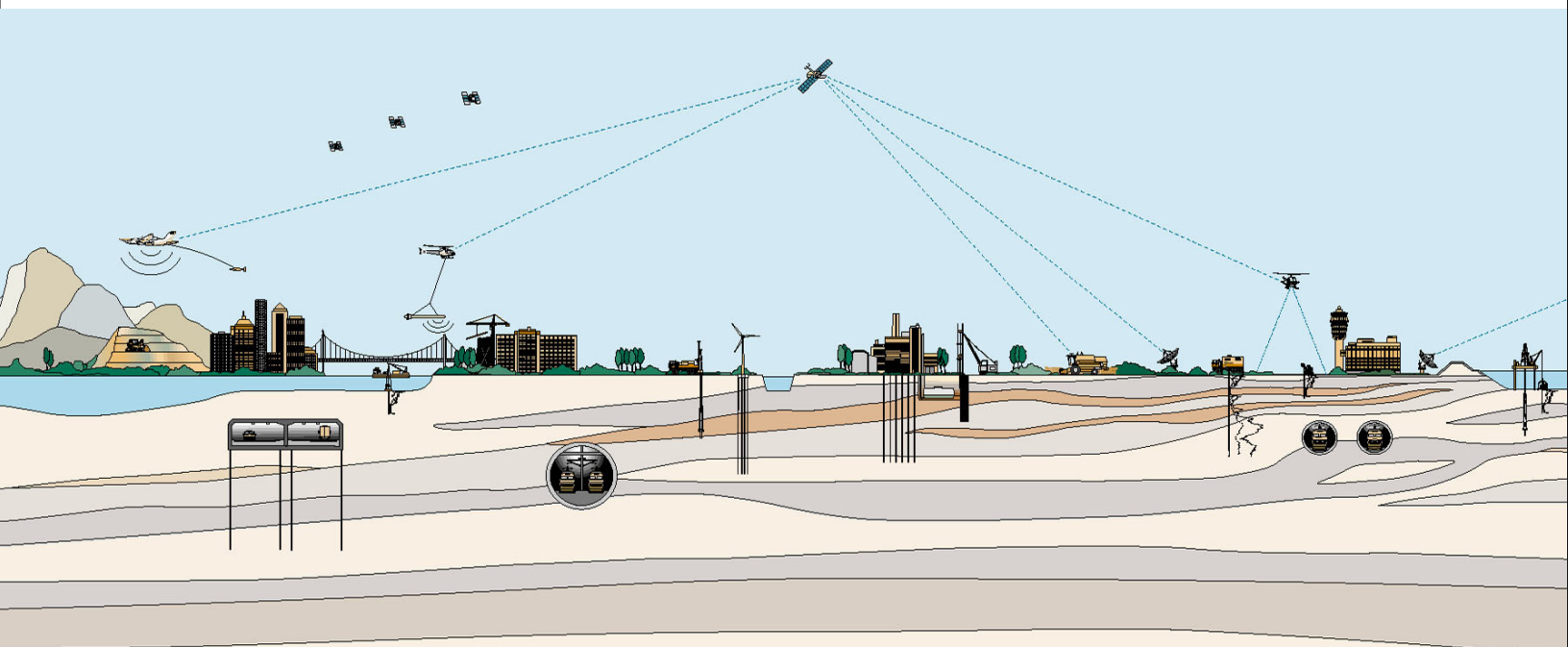




UPDATE OF THE THREE-DIMENSIONAL VELOCITY MODEL FOR THE DIABLO CANYON POWER PLANT (DCPP) FOUNDATION AREA SUPPLEMENTAL REPORT

Prepared for:
PACIFIC GAS AND ELECTRIC

November 2015
Fugro Job No. 04.76140022





1777 Botelho Drive, Suite 262
Walnut Creek, California 94596
Tel: (925) 949-7100
Fax: (925) 949-7070

November 20, 2015

Project No. 04.76140022

Pacific Gas and Electric
77 Beale Street #100
San Francisco, California 94105

Attention: Dr. Norm Abrahamson

Subject: Update of the Three-Dimensional Velocity Model for the Diablo Canyon Power Plant
(DCPP) Foundation Area, Supplemental Report

Dear Dr. Norm Abrahamson:

Fugro Consultants Inc. is providing engineering services to Pacific Gas and Electric (PG&E) for the Diablo Canyon Power Plant (DCPP) under the work authorization (CWA No. 2501115798). This supplemental report addresses the comments from the project peer review panel (PPRP) to the update and validation of the three-dimensional (3-D) velocity model for the DCPP Foundation Area presented in Fugro (2015). Additionally this supplemental report presents an update to 3-D velocity model presented in Fugro (2015). We thank you for the opportunity to work on this project and are looking forward to continuing providing our services in the future.

Sincerely,

FUGRO CONSULTANTS, INC.

A handwritten signature in black ink, appearing to read "Daniel R.H. O'Connell".

Daniel R.H. O'Connell, Ph.D.
Senior Principal Geophysicist

Copies Submitted: (1) PDF, Addressee

CONTENTS

	Page
1.0 INTRODUCTION.....	1-1
2.0 UPDATE OF THE 3-D VELOCITY MODEL	2-1
2.1 Updated Approach for Vs Uncertainty Estimation	2-2
2.2 Comparison of Updated 3-D Vs Model with Previous DCPD Measurements of Vs- Depth	2-4
2.2.1 Vs-Depth Measurements Inside the Turbine Building-Containment Structures Area of DCPD	2-4
2.2.2 Vs-Depth Measurements Outside of the Turbine Building-Containment Structures Area of DCPD	2-8
2.3 Discussion of Updated Analyses With Respect to Peer Review Comments.....	2-16
3.0 REFERENCES.....	3-1

TABLES

	Page
2.1-1 Summary of Blume (1968; 1969) Downhole and Refraction Vs Results	2-5
2.2-2 Additional Downhole and Seismic Refraction Vs Data used to Constrain Vs in the 0-25 m Depth Range in the Central DCPD Area	2-6
2.2-3 Waveform Misfit and Source-Receiver Path Velocity Misfit for Source-Receiver Paths Transecting Station ESTA27	2-9
2.2-4 Waveform Misfit and Source-Receiver Path Velocity Misfit for Source-Receiver Paths Transecting Station ESTA28	2-10
2.2-5 Dispersion Inversion $\sigma \ln(Vs(z))$ and Vs Velocity Gradient (dvdz)	2-12
2.2-6 Median Vs Uncertainty Components by Area and Depth.....	2-15
2.2-7 Natural Logarithm Lower Bound Vs Uncertainty Components by Area and Depth.	2-16
2.2-8 Natural Logarithm Upper Bound Vs Uncertainty Components by Area and Depth.	2-16

FIGURES

	Figure
Locations of Vs Measurements in the DCPD Area	2.0-1
Location Map for 1968 Boreholes and 1968 Vs-refraction Profiles	2.0-2
Vs-depth Density Distribution from the Updated 3-D Vs-depth Profiles for the Entire Area outlined by the Red Polygon in Figure 2.0-1	2.2-1
DDH-1 Location	2.2-2
Comparison of Vs at DDH-1 Location	2.2-3
DDH-2 Location	2.2-4
Comparison of Vs at DDH-2 Location	2.2-5
DDH-3 Location	2.2-6
Comparison of Vs at DDH-3 Location	2.2-7
DDH-4 Location	2.2-8

DDH-4 Location	2.2-9
1969 Vs-refraction Line SL-4 Midpoint Location	2.2-10
Comparison of Vs at Refraction Line SL-4 Midpoint Location	2.2-11
GeoTomo 3-D Vp Tomography Vp-depth Profiles at Blume (1968) Borehole Locations ..	2.2-12
DDH-A-2 Location	2.2-13
Comparison of Vs at DDH-A-2 Location	2.2-14
DDH-C Location	2.2-15
DDH-C Travel Time Picks	2.2-16
Comparison of Vs at DDH-C Location	2.2-17
DDH-D Location	2.2-18
Comparison of Vs at DDH-D Location	2.2-19
Seismographic Stations ESTA27 and ESTA28	2.2-20
Vs-depth Density Distribution from the Updated 3-D Vs-depth Profiles within 10, 20, 25, and 50 m of Seismographic Station ESTA27	2.2-21
Vs-depth Density Distribution from the Updated 3-D Vs-depth Profiles within 10, 20, 25, and 50 m of Borehole DDH-C	2.2-22
Vs-depth Density Distribution from the Updated 3-D Vs-depth Profiles within 10, 20, 25, and 50 m of Seismographic Station ESTA28	2.2-23
Vs-depth Density Distribution from the Updated 3-D Vs-depth Profiles for the Entire Area outlined by the Red Polygon in Figure 2.0-1	2.2-24
Vs-depth Density Distributions from the Updated 3-D Vs-depth Profiles within 10, 20, 25, and 50 m of Seismographic Station ESTA28	2.2-25
Vs-depth Density Distributions from the Updated 3-D Vs-depth Profiles within 10, 20, 25, and 50 m of Seismographic Station ESTA27	2.2-26
Example Probabilistic Vs-depth Density Distribution for ESTA28	2.2-27
Example Probabilistic Vs-depth Density Distribution for ESTA27	2.2-28

APPENDICES

APPENDIX A	WAVEFORM CROSS-CORRELATION ANALYSES FOR SOURCE-RECEIVER PATHS THAT INTERSECT STATION ESTA27
APPENDIX B	WAVEFORM CROSS-CORRELATION ANALYSES FOR SOURCE-RECEIVER PATHS THAT INTERSECT STATION ESTA28
APPENDIX C	WAVEFORM CROSS-CORRELATION ANALYSES FOR SOURCE-RECEIVER PATHS OF SOUTHERN SET
APPENDIX D	WAVEFORM CROSS-CORRELATION ANALYSES FOR SOURCE-RECEIVER PATHS OF NORTHERN SET
APPENDIX E	ELECTRONIC FILES

1.0 INTRODUCTION

Fugro (2015) presented the methodology and results of an update and validation of a three-dimensional (3-D) velocity model for the Diablo Canyon Power Plant (DCPP) Foundation Area. That report was reviewed by the project peer review panel (PPRP), and its comments were submitted to Fugro in a letter dated July 15, 2015. This supplemental report addresses the PPRP comments regarding the update of the 3-D velocity model. Additionally, this supplemental report presents an update to 3-D velocity model presented in Fugro (2015). The updated model is provided as an electronic attachment in Appendix E.

2.0 UPDATE OF THE 3-D VELOCITY MODEL

The Fugro (2015) DCPD 3-D foundation velocity model was updated in two steps. Vibroseis ground motion data were used to improve 3-D shear wave velocity (V_s) resolution in the areas where a dense concentration of intersecting Vibroseis source-receiver paths were available, which also coincided with the locations of seismographic stations ESTA27 and ESTA28 (Figure 2.0-1). The model was updated with an additional iteration of 3-D waveform-modeling inversion with the final 3-D velocity model from Fugro (2015) as the starting model and Vibroseis waveforms from the source-receiver paths that crossed through the ESTA27 and ESTA28 seismographic station positions shown in blue in Figure 2.0-1. The waveform inversion update also provides refined estimates of V_s -depth uncertainties relative to the Rayleigh dispersion estimates of V_s -depth used to construct the initial 3-D V_s model in Fugro (2015). There is a portion of the central DCPD area where there are no surface-wave dispersion data (Figure 2.0-1). This updated 3-D V_s model was further modified to incorporate downhole V_s -depth and V_s refraction data from Blume (1968; 1969; 1978) to constrain upper and lower bounds on the 3-D V_p/V_s model in the 0 to 25 m depth range within the magenta polygon encompassing most of the turbine building, containment structures, and auxiliary building (Figure 2.0-1) to ensure the final updated 3-D V_s model provided with this report is consistent with all available V_s -depth data within the area outlined by the red polygon in Figure 2.0-1.

Uncertainty estimates are derived for four components of V_s -depth uncertainties:

1. V_s scale (long-wavelength) uncertainties that are estimated either using direct comparison with independent measurements of V_s -depth, waveform inversion misfits for seismographic station sites ESTA27 and ESTA28, and DCPD site-specific estimates of V_s -depth from dispersion (Fugro, 2015) supplemented by published estimates of V_s scale uncertainties from comprehensive investigations of the uncertainties in surface-wave estimates of V_s -depth using multiple independent methods (Stephenson et al., 2005; Boore and Asten, 2008; 2014; Hollender et al., 2014; Garofalo et al., 2015).
2. V_s intermediate-scale uncertainties associated with fundamental uncertainties in the nonlinear mapping of exact surface-wave dispersion shapes to V_s -depth (Griffiths, 2015).
3. V_s uncertainties associated with short-wavelength vertical V_s variability that typically can only be resolved with high-resolution V_s -depth imaging from suspension or sonic logging in boreholes.
4. V_s uncertainties associated with intermediate and short-wavelength lateral V_s -depth variability. The variability of the 3-D velocity model in the immediate neighborhood of a V_s -depth profile provides useful information about lateral V_s -depth variability for the purpose of developing randomized one-dimensional (1-D) V_s -depth profiles for site response analyses at particular sites.

These uncertainty components are estimated as a function of depth and site position. Uncertainties are specifically developed for V_s -depth at seismographic stations ESTA27 and ESTA28, the region containing the turbine building, containment structures, and auxiliary building. These uncertainties are based on a comparison of the 3-D model estimated V_s -depth and V_s -depth measured at nine distinct measurement locations (Blume, 1968; 1969; 1978),

which included four shallow downhole surveys (DDH-1, DDH-2, DDH-3, and DDH-4), four Vs refraction lines, and one deep downhole survey (DDH-D) and the region surrounding the turbine building, containment structures, and auxiliary building where the 99 surface-wave dispersion measurement centroids from Fugro (2015) and two 1978 deep downhole Vs measurements at DDH-A-2 and DDH-C (Blume, 1978) constrain Vs-depth (Figures 2.0-1 and 2.0-2).

2.1 UPDATED APPROACH FOR VS UNCERTAINTY ESTIMATION

The best approach to estimate Vs uncertainties is an approach that provides accurate estimates of site response uncertainties. Griffiths (2015) used surface wave data from Grenoble, France and Mirandola, Italy to determine Vs profiles from inversion of surface wave data to evaluate several approaches to estimate Vs uncertainties and determine which approach produces Vs uncertainties most appropriate to estimate site responses. Griffiths (2015) used Vs profiles from dispersion inversions to determine boundary, median, and statistically-based randomly generated Vs-depth profiles. Then the theoretical dispersion curves from inversion analyses, as well as the boundary, median and randomly generated Vs profiles, were compared with experimentally measured surface wave dispersion data. Griffiths (2015) found that the median model dispersion curve provides a satisfactory fit to the experimental data, but the boundary-type models' dispersion curves do not. Randomly generated profiles result in some theoretical dispersion curves that fit the experimental data, and many that do not. Griffiths' (2015) site response analyses revealed that greater variability in the response spectra and amplification factors resulted from using the randomly generated Vs and/or boundary Vs profiles than using the median inversion Vs profiles. This increased site response variability was associated with randomly-generated and boundary Vs models that were inconsistent with the overall dispersion curve shapes that are well constrained by the observed dispersion data.

A boundary approach attempts to estimate upper- (i.e., stiffer) and lower-boundary (i.e., softer) Vs profiles. Griffiths (2015) considered two approaches to Vs boundary uncertainty estimation including computing the counted 5th and 95th percentile Vs from 50 inversion Vs profiles. Griffiths (2015) counted 5th and 95th percentile Vs for each layer as well as the counted 5th and 95th percentile depth to the bottom of each layer (termed the bottom depth). The 95th percentile Vs profile represents the combination of the 95th percentile Vs with the 5th percentile bottom depth in each layer. Similarly, the 5th percentile Vs profile was determined by combining the 5th percentile Vs with the 95th percentile bottom depth for each layer. Griffiths' (2015) reason for pairing high velocities with shallow depths and low velocities with greater depths was to develop relatively stiff and soft boundary profiles that encapsulate the majority of the 50 inversion Vs profiles under consideration. The Vs-depth uncertainty estimation approach of O'Connell and Turner (2011) most closely corresponds to a boundary approach to Vs uncertainty estimation.

MacKay (2003) discussed the pathologies of maximum likelihood which motivated the development of the Monte Carlo inversion approach in O'Connell and Turner (2011) to develop multiple "best-fitting" models instead of focusing on finding a single "best" model. Unfortunately, there seem to be comparable pathologies to using single summary statistics like chi-squared or total absolute deviation to evaluate uncertainties and score models as acceptable or unacceptable. The chi-squared or total absolute deviation misfit approach to Vs-depth of O'Connell and Turner (2011) includes models that have systemic deviations of the calculated dispersion from observed dispersion in subsets of frequency bands that clearly do not honor the

well-constrained shape of the observed dispersion. The conundrum is that approaches to 1-D Vs-depth uncertainty estimation like chi-squared, total absolute deviation, or the common methods of randomization (Toro, 1993; Toro and Silva, 2001; Romero and Rix, 2005) often results in Vs models that do not match the experimentally measured dispersion data over the entire frequency range of observed dispersion. Griffiths (2015) found that using median models is effective because the intrinsic epistemic uncertainty in the mapping of dispersion shape to Vs-depth is accurately estimated resulting in site-response estimates that are consistent with observed dispersion and fully account for the epistemic uncertainties of the nonlinear mapping of surface-wave dispersion shapes to Vs-depth.

The Griffiths (2015) median approach is used here to estimate the component of intrinsic epistemic uncertainty associated with the nonlinear mapping of surface-wave dispersion to Vs-depth. The dispersion uncertainty picking approach used in Fugro (2014a) was designed to produce boundary Vs uncertainties using the Monte-Carlo uncertainty estimation approach of O'Connell and Turner (2011). Fugro (2015) adopted the Griffiths (2015) median approach to estimate Vs-depth uncertainties after discussion with Prof. Brady Cox in March 2015 but prior to the filing of Griffiths' dissertation in August 2015. This update of Fugro (2015) more completely explains the rational and basis for using Griffiths' (2015) median approach to estimate one of the four components of Vs-depth uncertainties.

The Monte Carlo inversions in O'Connell and Turner (2011) save twenty or more of these dispersion consistent models from the large sets of Vs models evaluated and use at least three different starting models. To reduce potential biases due to starting models, Fugro (2015) used initial layer thicknesses from three different starting models with systematically different layer thicknesses in three independent full Monte Carlo inversions to generate classes of 1-D Vs-depth models consistent with the picked dispersion curves over the entire frequency bandwidth of observed dispersion. Additional details of the initial implementation of median approach to calculating the second component of Vs uncertainty the epistemic of Vs-depth uncertainty associated with inversion of surface wave dispersion data for Vs-depth are presented in Fugro (2015). This report extends the median uncertainty analyses to formally calculate Vs uncertainties within 10-m depth intervals and estimate additional Vs epistemic uncertainties as a function of Vs vertical velocity gradients.

Analysis of the waveform inversion misfits provides strong quantitative constraints on the first component of Vs uncertainty, Vs scaling uncertainties, because changes in Vs of only several percent produce complete dephasing of the synthetic and observed waveforms in the 8 to 28 Hz frequency band that Fugro (2015) showed constrain Vs-depth particularly well in the 0 to 45 m depth range. The substantial reduction in waveform misfit in the region where the 3-D velocity model was updated using waveform misfit residuals showed that approximation of the Hessian and hence covariances using Taylor-series expansion accurately represents Vs model waveform sensitivities and Vs uncertainties. The waveform sensitivity analyses demonstrated that the potential for 3-D Vs-depth scaling biases is very low, on the order of a couple percent in the 3-D region where the tomographic 3-D Vs updates were based on waveform misfit inversion.

Lateral and vertical variations in Vs-depth in the 3-D model provide first-order information about how 1-D Vs-depth profiles should be randomized to account for first-order velocity variability at particular sites within the span of the 3-D velocity model. The 3-D model

thus provides a way to quantitatively estimate short (1-5 m) -to-intermediate (5-10 m) scale Vs uncertainties associated with unresolvable velocity complexity, particularly short-to-intermediate Vs details below low-velocity zones; low-velocity zones decrease velocity resolution and increase velocity uncertainties below the top of low-velocity zones.

2.2 COMPARISON OF UPDATED 3-D VS MODEL WITH PREVIOUS DCPD MEASUREMENTS OF VS-DEPTH

The uncertainty analyses of the updated 3-D Vs model use a comparison with independent Vs-depth measurements, where available, to estimate 3-D Vs scale uncertainties as well as to inform estimates of vertical and horizontal short-wavelength variability uncertainties. Waveform misfit uncertainty analyses are used to obtain the most accurate estimates of Vs uncertainties for seismographic stations ESTA27 and ESTA28. Vs uncertainties for the rest of the area which comprise the region around the DCPD turbine, containment structures, and auxiliary buildings are based on Vs uncertainties calculated using an approach similar to Griffiths (2015) to obtain a realistic estimate of Vs baseline model uncertainties appropriate for site response analyses.

Because four of the boreholes are relatively shallow, they don't provide sufficient data to evaluate Vs throughout the entire 100 m depth range of the 3-D Vs model. However, they provide valuable data to compare to the shallow portions of the 3-D Vs model that are below foundation grade where the largest changes of velocity occur in the top 15 m as indicated in the density function for Vs from the 3-D Vs model as a function of depth (Figure 2.2-1) using the Vs data from the entire area including DCPD as outlined by the red polygon in Figure 2.0-1. A primary feature clearly delineated in Figure 2.2-1 is that throughout the DCPD area the primary surficial weathering zone extends to 10-15 m depth and there is often a second deeper weathering layer between 10-15 m depth and 50 m depth where velocities increase to relatively constant Vs between 50 m depth and 100 m depth (Figure 2.2-1).

2.2.1 Vs-Depth Measurements Inside the Turbine Building-Containment Structures Area of DCPD

Vs-depth measurements for DCPD started with pre-construction geophysical investigations including downhole and Vs refraction surveys (Blume, 1968; 1969) in the area containing the turbine building and containment structures shown in Figures 2.0-1 and 2.0-2. The Blume (1969) refraction profiles present additional P-wave and limited S-wave refraction profiles that extend through Unit 2 and extend south of the main DCPD building with the 1969 SL-4 Vs refraction profile spanning Unit 2 (Figure 2.0-1). The 1968 and 1969 Vs refraction and four shallow downhole logs (maximum depth 40-50 feet) provide first-order pre-construction Vs constraints on foundation Vs from the pre-construction surface to the base of the surficial weather zone at 10-15 m depth and below basement elevations in the turbine building and both containment structures (Figures 2.0-1 and 2.0-2). Much of the shallow portion of this area between the containment structures and the turbine building is now occupied by inlet pipes and plumbing associated with the outlet structures so new velocity measurements in many parts of this area would be difficult.

The Blume (1968) Vs results are contained in Table 2.2-1 with the surficial Vs omitted since those surficial units were always removed during excavation. Downhole DDH-1 Vs data beneath the central portion of the turbine building (Figure 2.2-2) indicate that the weathered rock was removed to an elevation of 62 feet (depth of 30 feet in DDH-1) that had a Vs of

approximately 550 m/s and that the top of rock below the turbine building foundation has a Vs of approximately 865 m/s (Figure 2.2-3). Downhole DDH-2 data between the two containment structures (Figure 2.2-4) indicate that at the foundation level of the south side of Unit 1 (elevation of 52 feet and DDH-2 depth of 43 feet), the top of rock Vs is approximately 1750 m/s and the Vs of the removed weathered rock was approximately 770 m/s (Figure 2.2-5). Downhole DDH-3 located slightly WNW of the center line of Unit 1 (Figure 2.2-6) shows that weathered rock with Vs of approximately 480 m/s was removed along with about 6 m of rock with a Vs of approximately 1844 m/s to the foundation level of 52 feet above sea level (Figure 2.2-7). There is a low-velocity zone 5 feet below foundation grade in DDH-3 with a Vs of approximately 832 m/s that has a thickness of at least 3 m (Figure 2.2-7). Borehole DDH-4 beneath the northern portion of the turbine building (Figure 2.2-8) has a weathered rock Vs of approximately 427 m/s that was entirely removed by excavation and a top of rock Vs of approximately 937 m/s (Figure 2.2-9). The Vs refraction lines represent lateral averages over a much larger extent than downhole Vs measurements and have less vertical resolution of vertical velocity details than the downhole Vs data (Table 2.2-1).

Table 2.2-1. Summary of Blume (1968; 1969) Downhole and Refraction Vs Results

Site	Building/Orientation	Weathering Vs (m/s)	Top of Rock Vs (m/s)
DDH-1	Turbine	552	866
DDH-2	North Containment	770	1753
DDH-3	North Containment	480	1844
DDH-4	Turbine	427	937
Refraction SL-1	Turbine S of North Containment	792	1067
Refraction SL-2	Turbine Center Line	747	1097
Refraction SL-3	Turbine Center North Containment	975	1021
<i>Ln Average Vs</i>		652	1177
<i>Ln σ</i>		0.30	0.30

All the Vs refraction analyses of Blume (1968; 1969) consisted of one or two constant-velocity layer interpretations over half-spaces which was the common approach to seismic refraction processing and interpretation in that time period. Modern seismic inversion approaches including the 3-D P-wave tomography and IMASW S-wave tomography use a sufficient number of thin layers to allow and resolve vertical velocity gradients that exist throughout the DCPD area as revealed in 3-D Vp tomography (Fugro, 2014a) and in the curvature of P-wave first arrivals (Fugro, 2014b). Similarly, the Blume (1978) downhole interpretations used a small number of constant-velocity layers with measured average S-wave arrival time slownesses throughout each layer depth interval to estimate constant-velocity layer Vs. This approach to downhole interpretation ensures that estimated Vs is not influenced by a small number of arrival time picks and results in models that are simple and smoothed at a large scale. However, Vs-depth models comprised of 2-3 constant-velocity layers nearly always are clearly inconsistent with observed surface-wave dispersion because there are vertical-velocity-gradient zones that generally persist across most of the DCPD site associated with decreasing

weathering (increasing Vs) with increasing depth (Figure 2.2-1), as well as gradational vertical and horizontal composition and cementation changes in Obispo Formation sedimentary units. Consequently, as found in Stephenson et al. (2005), Boore and Asten (2008), Hollender et al. (2014), and Garofalo et al. (2015), it is appropriate to compare velocity estimates over depth intervals to quantify the differences in estimated shallow Vs between different measurement methods. This is particularly useful at DCPD because the primary velocity changes that affect site response are the difference between the lowest velocity surficial weathering layer at depths of 0 m to 10-15 m and the secondary deeper weathering layer between 10-15 m depth and 50 m depth (Figure 2.2-1).

Within the surficial weathering zone, the Blume (1968; 1969) Vs measurements (Table 2.2-1) show that the DCPD main building area has velocities that exceed 3-D estimated Vs at shallow depths while *ln* average Vs in the surficial weathering layer in the DCPD building area is about the same as the modal Vs of the entire 3-D velocity model (Figure 2.2-1). However, Vs within the top portion of the second weathering layer below 15 m depth in the DCPD plant area is systematically higher than the modal Vs for the entire area containing DCPD (Figure 2.2-1).

Table 2.2-2 summarizes the comparison of 3-D Vs model Vs-depth compared to Blume (1968; 1969; 1978) Vs-depth measurements. The Vs values reported in Table 2.2-2 are *ln* averaged over the depth intervals listed. The yellow highlighted rows correspond to locations beneath the primary DCPD buildings (turbine building, containment structures, or auxiliary building as listed in Table 2.2-1).

Table 2.2-2. Additional Downhole and Seismic Refraction Vs Data used to Constrain Vs in the 0-25 m Depth Range in the Central DCPD Area

Profile	Min. Elev. (ft)	Max. Elev. (ft)	Measured Vs (m/s) (<i>ln</i> -average of downhole and refraction)	3-D Vs (m/s)	3-D Vs / Measured Vs
1968 DDH-1	46	86	772	738	0.96
1968 DDH-2	46	89	917	999	1.09
1968 DDH-3	47	81	1034	1005	0.97
1968 DDH-4	46	79	887	818	0.92
1969 SL-4	10	90	1028	1081	1.05
1978 DDH-A-2	-160	70	1142	1047	0.92
1978 DDH-C	-200	85	1194	1217	1.02
1978 DDH-D	-160	95	1370	1330	0.97
All Sites Mean 3-D Vs / Measured Vs					0.99
All Sites Standard Deviation 3-D Vs / Measured Vs					0.06
Main DCPD Building Sites Mean 3-D Vs / Measured Vs					0.99
Main DCPD Building Sites Standard Deviation 3-D Vs / Measured Vs					0.06

The Blume (1968; 1969) Vs data indicate that velocity variability is probably higher in the central-north portion of the main DCPD area outlined by the magenta polygon in Figure 2.0-1. For instance, the borehole DDH-2 downhole Vs model located between the two containment buildings (Figure 2.2-4) has a very high Vs below foundation grade larger than 1700 m/s, which is much larger than the Blume (1968) Vs-refraction estimate of 1100 m/s (Figure 2.2-5). This suggests that borehole DDH-2 may have been located in a local high-velocity area too small to detect with Vs-refraction profiling. The 3-D Vs depth average of 999 m/s at DDH-2 is 9% faster than the Blume (1968) combined downhole and Vs refraction depth-averaged Vs of 917 m/s mostly because the 3-D Vs model has higher velocities in the shallow material that was removed during excavation after the Blume (1968) Vs measurement. Otherwise, the 3-D Vs model agrees closely with the combined DDH-2 downhole and Vs refraction Vs profile in the foundation (Figure 2.2-5). The Blume (1968) downhole and Vs refraction profiles at DDH-3 under Unit 1 (Figure 2.2-6) also exhibit quite different Vs estimates between the downhole Vs and the SL-3 refraction Vs with the DDH-3 downhole Vs having a high Vs layer while the SL-3 refraction Vs profile has a much lower Vs increase at an elevation of about 70 feet (Figure 2.2-7). The 3-D Vs profile at DDH-3 is quite similar to the SL-3 Vs refraction profile with the 3-D Vs depth-average 3% slower than the Vs depth average of the combined downhole and refraction data (Figure 2.2-7). The DDH-4 borehole is below the north-central section of the turbine building (Figure 2.2-8). The DDH-4 downhole and SL-2 refraction Vs profiles are slightly slower on average near the surface in the material that was later removed during excavation and slightly faster at depth than the 3-D Vs profile (Figure 2.2-9) with the 3-D depth-average Vs 8% slower than the DDH-4 combined downhole-refraction depth-average Vs (Table 2.2-2). Blume (1969) refraction line SL-4 extends beneath Unit 1 (Figure 2.2-10). The 3-D depth-average Vs is 5% faster than the refraction line SL-4 depth-average Vs (Figure 2.2-11 and Table 2.2-2).

The DDH-2 and DDH-3 downhole logs show a local relatively thin high-velocity layer at about 10 m depth that also is imaged in the 3-D Vp tomography at these locations (Figure 2.2-12). The downhole data from boreholes DDH-2 and DDH-3 (Figures 2.2-5 and 2.2-7) and the 3-D Vp profiles (Figure 2.2-12) illustrate the scale of vertical and horizontal Vs variability that can occur over a distance of about 50 m within the DCPD main facility area.

The updated 3-D Vs-elevation profiles are compared to the three deep Blume (1978) boreholes with Vs interval velocity estimates from near the surface to the bottoms of the boreholes. Borehole DDH-A-2 is located southwest of the main area of interest and slightly outside the area of surface-wave dispersion measurement centroids (Figure 2.2-13). The closest 3-D Vs constraints from dispersion are located >30 m from borehole DDH-A-2. The Blume (1978) DDH-A-2 downhole Vs model is very simple with a single constant-velocity layer over a half-space (Figure 2.2-14). Like the modal Vs-depth profile for the site as a whole (Figure 2.2-1), most of the adjacent dispersion data require significant depth extents of velocity-gradients (Figure 2.2-14). However, there are only modest differences in the depth-averaged Vs with 3-D Vs about 8% slower than the downhole DDH-A-2 Vs (Table 2.2-2) which is within the typical uncertainty of different Vs estimation techniques of 10% (Stephenson et al., 2005; Boore and Asten, 2008; 2014; Hollender et al., 2014; Garofalo et al., 2015).

Borehole DDH-C is located near the southwest corner of the turbine building (Figure 2.2-15). The layers are as numbered in Figure 2.2-16 since there are not multiple arrivals times in the interval from the surface to 16 ft depth in Figure 2.2-16 to define an

apparent velocity for a layer between the surface and 16 ft depth; an average velocity is shown in this depth interval in Figure 2.2-17. The S-wave first-arrival times in the second layer for the DDH-C travel times were used to define the apparent V_s as shown by the red dashed line in Figure 2.2-16 consistent with the original interpreter ignoring the later P-wave phase and using the first arrivals in the same layer (Figure 2.2-16). The resulting downhole V_s profile essentially consists of two layers over a half-space since the first and second layer velocities are essentially the same to measurement uncertainties (Figure 2.2-17). There are only modest differences in the depth-averaged V_s with 3-D V_s about 2% faster than the DDH-C downhole V_s (Table 2.2-2) which is within the typical uncertainty of different V_s estimation techniques of 10% (Stephenson et al., 2005; Boore and Asten, 2008; 2014; Hollender et al., 2014; Garofalo et al., 2015).

Borehole DDH-D is located along the southeast edge of the auxiliary building (Figure 2.2-18). The 3-D depth-averaged V_s is 3% slower than the downhole depth-averaged V_s and the velocity profiles are similar except that the deepest portion of the downhole V_s is shown as constant velocity while the 3-D V_s model shows a low-velocity zone in the lower 70 feet of the borehole location (Figure 2.2-19). A pronounced low-velocity zone below -60 feet elevation is a prominent feature along the east side of DCPD in the 3-D V_p tomography that is well constrained by over 6 million P-wave travel-time arrivals in the surface to -300 feet below sea level elevation range. The modest differences in the depth-averaged V_s with 3-D V_s about 3% slower than the DDH-D downhole V_s (Table 2.2-2) is within the typical uncertainty of different V_s estimation techniques of 10% (Stephenson et al., 2005; Boore and Asten, 2008; 2014; Hollender et al., 2014; Garofalo et al., 2015).

Table 2.2-2 shows that the 3-D V_s model has a bias of 1% slow on average, well within the measurement uncertainties of the Blume (1968; 1969; 1978) V_s measurements. The maximum differences between the 3-D V_s and Blume (1968; 1969; 1978) V_s measurements are all less than 10% (Table 2.2-2) consistent with blind testing of V_s uncertainties from multiple methods that indicates that independent V_s estimation methods typically provide depth-averaged V_s estimates with 10% of each other (Stephenson et al., 2005; Boore and Asten, 2008; 2014; Hollender et al., 2014; Garofalo et al., 2015). Thus, the updated 3-D V_s model is verified in the main DCPD building area to be unbiased and consistent with independent Blume (1968; 1969; 1978) V_s measurements that extended below the surficial lower-velocity weathering layer into the foundation rock of the turbine building and containment structures.

2.2.2 V_s -Depth Measurements Outside of the Turbine Building-Containment Structures Area of DCPD

The waveform inversion update also provides refined estimates of V_s -depth uncertainties relative to the Rayleigh dispersion estimates of V_s -depth and is presented first to document uncertainties specifically for seismographic station sites ESTA27 and ESTA27 (Figure 2.2-20). Dispersion estimates of V_s uncertainties using the approach of Griffiths (2015) and standard estimates of non-invasive surface-wave V_s estimation uncertainties is present second.

V_s -Depth Uncertainties from 3-D Waveform Misfit Inversion

Table 2.2-3 shows the waveform cross correlations and percentage velocity biases (misfit %) along the source-receiver paths that intersect station ESTA27 with waveform

analyses plots shown in Appendix A. The velocity biases average -0.26% along these source-receiver paths with a standard deviation of 5%. The observed Vibroseis ground motions are well modeled with average cross correlations of 0.81 for the ground motions in the 8 to 28 Hz frequency band (Table 2.2-3). The group-velocity kernels show significant velocity sensitivity to 45 m depth (Fugro, 2015) indicating that the long-wavelength epistemic uncertainty in Vs from the surface to 45 m depth is 5% and the scaling uncertainty (bias) is less than 1%. All waveform analyses for the source-receiver paths denoted by the southern set of blue source-receiver paths in Figure 2.2-20 are provided in Appendix C.

Statistics encompassing the lateral variability of Vs-depth beneath ESTA27 are shown in Figure 2.2-21 which plots the density of Vs as function of depth for lateral averaging radii of 10, 20, 25, and 50 m from the position of seismographic station ESTA27. Within 10 m of ESTA27 velocities are nearly laterally homogenous in the top 45 m with only a single small depth interval between 5 m and 10 m where a constant velocity layer approximation is appropriate to represent Vs-depth (upper left plot in Figure 2.2-21). The depth intervals of 0 to 5 m, and 10 to 45 m require parameterization using many small layers or linear gradient layers to reproduce observed Vibroseis ground motions (upper left plot in Figure 2.2-21). Similarly, at the location of deep borehole DDH-C, a nearly constant Vs-depth gradient parameterization of Vs-depth is required to reproduce the Vibroseis waveforms for the source-receiver paths beneath DDH-C (Figure 2.2-16) as illustrated by the Vs-depth profiles beneath borehole DDH-C and its surrounding area (Figure 2.2-22). Thus, the full waveform analyses Vs-depth profiles beneath borehole DDH-C and seismographic station ESTA27 indicate that the thick constant-velocity layer interpretation models from the 1978 deep boreholes are generally poorly suited to use to represent Vs-depth for site response analyses in this area.

