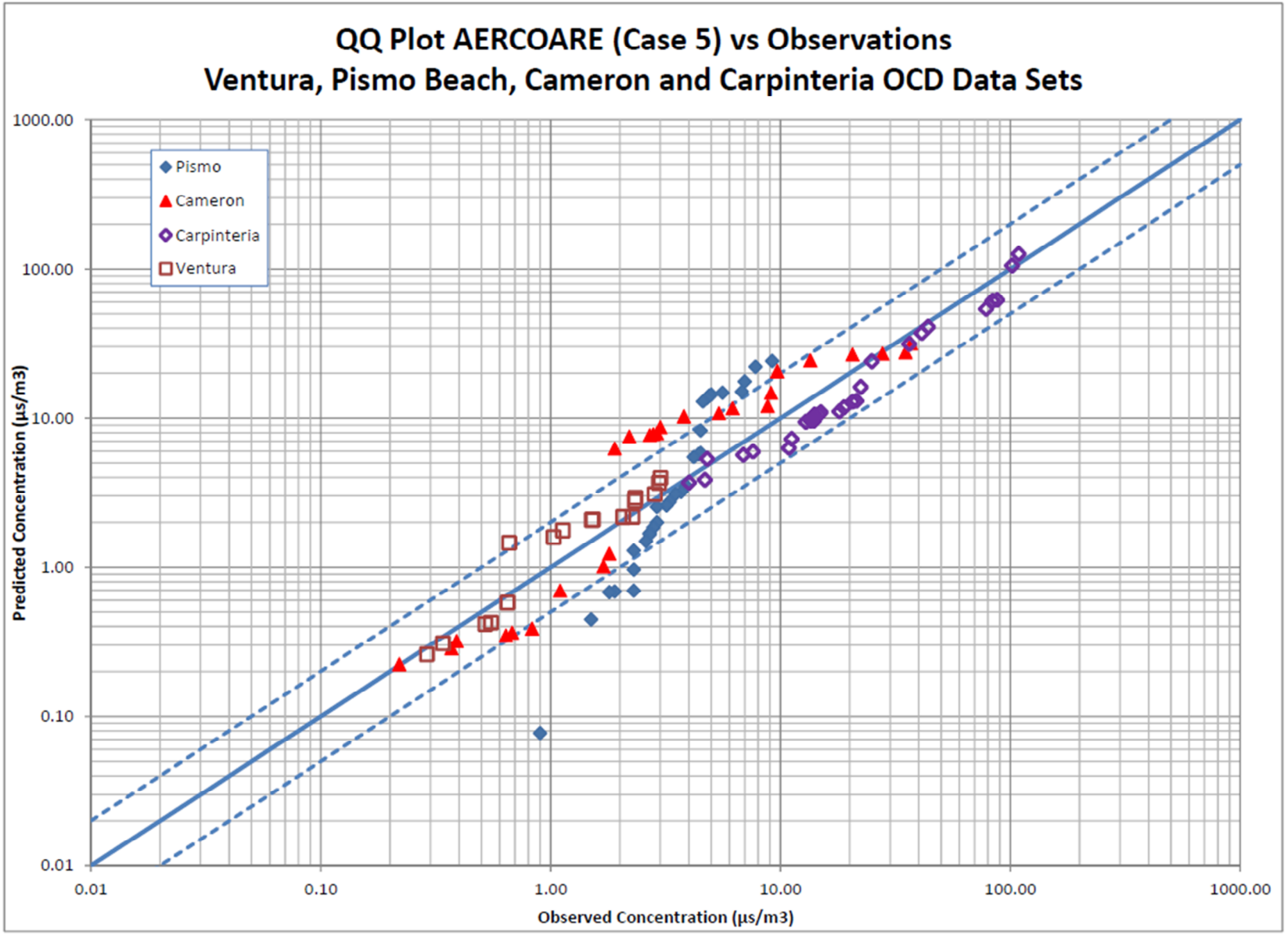

Figure 19. QQ Plot of AERCOARE Case 5 versus Observations

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 (µs/m3)	Geom. Std.	MG	VG	Geom. Correl. Coef.	Frac. Factor of 2	RHC (µs/m3)
All Data (101 samples)	0	Observations	4.5	1.36	1.00	1.00	1.00	1.00	125
	1	Abs(L)>5, Obs σΘ, Venk Zi	4.7	1.60	0.96	3.21	0.75	0.54	146
	2	Abs(L)>5, Pred σΘ, Venk Zi	6.8	1.73	0.67	4.93	0.72	0.47	311
	3	Abs(L)>1, Obs σΘ, Obs Zi	4.7	1.67	0.97	4.05	0.71	0.48	493
	4	Abs(L)>5, Obs σΘ, Obs Zi	4.9	1.57	0.93	3.23	0.74	0.47	333
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	**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 σΘ, Venk Zi	1.6	1.03	0.73	1.81	0.73	0.77	6
	2	Abs(L)>5, Pred σΘ, Venk Zi	2.4	1.37	0.50	5.28	0.62	0.59	20
	3	Abs(L)>1, Obs σΘ, Obs Zi	2.1	1.18	0.57	2.58	0.75	0.59	8
	4	Abs(L)>5, Obs σΘ, Obs Zi	2.1	1.18	0.57	2.58	0.75	0.59	8
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	**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 σΘ, Venk Zi	3.7	1.39	0.93	6.17	0.27	**0.45**	43
	2	Abs(L)>5, Pred σΘ, Venk Zi	5.9	1.45	0.59	12.90	0.04	0.26	55
	3	Abs(L)>1, Obs σΘ, Obs Zi	3.2	1.40	1.09	7.53	0.14	**0.45**	**19**
	4	Abs(L)>5, Obs σΘ, Obs Zi	3.8	**1.23**	0.91	**4.30**	0.26	**0.45**	20
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	**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 σΘ, Venk Zi	4.1	1.84	0.78	3.03	0.83	0.42	49
	2	Abs(L)>5, Pred σΘ, Venk Zi	4.2	1.87	0.76	3.60	0.81	0.42	53
	3	Abs(L)>1, Obs σΘ, Obs Zi	**3.7**	1.77	**0.86**	2.67	0.83	**0.46**	**40**
	4	Abs(L)>5, Obs σΘ, Obs Zi	3.7	1.79	0.84	2.68	**0.84**	**0.46**	44
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	4.1	**1.70**	0.76	**2.58**	0.84	**0.46**	36

VG is a measure of geometric variance or scatter, VG = exp(average(ln(Co/Cp)))
MG is a measure of bias about the geometric mean, MG = exp(average((ln(Co/Cp))^2))
RHC = "Robust Highest Concentration" based on top 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 (µs/m3)	Geom. Std.	MG	VG	Geom. Correl. Coef.	Frac. Factor of 2	RHC (µs/m3)
Carpinteria, CA (27 samples)	0	Observations	20.1	0.93	1.00	1.00	1.00	1.00	137
	1	Abs(L)>5, Obs σΘ, Venk Zi	14.0	1.19	1.44	2.29	0.72	0.59	172
	2	Abs(L)>5, Pred σΘ, Venk Zi	**24.3**	1.29	**0.83**	2.10	**0.76**	**0.67**	330
	3	Abs(L)>1, Obs σΘ, Obs Zi	15.0	1.50	1.34	3.95	0.66	0.44	470
	4	Abs(L)>5, Obs σΘ, Obs Zi	14.2	1.36	1.42	3.19	0.67	0.41	329
	5	Abs(L)>5, Obs σΘ, Venk Zi, Draxler σy	15.5	**0.97**	1.30	**1.90**	0.69	0.56	**129**

VG is a measure of geometric variance or scatter, VG = exp(average(ln(Co/Cp)))

MG is a measure of bias about the geometric mean, MG = exp(average((ln(Co/Cp))^2))

RHC = "Robust Highest Concentration" based on top 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.