Table 2.2-3. Waveform Misfit and Source-Receiver Path Velocity Misfit for Source-Receiver Paths Transecting Station ESTA27

Waveform Set	Offset (m)	Waveform Cross-Correlation	Velocity Misfit (%)
Central Southeast	116	0.89	0.3
Central Southeast	93	0.77	-2.7
Central Southeast	96	0.93	-0.4
West of ESTA27	104	0.84	1.3
West of ESTA27	132	0.82	3.3
West of ESTA27	160	0.81	-5.6
West of ESTA27	181	0.71	8.7
West of ESTA27	180	0.72	-7
Average		0.81	-0.26
Standard Deviation		0.08	5.01

Table 2.2-4 shows the waveform cross correlations and percentage velocity biases (misfit %) along the source-receiver paths that intersect station ESTA28 with corresponding waveform analysis plots provided in Appendix B. The velocity biases average 0.42% along

these source-receiver paths with a standard deviation of less than 2%. The observed Vibroseis ground motions are not as well modeled through station ESTA28 with average cross correlations of 0.57 for the ground motions in the 8 to 28 Hz frequency band (Table 2.2-4) compared to the average cross correlations from waveforms from the source-receiver paths transecting station ESTA27 of 0.81 (Table 2.2-3). The velocity misfit bias and standard deviation are quite low for paths transecting station ESTA28 with a velocity uncertainty of 5% for Vs estimated from the surface to 45 m depth beneath station ESTA28 which is consistent with the group-velocity sensitivity kernels (Fugro, 2015). All waveform analyses for the source-receiver paths denoted by the northern set of blue source-receiver paths in Figure 2.2-20 are provided in Appendix D.

In contrast to the vertical gradient velocity structures beneath station ESTA27 (Figure 2.2-21) and borehole DDH-C (Figure 2.2-22) most of the depth range from 0 to 45 m beneath station ESTA28 could be approximated by several constant-velocity layers, although the depth range of 10 to 15 m needs to be represented by a large velocity gradient (Figure 2.2-23). There is a moderate low-velocity zone beneath ESTA28 below 20 m depth extending to 40 m depth (upper left plot in Figure 2.2-23) that becomes a much more pronounced velocity inversion in the 50 m area around station ESTA28 (lower right plot in Figure 2.2-23). Substantial lateral velocity variability occurs within 20 to 25 m of station ESTA28 as indicated by the nearly bimodal distribution of Vs-depth below 50 m depth (upper right and lower left plots of Figure 2.2-23).

Table 2.2-4. Waveform Misfit and Source-Receiver Path Velocity Misfit for Source-Receiver Paths Transecting Station ESTA28

Waveform Set	Offset (m)	Waveform Cross-Correlation	Velocity Misfit (%)
North	112	0.65	-1.9
North	135	0.43	2.7
North 3	110	0.7	-0.8
North 3	136	0.53	1
North 3	134	0.52	1.1
Average		0.57	0.42
Standard Deviation		0.11	1.79

The substantial Vs-depth variability over the larger DCPD area enclosed within the red polygon in Figure 2.0-1 is illustrated in Figure 2.2-24. The primary modal Vs-depth profile is nearly 300 m/s wide throughout the 0 to 115 m depth range (broad green-red zone in Figure 2.2-24), with distinct secondary modes (light green areas in Figure 2.2-24) illustrating the broad Vs-depth variability within the DCPD plant area. Most of the large Vs-depth variability in the DCPD area occurs in the top 45 to 50 m of depth (Figure 2.2-24). This is graphically illustrated by the divergence of the primary modal Vs-depth curve (solid black line) from the *ln*-mean Vs-depth curve (solid white line) in Figure 2.2-24, as well as the strong bias for the modal curve to approach and even cross the 16% (left dashed black line) and minus one-sigma (left magenta curve) in Figure 2.2-24. The *ln*-mean Vs-depth profile (solid black curve) and

primary mode Vs-depth profile (white curve) are very similar below 65 m depth (Figure 2.2-24) indicating that a single base Vs input condition at depths greater than 65 m can well represent Vs variability using a single Vs 1250 m/s and $\ln\text{-}\sigma$ of 0.14. However, for 1-D Vs-depth site response analyses, it is necessary to use site-specific Vs-depth profiles and characteristics of lateral variability along with a model of correlated vertical variability to produce 1-D Vs-depth site-specific profiles for site response analyses. Figures 2.2-21 to 2.2-24 clearly show that the Vs-depth variations in the top 45 to 50 m depth will dominate the site responses at DCPD and that either full 3-D site responses analyses or site-specific 1-D Vs-depth profile site response analyses are necessary to accurately estimate site responses in different parts of the DCPD area.

Tables 2.2-3 and 2.2-4 illustrate that 1-D Vs-depth profile uncertainties and biases are relatively small in the 0 to 45 m depth range where the waveform analyses provide strong constraints on 3-D Vs along the Vibroseis source receiver paths intersecting stations ESTA27 and ESTA28 and the area around them denoted by the thin blue lines in Figure 2.0-1. Uncertainties in Vs at depths larger than 45 to 50 m are less well constrained and will be similar to Vs-depth uncertainties from the surface-wave dispersion uncertainty analyses presented in the next section since the phase-velocity dispersion sensitivity kernels extend to approximately 100 m depth while the group-velocity sensitivity kernels for the waveform analyses primarily constrain Vs-depth to a maximum depth of 50 m (Fugro, 2015).

Vs-Depth Uncertainties from Surface-Wave Dispersion Inversion

Median Vs-depth model uncertainty analyses were completed at each of the 93 receiver-array surface-wave dispersion centroid positions shown in Figure 2.0-1. The Monte Carlo searches included evaluating a minimum of 72,000 Vs-depth models and often involved evaluating 100,000 to 200,000 or more separate Vs-depth models. At each centroid position there were typically 40 to 60 Vs-depth profiles from Monte-Carlo searches with three-different starting model layer thickness distributions that consistently fit the observed dispersion velocity curve throughout the entire frequency bandwidth of observed dispersion consistent with Griffiths' (2015) approach for selecting Vs-depth models for median model estimation. At each centroid location in Figure 2.0-1, the standard deviation of the natural logarithm of median Vs-depth, $\sigma(\ln(Vs(z)))$ and abbreviated as σ_{Vs} , was calculated using the 40 to 60 Vs-depth profiles at each centroid position that closely reproduce the observed phase-velocity dispersion throughout the entire frequency bandwidth of observed dispersion. Vs-depth was approximated with 0.5 m increments in depth to 100 m depth. As shown in Fugro (2015), these 40 to 60 models at each centroid position produce synthetic dispersion that closely conforms to the observed dispersion shape throughout the entire frequency bandwidth of observed dispersion which is tightly constrained by the slowness-frequency peak amplitude from active source seismic data. Thus, σ_{Vs} quantifies the fundamental epistemic Vs uncertainty associated with inversion of phase-dispersion curve shape for Vs-depth.

As discussed in O'Connell and Turner (2011) and Fugro (2015), group slowness constrains changes in phase slowness slope are related to first-order to depth regions where the vertical gradient of Vs denoted dVs/dz becomes large. These depth regions of large dVs/dz often correspond to layer boundaries or transition intervals between regions of relatively constant velocity or nearly constant moderate dVs/dz . Thus, we expect σ_{Vs} to increase on average with the absolute value of dVs/dz and be largest in depth intervals corresponding to the

top of low-velocity zones where dV_s/dz is negative which O'Connell and Turner (2011) showed are depth regions with the largest σ_{V_s} when only phase-velocity constraints are used to invert for Vs-depth.

Total Vs uncertainty becomes large in regions of large negative dV_s/dz because the uncertainty in the depths of the velocity decreases that defines the top of a low-velocity zones have higher uncertainty than depths associated with velocity increases from a shallow lower velocity layer to a deeper higher velocity layer. Velocity increasing with increasing depth is best constrained by kinematic seismic data (Bessonova et al., 1974), particularly phase-dispersion data (O'Connell and Turner, 2011; Garofalo et al., 2015). The maxima of σ_{V_s} usually correspond to uncertainties in the depth of the velocity transition which are typically parameterized in terms of uncertainties in layer thicknesses or layer depth boundaries in velocity randomizations for site response analyses. Depth uncertainties are largest at the bottom of low-velocity zones (e.g., it is most difficult to resolve the depth of the bottom of the low-velocity zone).

Table 2.2-5 provides Vs uncertainties as a function of depth interval associated with uncertainties in inversion of phase-dispersion for Vs-depth. The zero gradient intercept value, denoted as σ_{V_s} in Table 2.2-5, increases with increasing depth since fundamental-model phase-dispersion Vs-depth sensitivity kernels decrease with increasing depth (Fugro, 2015). As expected, Vs uncertainties increase the most in regions with large negative Vs-depth gradients corresponding to entering the regions of low-velocity zones where velocity decreases with increasing depth (Table 2.2-5). Specifically, in the 30 to 60 m depth range, Vs uncertainties are about twice as large in areas where Vs decreases with increasing depth than in areas where velocities increase with increasing depth (Table 2.2-5). Thus, regions in 1-D Vs-depth models extracted from the 3-D Vs model where $d\sigma_{V_s}/dV_s/dz$ is large and negative should be parameterized with increased layer boundary depth uncertainties that combined with σ_{V_s} from Table 2.2-5 and the average $d\sigma_{V_s}/dV_s/dz$ in the depth interval correspond to the total uncertainties in the appropriate $d\sigma_{V_s}/dV_s/dz_{neg}$ column of Table 2.2-5.

Table 2.2-5. Dispersion Inversion $\sigma_{\ln(V_s(z))}$ and Vs Velocity Gradient (dV_s/dz)

Ztop (m)	Zbot (m)	σ_{V_s}	$\sigma_{V_s} - \sigma_{\sigma}$	$\sigma_{V_s} + \sigma_{\sigma}$	$d\sigma_{V_s}/dV_s/dz_{neg}$	$d\sigma_{V_s}/dV_s/dz_{pos}$
0	10	0.069	0.034	0.104	-0.0009	0.0009
10	20	0.077	0.040	0.113	-0.0010	0.0009
20	30	0.081	0.041	0.121	-0.0016	0.0014
30	40	0.087	0.045	0.128	-0.0025	0.0012
40	50	0.112	0.062	0.162	-0.0019	0.0010
50	60	0.124	0.069	0.179	-0.0017	0.0010
60	70	0.138	0.073	0.203	-0.0013	0.0012
70	80	0.149	0.084	0.214	-0.0019	0.0013
80	90	0.169	0.104	0.234	-0.0010	0.0015
90	100	0.170	0.105	0.235	-0.0013	0.0020

For an area not close to seismographic stations ESTA27 and ESTA28, Vs point uncertainties and 1-D Vs-depth layer depth uncertainties can be calculated from Table 2.2-5 using a site-specific baseline Vs-depth model from the 3-D Vs model. We recommend using the modal Vs-depth model with a lateral average that accounts for the generally Gaussian decay of Vs site-response sensitivity to Vs-depth with increasing distance of Vs-depth profiles from the site of interest. For example, the modal Vs-depth models within 10 to 20 m of a site provide a reasonable baseline Vs-depth model for a site as illustrated by the upper plots for station ESTA28 (Figure 2.2-25) and ESTA27 (Figure 2.2-26). The 16% and 84% fractiles for Vs at each depth provide a reasonable-first order estimate of site-specific 1-D Vs-depth variability. Typically, 1-D site-response analyses approximate variability around a specific site using statistic functions. Here, the 3-D Vs model provides direct information about systematic components of nearby lateral Vs variability that is appropriate to incorporate into 1-D site response analyses. Inspection of modal Vs-depth using a moderate averaging radius of 10 to 20 m can identify suitable simplification of Vs-depth to create baseline models that are consistent of the minimum number of constant-velocity layers and velocity gradient layers that need to be specified. Appropriate estimates of the variability required to account for lateral velocity variation in 1-D Vs-depth baseline models can be estimated by probabilistic weighting of lateral velocity variations using a lateral distance weighting approach that accounts for the width of the first-Fresnel zone. For this demonstration, random sampling of the Vs cumulative distributions at each depth consisted of 1000 samples per depth. Figure 2.2-27 shows the resulting probabilistic 1-D Vs-depth distribution obtained using a 30-m width Gaussian standard deviation truncated at 50 m radius to generate Vs density distributions as a function of depth to account for lateral velocity variability in 1-D site-response analyses. The probabilistic lateral Gaussian weighting as a function of lateral distance results in a more unimodal Vs-depth function (Figure 2.2-27) than using single radius lateral averaged Vs-depth distributions (lower plots in Figure 2.2-25). Similarly, the probabilistic Gaussian lateral averaged Vs-density-depth function for station ESTA27 (Figure 2.2-28) is unimodal to first order unlike the 50-m radius-averaged Vs-density-depth distribution in Figure 2.2-26. While there may be substantial skew in some depth ranges (Figures 2.2-27 and 2.2-28) this can be accounted for with a unimodal statistical model. Consequently, the probabilistic Vs-depth functions like those constructed in Figures 2.2-27 and 2.2-28 are better suited to combine with correlated-random vertical variability estimates to generate random Vs-depth models for site-specific response calculations than single radius lateral average estimates (Figures 2.2-25 and 2.2-26).

Additional epistemic Vs uncertainties in the area without waveform constraints, and deeper than 50 m in the area with waveform constraints, should be used as a function of depth (Table 2.2-5). In regions without waveform constraints, additional uncertainties due to high gradient zones can be accounted for using the terms from Table 2.2-5.

Tables 2.2-6 to 2.2-8 capture all the component of Vs as a function of site area and depth with Table 2.2-6 representing midrange estimates of Vs uncertainty components, Table 2.2-7 representing lower-bounding Vs uncertainty estimates and Table 2.2-8 representing upper-bounding Vs uncertainty estimates. The component number in these tables refers to the uncertainty component presented at the beginning of Section 2.0. The scale (bias) uncertainty is smallest near the surface where velocities are best constrained. Median epistemic uncertainties at zero offset listed in Table 2.2-5 provide the basis for the epistemic uncertainties in the area where only surface-wave dispersion data were available. The epistemic uncertainties for the

DCPP main buildings are based on joint analyses of Blume (1968; 1969) Vs downhole and refraction data from the turbine building and containment structure areas. Epistemic uncertainties for the ESTA27 and ESTA28 areas are from the standard deviations of the waveform misfits separated into shallow and deeper depth ranges. Vertical uncertainties are associated with unresolvable short-wavelength vertical variability of Vs-depth profiles and are based on suspension-log Vs variability observed at ISFSI as discussed in Fugro (2015). Lateral uncertainties represent short-wavelength lateral variability that could not be resolved in the 3-D Vs model. Both the vertical and lateral uncertainties should account for correlation lengths using approaches comparable to Toro (1993) and Toro and Silva (2001) to avoid unrealistic short-wavelength randomization.

Diabase is widely distributed in the subsurface in the larger area containing the DCPD foundation but is not present in the mapped DCPD foundation excavations (Fugro 2014a, 2014b, 2014c, 2015; O'Connell et al., 2015). The distribution of diabase relative to the DCPD foundation is relevant because diabase and possibly nearby regions of dolomitic alteration are associated with Vp velocities 2-3 times larger than non-diabase Obispo Fm lithofacies Vp. Thus, to first-order, seismic velocities are likely to scale in inverse proportion to distance from diabase intrusive rock; high-velocity dolomitic alteration is most intense closest to the intrusive body and decreases with distance from the intrusive body. The 3-D Vs model resolves long-wavelength velocities below the weathering zone depth of 45-50 m that have saucer-shaped configurations consistent with diabase intrusive rocks and/or alteration surrounding the diabase intrusive rocks. However, at depths > 50 m available Vs measurements beneath the DCPD cannot resolve 1-10 m thick local high-velocity regions. Consequently, while the short-wavelength variability components of vertical and lateral variability may appear large in Table 2.2-6, they are required to account for observed velocity variability within 500 m of the central portion of the DCPD, particularly the complex diabase intrusive structures that are clearly imaged at depths > 50 m below portions of the DCPD (Fugro 2014a, 2014b, 2014c, 2015; O'Connell et al., 2015).

The highest profiles velocities in the 3-D Vs model below DCPD are about 1500 m/s. The highest Vp observed within 500 m of the DCPD is 6000 m/s corresponding to high Vp body observed below a diabase outcrop located about 400-500 m N30E from the central portion of the DCPD (Fugro 2014b, 2014c, O'Connell et al., 2015). Consequently, there is nearby precedent within 1 km of the DCPD for Vs on the order of 3000-3500 m/s (Poisson's ratio of 0.25-0.3) to exist with thicknesses less than could be resolved by any of the current Vs measurement beneath the DCPD. These diabase intrusions can be dipping to nearly flat since they retain their saucer-shaped sill 3-D configurations (O'Connell et al., 2015). Thus, it is necessary to specify components of short-wavelength σ_{Vs} of 0.2-0.25 for both the vertical and horizontal components of short-wavelength variability to obtain Vs on the order of 3000 m/s during randomization to account for unresolvable short-wavelength (1-10 m Vs variability) at 50 m depth below the weathering layers. The diabase intrusives are imaged in Vp tomography at depths > 50 m below eastern portion of the DCPD extending at least beneath parts of the main building portion of the DCPD. Two example calculations are provided below to illustrate the necessity of the values of vertical (#3) and horizontal (#4) short-wavelength Vs variability specified in Tables 2.2-6 to 2.2-8. First, using the median Vs short-wavelength uncertainty components from Table 2.2-6 below the DCPD buildings, the total short-wavelength variability of 0.25 for the vertical component and 0.2 for the lateral component correspond to a total short-wavelength σ_{Vs} of 0.32 which produces a $+2\sigma_{Vs}$ Vs of 2845 m/s (using a mean Vs of 1500 m/s).

Second, using the upper bound median Vs short-wavelength uncertainty components from Table 2.2-8 below the DCPD buildings, the total short-wavelength variability of 0.3 for the vertical component and 0.25 for the lateral component correspond to a total short-wavelength σ_{Vs} of 0.39 which produces a $+2\sigma_{Vs}$ Vs of 3272 m/s (using a mean Vs of 1500 m/s). Thus, the short-wavelength components of vertical and horizontal variability in Tables 2.2-6 and 2.2-8 produce a sufficient range of Vs properly account for observed velocity variability at depths > 50 below the weathering layers that could occur in layers of 1-10 m thickness. The highest probabilities should be assigned to the shortest wavelengths, consistent with the suspension logging Vs measurements 400 m northeast of the central portion of the DCPD (Fugro, 2015). It should be noted that the suspension logging measurements did not extend to sufficient depth to directly measure velocities in the diabase intrusive complex that is imaged below ISFSI (Fugro, 2014c). The examples provided above illustrate why it is necessary to specify uncertainties on the uncertainties as is done using Tables 2.2-6 and 2.2-8.

**Table 2.2-6. Median Vs Uncertainty Components
by Area and Depth**

Site	Z _{min} (m)	Z _{max} (m)	Scale (Bias) (#1) ¹	Epistemic Uncertainty (#2) ¹	Vertical (#3) ¹	Lateral (#4) ¹
ESTA27	0	50	0.015	0.03	0.15	0.08
	50	100	0.03	0.08	0.2	0.1
ESTA28	0	15	0.03	0.04	0.2	0.12
	15	100	0.06	0.1	0.2	0.12
DCPD Buildings	0	10	0.03	0.1	0.25	0.2
	10	100	0.06	0.15	0.25	0.2
DCPD Rest	0	10	0.04	Table 2.2-5 σ_{Vs}	0.15	0.15
	10	50	0.05	Table 2.2-5 σ_{Vs}	0.2	0.15
	50	100	0.08	Table 2.2-5 σ_{Vs}	0.2	0.15

¹ Component number refers to the uncertainty component presented at the beginning of Section 2.0

Table 2.2-7. Natural Logarithm Lower Bound Vs Uncertainty Components by Area and Depth

Site	Z _{min} (m)	Z _{max} (m)	Scale (Bias) (#1) ¹	Epistemic Uncertainty (#2) ¹	Vertical (#3) ¹	Lateral (#4) ¹
ESTA27	0	50	0.01	0.02	0.1	0.05
	50	100	0.02	0.05	0.1	0.06
ESTA28	0	15	0.02	0.02	0.1	0.08
	15	100	0.04	0.06	0.1	0.08
DCPP Buildings	0	10	0.01	0.05	0.18	0.18
	10	100	0.02	0.1	0.18	0.18
DCPP Rest	0	10	0.02	0.05	0.1	0.1
	10	50	0.03	0.1	0.1	0.08
	50	100	0.05	0.15	0.1	0.08

¹ Component number refers to the uncertainty component presented at the beginning of Section 2.0

Table 2.2-8. Natural Logarithm Upper Bound Vs Uncertainty Components by Area and Depth

Site	Z _{min} (m)	Z _{max} (m)	Scale (Bias) (#1) ¹	Epistemic Uncertainty (#2) ¹	Vertical (#3) ¹	Lateral (#4) ¹
ESTA27	0	50	0.02	0.04	0.2	0.1
	50	100	0.05	0.1	0.25	0.12
ESTA28	0	15	0.04	0.05	0.25	0.15
	15	100	0.08	0.12	0.25	0.15
DCPP Buildings	0	10	0.05	0.15	0.3	0.25
	10	100	0.08	0.2	0.3	0.25
DCPP Rest	0	10	0.06	0.1	0.2	0.2
	10	50	0.06	0.15	0.25	0.2
	50	100	0.1	0.2	0.25	0.2

¹ Component number refers to the uncertainty component presented at the beginning of Section 2.0

2.3 DISCUSSION OF UPDATED ANALYSES WITH RESPECT TO PEER REVIEW COMMENTS

The peer review identified four areas of concern with respect to the 3-D Vs model presented by Fugro (2015). These were documented in a memorandum dated July 15, 2015 and are summarized below. The peer review identifies two issues related to the size of the uncertainty in the velocity profile at ESTA28, which is used as the control point for the DCP

GMRS. First, the peer review notes that the range of the velocity profiles does not span the full range of allowable velocity models given the dispersion curves and dispersion picking uncertainties presented in Fugro (2014a) and Fugro (2015). Second, the peer review also noted that there are two estimates of uncertainty of the velocity profiles shown in the Fugro (2015) report, but that the final uncertainty is based on only one estimate. Third, the peer review expressed concern that there was an absence of shallow data to directly constrain Vs in the immediate vicinity of the primary buildings of the DCP. Fourth, the peer-review panel recommended direct comparison of Vs-depth profiles from the 3-D Vs model with Vs-depth profiles from independent previous measurements instead of just comparing travel-time data.

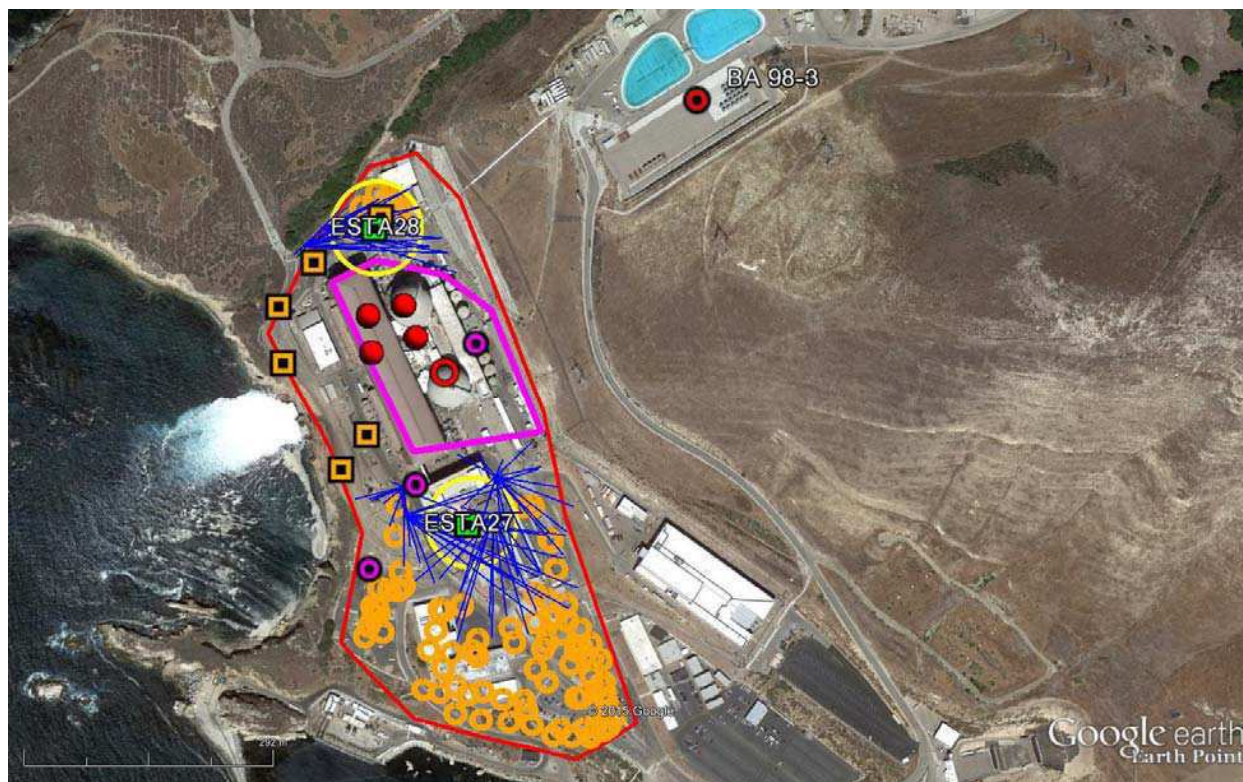
This report addresses the first peer review concern with several new analyses with expanded and updated documentation. First, as noted, the phase-slowness uncertainty picking and analyses approach used by O'Connell and Turner (2011) to estimate Vs-depth uncertainties is classified as a boundary approach that Griffiths (2015) showed is not appropriate to develop velocity model uncertainties for site response analyses. Fugro (2015) presented a median approach for Vs uncertainty estimate to replace the boundary approach of O'Connell and Turner (2011) prior to the availability of the full analyses presented in Griffiths (2015). This report fully documents and expands the median Vs uncertainty analyses of Fugro (2015) to completely replace the boundary approach for estimating Vs-depth uncertainties. This report employs and documents a median approach following Griffiths' (2015) methodology to estimate one of four components of Vs uncertainties. This report carries the median estimation approach further to explicitly calculate Vs estimation uncertainties as a function of depth and vertical velocity gradient. Second, the Fugro (2015) report used waveform inversion uncertainty analyses to discuss an alternative approach to refine and update uncertainties in areas where waveform analyses were completed. This report formally includes waveform inversion Vs uncertainty analyses for the two areas where waveform inversions and uncertainty analyses were completed that are centered on seismographic stations ESTA27 and ESTA28. Consequently, for seismographic stations ESTA27 and ESTA28, uncertainty analyses are based on the waveform inversion analyses that have higher resolution of Vs-depth and provide better constraints on Vs-depth uncertainties than phase-dispersion Vs-depth uncertainty analyses.

To address the second concern, this update computes and provides four components of Vs uncertainties and first-order uncertainties for Vs uncertainty terms as a function of depth ranges to fully document Vs uncertainties in four different areas of the DCP associated with different levels of Vs constraints by different types of data. Thus, the uncertainty analyses have been subdivided into four different areas including separate Vs uncertainty analyses for the two seismographic stations, ESTA27 and ESTA28, the region where only surface-wave dispersion data are available to constrain Vs, and the inner portion of the DCP area containing the turbine building, containment structures, and auxiliary building, where only previous borehole downhole measurements and S-wave refraction data are available to directly constrain Vs.

The uncertainty analyses now provide estimates of 3-D Vs model biases, long-wavelength Vs-depth uncertainties as a function of depth interval, and short-wavelength vertical and horizontal components of Vs uncertainties that would not be directly resolved by any of the geophysical measurements made to date within the DCP foundation area. A method is demonstrated to use 3-D variability in the vicinity of a specific site to develop probabilistic estimates of first-order lateral Vs variability for 1-D site response analyses. Known of the existing Vs measurements in the DCP foundation area resolved vertical Vs variations at

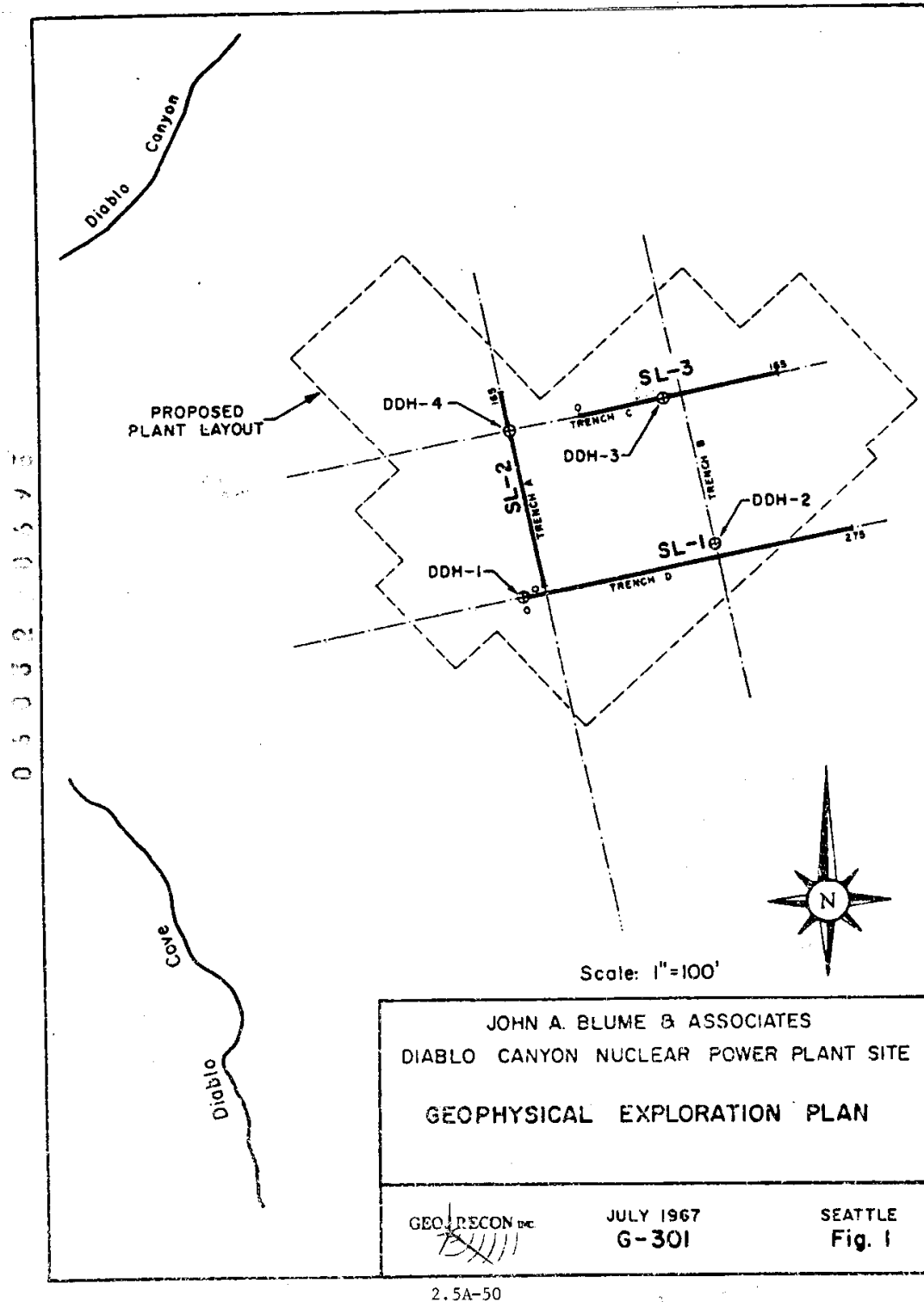
wavelengths less than 5 m. The 3-D Vs model contains no constraints on lateral Vs variations over distances less than a grid cell of 15 m and more realistically on the order of 20 to 25 m. Consequently, it is necessary to develop statistical models to represent Vs variations at vertical and horizontal wavelengths shorter than what can be resolved by the Vs measurements. The analyses of the suspension log Vs measurements about 500 m northeast of the DCPD from Fugro (2015) are used to estimate the range of short-wavelength Vs uncertainties that should be considered to create statistical Vs variations using methods such as Toro (1993), Toro and Silva (2001), Romero and Rix (2011), or variations on these approaches, to develop appropriate correlated-random models of Vs variability to construct Vs profiles for probabilistic site response analyses. Thus, the updated report provides sufficient Vs uncertainty estimates, and an example of an approach to use the 3-D Vs model to develop statistical models for 1-D site response analyses, to generate statistical (alternative) Vs models that are consistent with available Vs measurements in the DCPD foundation area.

To address the third and fourth peer review concerns about possible lack of Vs measurements in key building areas and the need for direct comparison of Vs estimates from previous measurements with 3-D Vs profiles, this report compares Vs-depth profiles from the 3-D Vs model with eight previous Vs data measurement locations beneath or adjacent to the turbine building, containment structures, and auxiliary building (Blume, 1968; 1969; 1978). These independent previous measurements of Vs data are used to compute 3-D Vs model biases and uncertainties in the areas that do not contain waveform inversion or phase-dispersion data to constrain Vs. This report shows that there are direct Vs measurements beneath and adjacent to all the key DCPD buildings including the turbine building, the two containment structures, and the auxiliary building and that the estimated 3-D Vs model is consistent with these previous Vs measurements (Figure 2.0-1). This report shows that estimated Vs-depth profiles extracted from the updated 3-D Vs model are unbiased in comparison to previous independent measurements of Vs-depth.

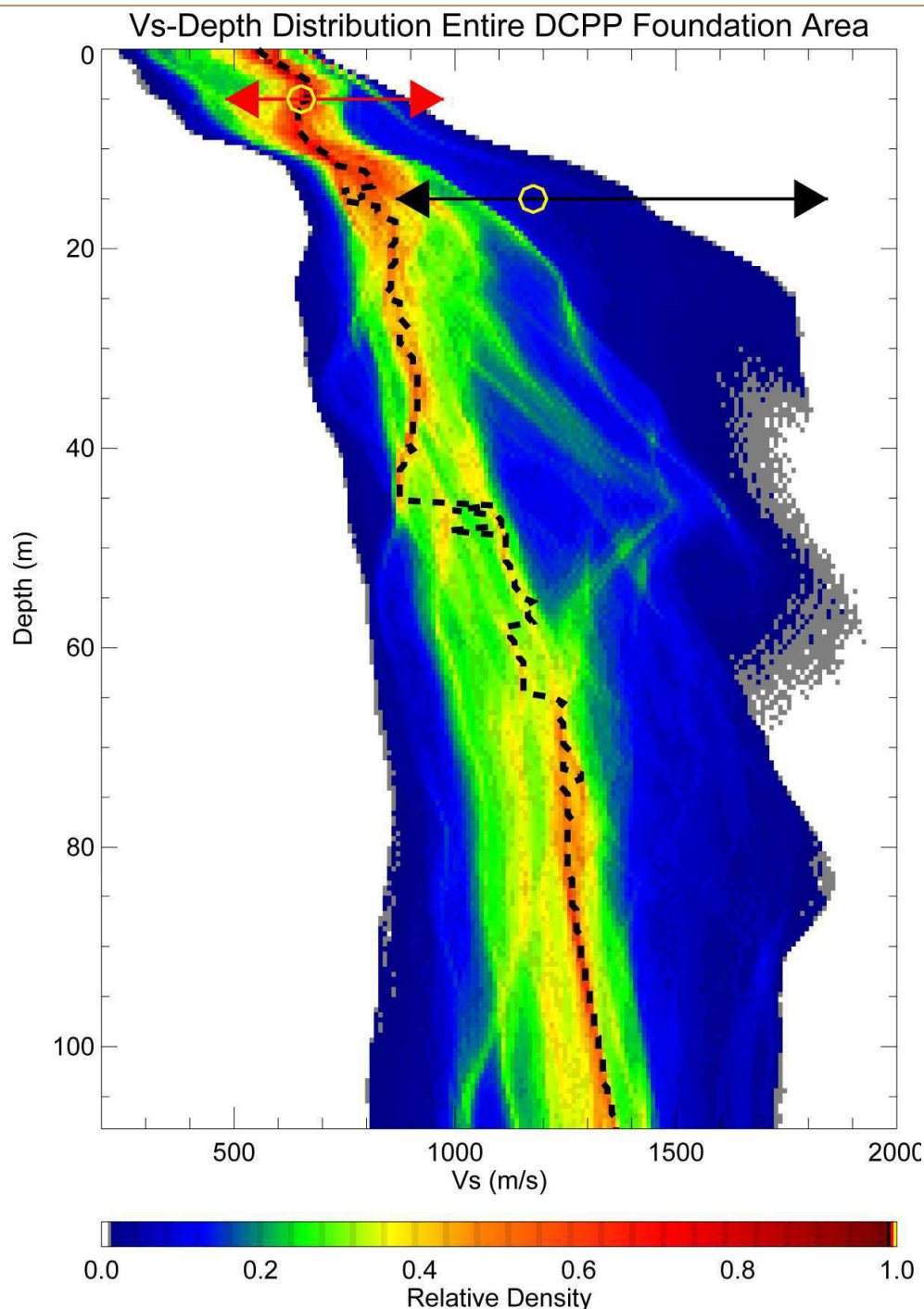


Magenta circles with black centers are 1978 deep downhole sites. Solid red circles are 1968 downhole sites that extend into existing foundation rock. The open red circle is the center point of 1969 shear-wave refraction velocity profile. Orange squares with black centers are center positions of source-receiver arrays used to estimate V_s -depth with phase-slowness Rayleigh dispersion data from Vibroseis sources in Fugro (2014a). Orange circles are receiver centroid positions for 3-D Rayleigh dispersion measurements used to estimate V_s -depth in Fugro (2015). Blue lines are source-receiver paths used to update the 3-D V_s model using waveform inversion to update and refine the Fugro (2015) 3-D velocity model beneath the two seismographic stations shown as green squares with black centers (ESTA27 is the south station and ESTA28 is the north station slightly obscured below a V_s -depth measurement location). The red circle with black center is the suspension log location for borehole 98-3 at the ISFSI site east of DCP discussed in Fugro (2015). The red polygon encircling DCP is the region of the updated 3-D velocity model used to calculate V_s statistics in Figure 2.2-1. The magenta polygon is the region where Blume (1968; 1969; 1978) V_s data were used to constrain adjustments of V_s in the 0-25 m depth range.

LOCATIONS OF VS MEASUREMENTS IN THE DCP AREA
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



LOCATION MAP FOR 1968 BOREHOLES AND 1968 VS-REFRACTION PROFILES
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



Dotted black line shows the mode (maximum density) curve. Ranges of 1968-1969 measured Vs are shown by labeled double arrows (red for layer 1 and black for layer 2) and the $\ln$ average Vs in each of the two 1968-1969 layers is denoted by the open yellow circles.

**VS-DEPTH DENSITY DISTRIBUTION FROM THE UPDATED
3-D VS-DEPTH PROFILES FOR THE ENTIRE AREA
OUTLINED BY THE RED POLYGON IN FIGURE 2.0-1**
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California

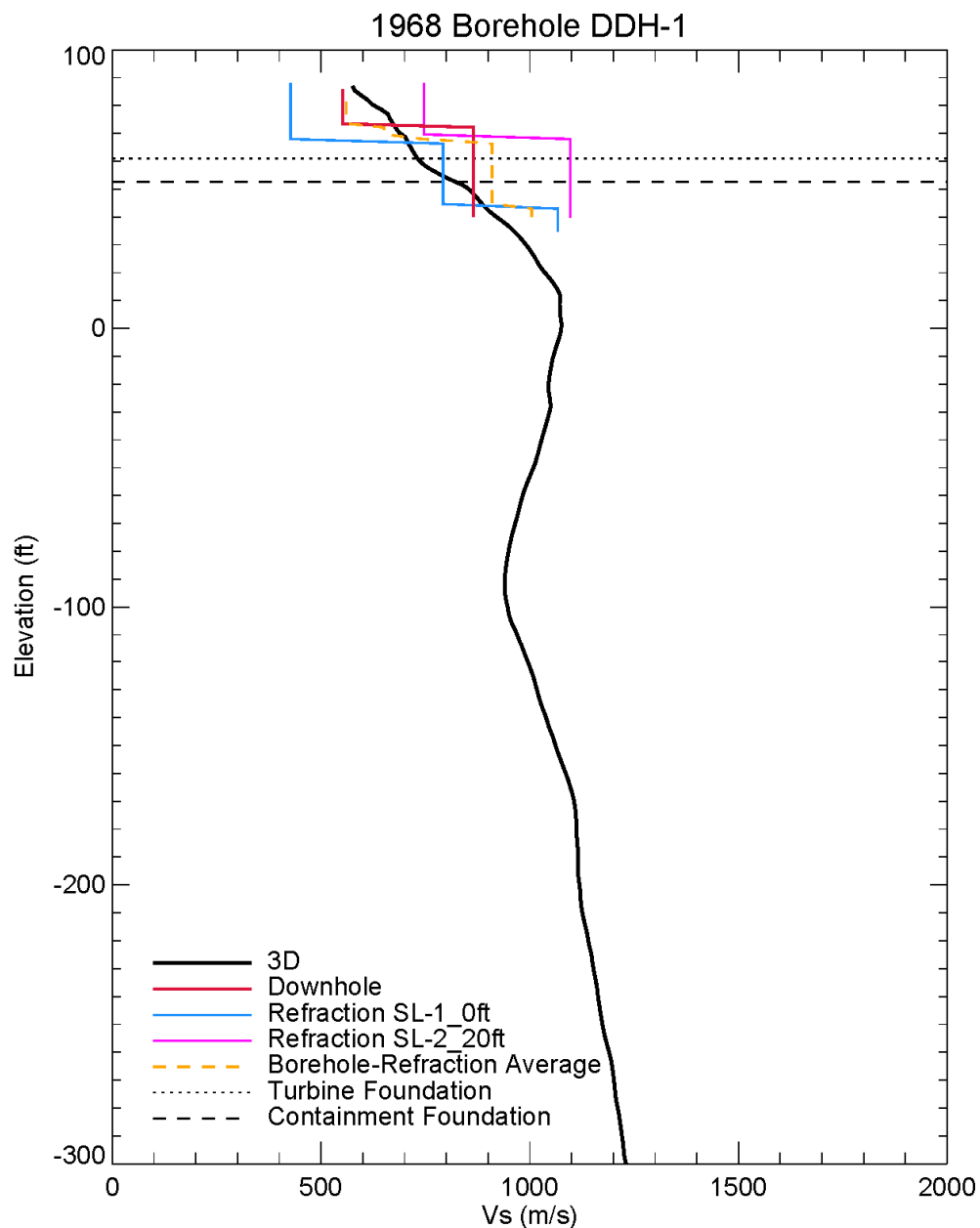


Borehole DDH-1 shown as the enlarged solid red circle. See Figure 2.0-1 for detailed legend.

DDH-1 LOCATION

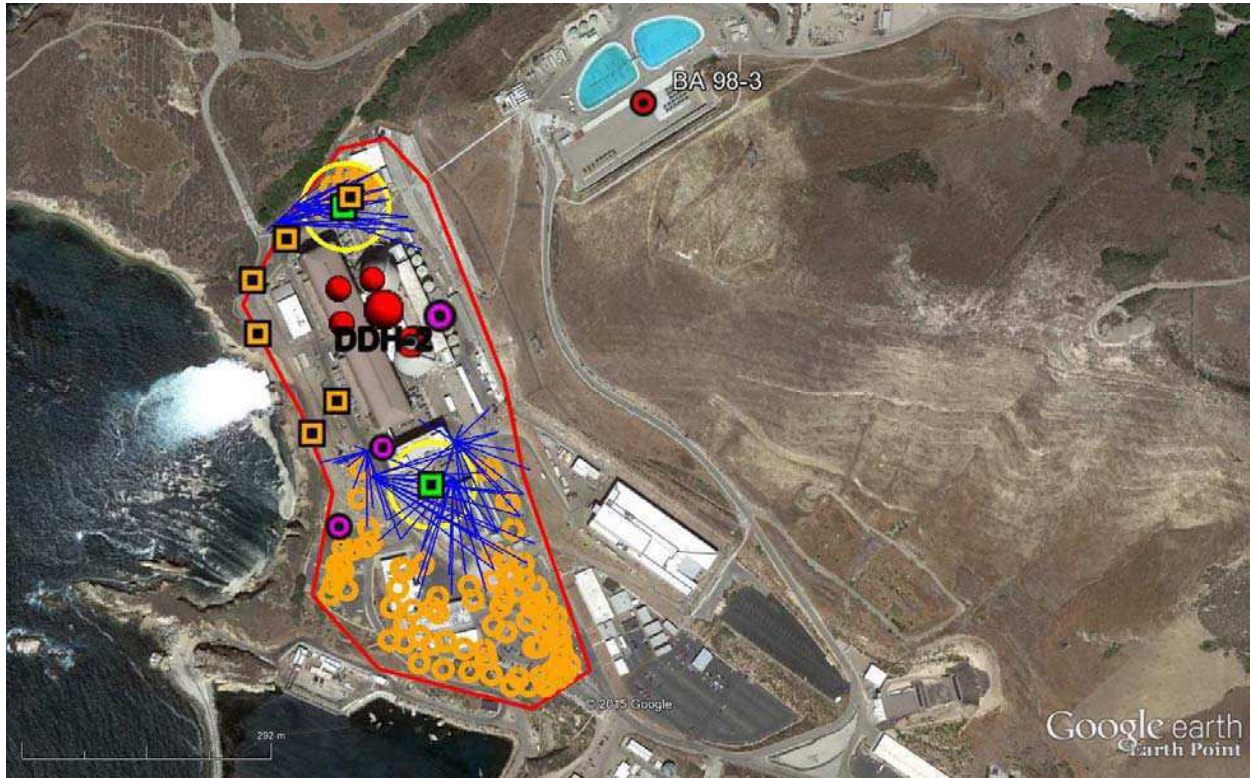
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California

FIGURE 2.2-2



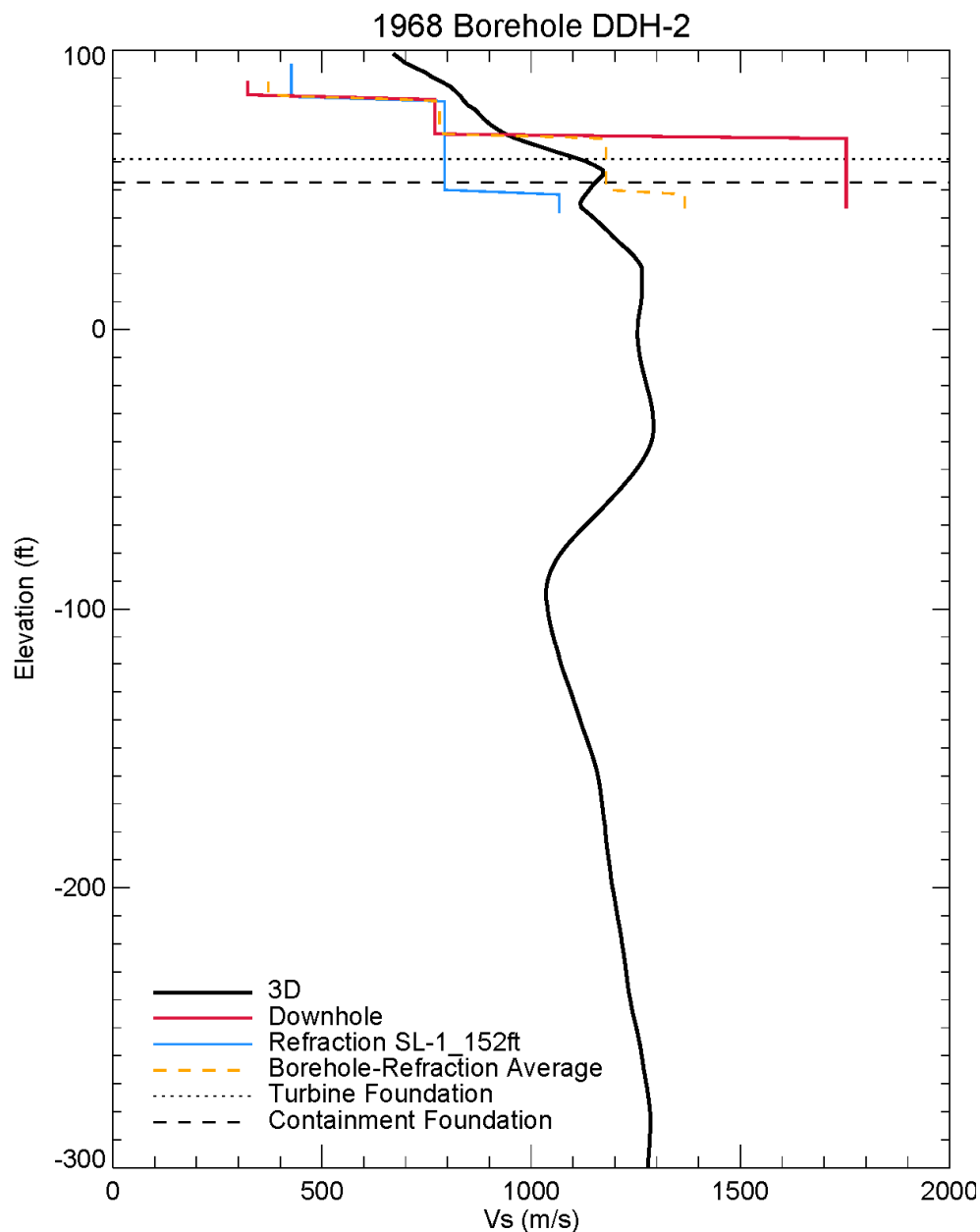
Comparison of 1968 downhole DDH-1 Vs-elevation estimate and 1968 Vs-refraction velocity profiles at the DDH-1 position with the Vs-elevation profile from the updated 3-D velocity model at the position of DDH-1. The black line is the Vs-elevation profile extracted below the site position.

COMPARISON OF VS AT DDH-1 LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



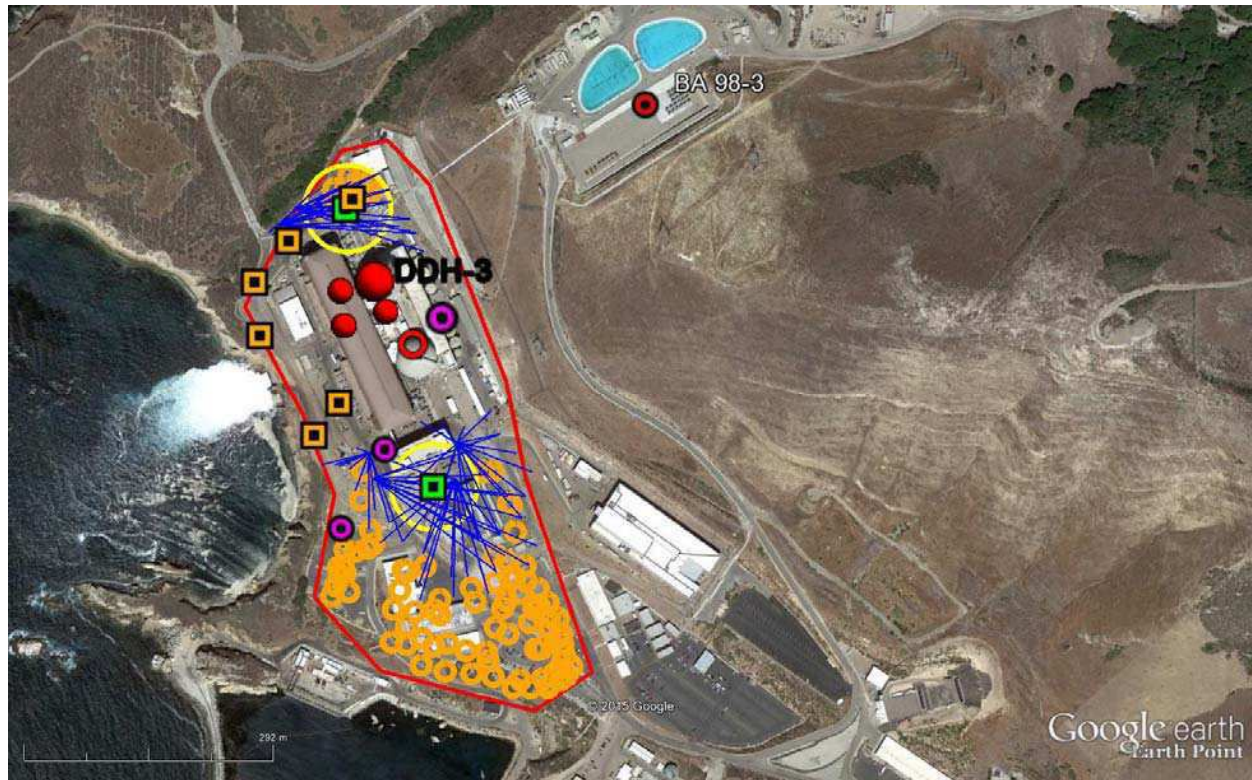
Borehole DDH-2 shown as the enlarged solid red circle. See Figure 2.0-1 for detailed legend.

DDH-2 LOCATION
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



Comparison of 1968 downhole DDH-2 Vs-elevation estimate and 1968 Vs-refraction velocity profiles at the DDH-2 position with the Vs-elevation profile from the updated 3-D velocity model at the position of DDH-2. The black line is the Vs-elevation profile extracted below the site position.

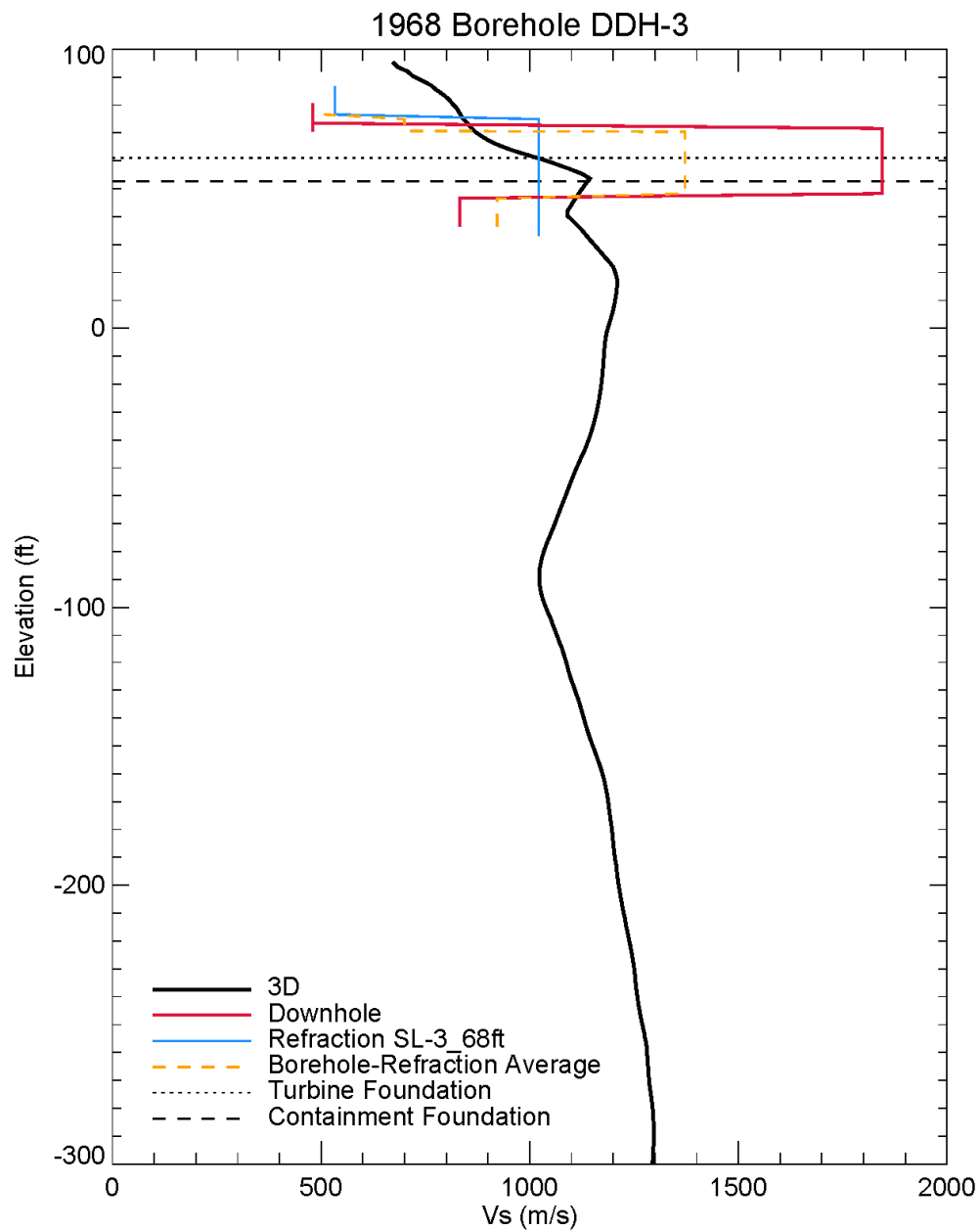
COMPARISON OF VS AT DDH-2 LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



Borehole DDH-3 shown as the enlarged solid red circle. See Figure 2.0-1 for detailed legend.

DDH-3 LOCATION

Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



Comparison of 1968 downhole DDH-3 Vs-elevation estimate and 1968 Vs-refraction velocity profiles at the DDH-3 position with the Vs-elevation profile from the updated 3-D velocity model at the position of DDH-3. The black line is the Vs-elevation profile extracted below the site position.

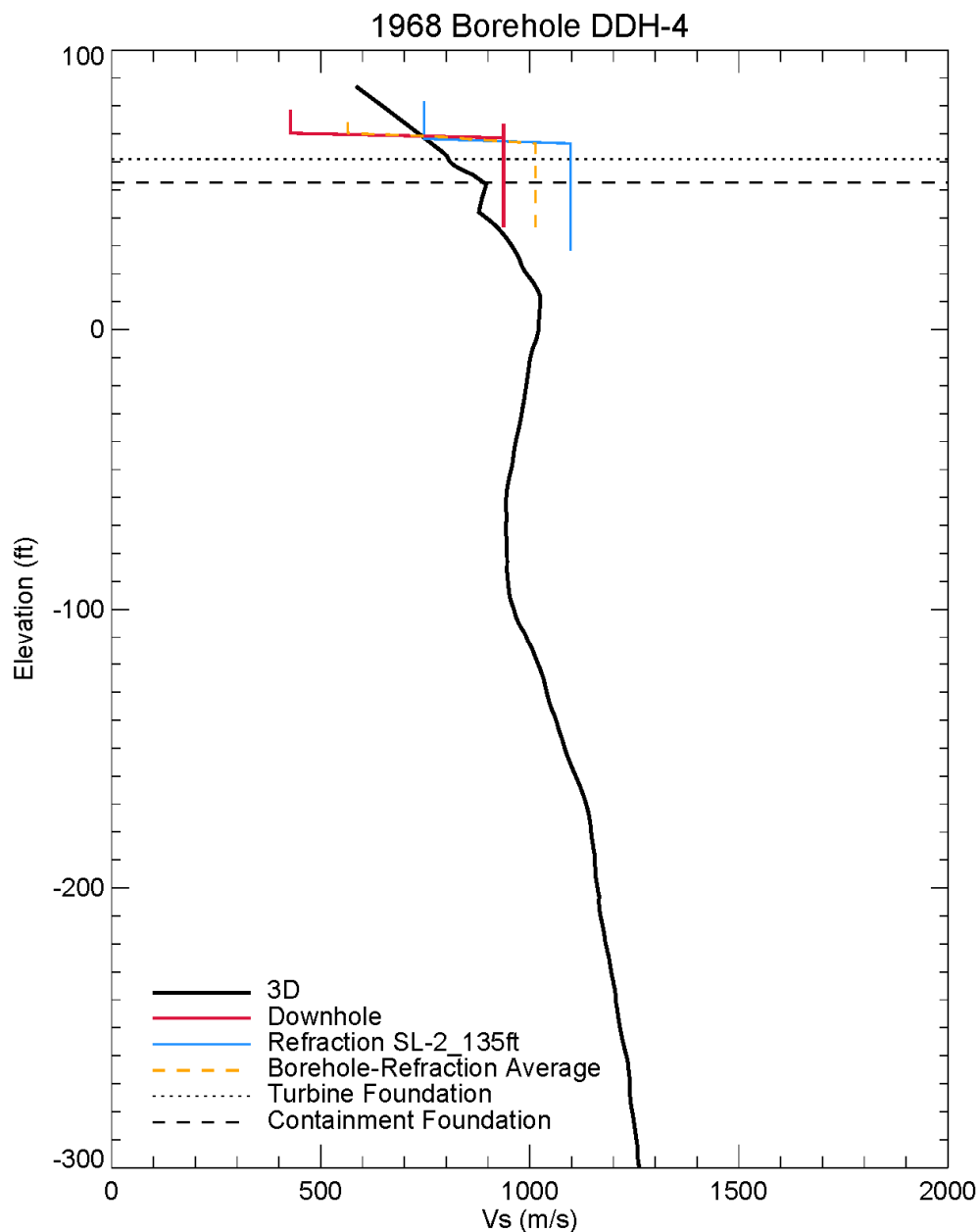
COMPARISON OF VS AT DDH-3 LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



Borehole DDH-4 shown as the enlarged solid red circle. See Figure 2.0-1 for detailed legend.

DDH-4 LOCATION

Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



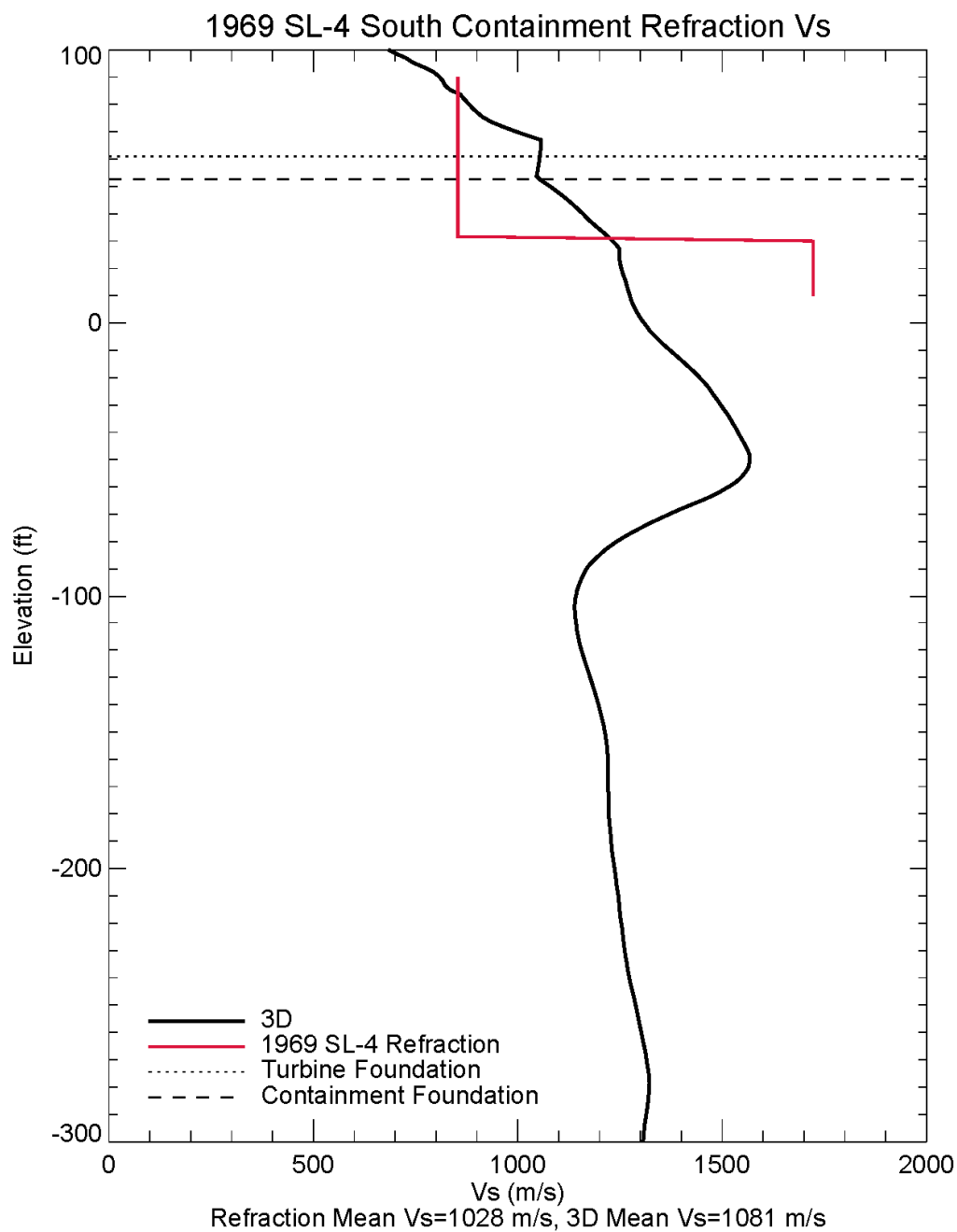
Comparison of 1968 downhole DDH-4 Vs-elevation estimate and 1968 Vs-refraction velocity profiles at the DDH-4 position with the Vs-elevation profile from the updated 3-D velocity model at the position of DDH-4. The black line is the Vs-elevation profile extracted below the site position.

COMPARISON OF VS AT DDH-4 LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



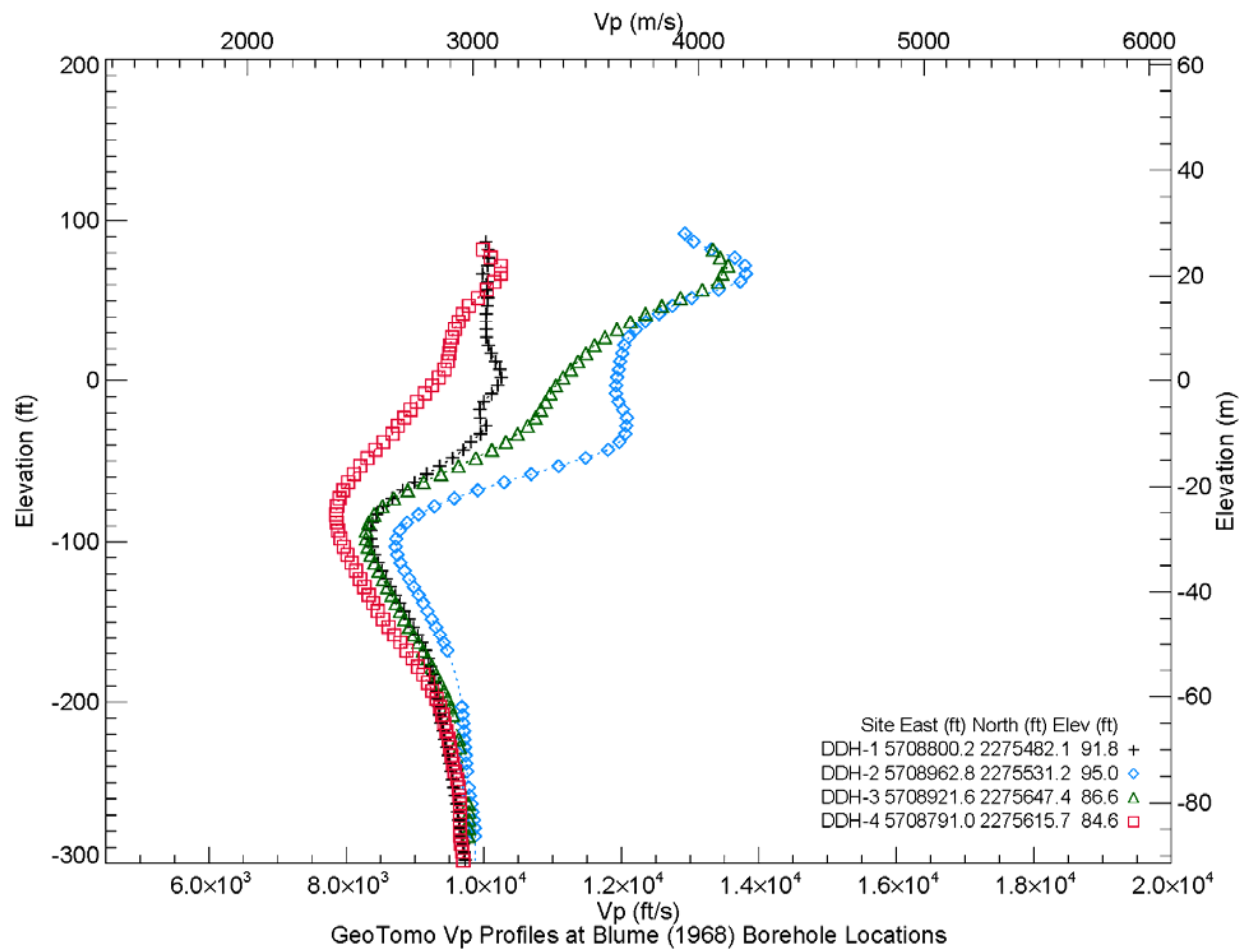
1969 Vs-refraction line SL-4 midpoint location emphasized with borehole DDH-4 shown as the enlarged open red circle. See Figure 2.0-1 for detailed legend.

1969 VS-REFRACTION LINE SL-4 MIDPOINT LOCATION
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



Comparison of 1969 Vs-refraction velocity profiles at the refraction line SL-4 midpoint position with the Vs-elevation profile from the updated 3-D velocity model at the same position.

COMPARISON OF VS AT REFRACTION LINE SL-4 MIDPOINT LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



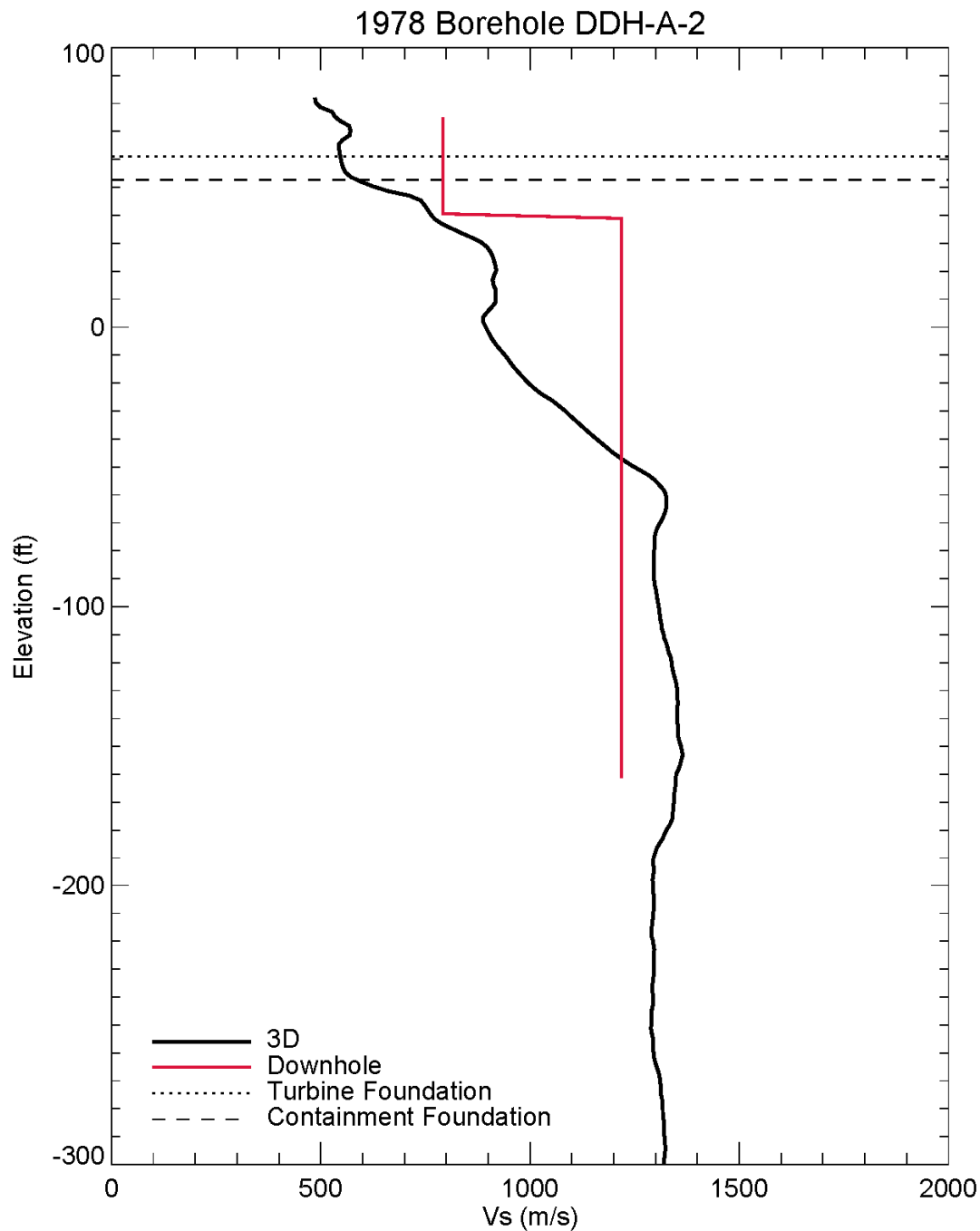
Missing diamonds along the blue profile for DDH-3 show a shadow zone where there is no 3-D ray coverage in the -175 ft to -205 ft elevation range.

**GEOTOMO 3-D VP TOMOGRAPHY VP-DEPTH PROFILES
AT BLUME (1968) BOREHOLE LOCATIONS**
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



Borehole DDH-A-2 location shown as the enlarged solid magenta circle. See Figure 2.0-1 for detailed legend.

DDH-A-2 LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



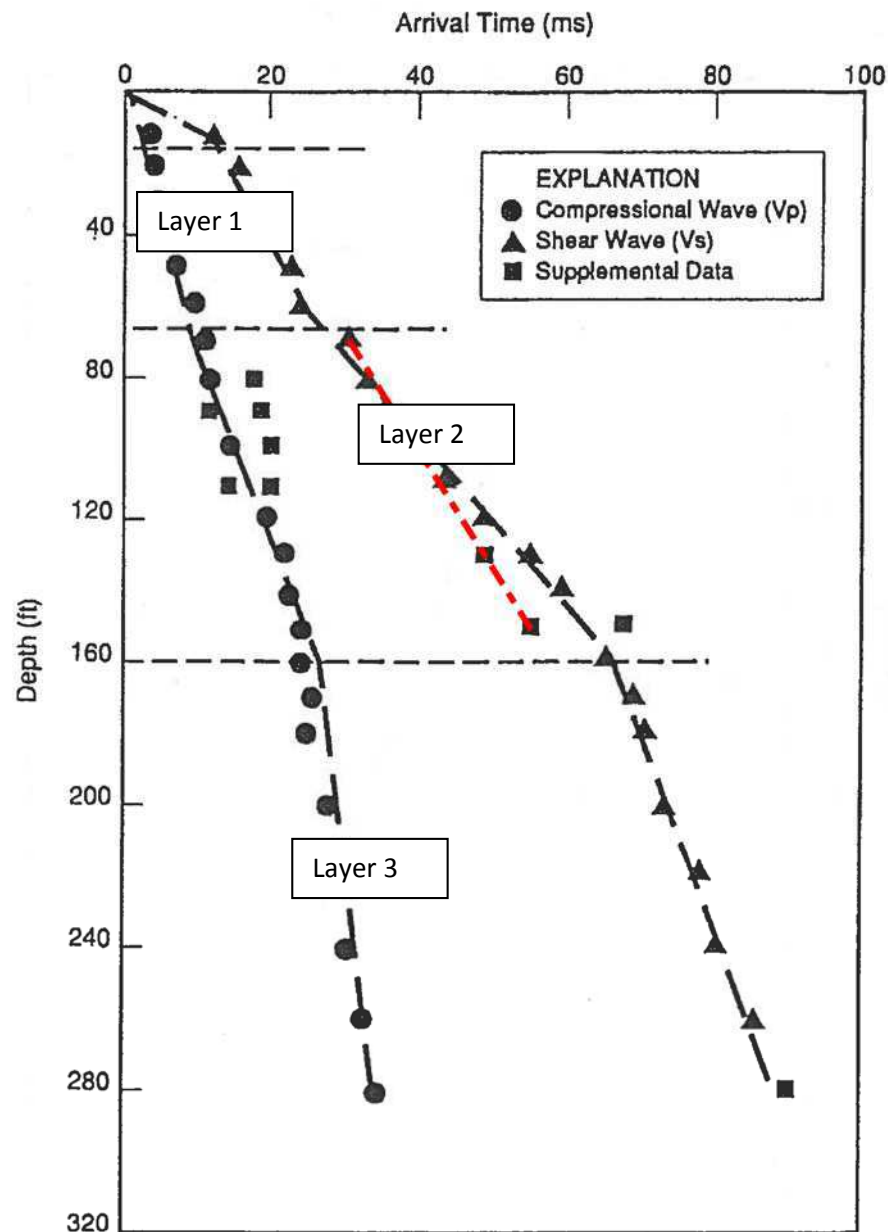
Comparison of 1978 DDH-A-2 downhole Vs profile with the Vs-elevation profile from the updated 3-D velocity model at the same position.