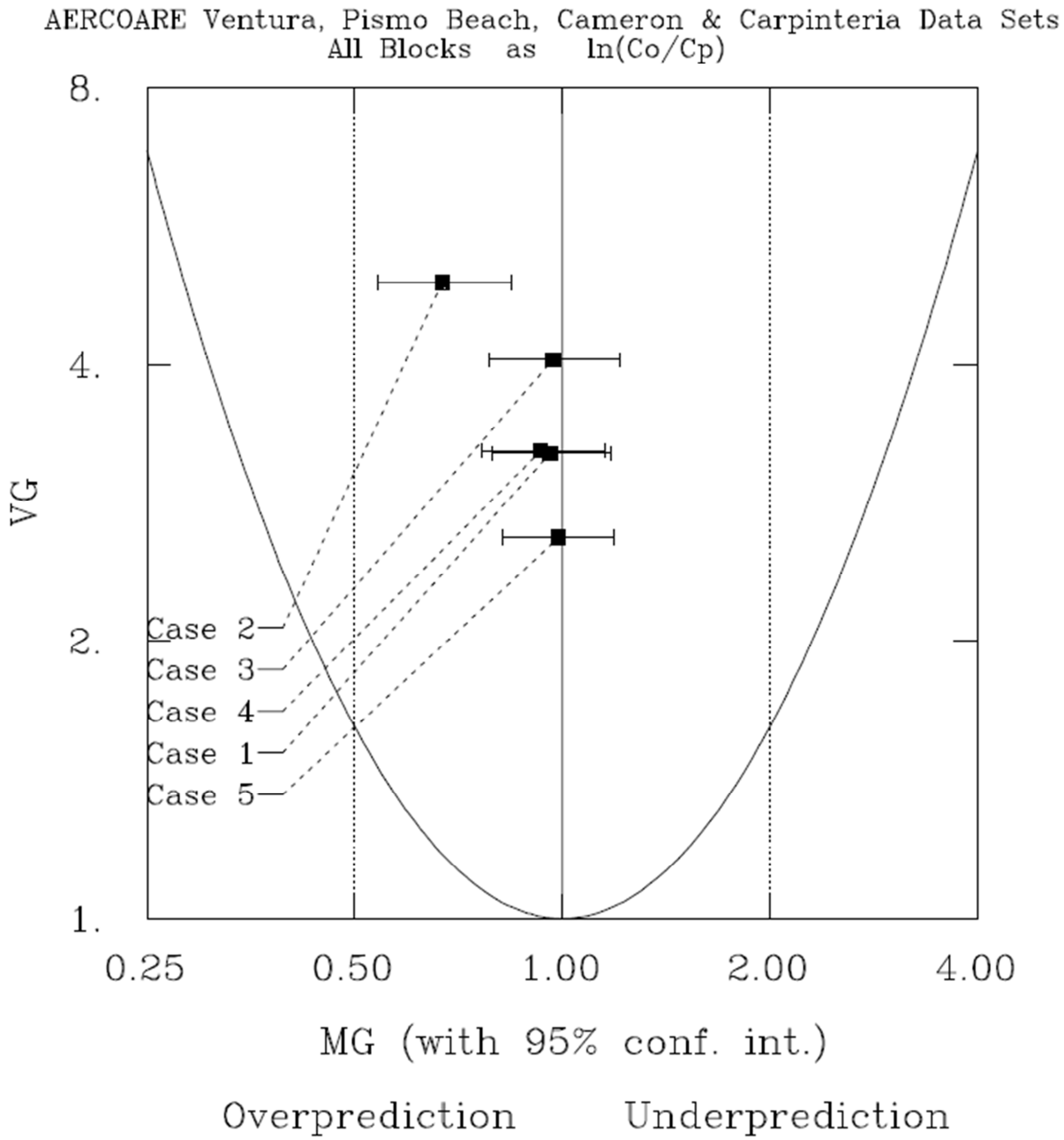

Figure 20. Sigma Plot for All Sites

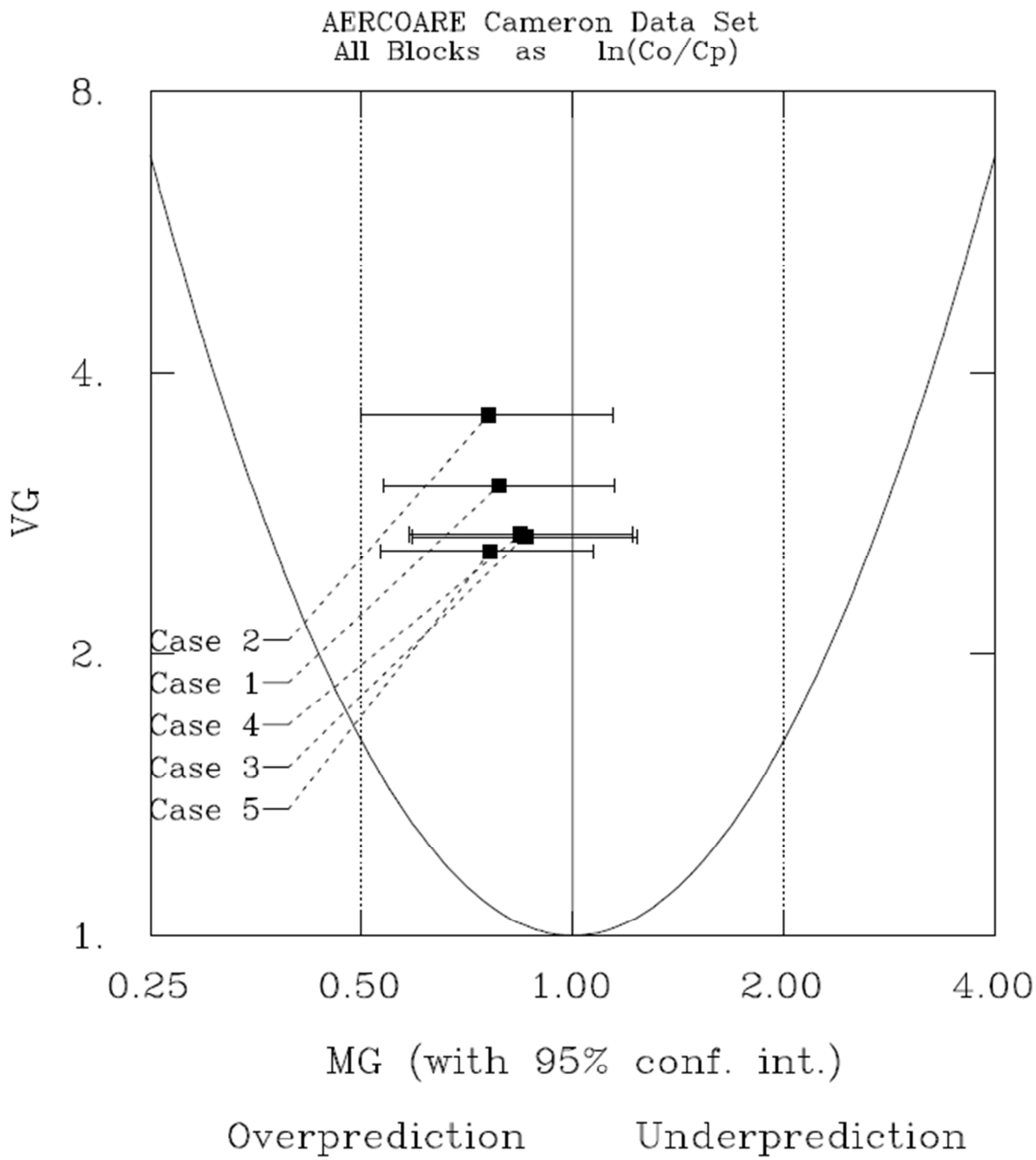

Figure 21. Sigma Plot for Cameron