COMPARISON OF VS AT DDH-A-2 LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



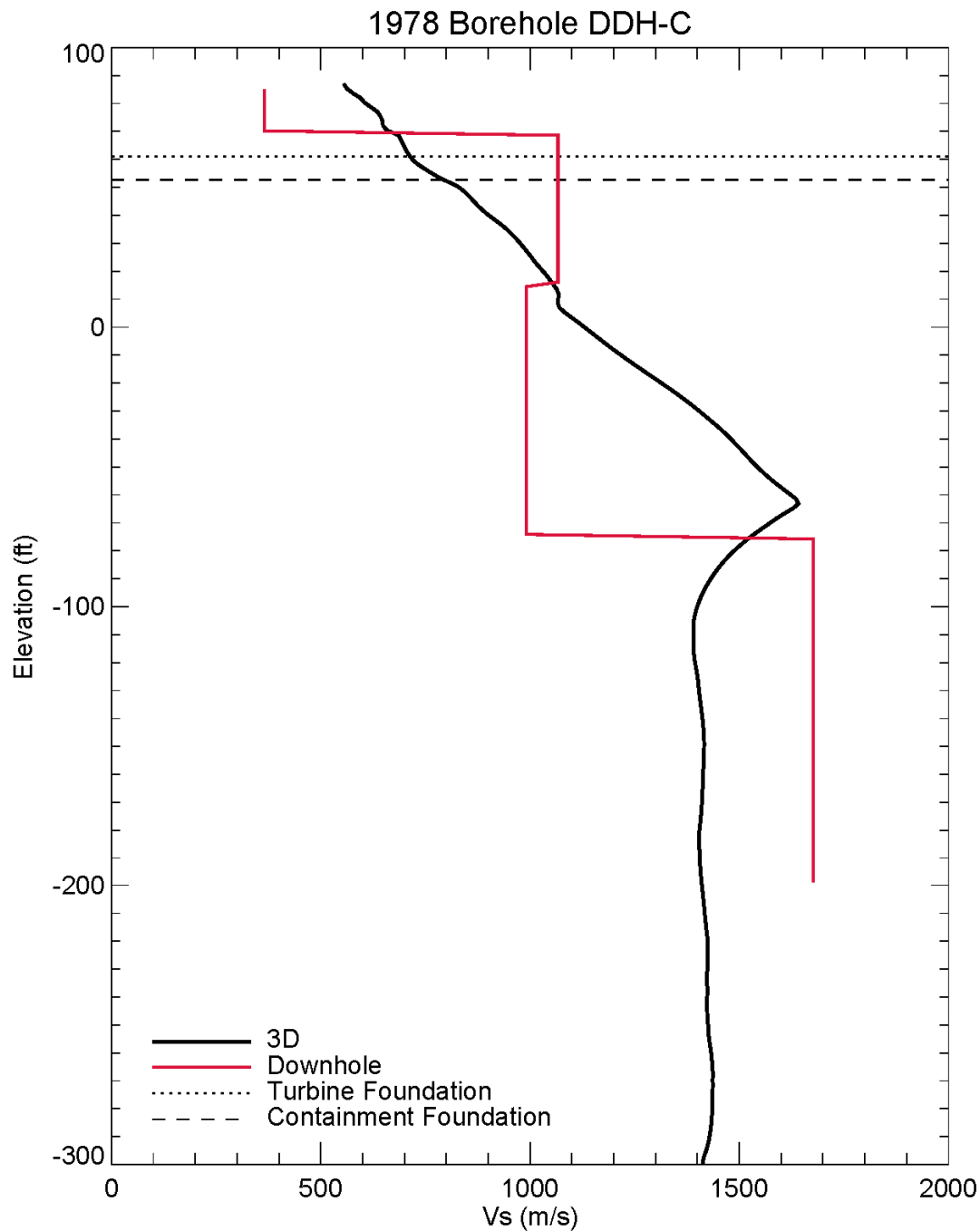
Borehole DDH-C location shown as the enlarged solid magenta circle. See Figure 2.0-1 for detailed legend.

DDH-C LOCATION
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



DDH-C travel time picks as black symbols and repicked V_s travel times in the second layer (red line) to conform to the shear-wave first-arrival picks across the entire layer. Second layer V_s in Figure 2.2-17 corresponds to the apparent velocity of the red dashed line.

DDH-C TRAVEL TIME PICKS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



Borehole Mean Vs=1194 m/s, 3D Mean Vs=1217 m/s

Comparison of 1978 DDH-C downhole Vs profile with the Vs-elevation profile from the updated 3-D velocity model at the same position.

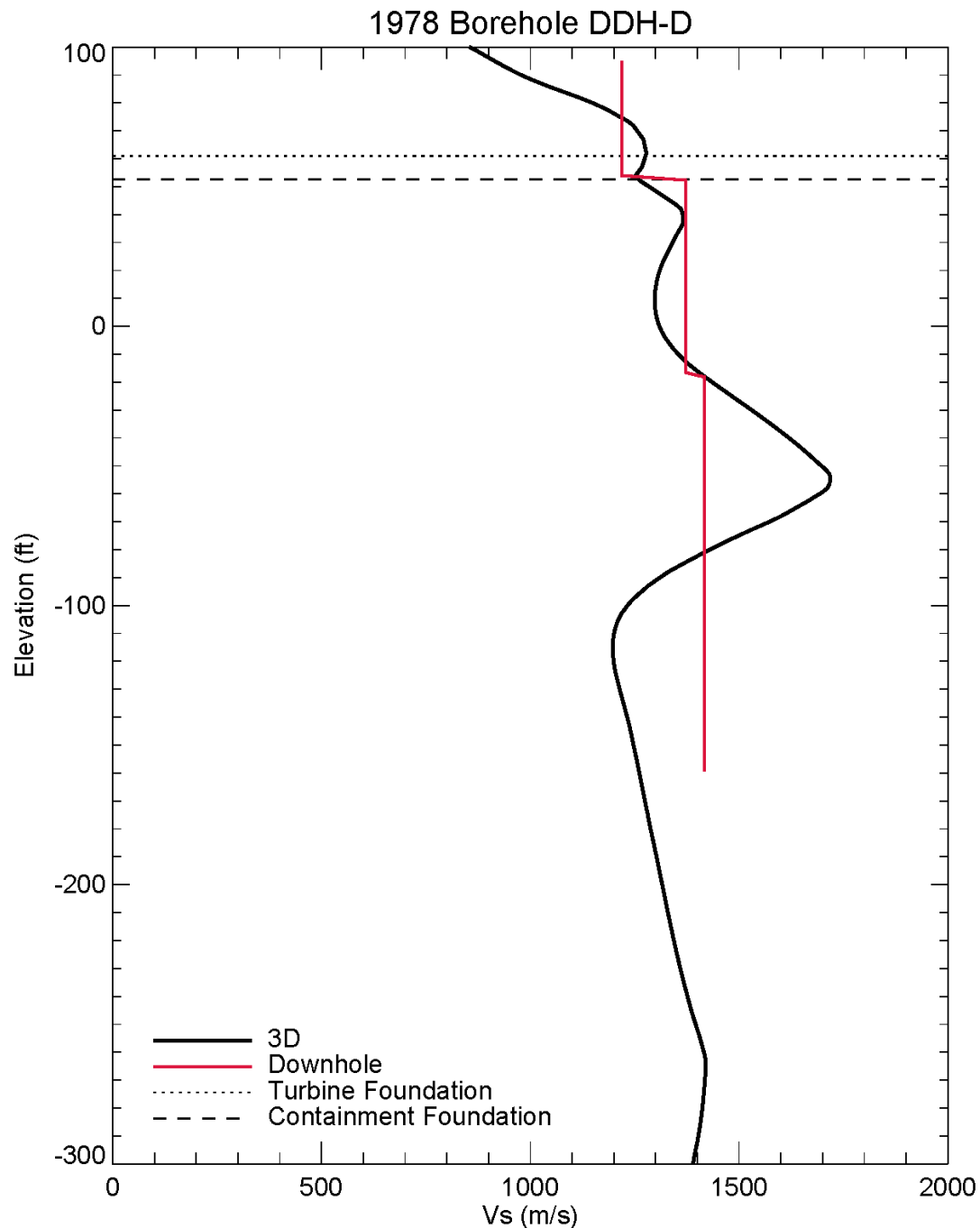
COMPARISON OF VS AT DDH-C LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



Borehole DDH-D shown as the enlarged solid magenta circle. See Figure 2.0-1 for detailed legend.

DDH-D LOCATION

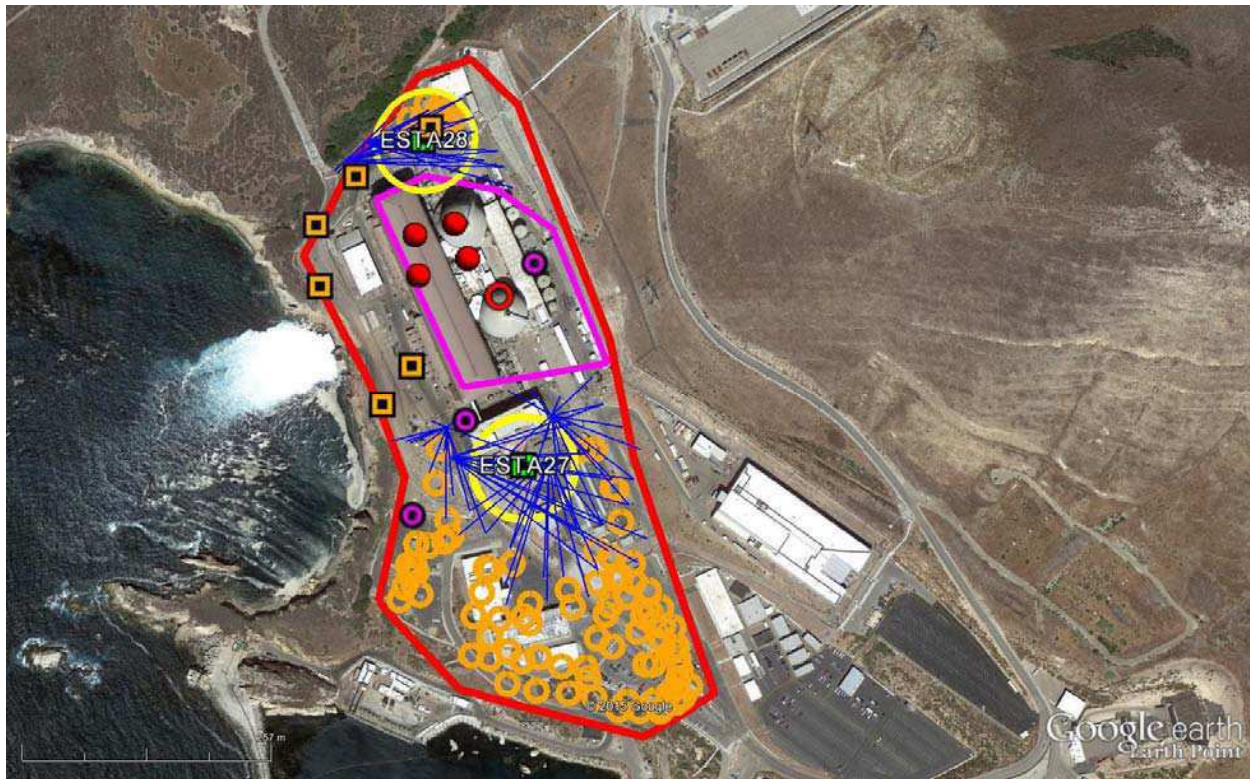
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



Borehole Mean Vs=1370 m/s, 3D Mean Vs=1330 m/s

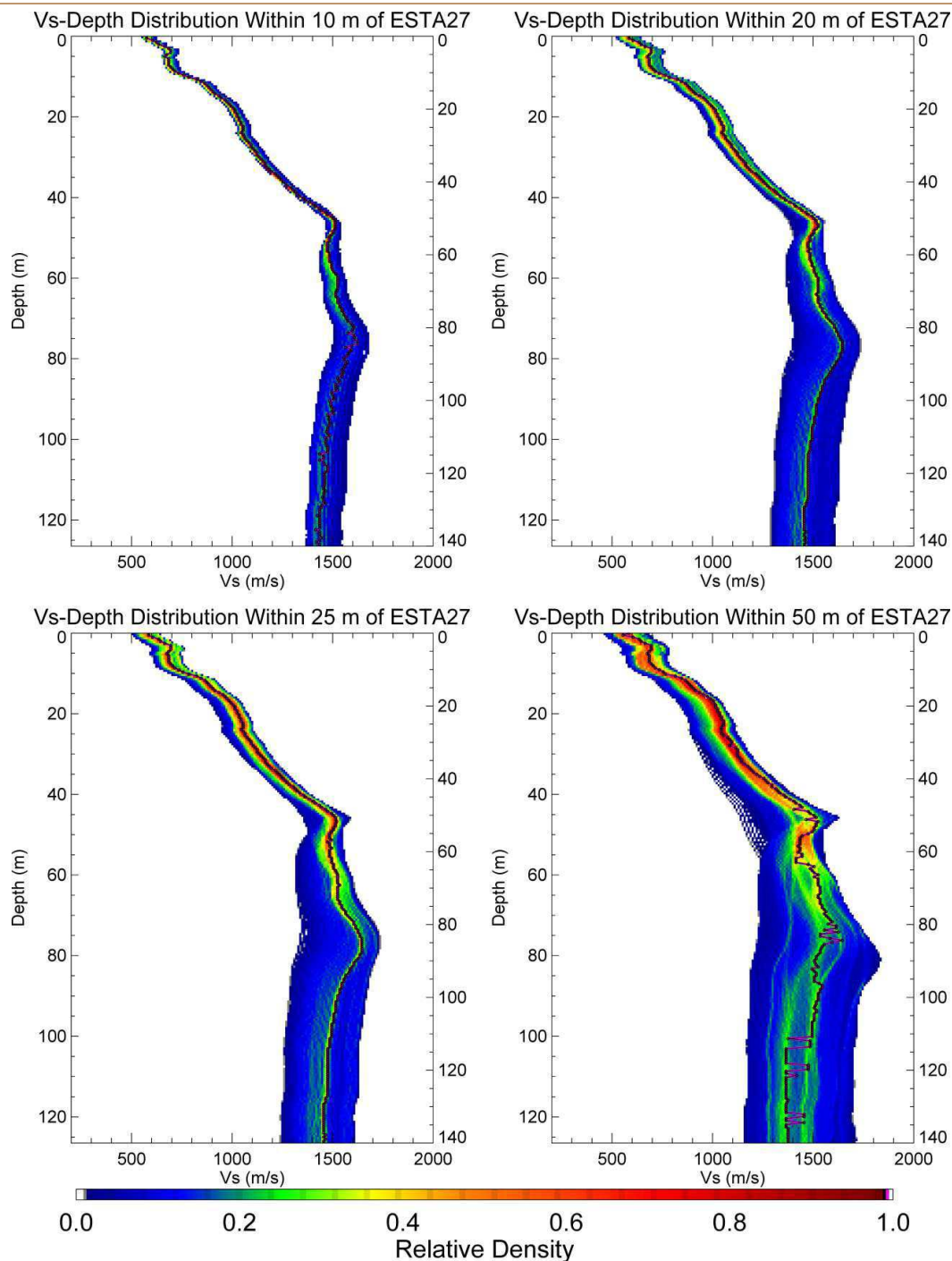
Comparison of 1978 DDH-D downhole Vs profile with the Vs-elevation profile from the updated 3-D velocity model at the same position.

COMPARISON OF VS AT DDH-D LOCATION
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



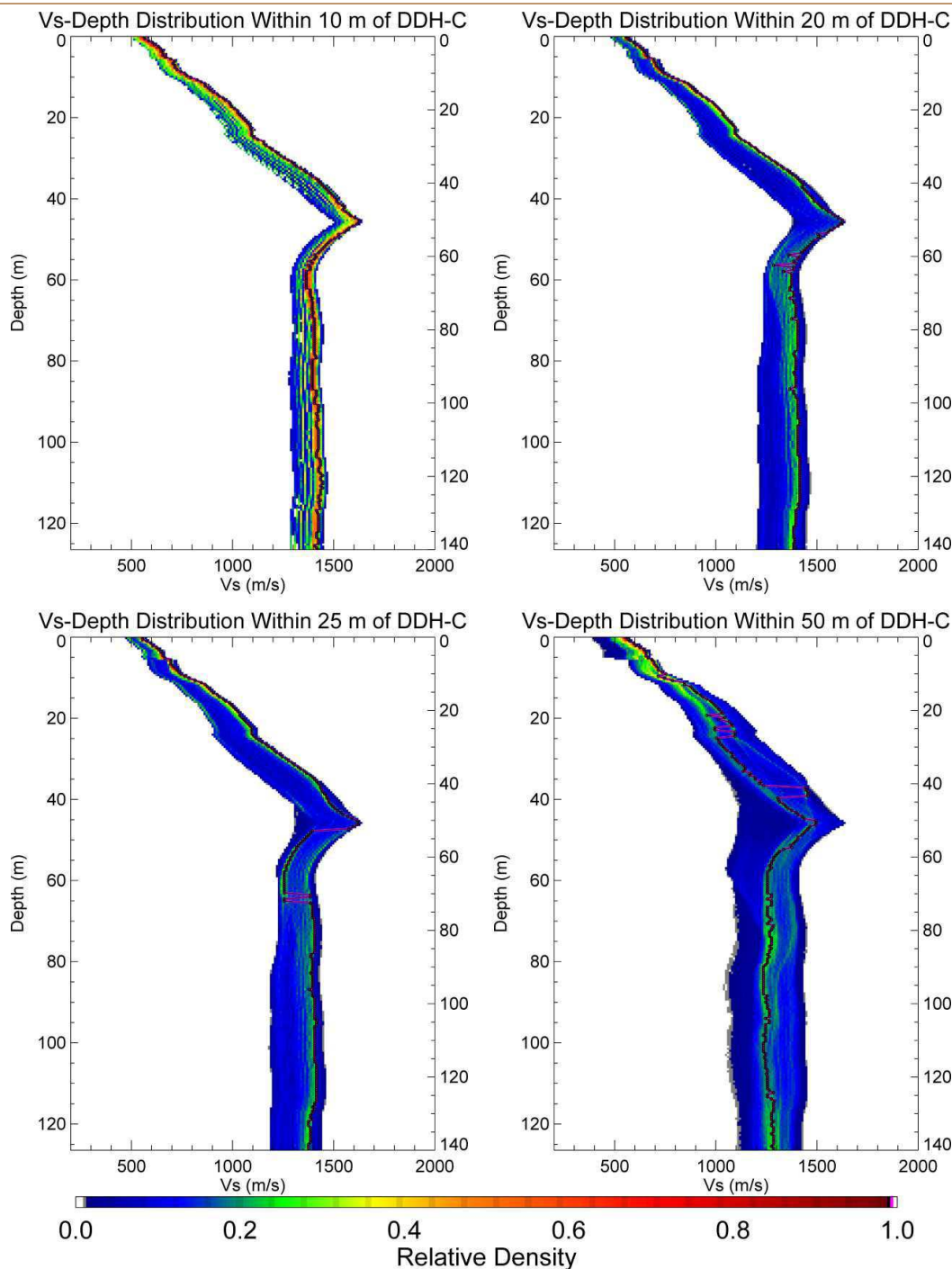
Seismographic stations ESTA27 and ESTA28 are shown as the green squares with a 50 m radius around each station as the yellow circles. See Figure 2.0-1 for detailed legend.

SEISMOGRAPHIC STATIONS ESTA27 AND ESTA28
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



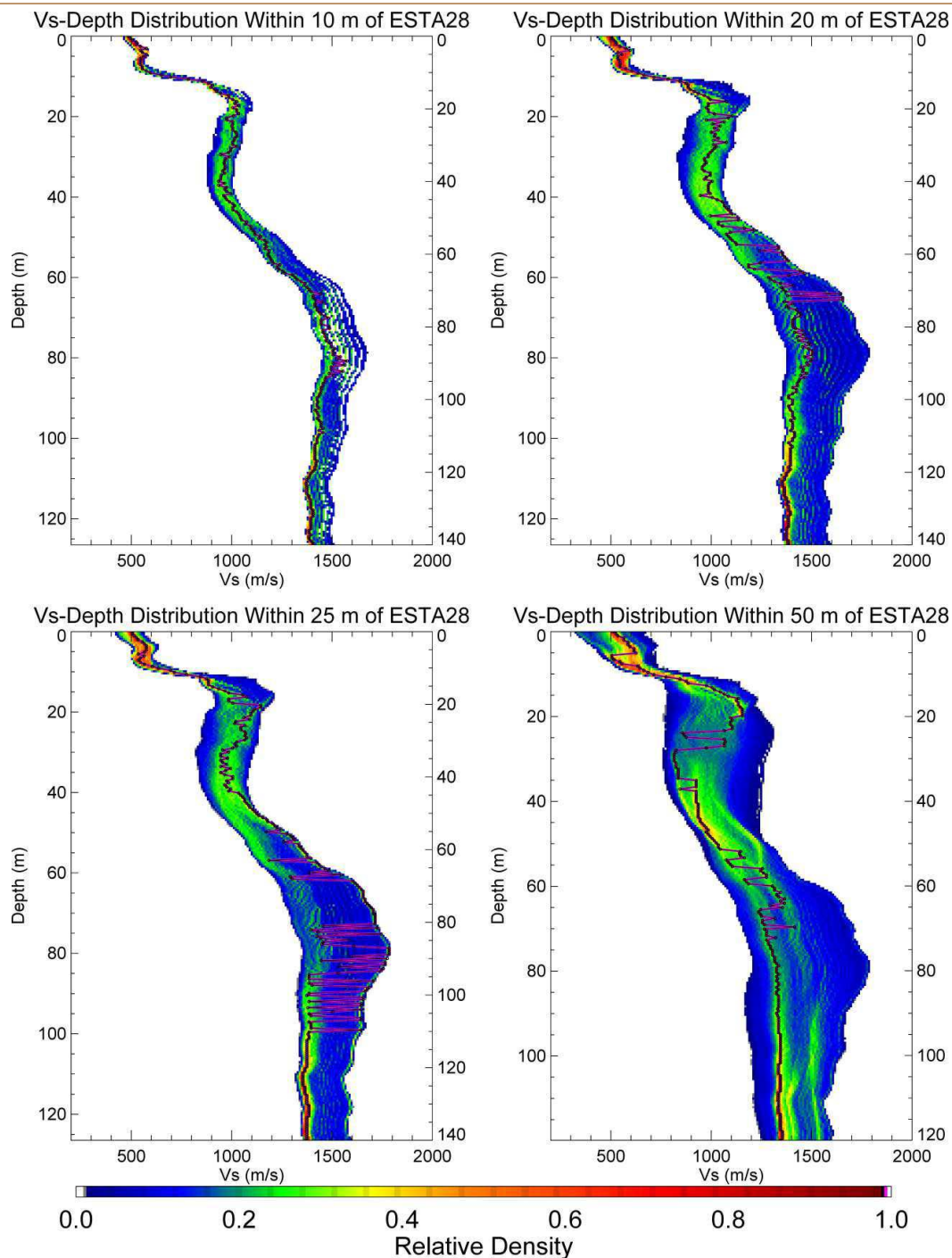
Vs-depth density distribution from the updated 3-D Vs-depth profiles within 10, 20, 25, and 50 m of seismographic station ESTA27 as labeled at the top of each plot. Magenta line overlaid with small black circles shows the modal (maximum density) curve.

**VS-DEPTH DENSITY DISTRIBUTION FROM
THE UPDATED 3-D VS-DEPTH PROFILES
WITHIN 10, 20, 25, AND 50 M OF SEISMOGRAPHIC STATION ESTA27**
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



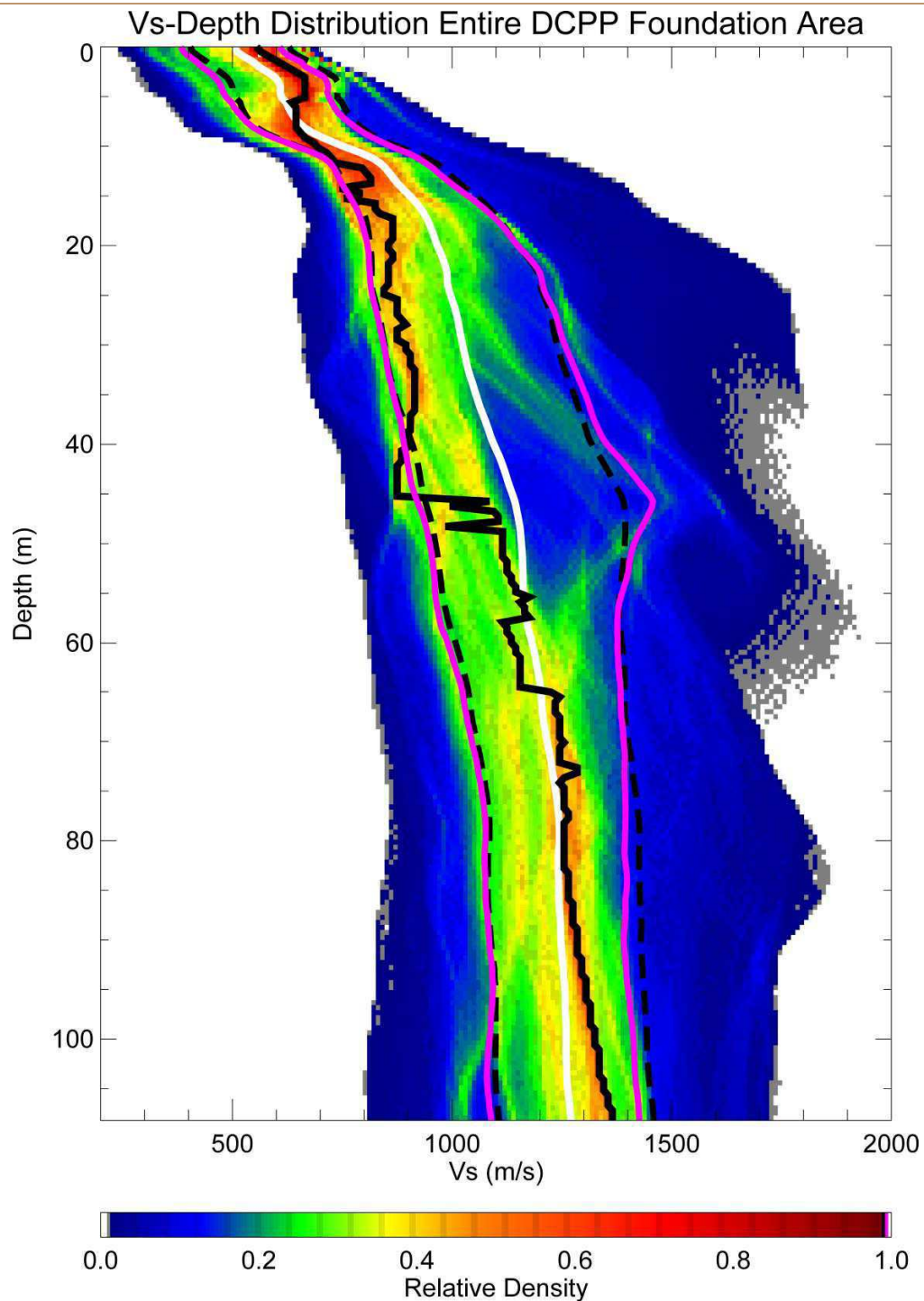
Vs-depth density distribution from the updated 3-D Vs-depth profiles within 10, 20, 25, and 50 m of borehole DDH-C as labeled at the top of each plot. Magenta line overlaid with small black circles shows the modal (maximum density) curve.

**VS-DEPTH DENSITY DISTRIBUTION FROM
THE UPDATED 3-D VS-DEPTH PROFILES
WITHIN 10, 20, 25, AND 50 M OF BOREHOLE DDH-C**
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



Vs-depth density distribution from the updated 3-D Vs-depth profiles within 10, 20, 25, and 50 m of seismographic station ESTA28 as labeled at the top of each plot. Magenta line overlaid with small black circles shows the modal (maximum density) curve.

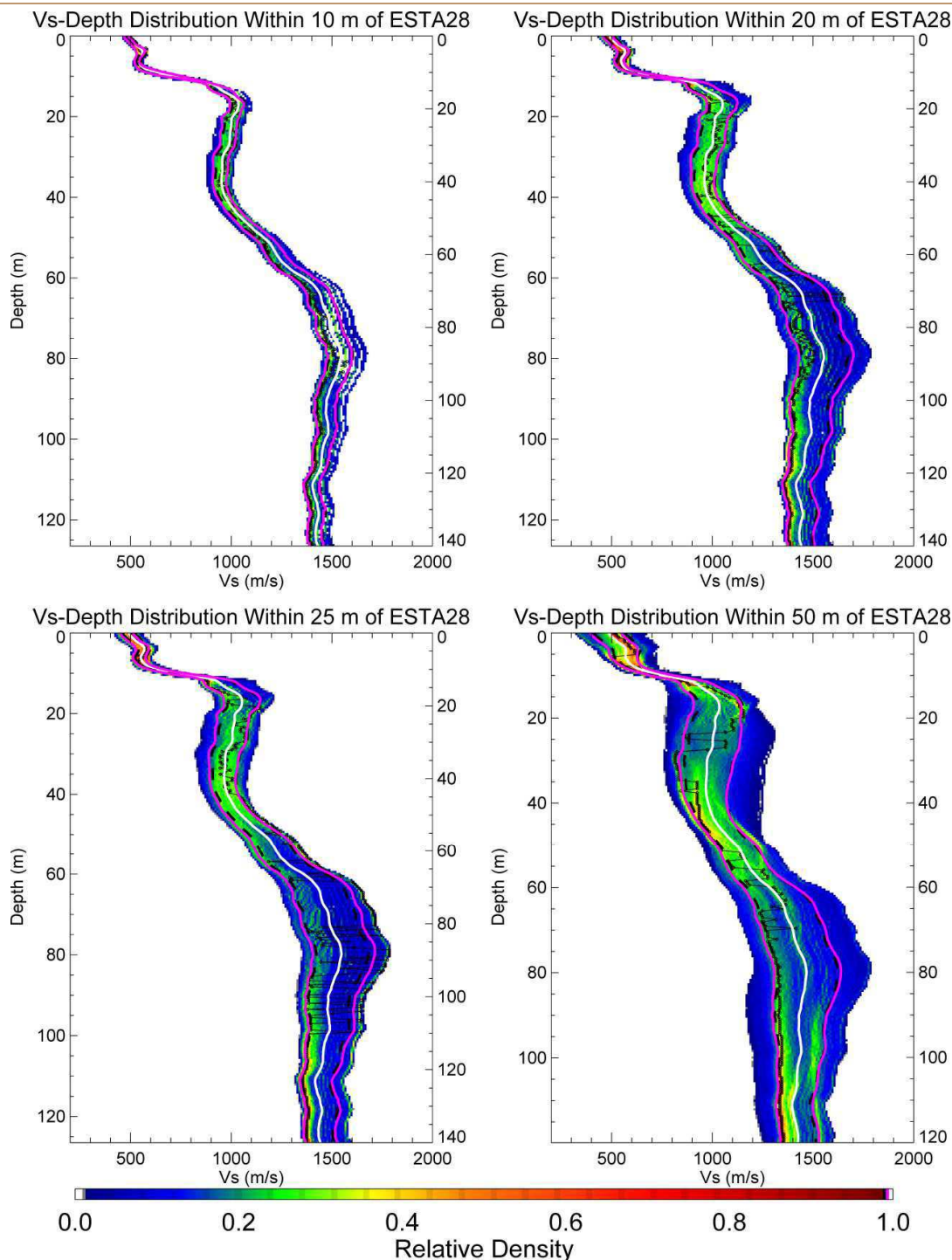
**VS-DEPTH DENSITY DISTRIBUTION FROM
THE UPDATED 3-D VS-DEPTH PROFILES
WITHIN 10, 20, 25, AND 50 M OF SEISMOGRAPHIC STATION ESTA28**
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



Solid black line shows the mode (maximum density), solid white curve is the $\ln$ -mean, magenta curves are 16th and 84th percentiles, and dashed black curves are one-sigma around the $\ln$ -mean (white) curve.

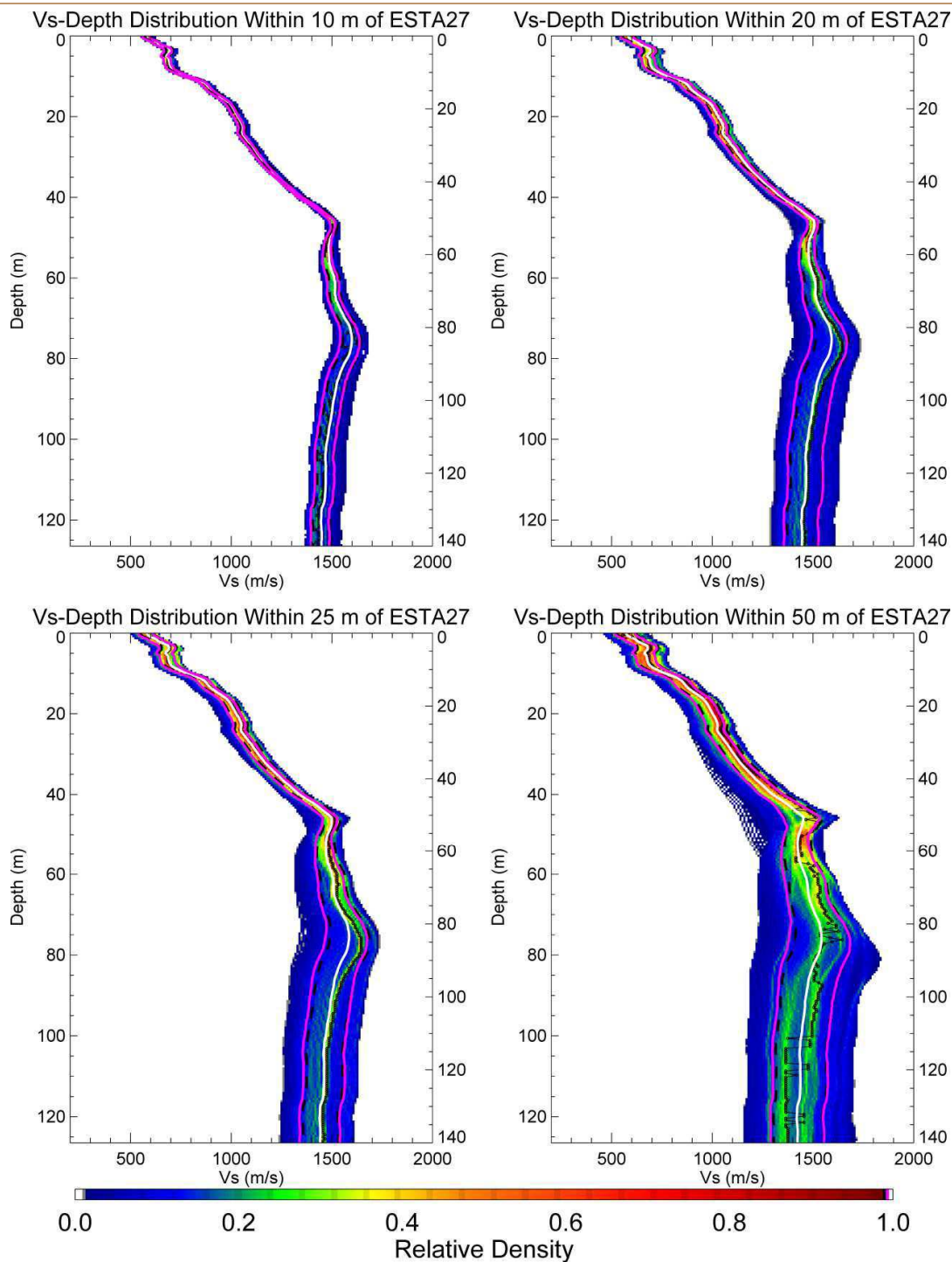
**VS-DEPTH DENSITY DISTRIBUTION FROM THE UPDATED 3-D VS-DEPTH PROFILES
FOR THE ENTIRE AREA OUTLINED BY THE RED POLYGON IN FIGURE 2.0-1**

Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



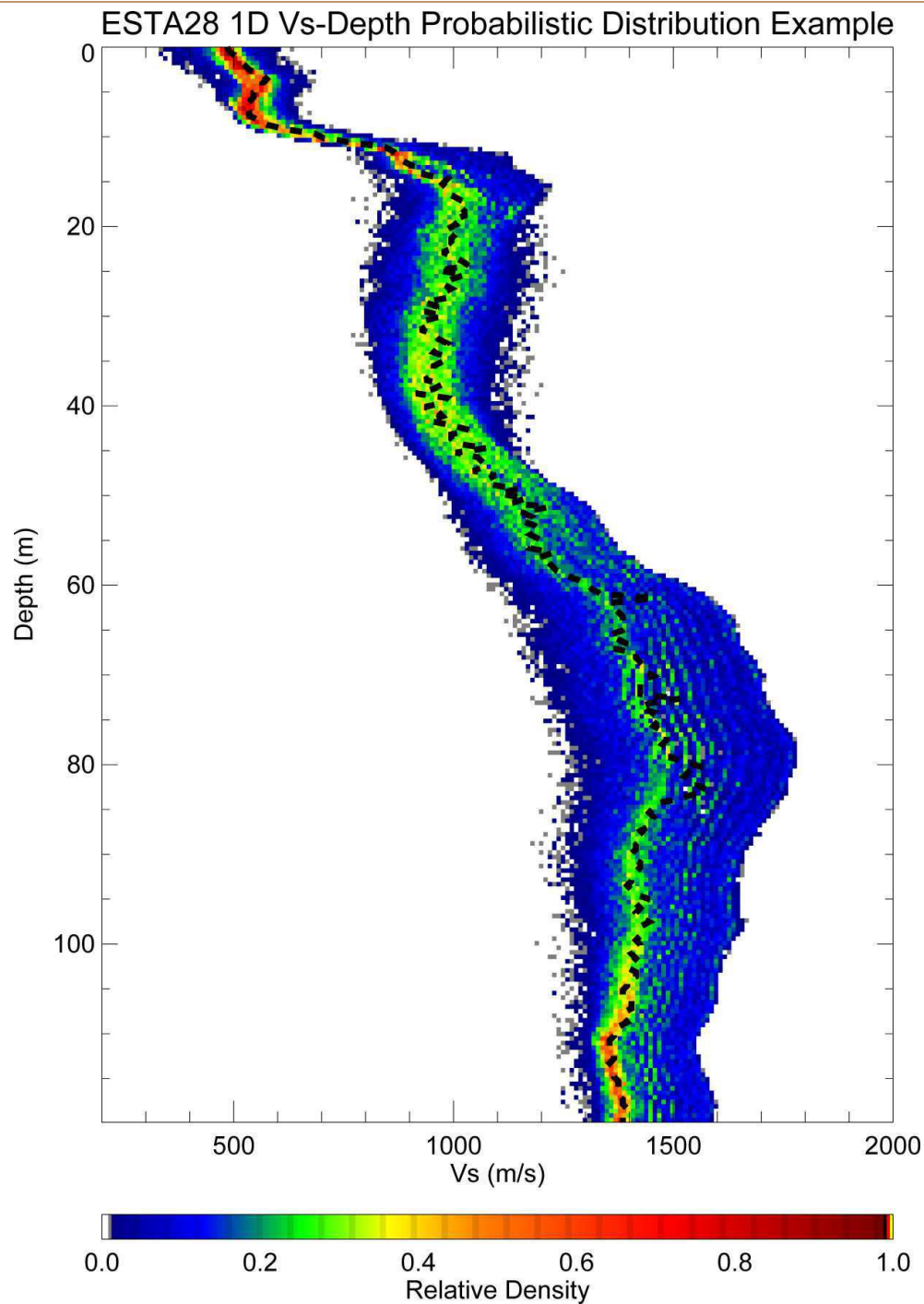
Solid black line shows the mode (maximum density), solid white curve is the *ln*-mean, magenta curves are 16th and 84th percentiles, and dashed black curves are one-sigma around the *ln*-mean (white) curve.