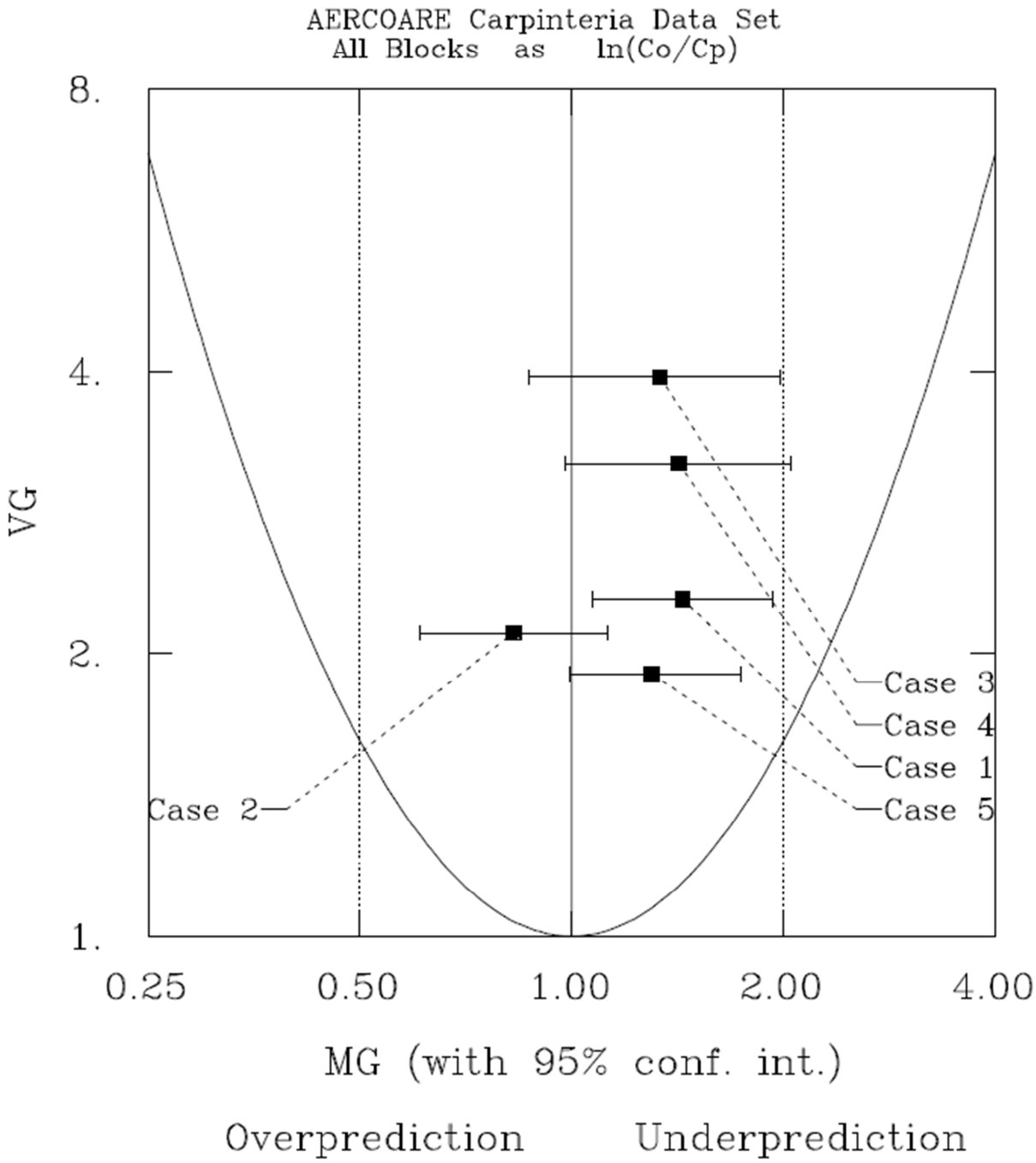

Figure 22. Sigma Plot for Carpinteria

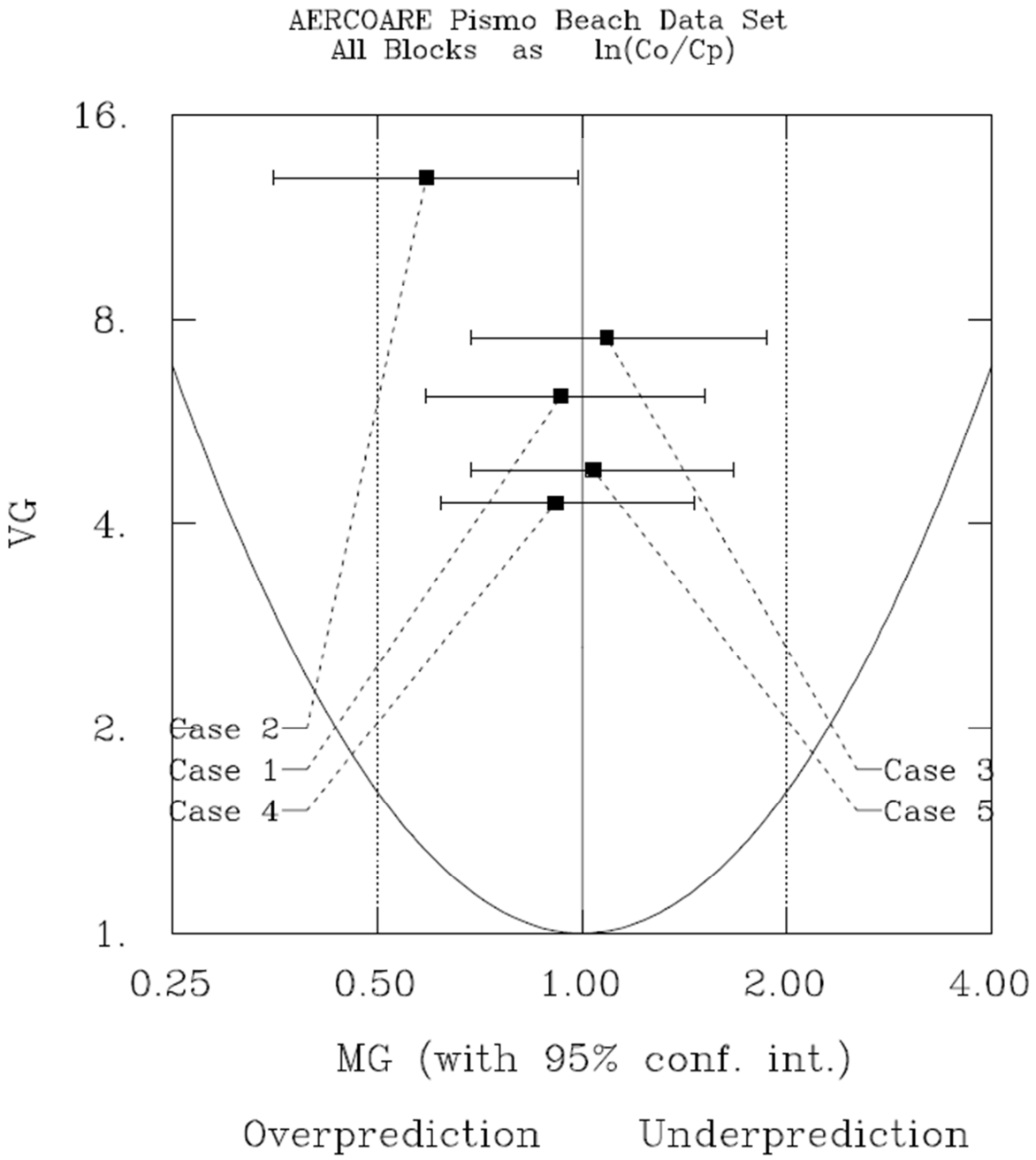

Figure 23. Sigma Plot for Pismo Beach

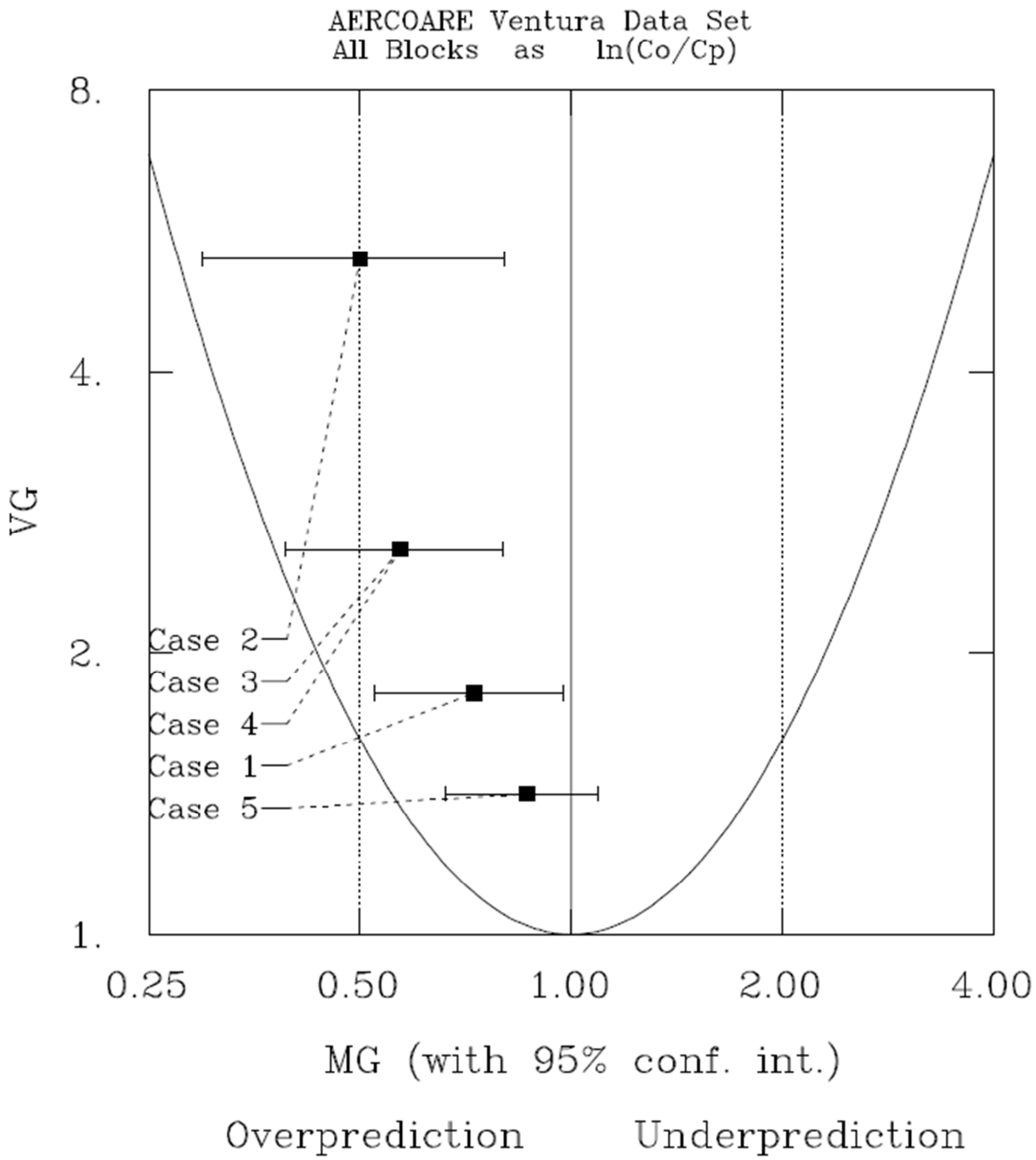

Figure 24. Sigma Plot for Ventura

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:

$$zi_m = 2300 {u_s}^{3/2}$$

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:

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

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"