**VS-DEPTH DENSITY DISTRIBUTIONS FROM
THE UPDATED 3-D VS-DEPTH PROFILES
WITHIN 10, 20, 25, AND 50 M OF SEISMOGRAPHIC STATION ESTA28**
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



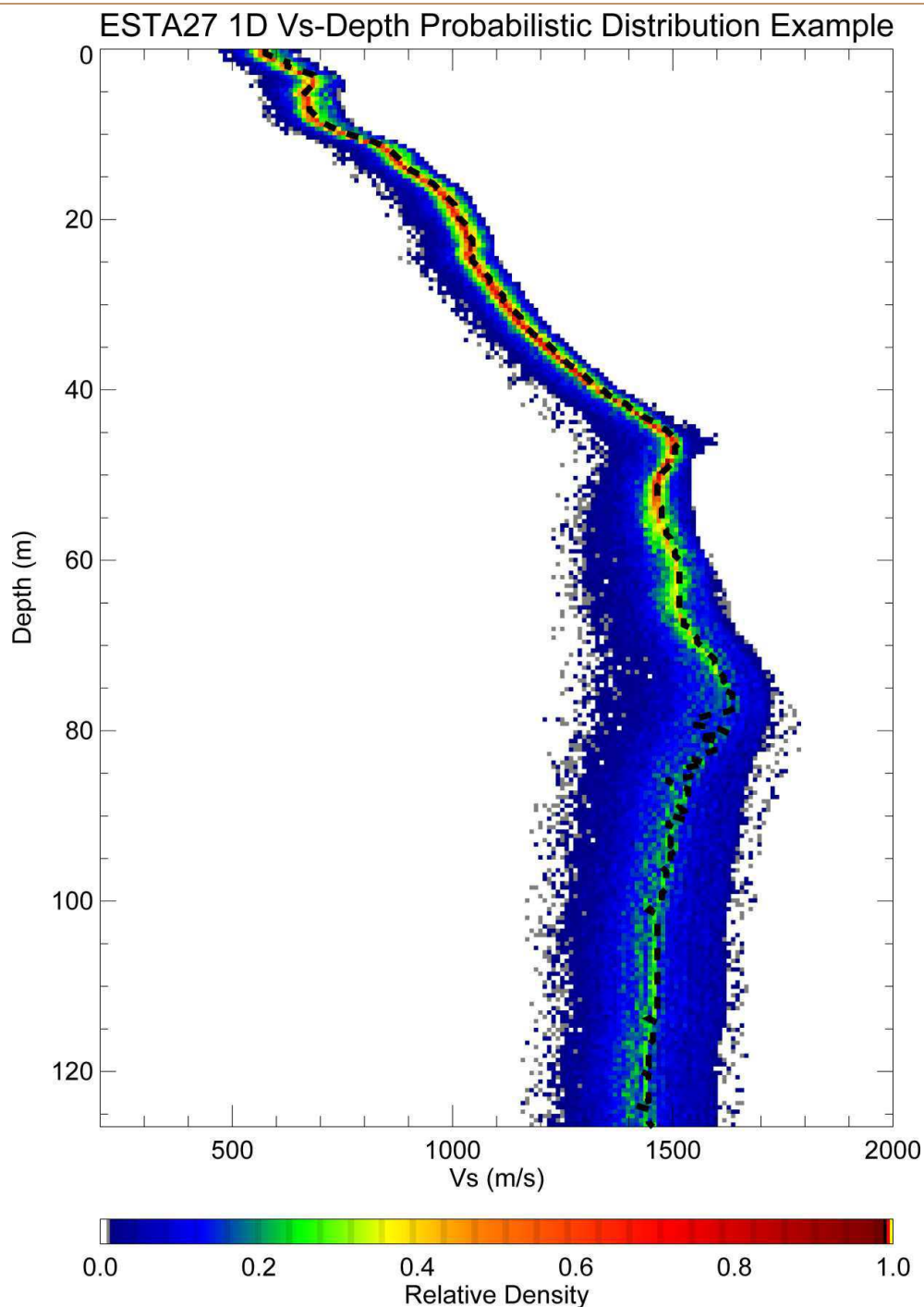
Solid black line shows the mode (maximum density), solid white curve is the $\ln$ -mean, magenta curves are 16th and 84th percentiles, and dashed black curves are one-sigma around the $\ln$ -mean (white) curve.

**VS-DEPTH DENSITY DISTRIBUTIONS FROM
THE UPDATED 3-D VS-DEPTH PROFILES
WITHIN 10, 20, 25, AND 50 M OF SEISMOGRAPHIC STATION ESTA27**
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



Example probabilistic Vs-depth density distribution for the ESTA28 calculated using a Gaussian lateral weighting of probabilistic sampling Vs cumulative functions from radii averages from 10 m to 50 m with a 5-meter spacing. A Gaussian standard deviation width of 30 m was used.

EXAMPLE PROBABILISTIC VS-DEPTH DENSITY DISTRIBUTION FOR ESTA28
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



Example probabilistic Vs-depth density distribution for the ESTA27 calculated using a Gaussian lateral weighting of probabilistic sampling Vs cumulative functions from radii averages from 10 m to 50 m with a 5-meter spacing. A Gaussian standard deviation width of 30 m was used.

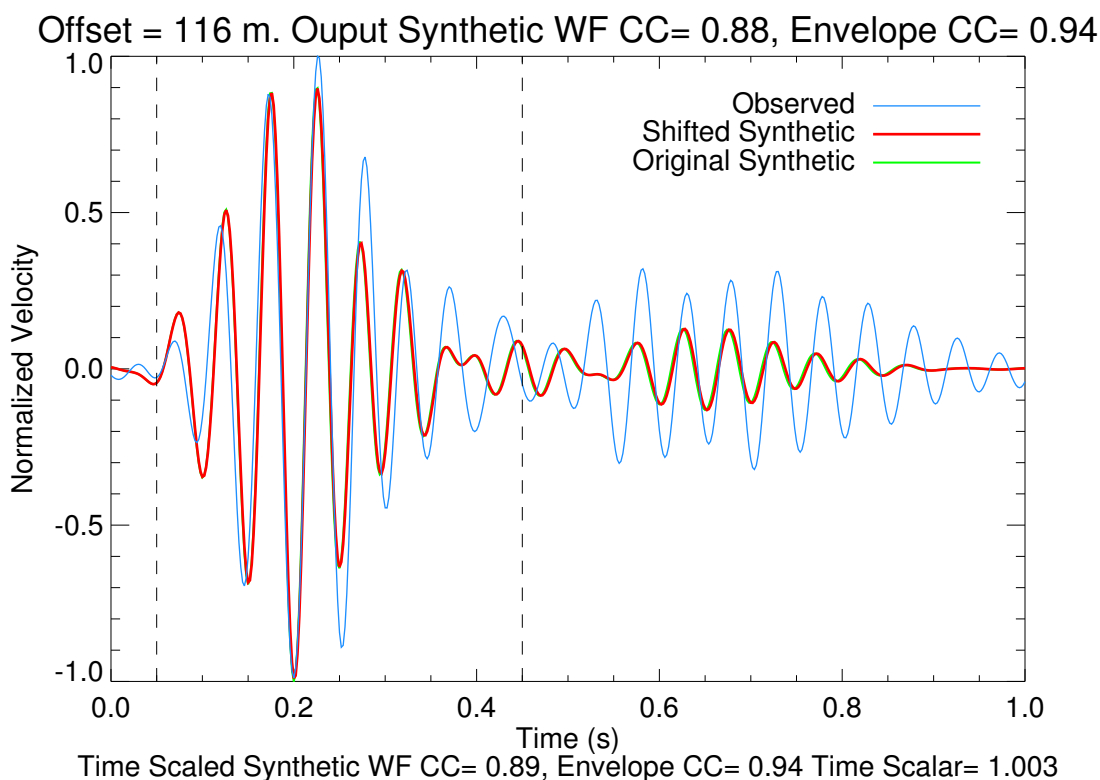
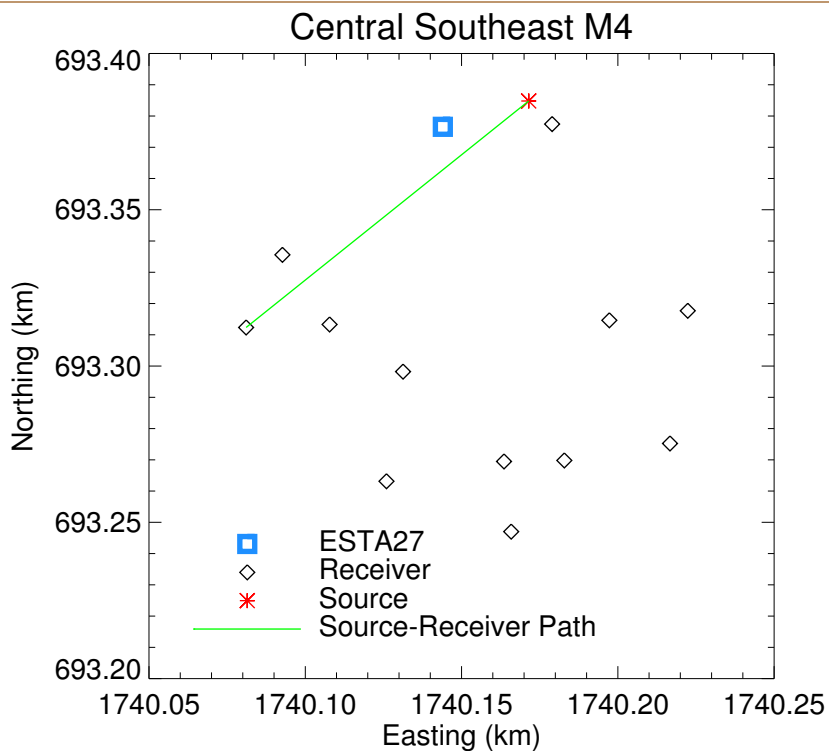
EXAMPLE PROBABILISTIC VS-DEPTH DENSITY DISTRIBUTION FOR ESTA27
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California

3.0 REFERENCES

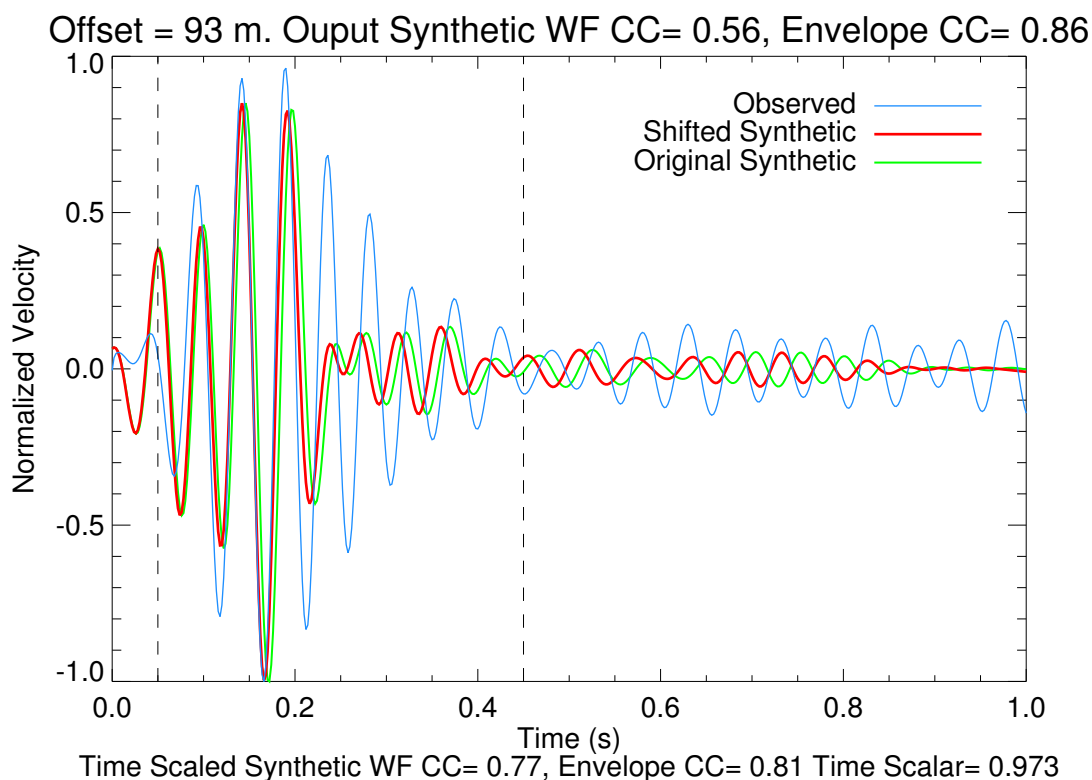
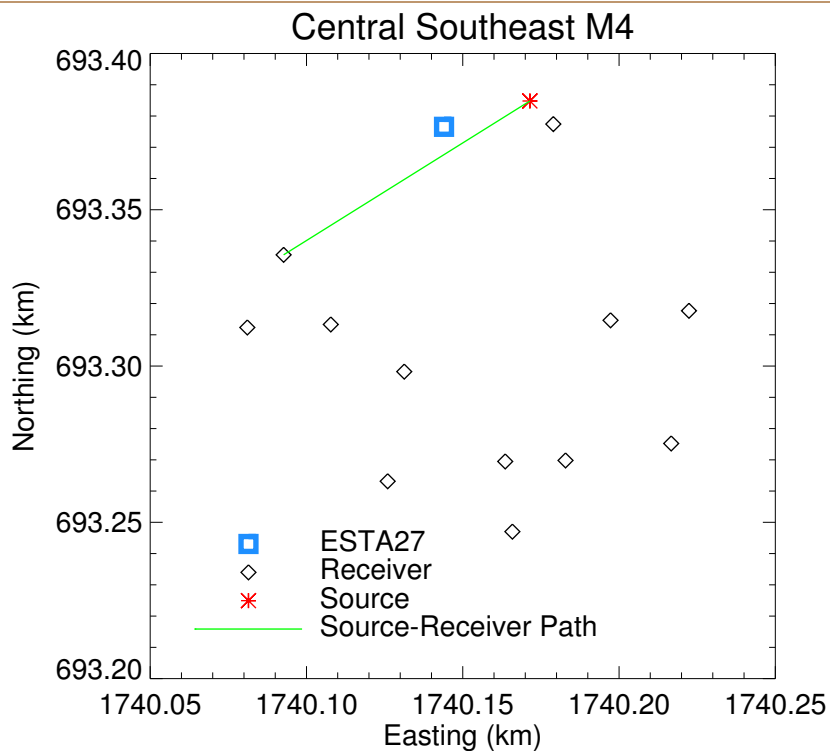
- Blume, John A. & Associates, Engineers, (1968), "Recommended Earthquake Design Criteria for the Nuclear Power Plant - Unit No. 2, Diablo Canyon Site," Diablo Canyon Unit 2 PSAR, Docket No. 50-323, June 24, 1968, Appendix C.
- Blume, John A. and Associates, (1969), "Results of Preliminary Geophysical Investigations of Area South of Unit 2, Diablo Canyon Reactor Site," unpublished consultant's report, March.
- Blume, John A. and Associates/URS, (1978), "Summary of Geophysical Measurements," unpublished consultant's report.
- Bessonova, E. N., V. M. Fishman, V. Z. Ryaboyi, and G. A. Sitnikova, (1974), "The tau method for inversion of travel times. I. Deep seismic sounding data," *Geophys. J. R. Astr. Soc.* 36, 377-398.
- Boore, D. M. and M. W. Asten, (2008), "Comparisons of shear-wave slowness in the Santa Clara Valley, California, using blind interpretations of data from invasive and non-invasive methods," *Bull. Seism. Soc. Am.* 98, 1983-2003
- Fugro (2014a), CCCSIP DCPD P- and S-Wave Foundation Velocity Report, Project Report PGEQ-PR-16, PG&E CCCSIP project, 52 pp, two appendices Consultant Report to PG&E
- Fugro (2014b), 2011-2012 Onshore 2D-3D Data Processing Report, Project Report PGEQ-PR-08, PG&E CCCSIP project, 62 pp, four appendices Consultant Report to PG&E
- Fugro (2014c), 2012 3D Onshore Seismic Survey Report, Project Report PGEQ-PR-21, PG&E CCCSIP project, 185 pp, Consultant Report to PG&E
- Fugro (2015), "Update of the Three-Dimensional Velocity Model for the Diablo Canyon Power Plant (DCPD) Foundation Area," Report prepared for Pacific Gas and Electric, Fugro Job No. 04.76140022, November.
- Garofalo, F., Foti, S., Hollender, F., Cornou, C., Bard, P.Y., Cox, B.R., Dechamp, A., Ohrnberger, M., Sicilia, D., Vergniault, C., (2015), "The Interpacific Project: an International Cooperative Benchmark for Assessing Reliability and Accuracy of Invasive and Non-invasive Seismic Methods for Site Characterization," *Seis. Res. Lett.*, v. 86, p. 76.
- Griffiths, S.C, (2015), "Issues related to site property variability and shear strength in site response analysis," Ph.D. Dissertation, The University of Texas at Austin, 115 pp. <https://repositories.lib.utexas.edu/handle/2152/31370>.
- Hollender F., Bard P.Y., Cornou C., Cox B.R., Foti S., Garofalo F., Ohrnberger M., Sicilia D., (2014), "The INTERPACIFIC project: a cooperative exercise for assessing reliability and accuracy of seismic methods, In: Experience the Energy EAGE - European Association of Geoscientists and Engineers (NLD)," 76th EAGE Conference & Exhibition 2014 (Amsterdam) 16 - 19 June 2014, Vol.WS6-C03 pp.2 (pp.1-2).
- MacKay, D. J. C. (2003). *Information Theory, Inference, and Learning Algorithms*, Cambridge University Press, London, United Kingdom, 640 pp.

- O'Connell, D.R.H., and Turner, J.P., (2011), Interferometric multichannel analysis of surface waves (IMASW), Bulletin Seismological Society of America, Vol. 101, No. 5, pp. 2122-2141
- Romero, S., and G. J. Rix, (2001), "Regional variations in near-surface shear wave velocity in the greater Memphis Area," Engineering Geology, 62, 137-158.
- Stephenson, W. J., J. N. Louie, S. Pullammanappallil, R. A. Williams, and J. K. Odum (2005), "Blind shear-wave velocity comparison of ReMi and MASW results with boreholes to 200 m in Santa Clara Valley: Implications for earthquake ground-motion assessment," Bull. Seism. Soc. Am. 95, 2506 – 2516.
- Toro, G., (1993), "Probabilistic model of soil-profile variability, in Guidelines for Determining Design Basis Ground Motions," Schneider, J. F. (Editor), Electric Power Research Institute, EPRI TR-102293, Vol. 2, Appendix 6A.
- Toro, G. R., and Silva, W. J., (2001), "Scenario earthquakes for Saint Louis, MO, and Memphis, TN, and seismic hazard maps for the central United States region including the effect of site conditions," Final technical report to the USGS, 10 January 2001, Risk Engineering, Inc., Boulder, Colorado.

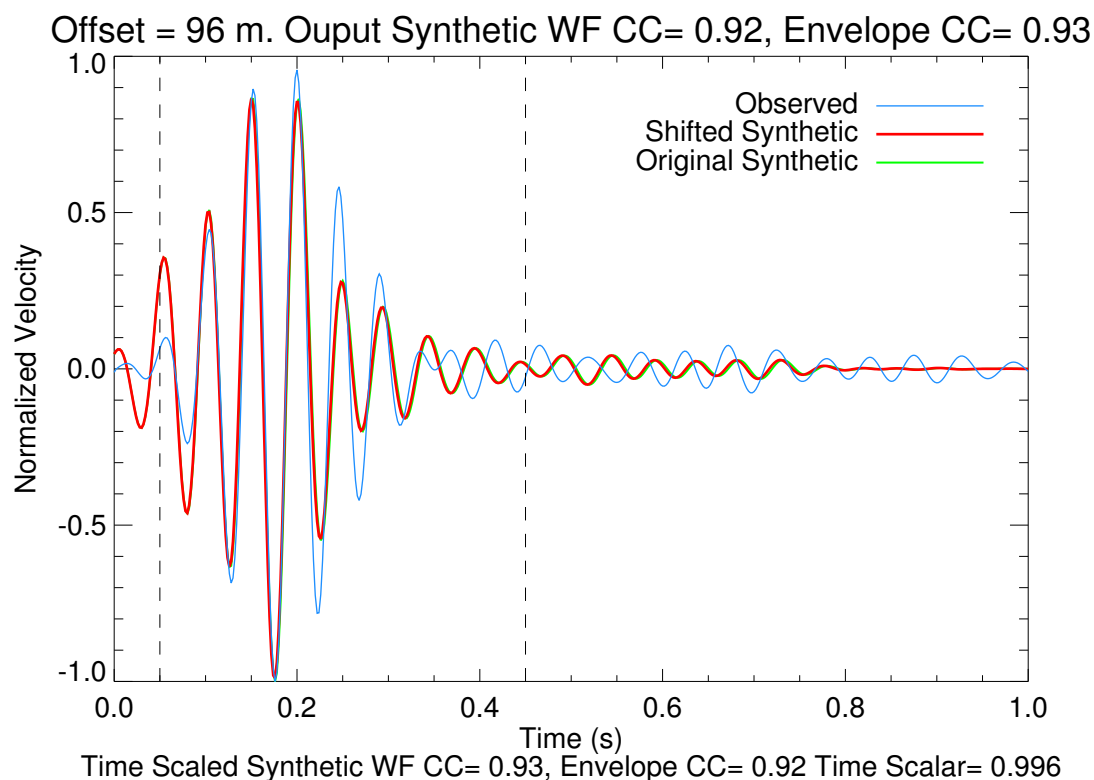
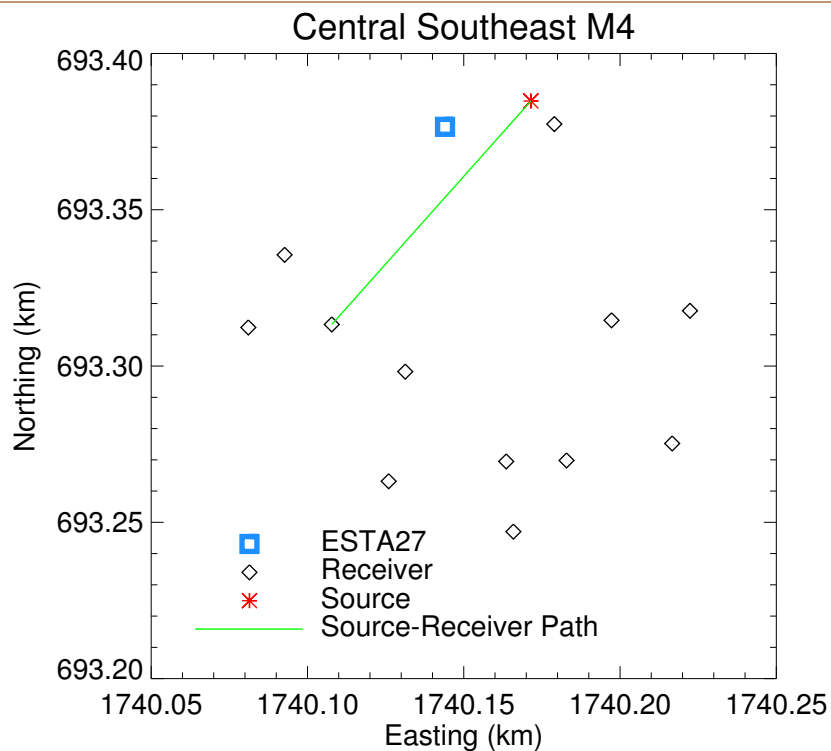
APPENDIX A



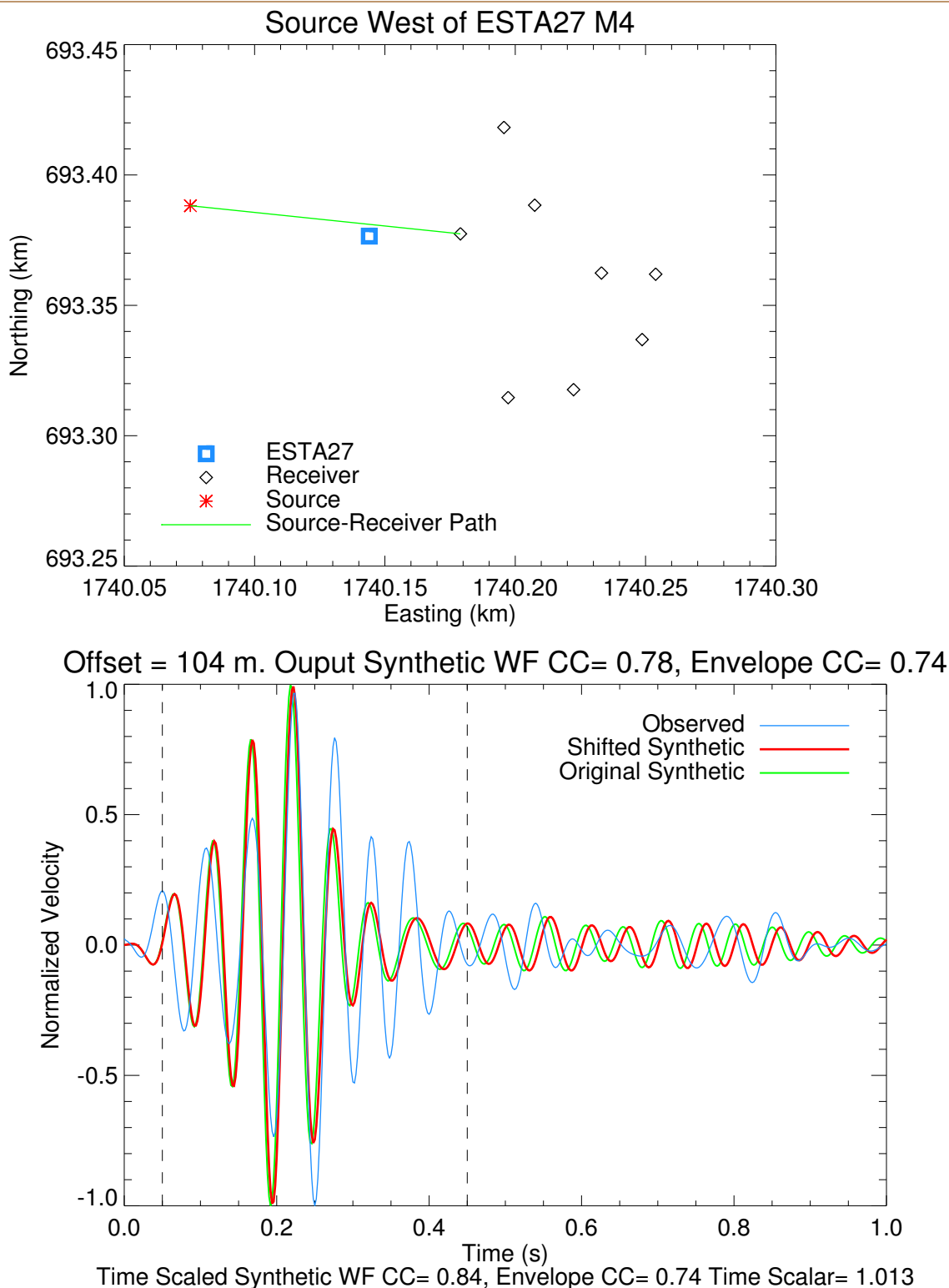
ESTA27 MODEL 4
SOURCE-RECEIVER PAIR 1 OFFSET = 116 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



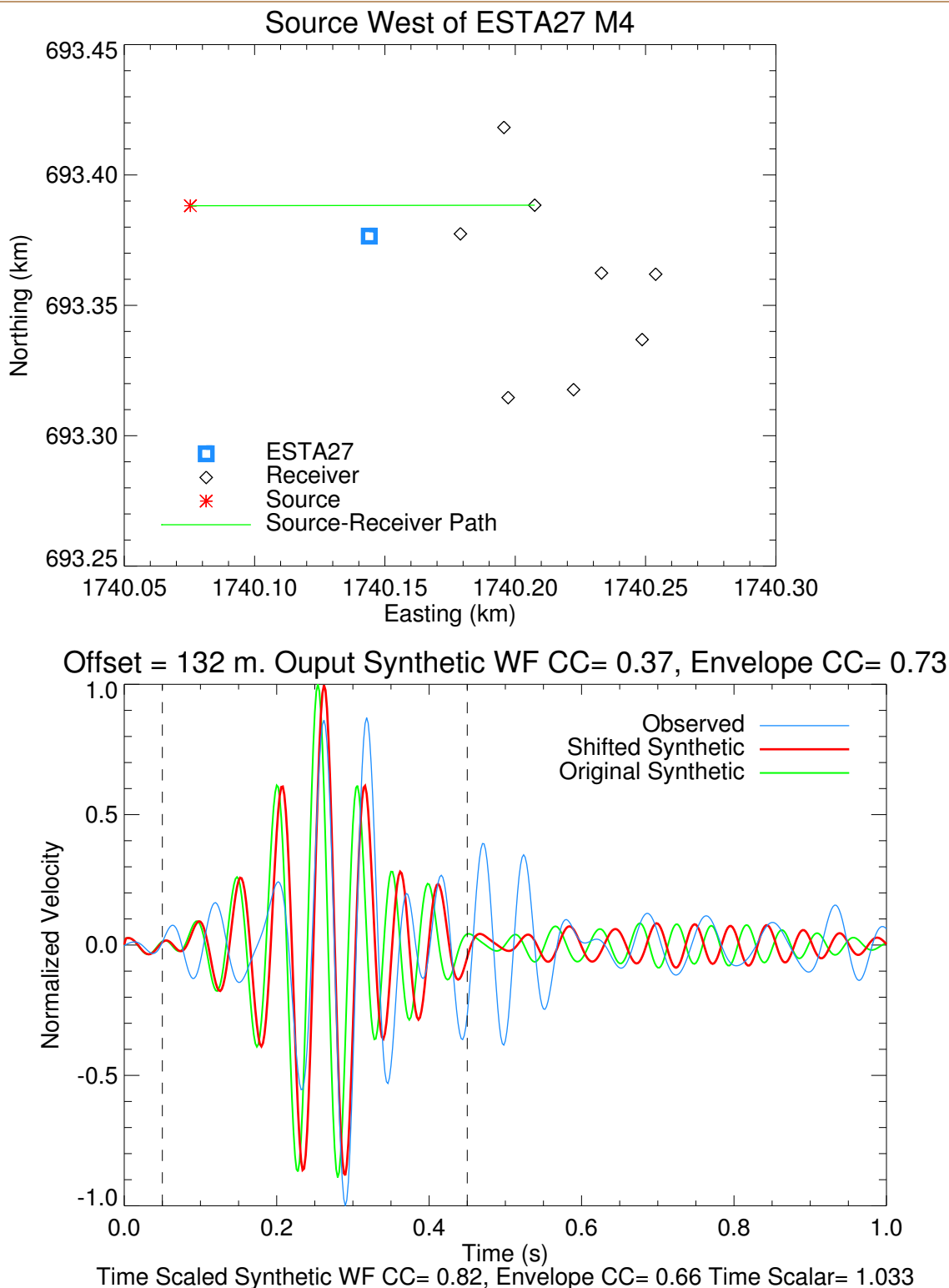
EST A27 MODEL 4
SOURCE-RECEIVER PAIR 2 OFFSET = 93 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



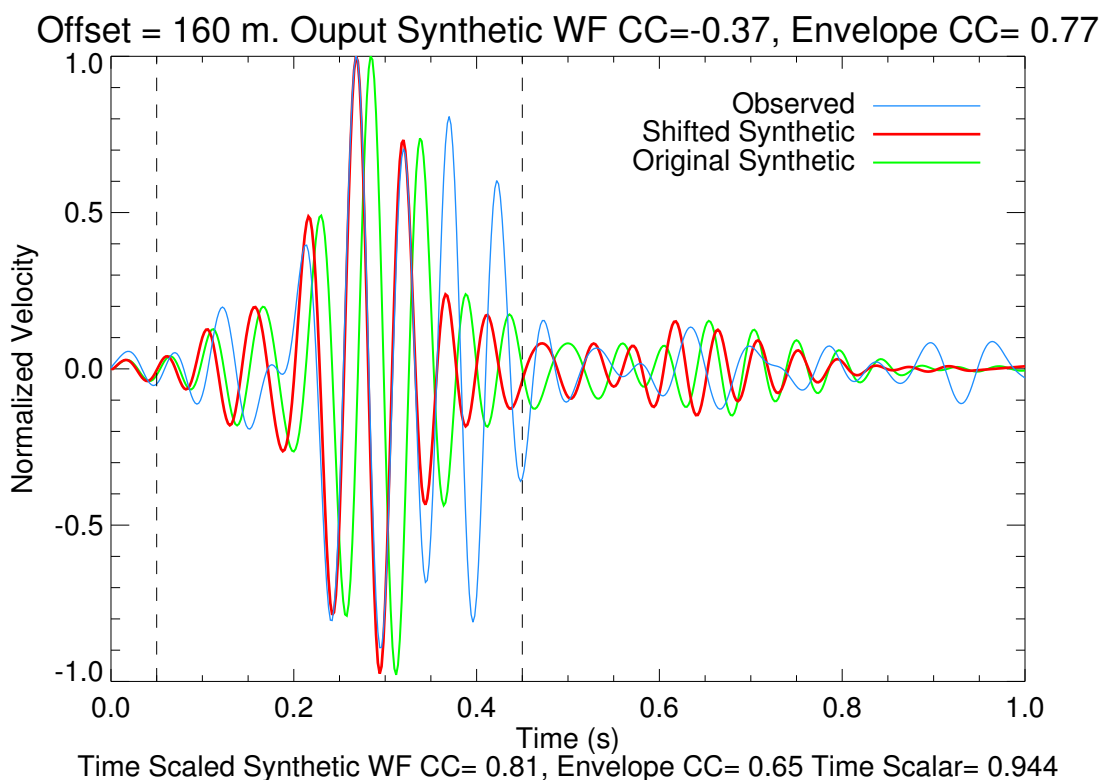
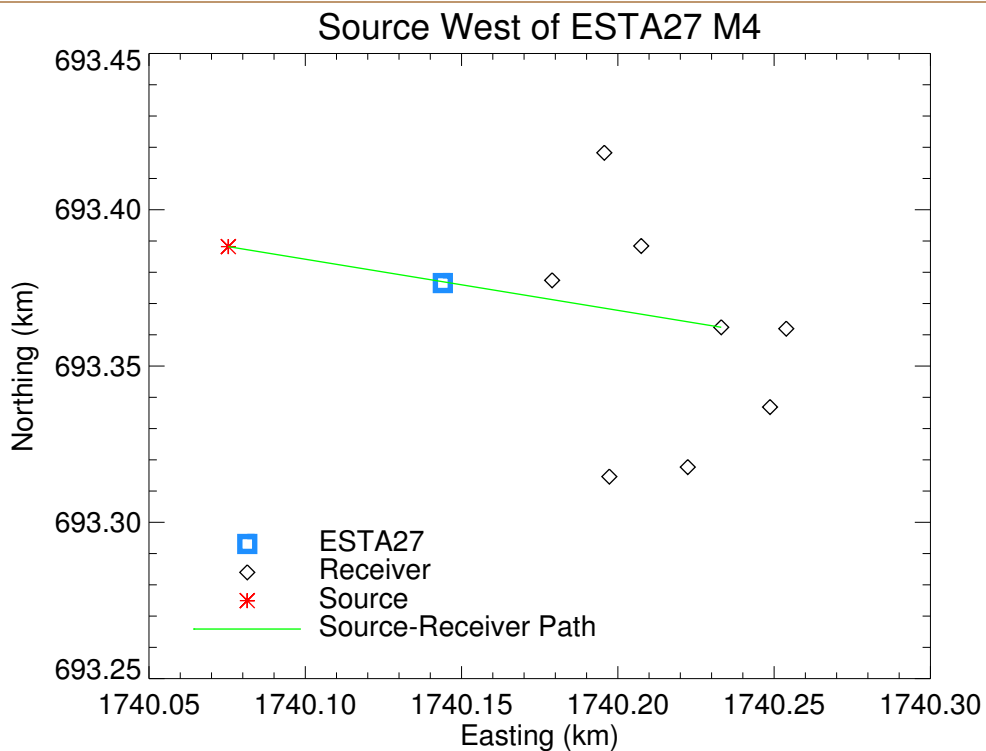
ESTA27 MODEL 4
SOURCE-RECEIVER PAIR 3 OFFSET = 96 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



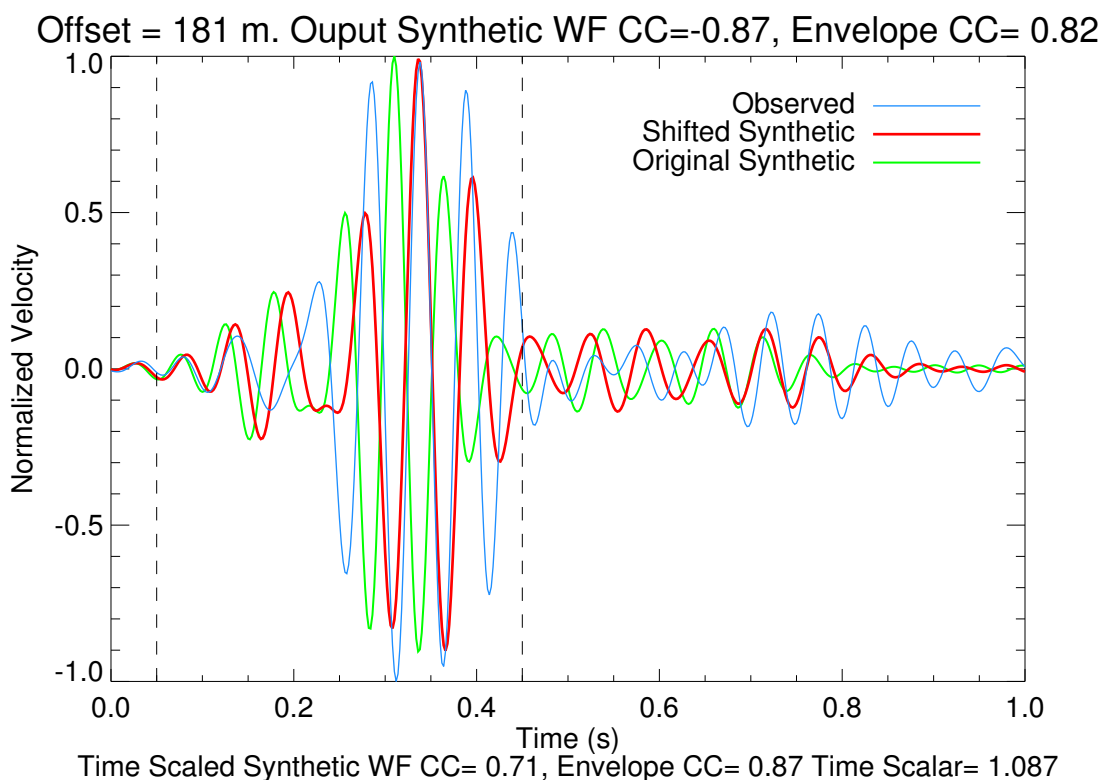
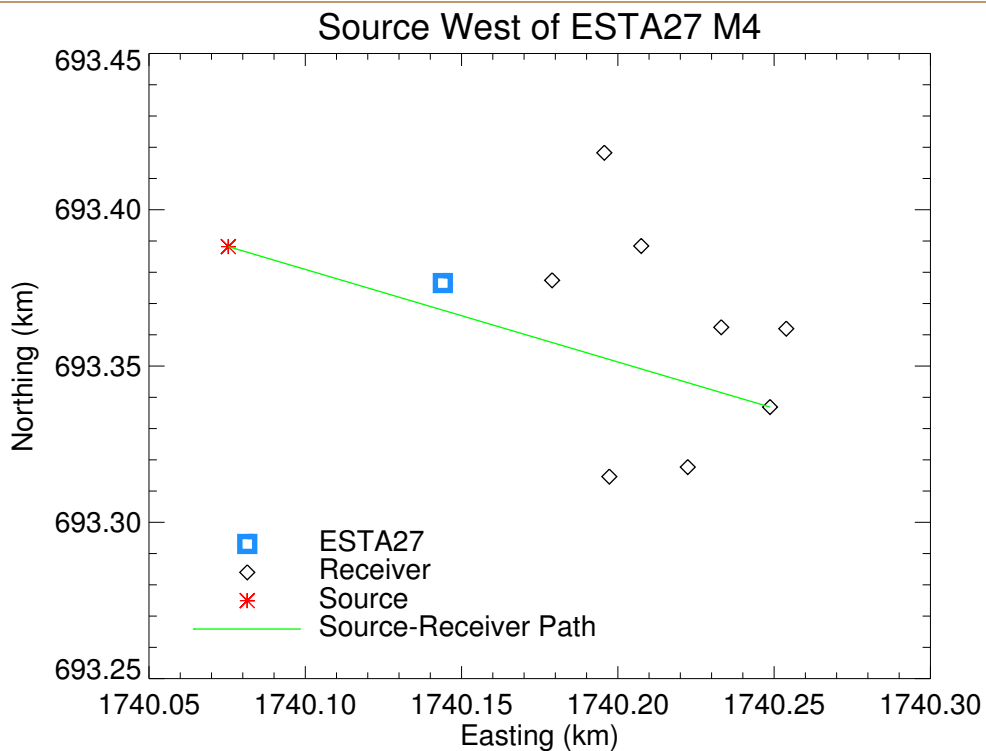
ESTA27 MODEL 4
SOURCE-RECEIVER PAIR 4 OFFSET = 104 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



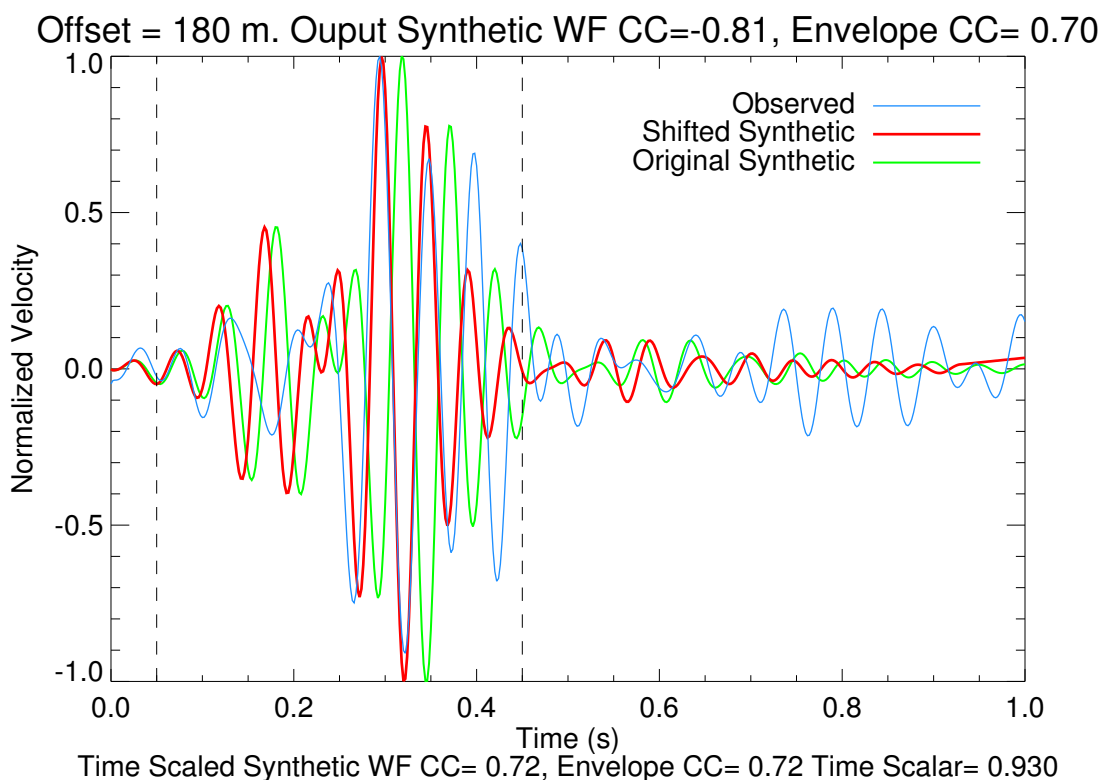
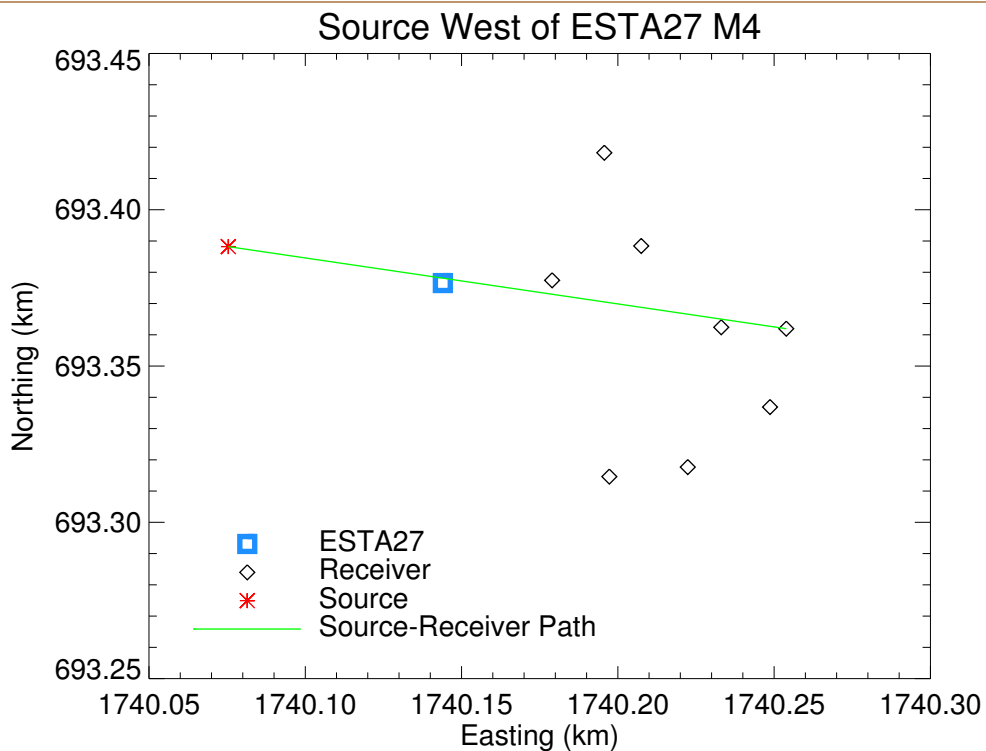
ESTA27 MODEL 4
SOURCE-RECEIVER PAIR 5 OFFSET = 132 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



ESTA27 MODEL 4
SOURCE-RECEIVER PAIR 6 OFFSET = 160 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California

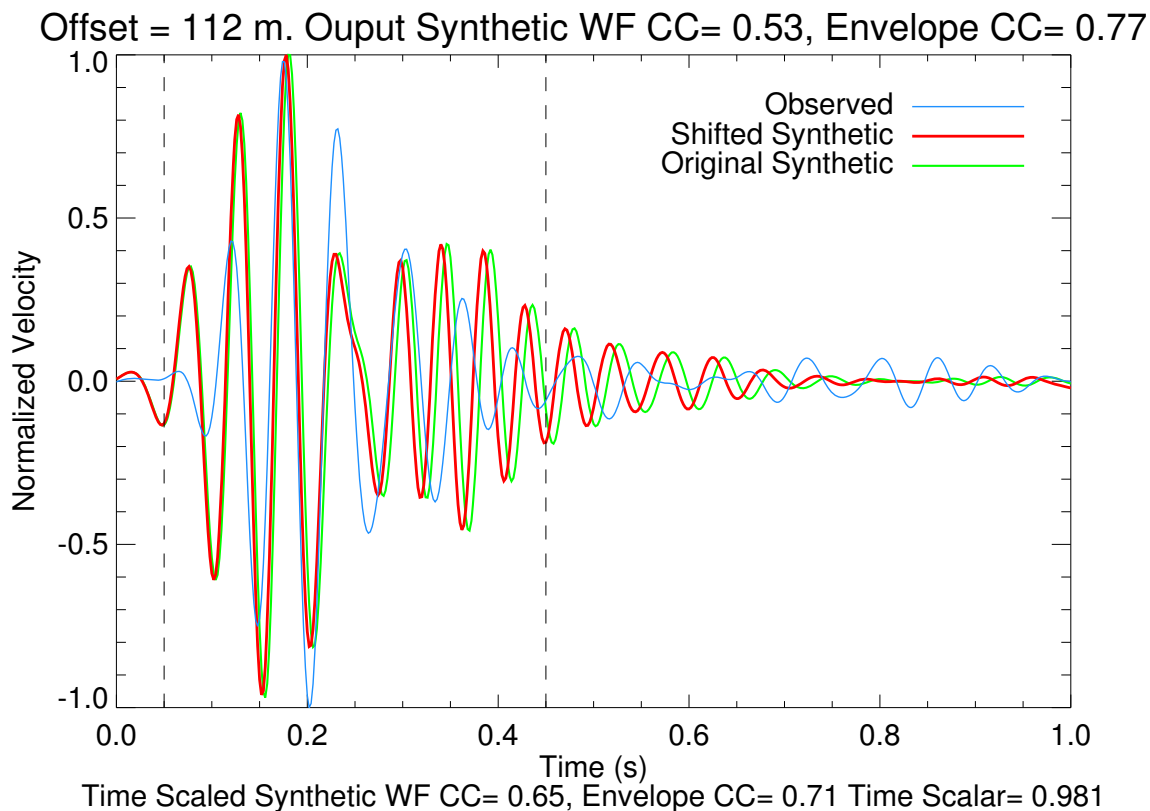
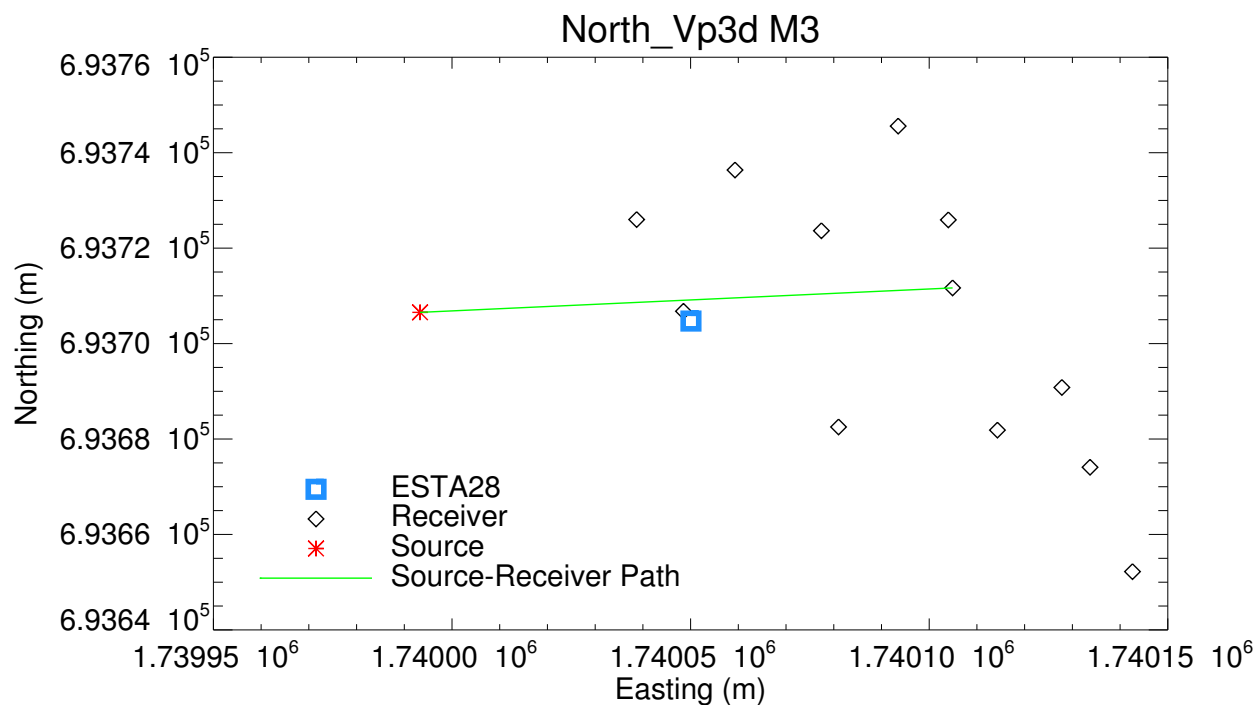


ESTA27 MODEL 4
SOURCE-RECEIVER PAIR 7 OFFSET = 181 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California

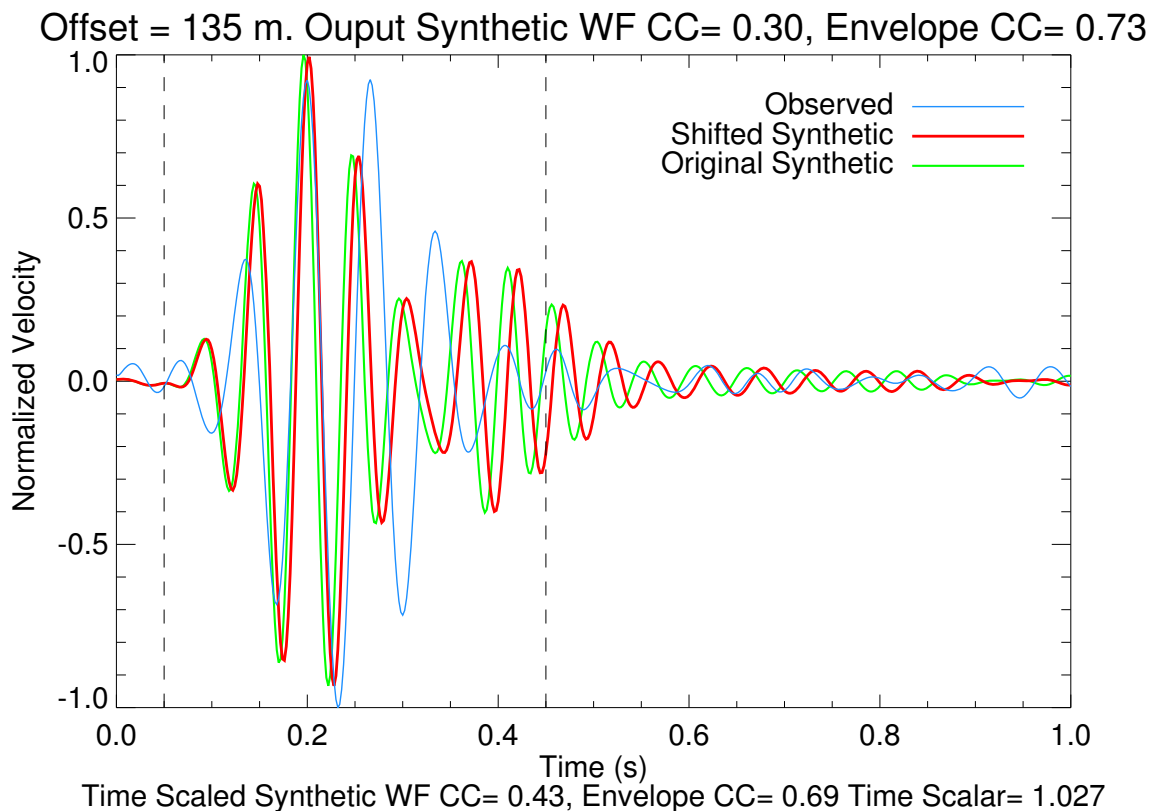
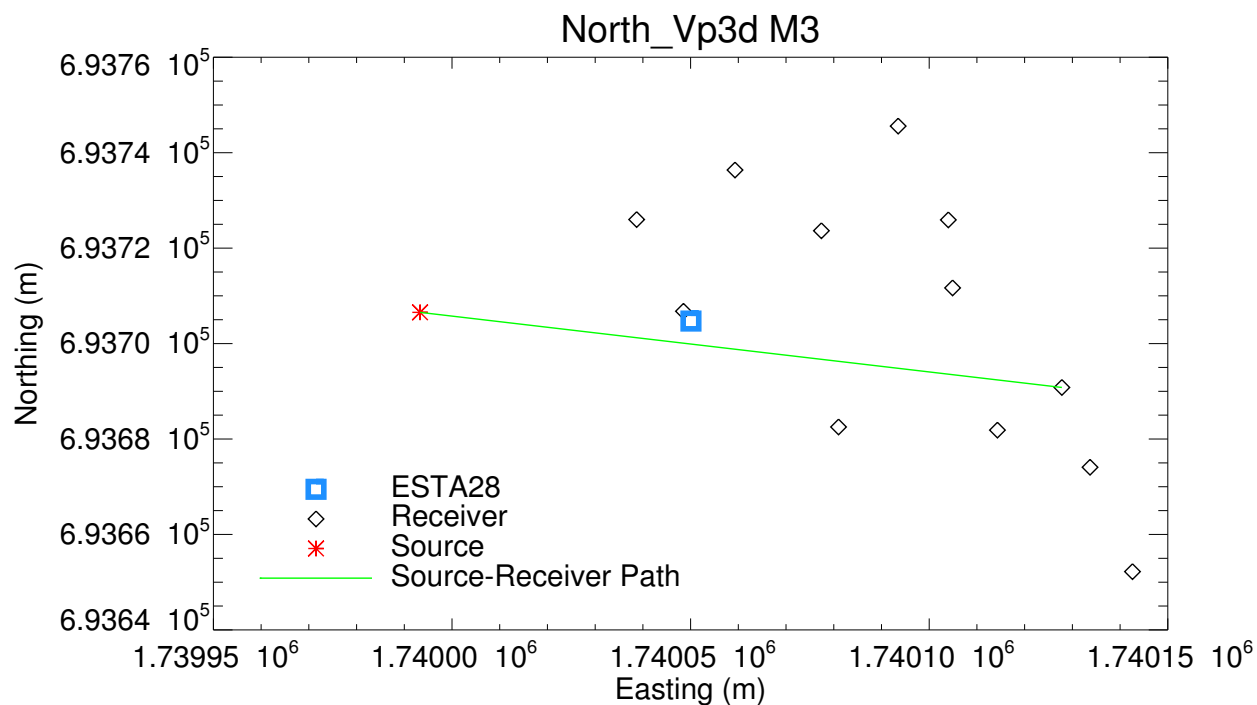


ESTA27 MODEL 4
SOURCE-RECEIVER PAIR 8 OFFSET = 180 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California

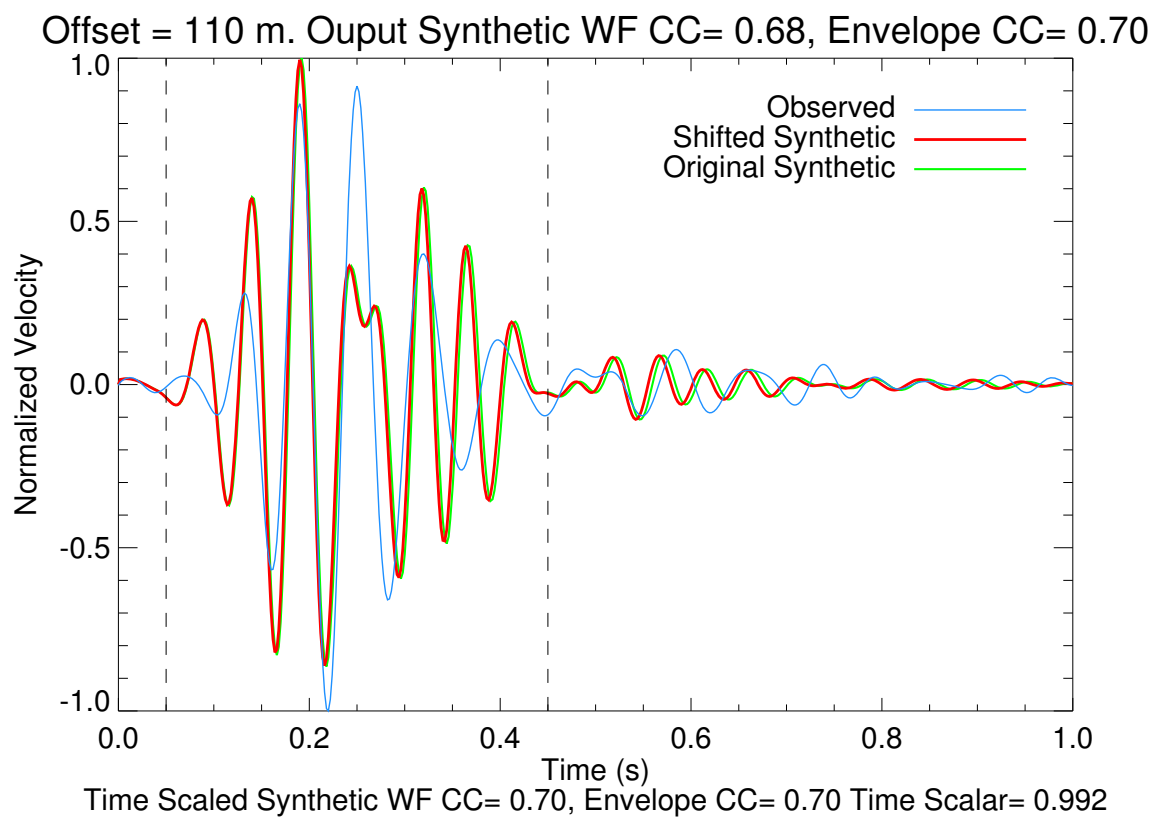
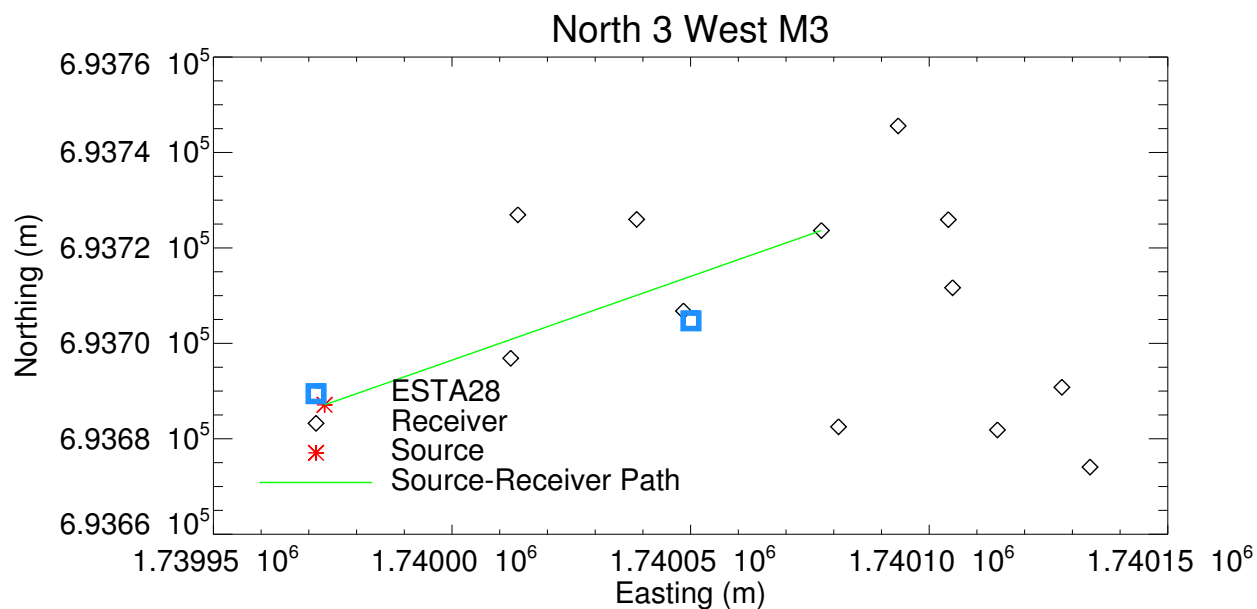
APPENDIX B



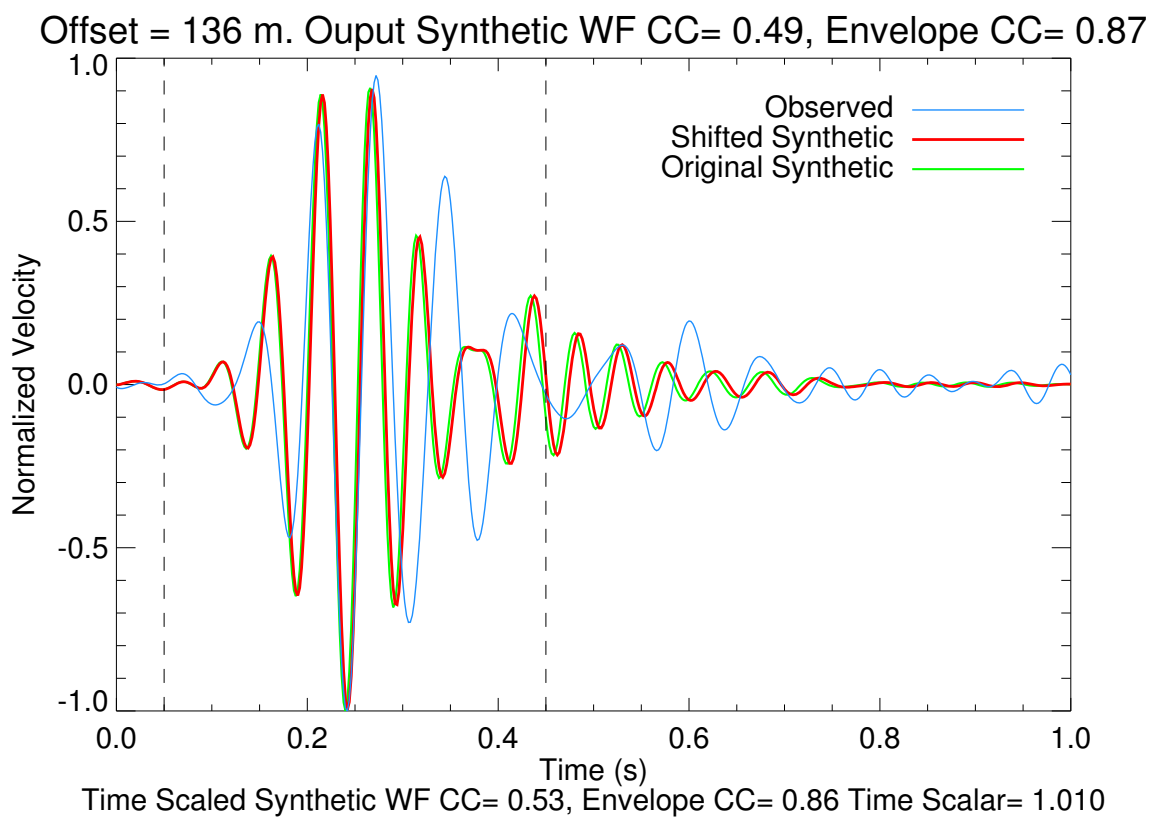
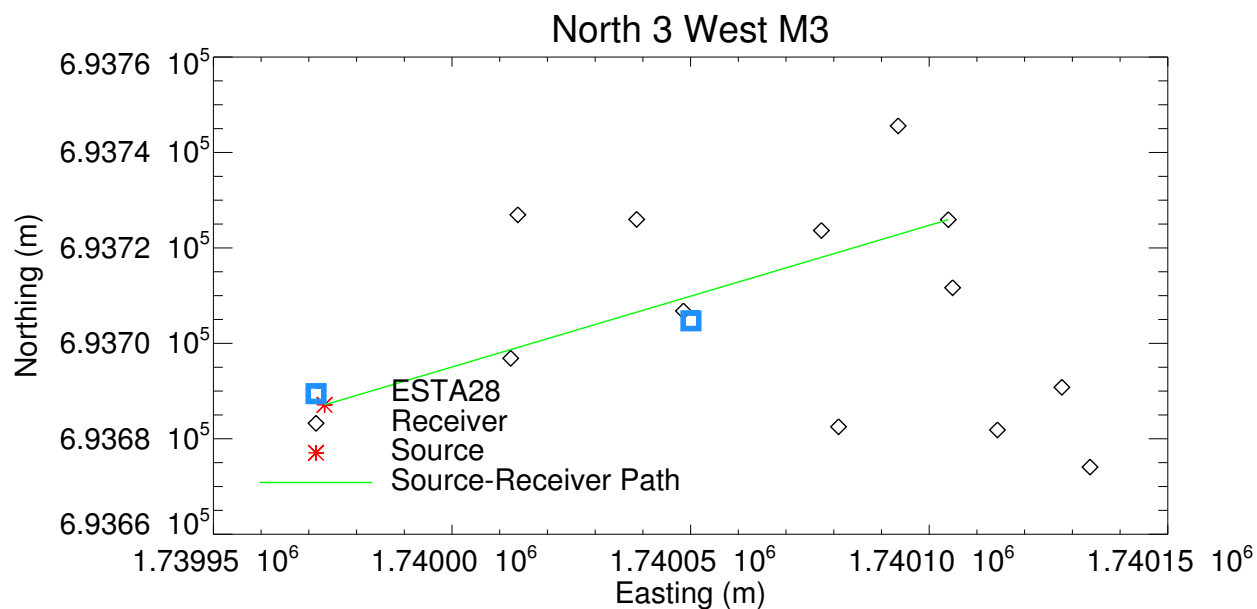
EST A28 MODEL 4
SOURCE-RECEIVER PAIR 1 OFFSET = 112 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