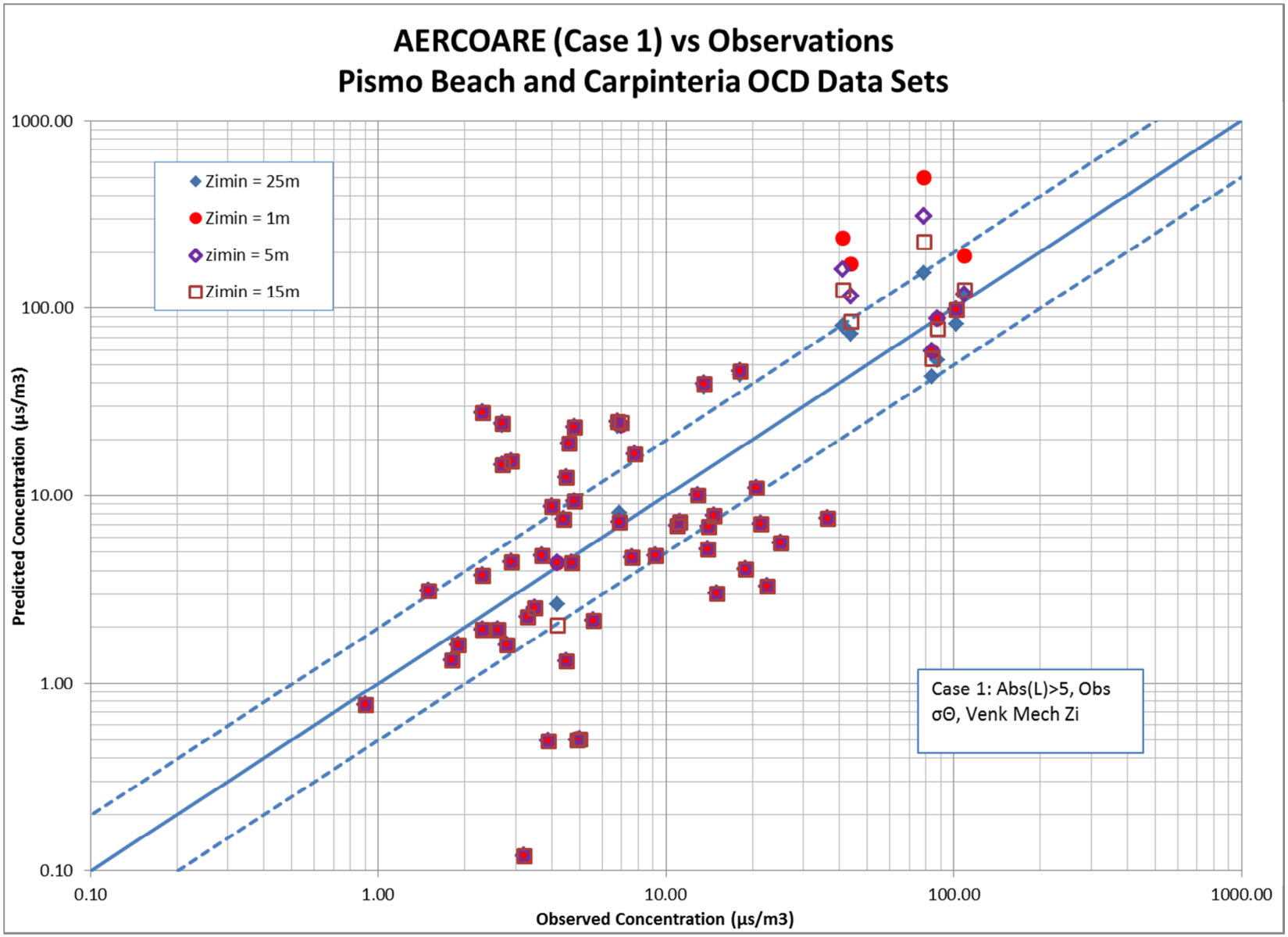

Figure A-1. Scatter Plot of Case 1 for Several Minimum Mixing Heights

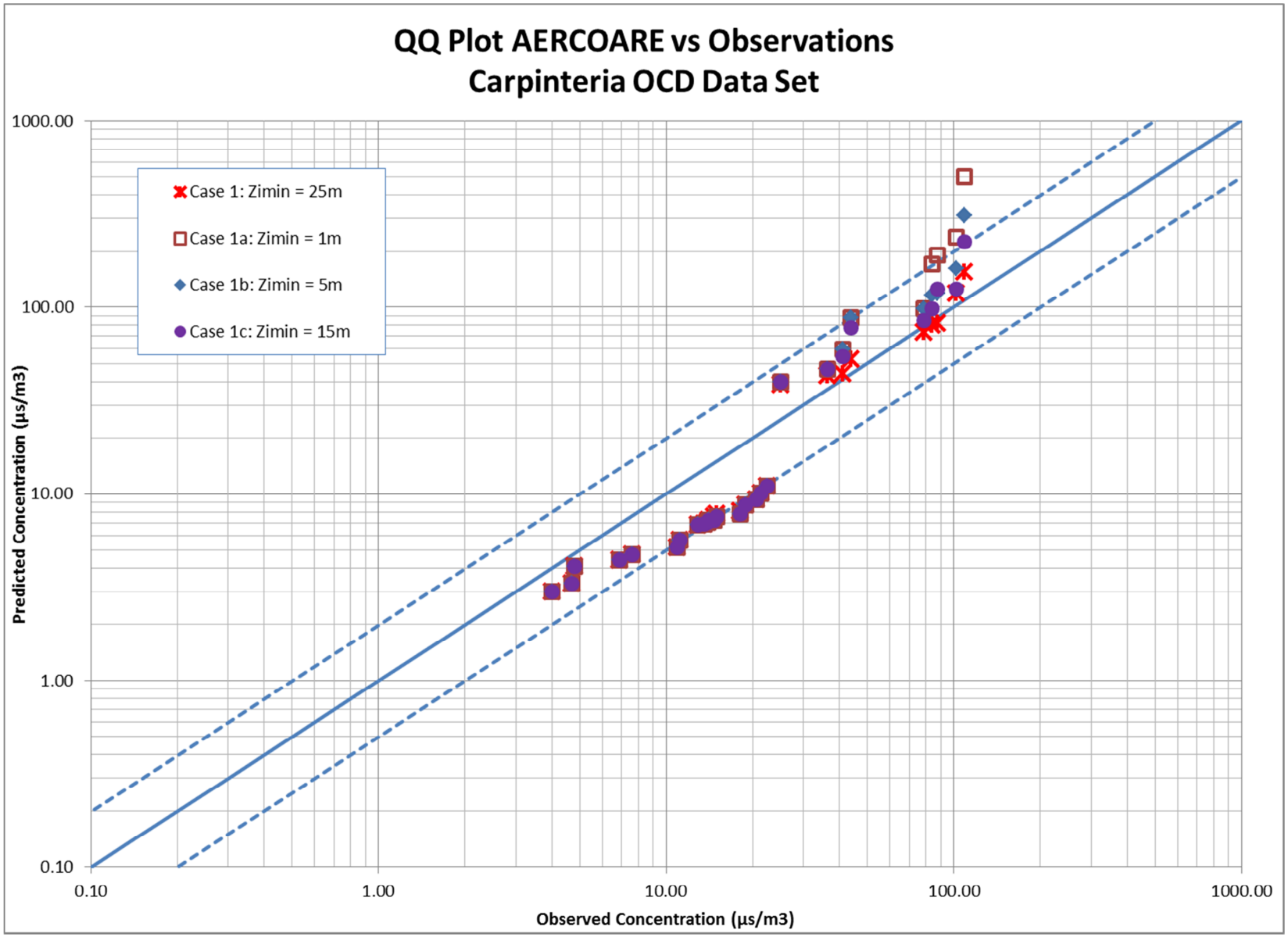

Figure A-2. QQ Plot for Case 1 Carpinteria for Several Minimum Mixing Heights

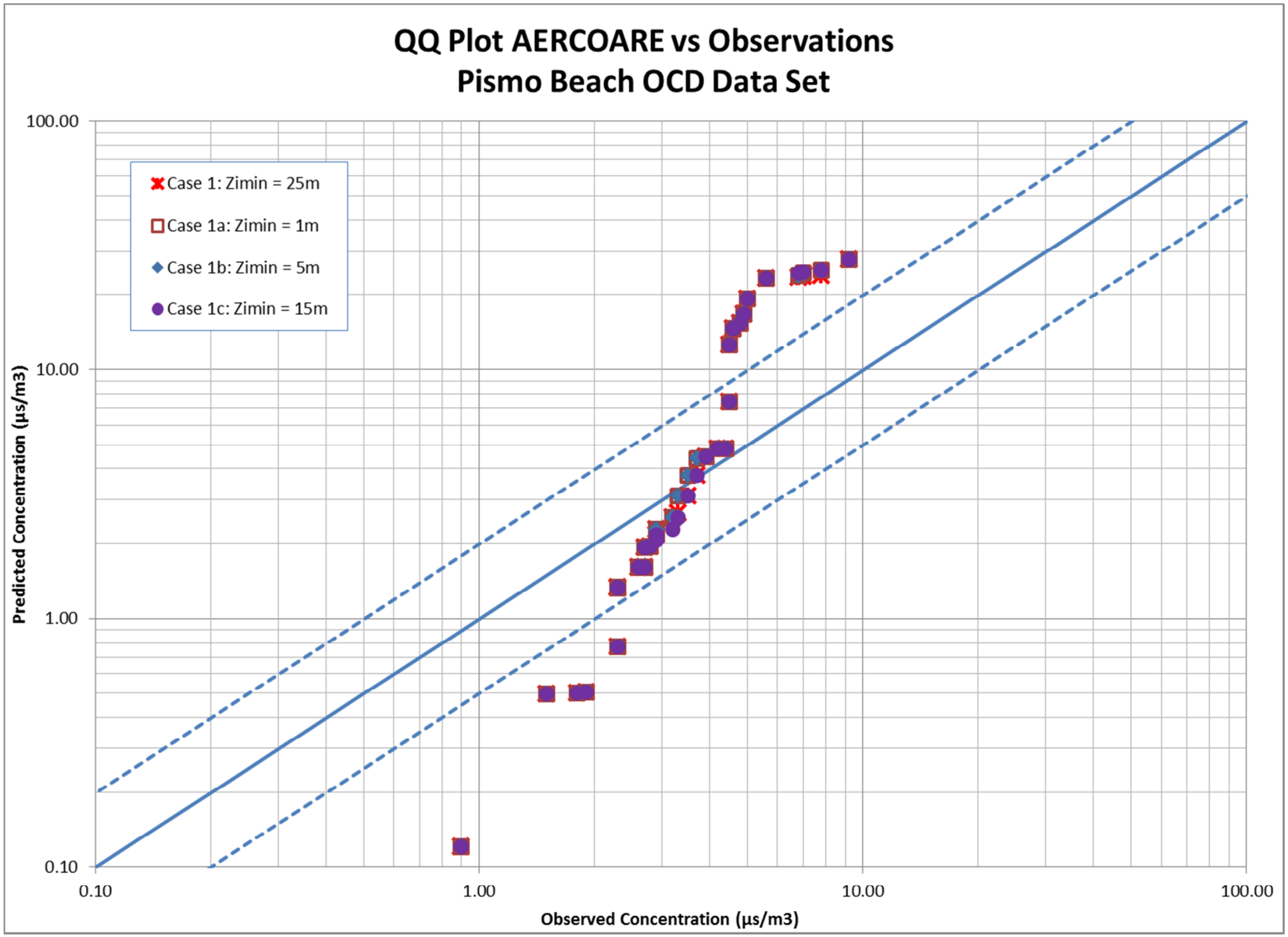

Figure A-3. QQ Plot for Case 1 Pismo Beach for Several Minimum Mixing Heights

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
  paried 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 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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

	MGfp	1.009	1.199	2.192	0.095	0.043	1.014	1.200
Case 4 - Case 5	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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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
  paried sampling                       =   30
  (there might be odd number of observations in each block)
  No. of blocks (regimes)               =    1
  No. of experiments in each block (regime)
    31


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




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

  Case 1     1.31       1.39      -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 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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	3.724
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 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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
```

Boot Program Output for Cameron

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


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


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




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

  Case 1     1.40       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)


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 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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
  paried sampling                       =   26
  (there might be odd number of observations in each block)
  No. of blocks (regimes)               =    1
  No. of experiments in each block (regime)
    27


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




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

  Case 1     2.64       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 95% Conf. limits		Student t	Mean	S.D.	Percentile 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 95% Conf. limits		Student t	Mean	S.D.	Percentile 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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
  paried 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.
```

Model(s)		Student's t 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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

Model(s)		Student's t 95% Conf. limits		Student t	Mean	S.D.	Percentile 95% 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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

	Case 1	Case 2	Case 3	Case 4	Case 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
```