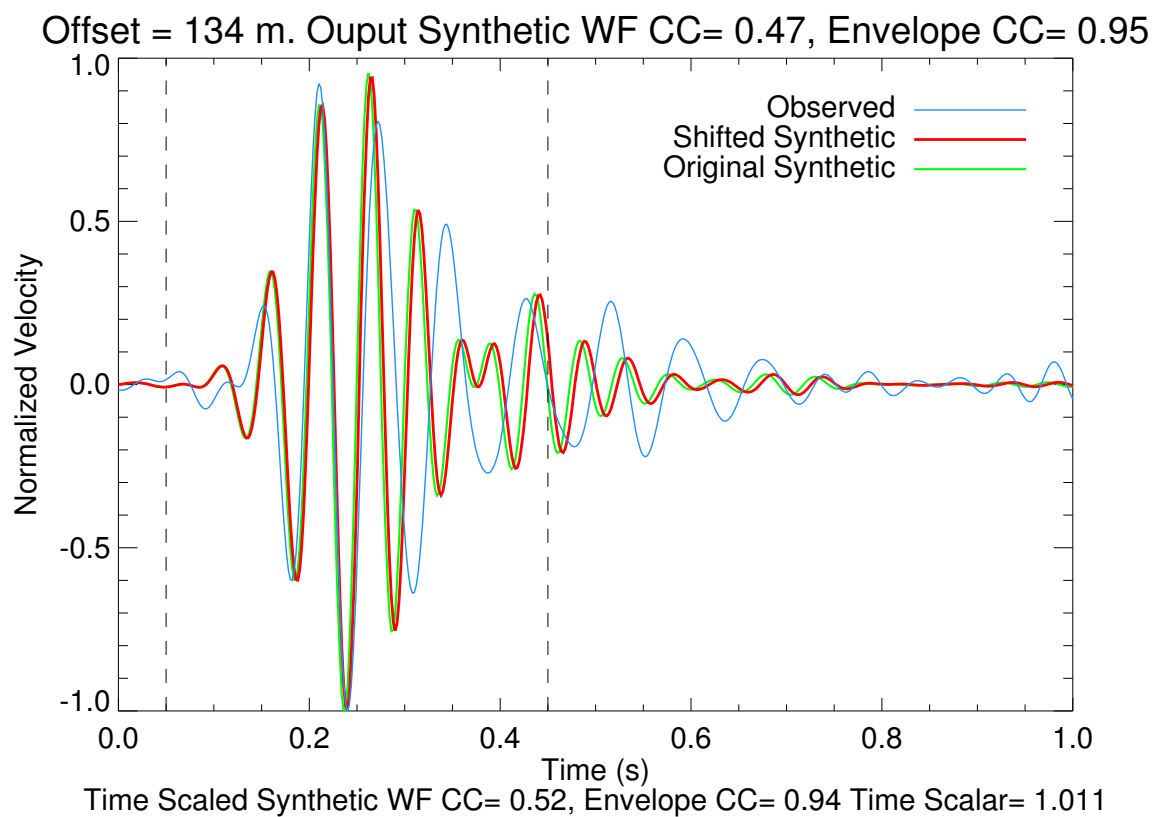
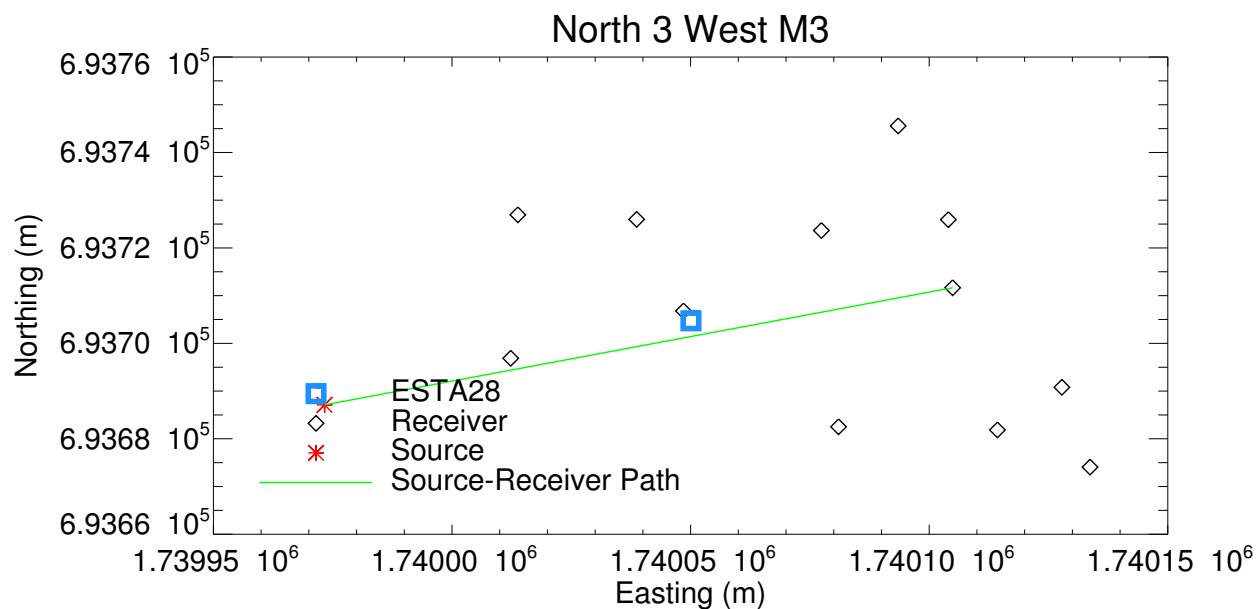
EST A28 MODEL 4
SOURCE-RECEIVER PAIR 2 OFFSET = 135 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California



ESTA28 MODEL 4
SOURCE-RECEIVER PAIR 3 OFFSET = 110 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California

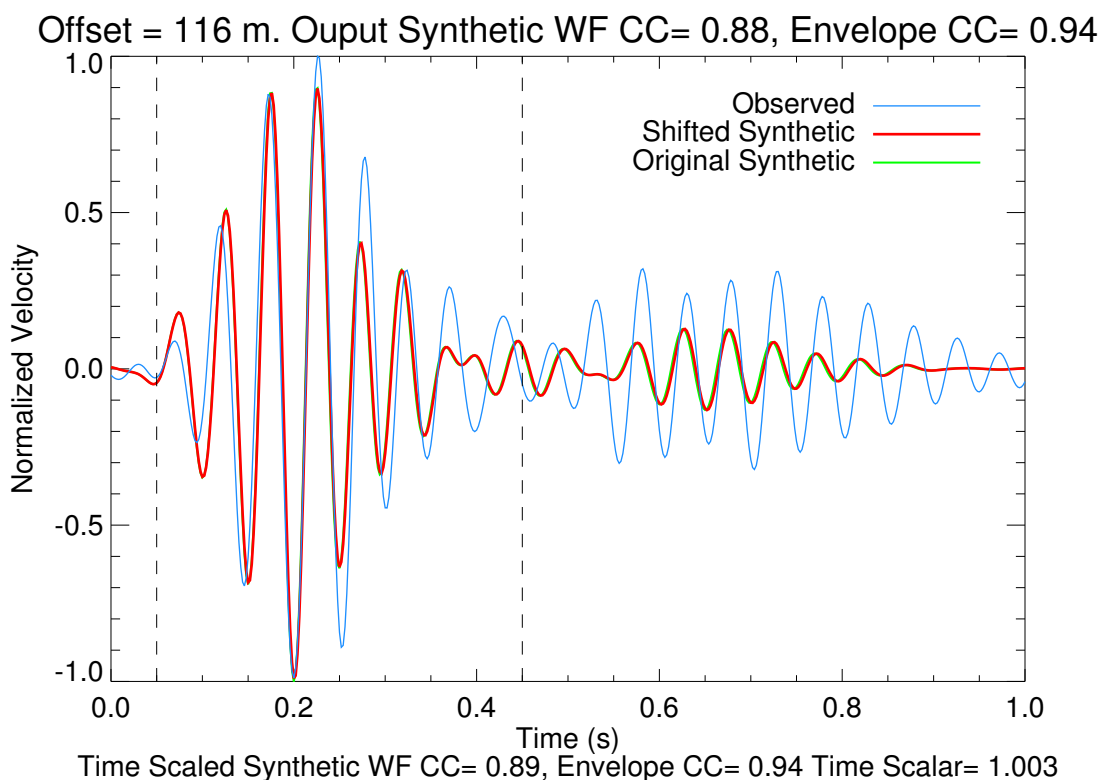
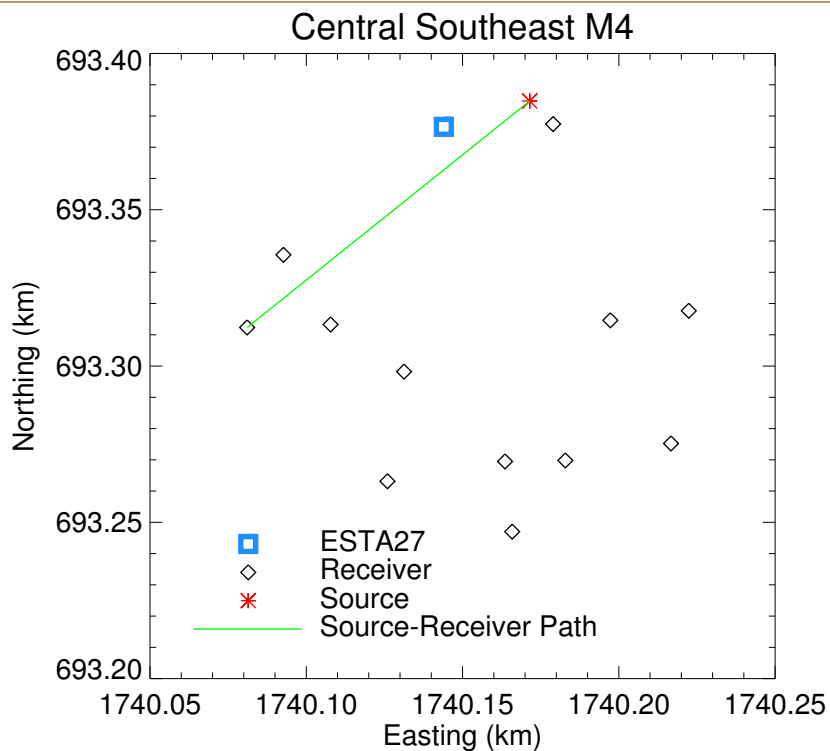


ESTA28 MODEL 4
SOURCE-RECEIVER PAIR 4 OFFSET = 136 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California

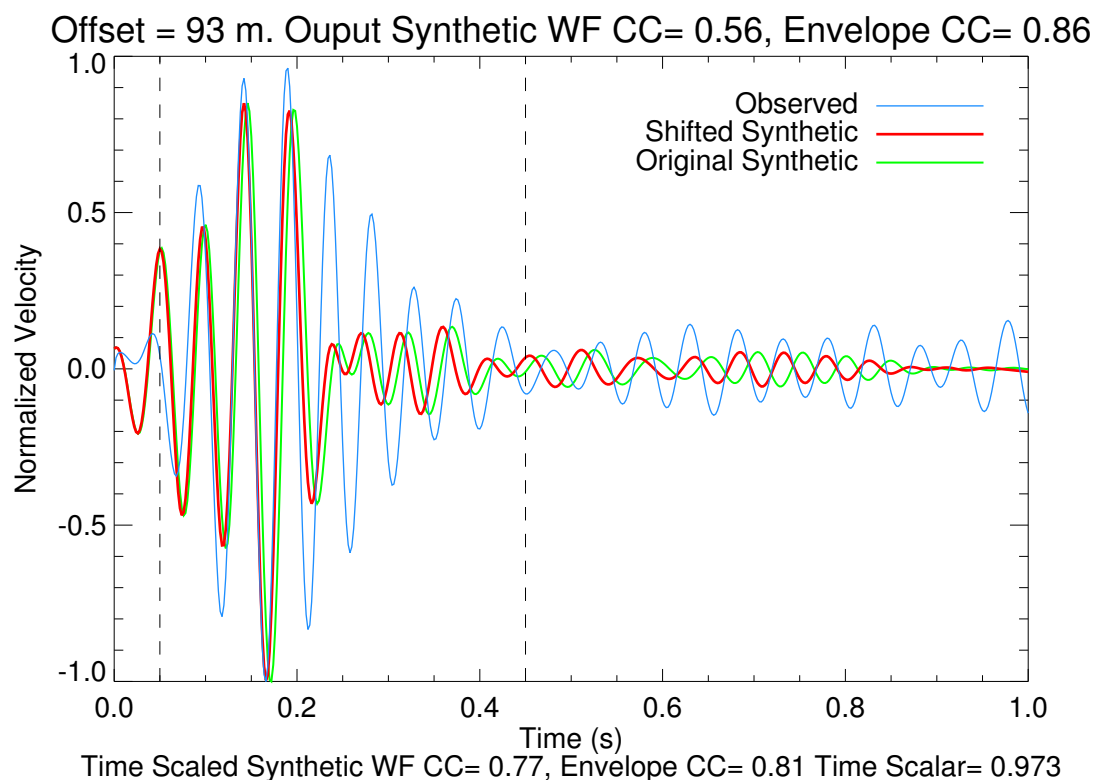
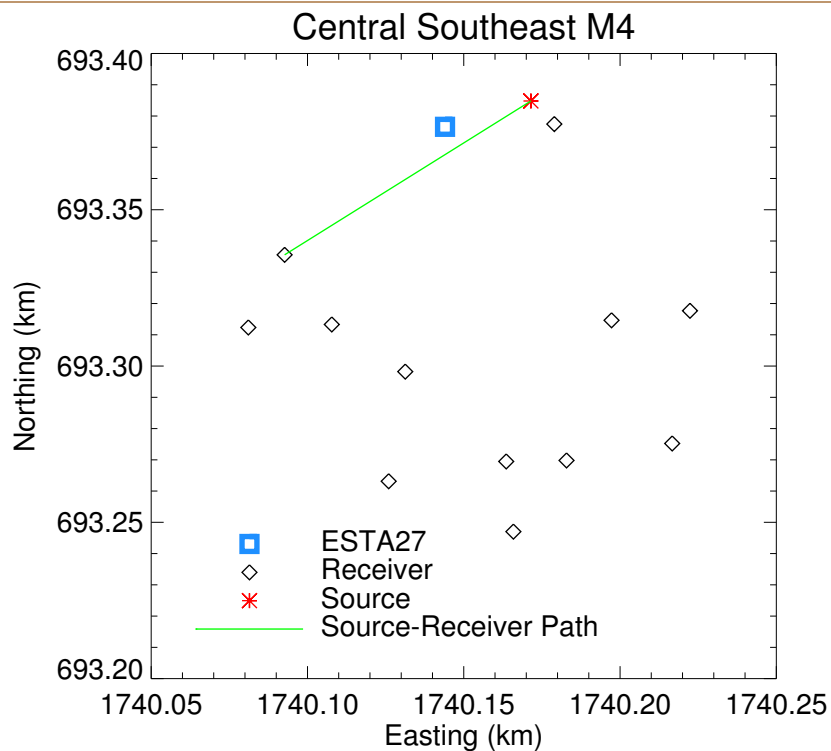


ESTA28 MODEL 4
SOURCE-RECEIVER PAIR 5 OFFSET = 134 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California

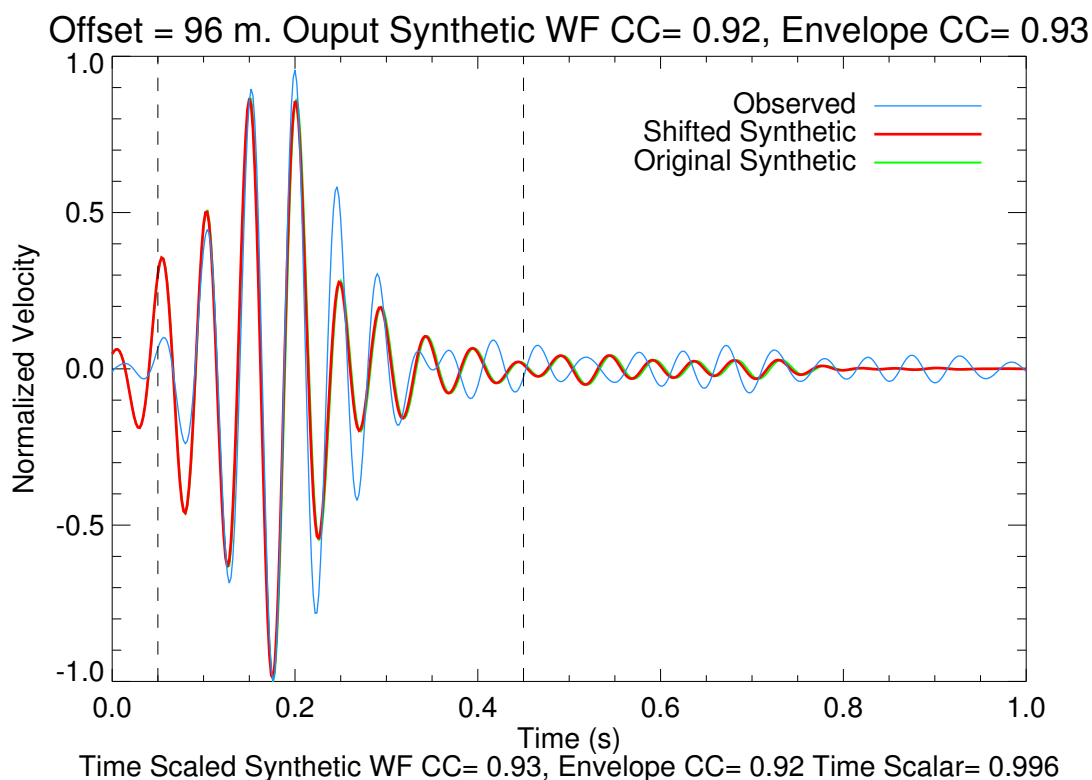
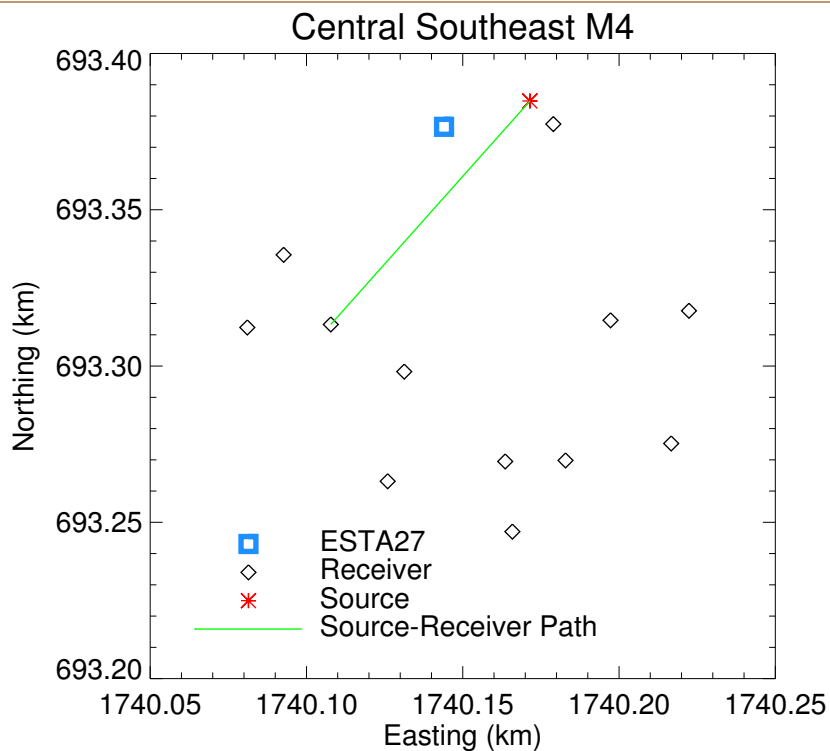
APPENDIX C



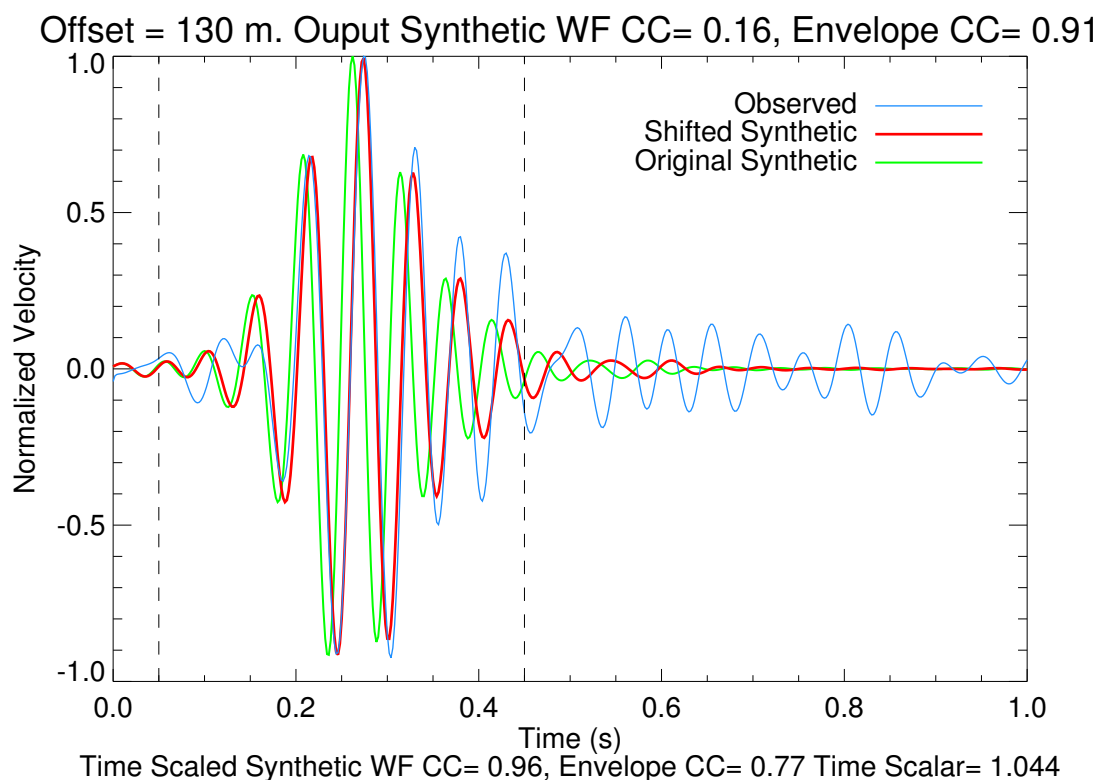
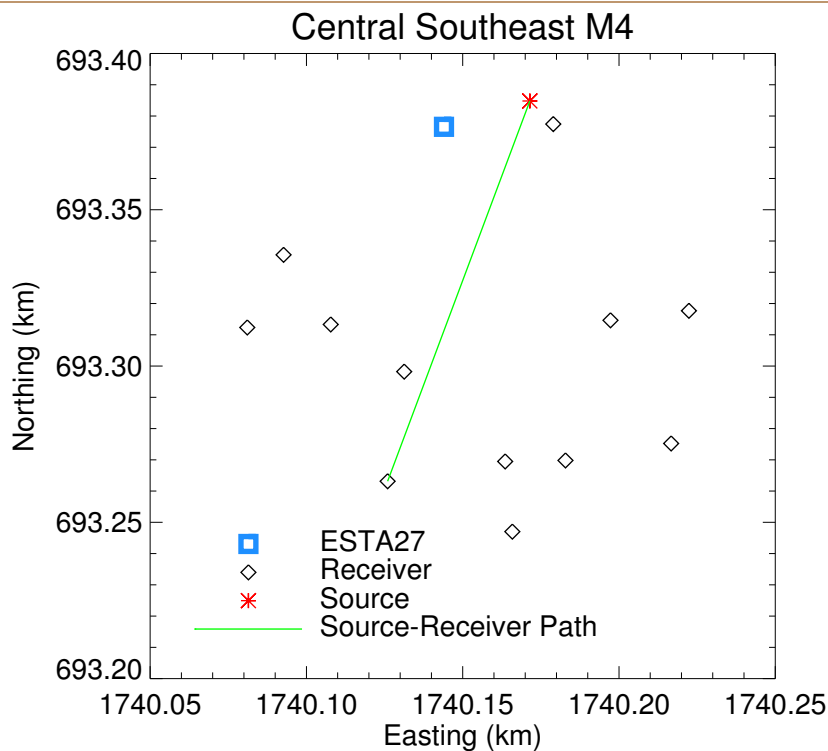
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 1 OFFSET = 116 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



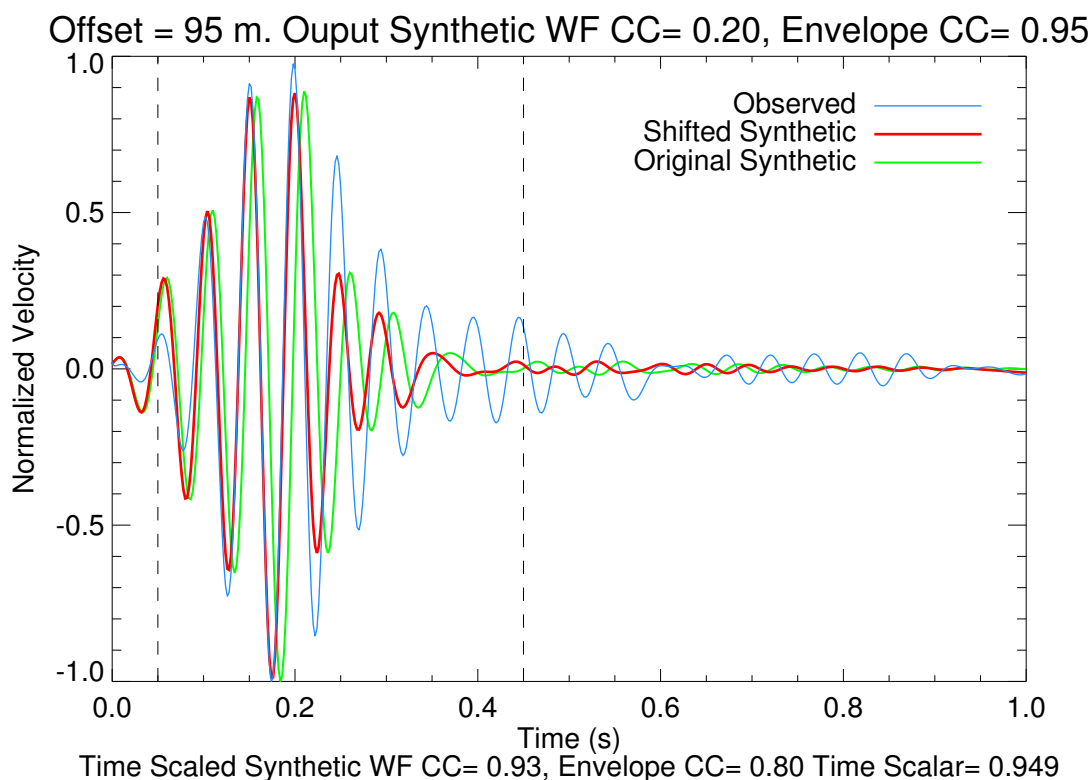
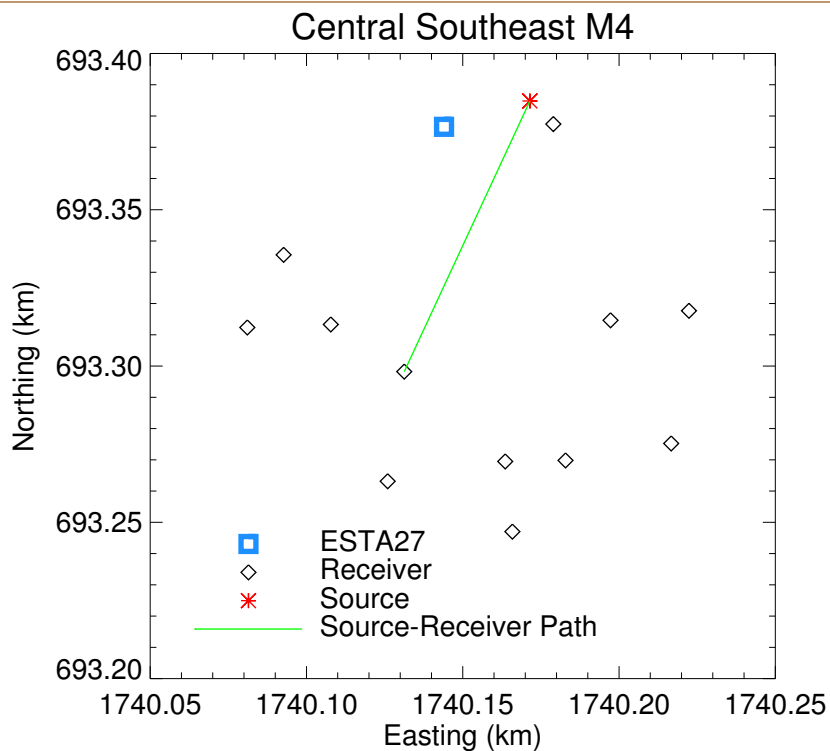
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 2 OFFSET = 93 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



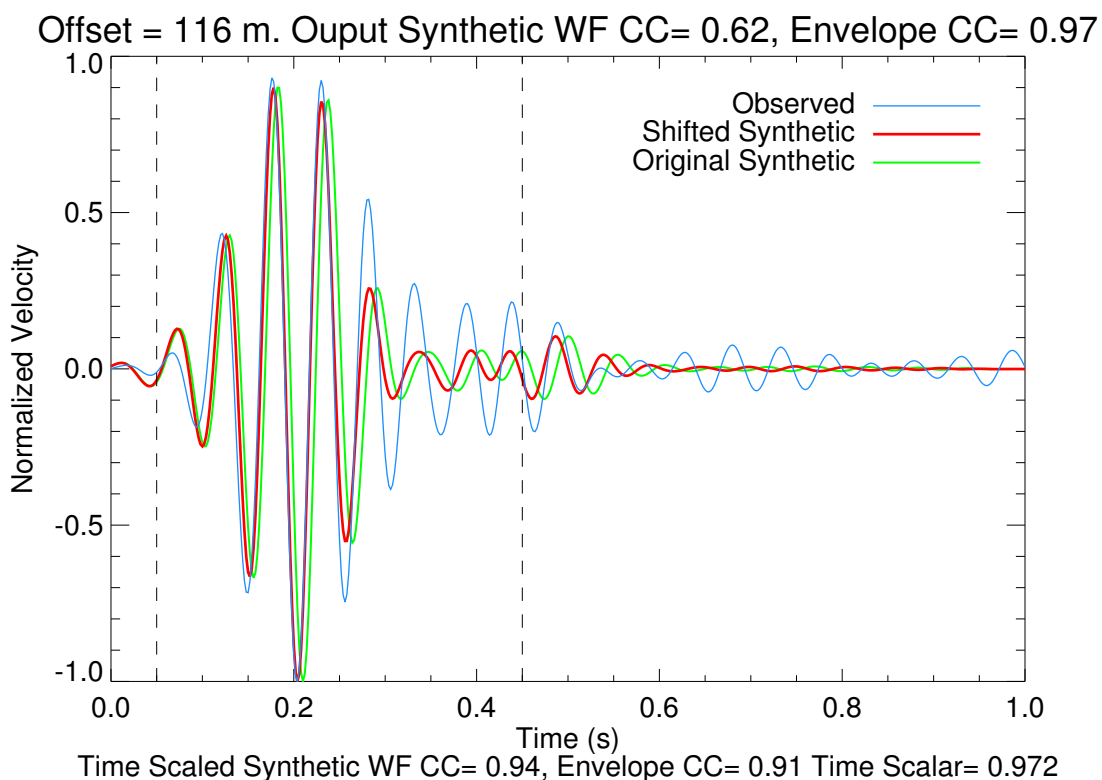
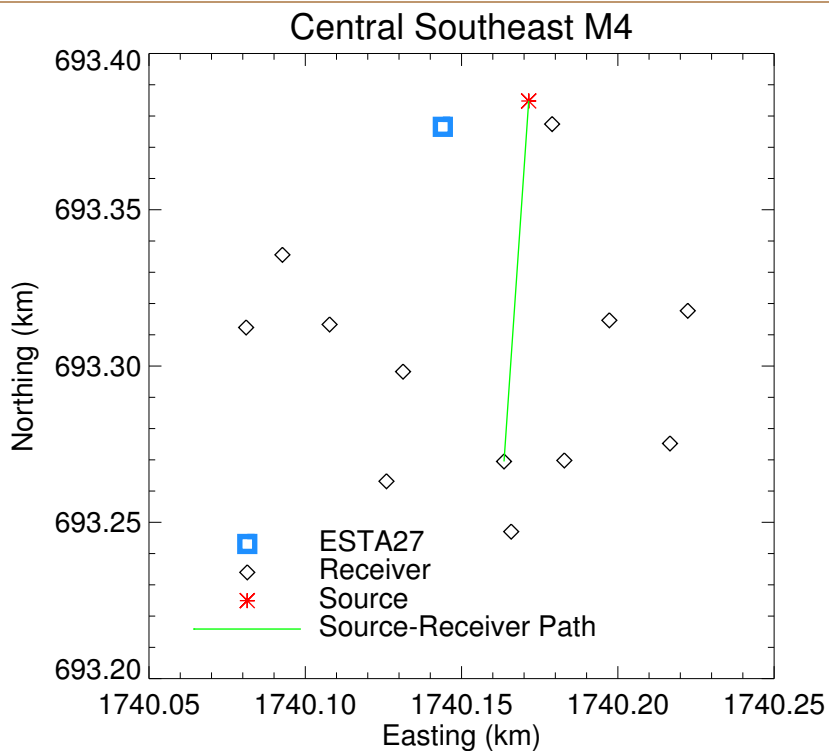
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 3 OFFSET = 96 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



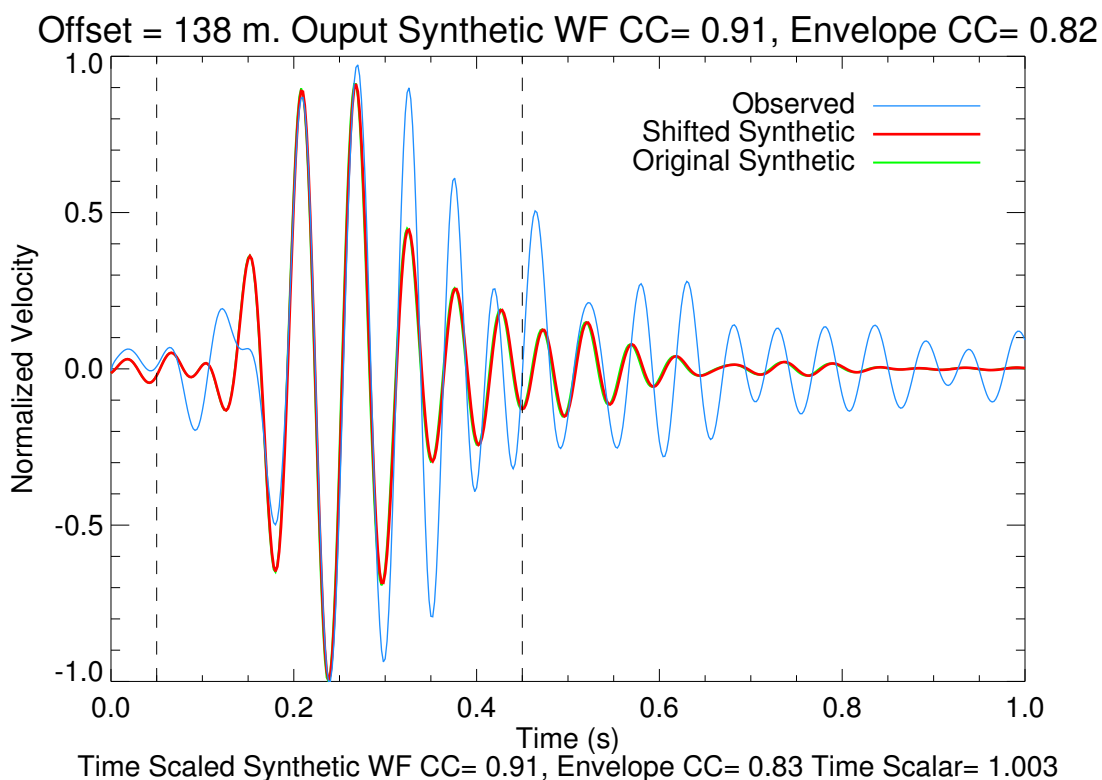
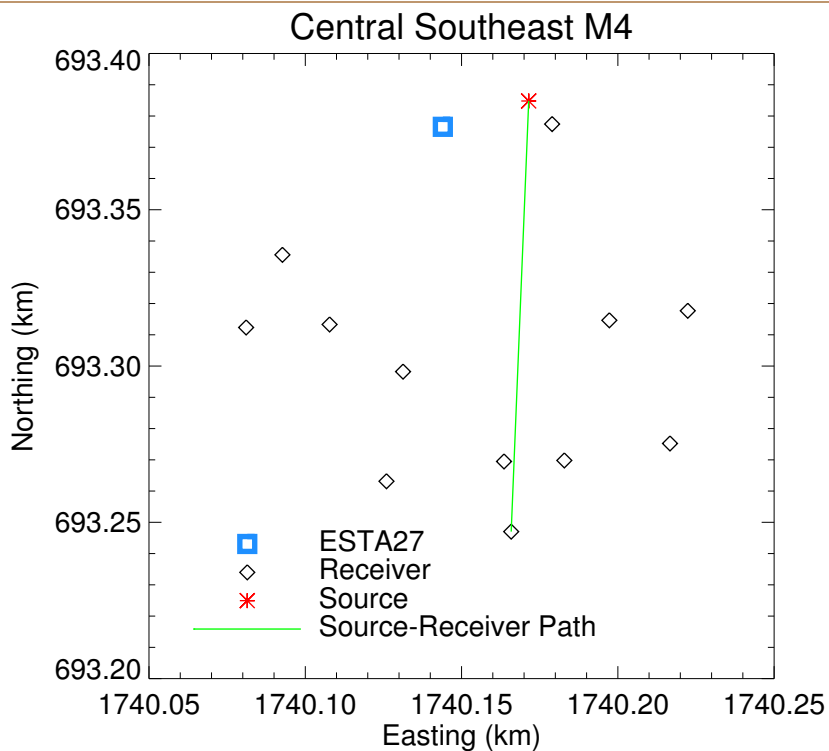
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 4 OFFSET = 130 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



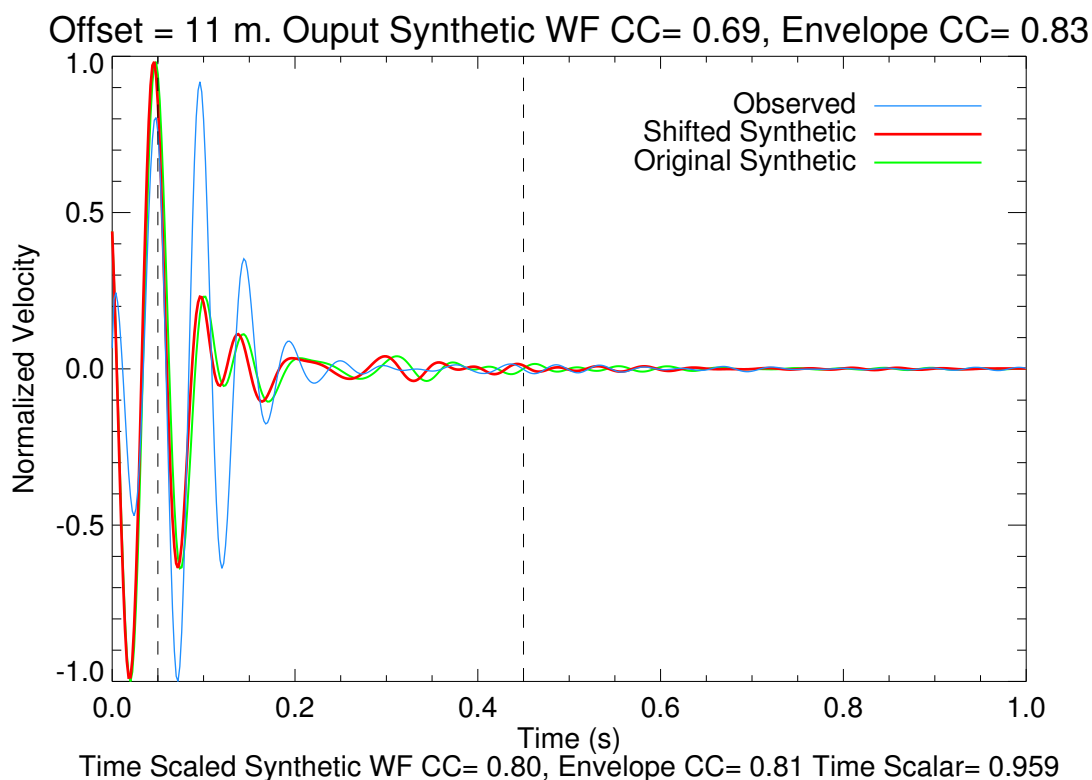
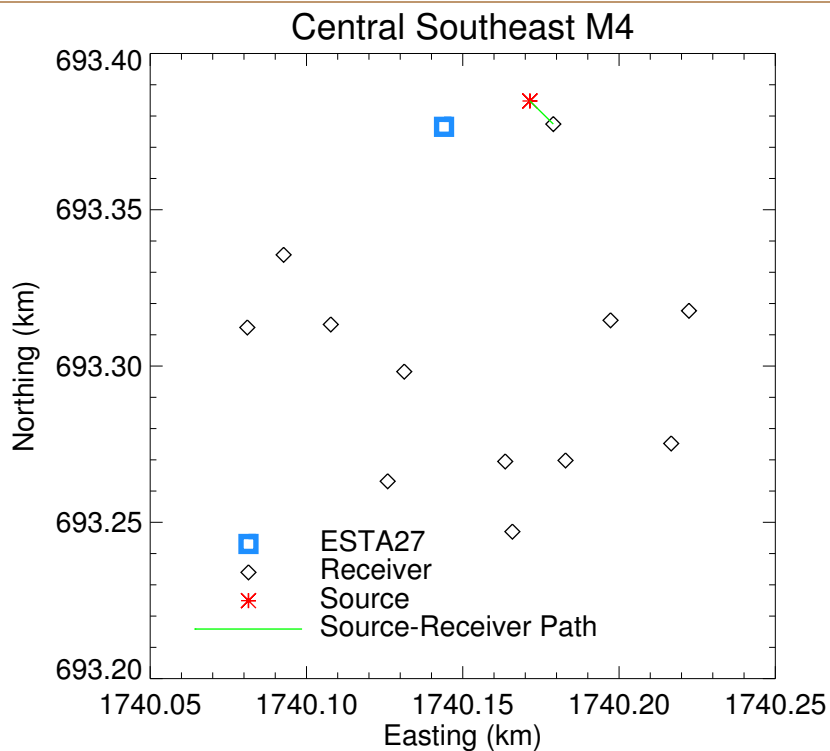
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 5 OFFSET = 95 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



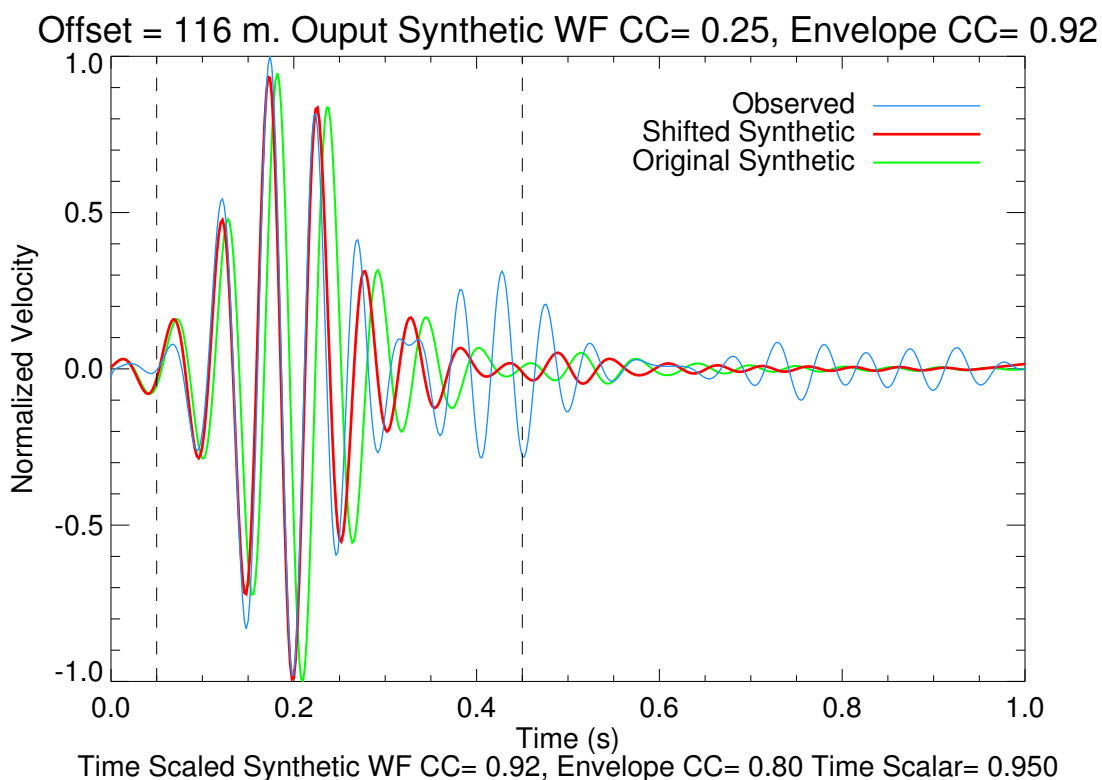
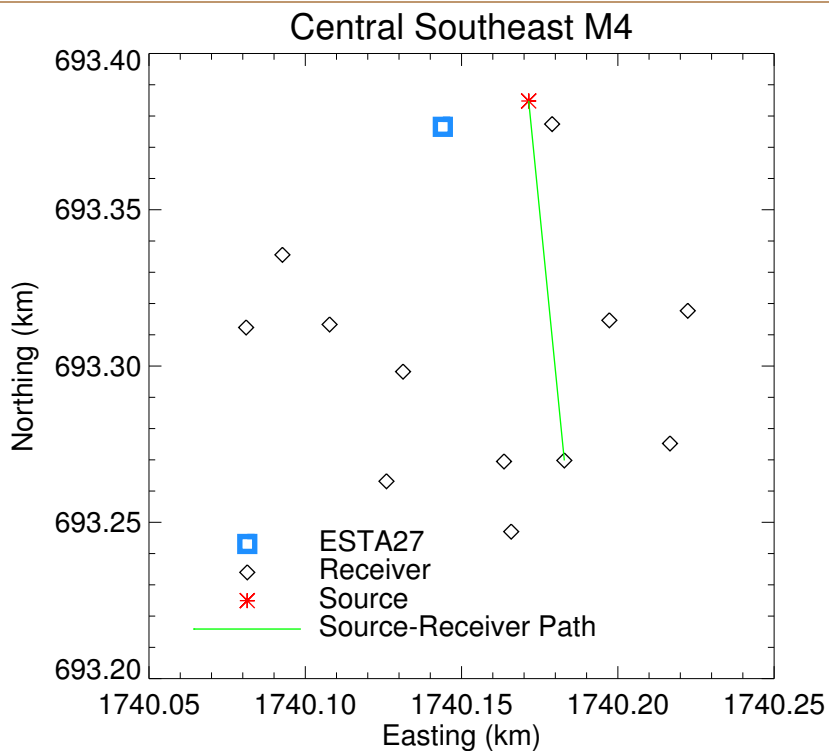
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 6 OFFSET = 116 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



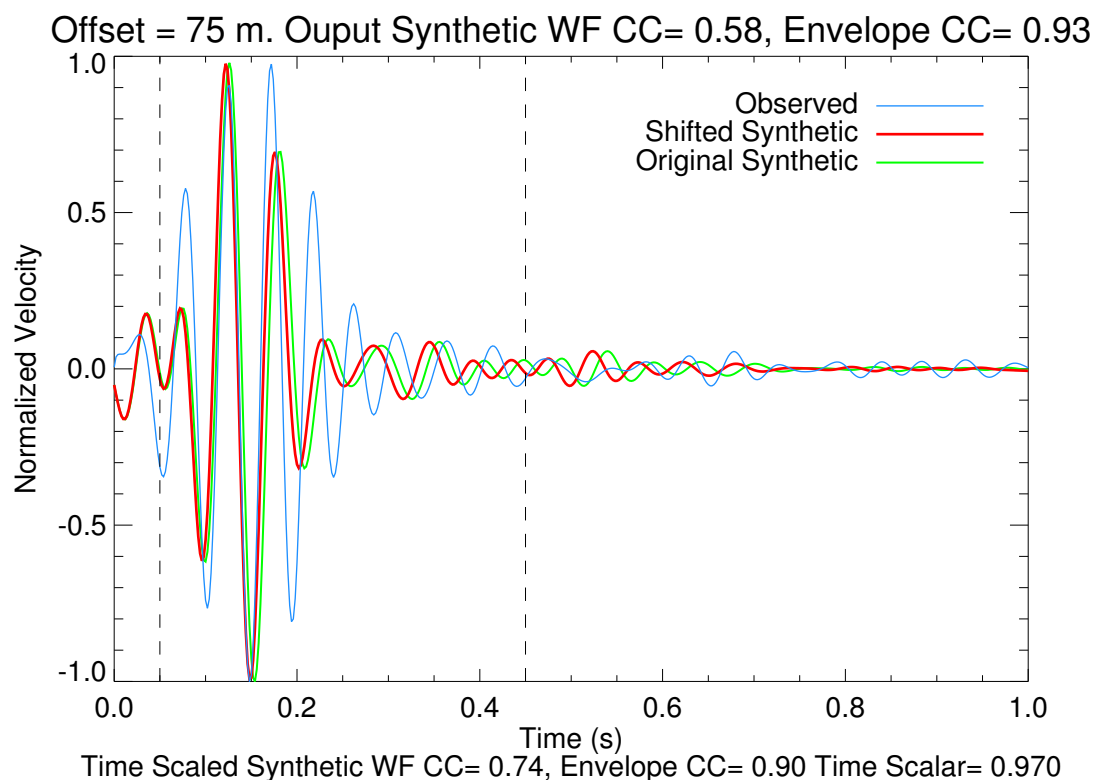
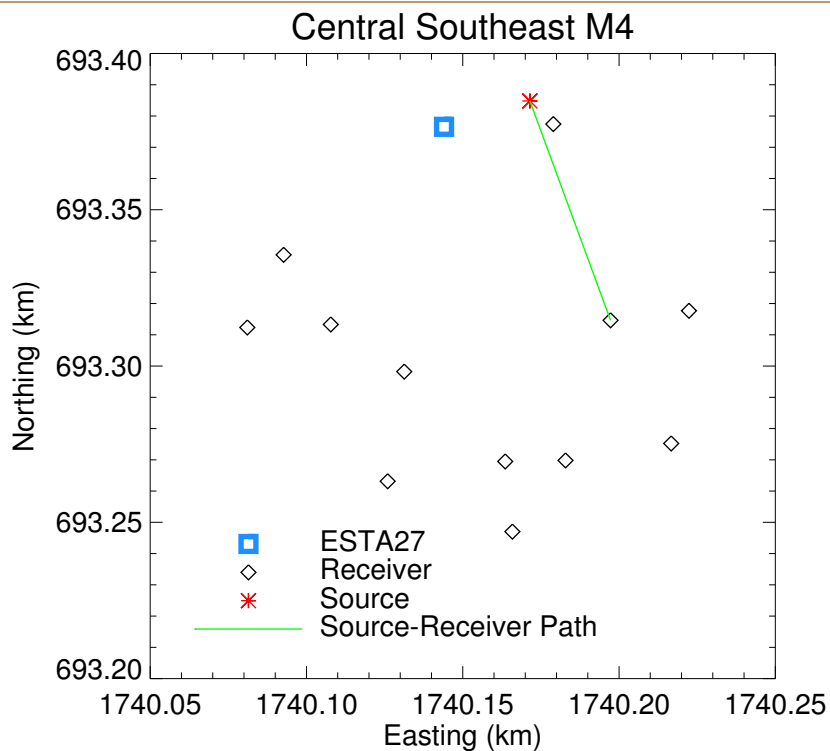
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 7 OFFSET = 138 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



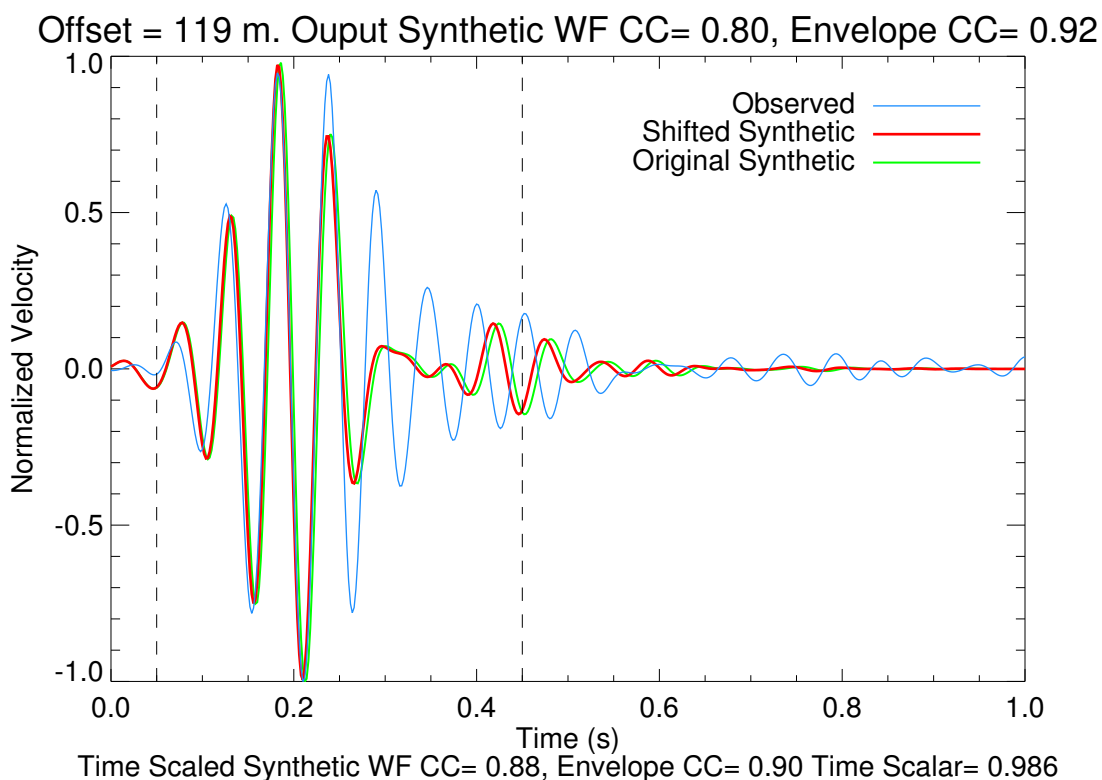
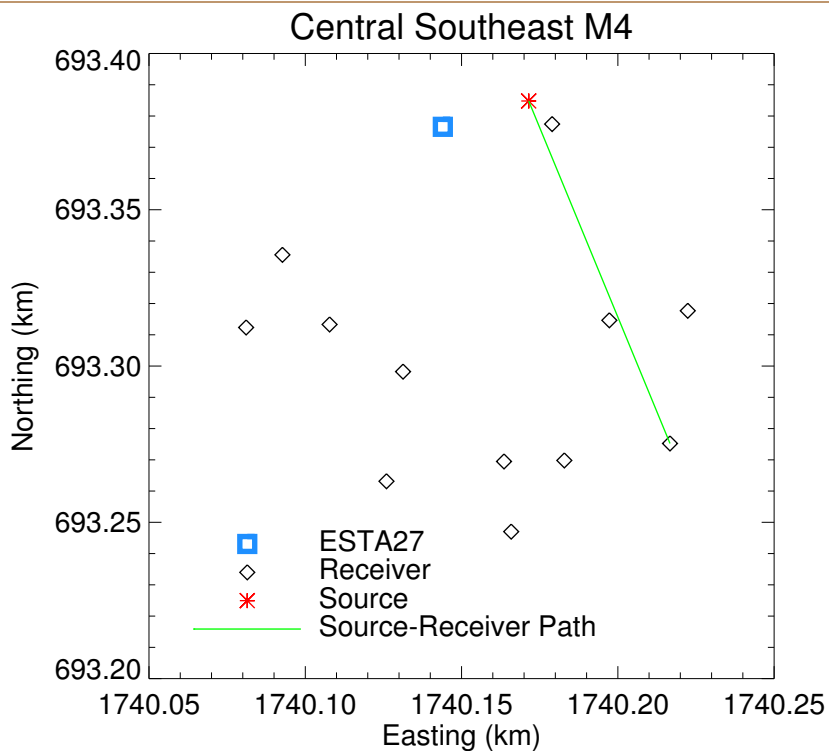
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 8 OFFSET = 11 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



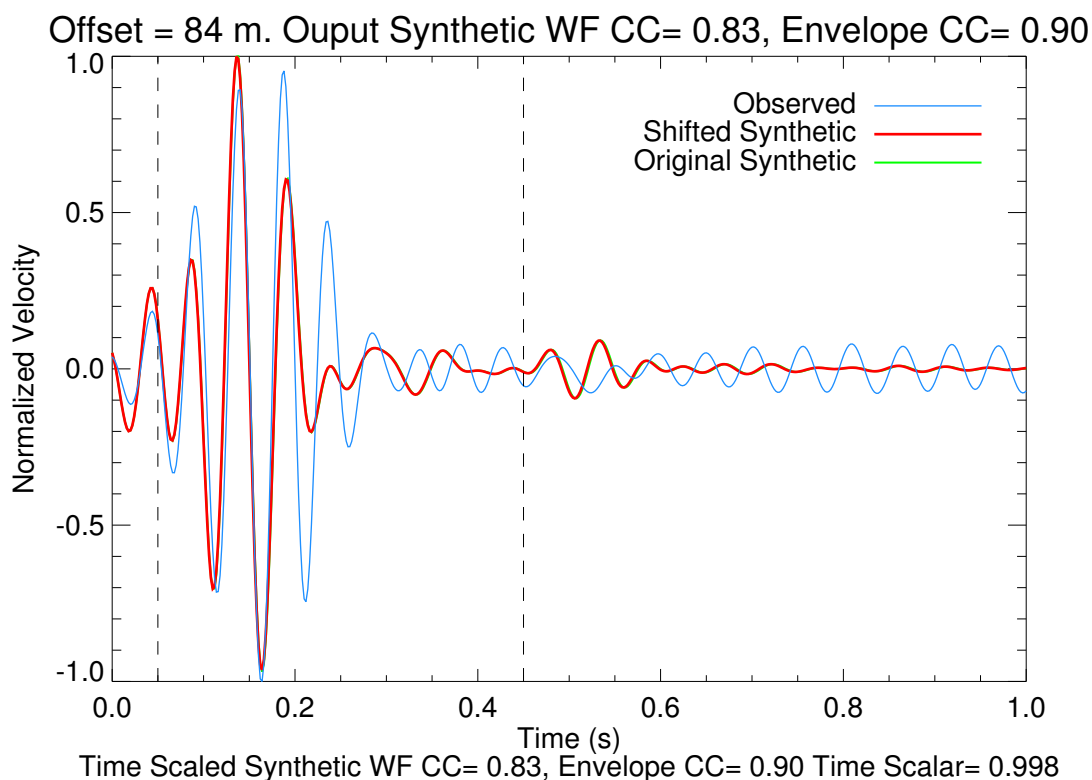
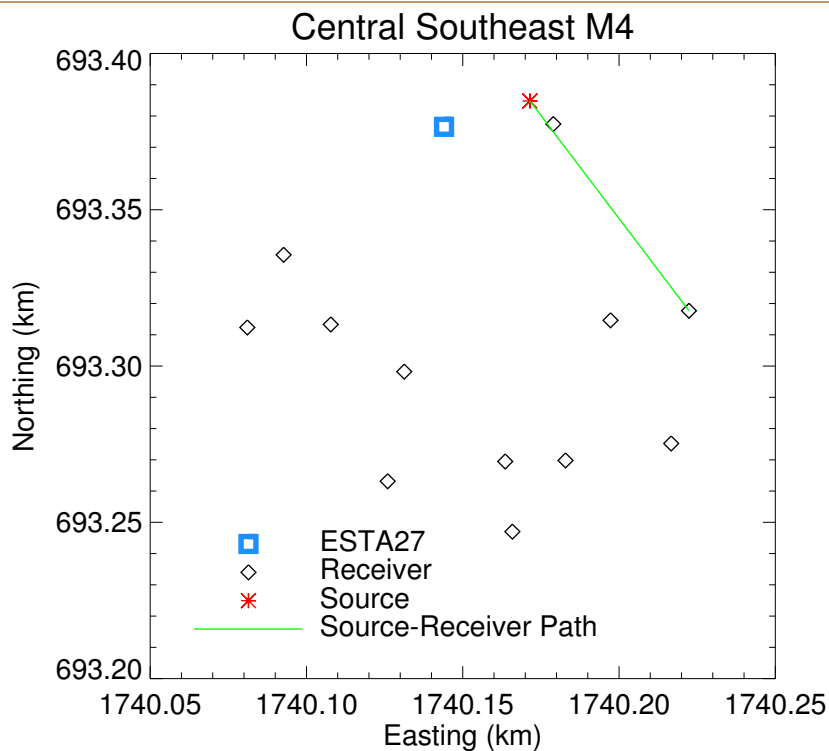
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 9 OFFSET = 116 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



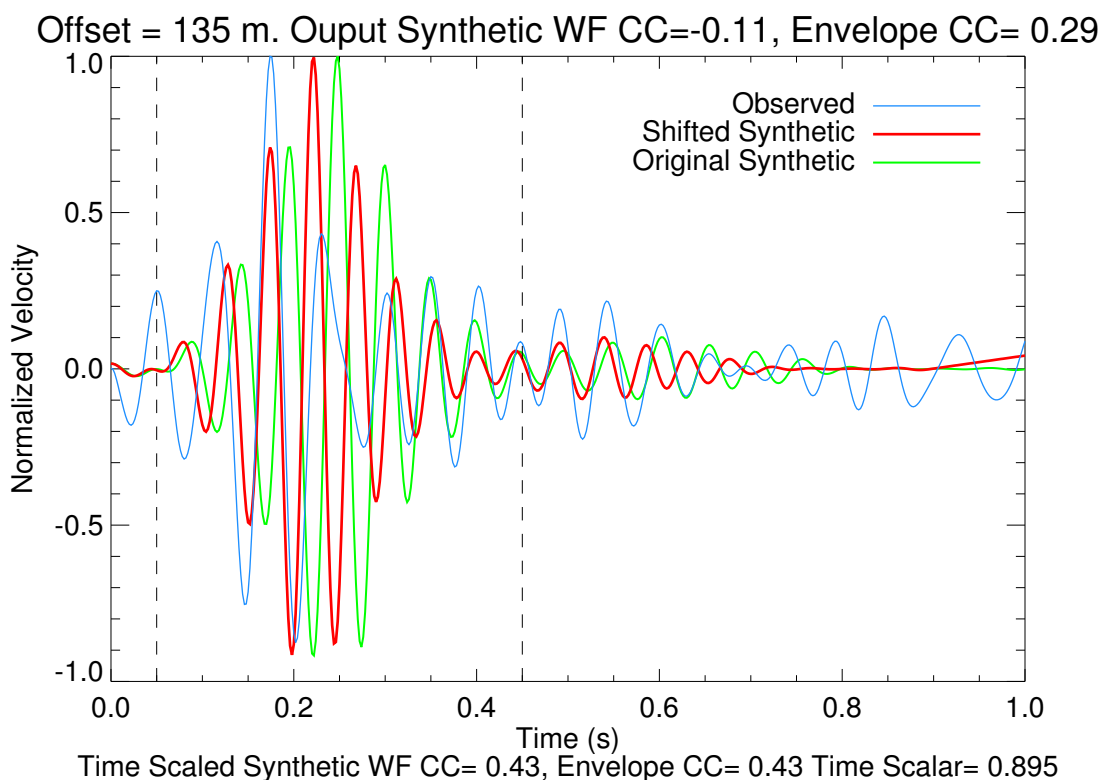
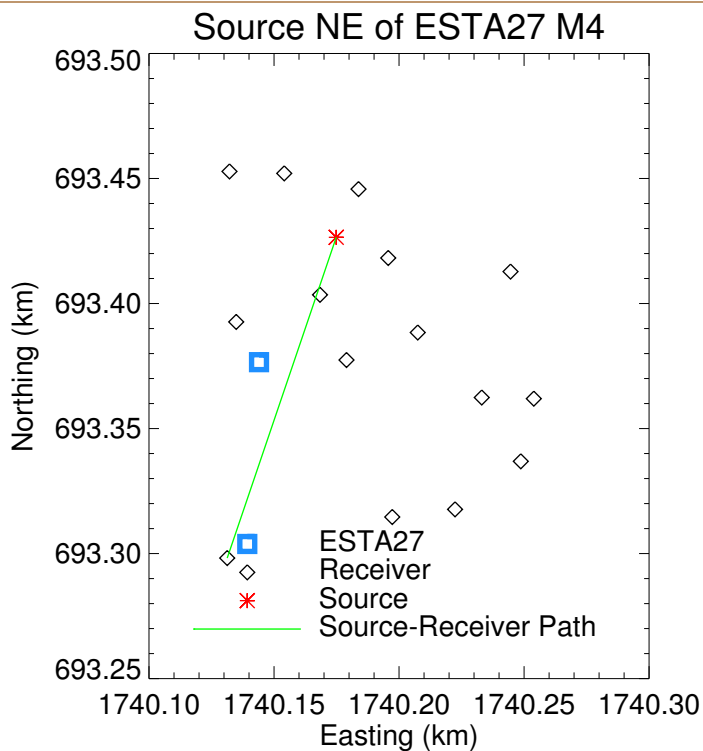
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 10 OFFSET = 75 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



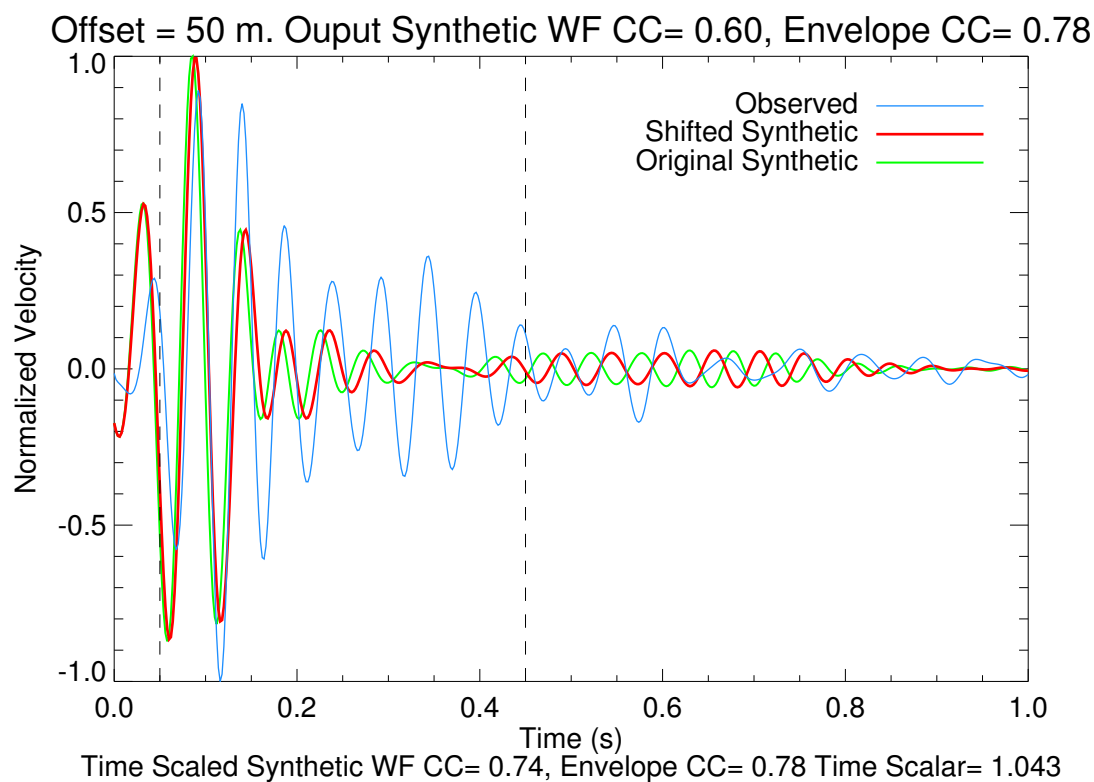
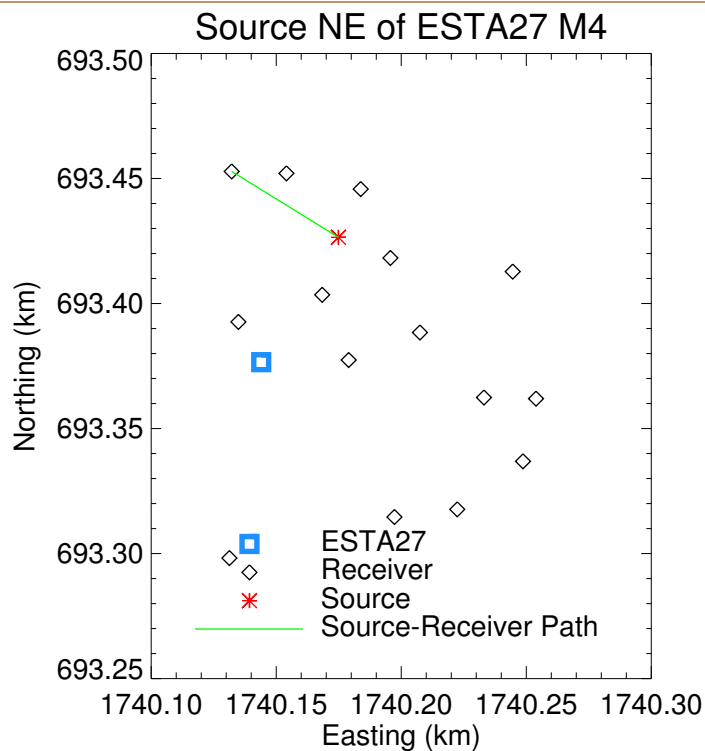
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 11 OFFSET = 119 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California



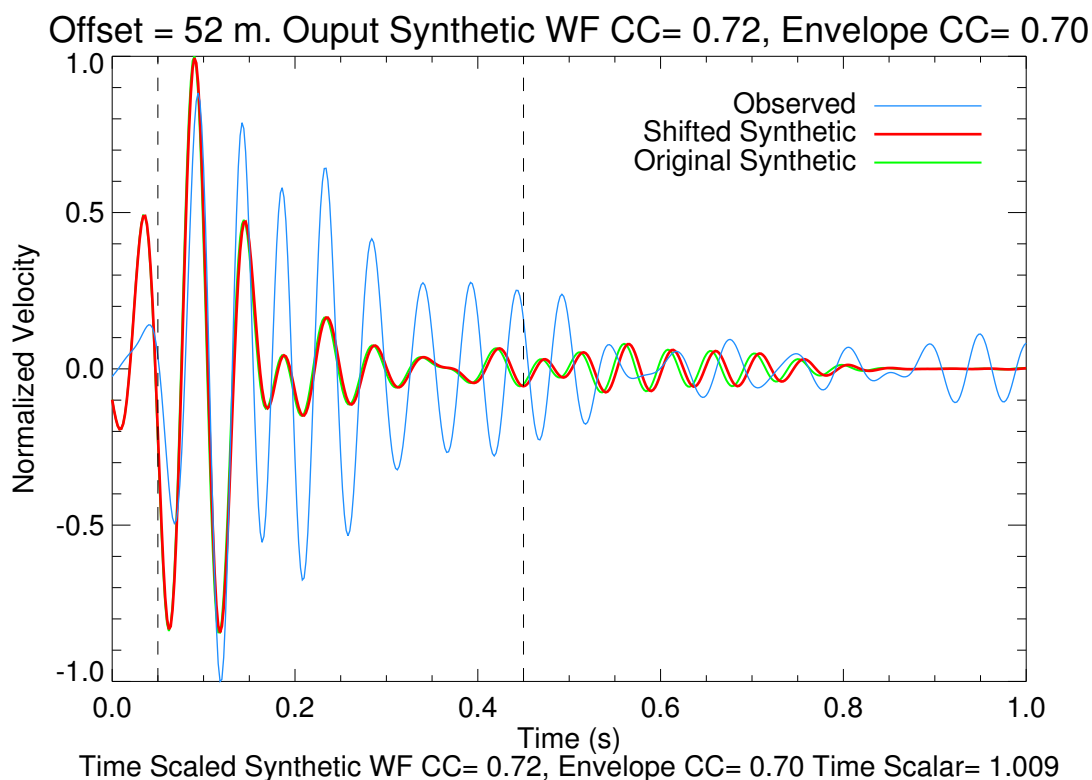
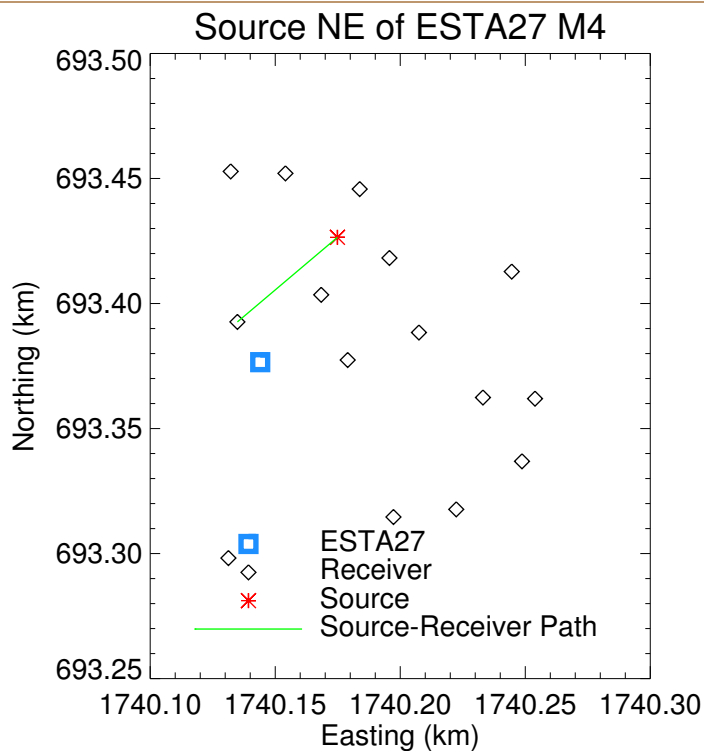
MODEL 4 CENTRAL SOUTHEAST
SOURCE-RECEIVER PAIR 12 OFFSET = 84 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California



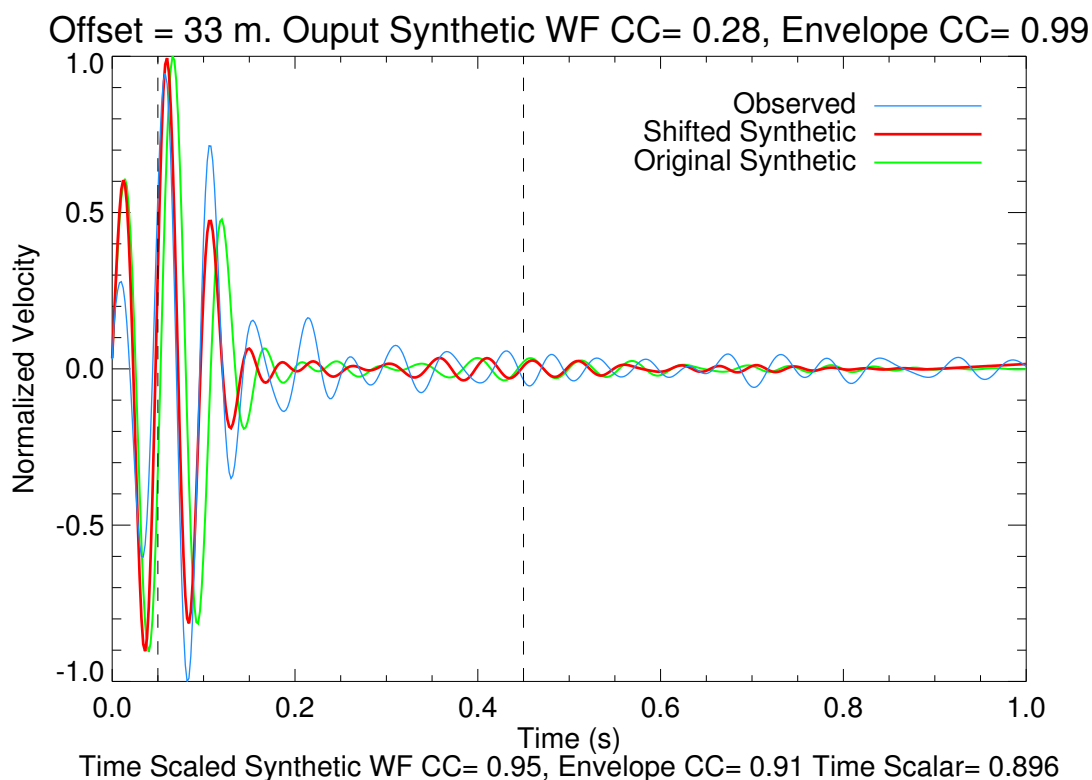
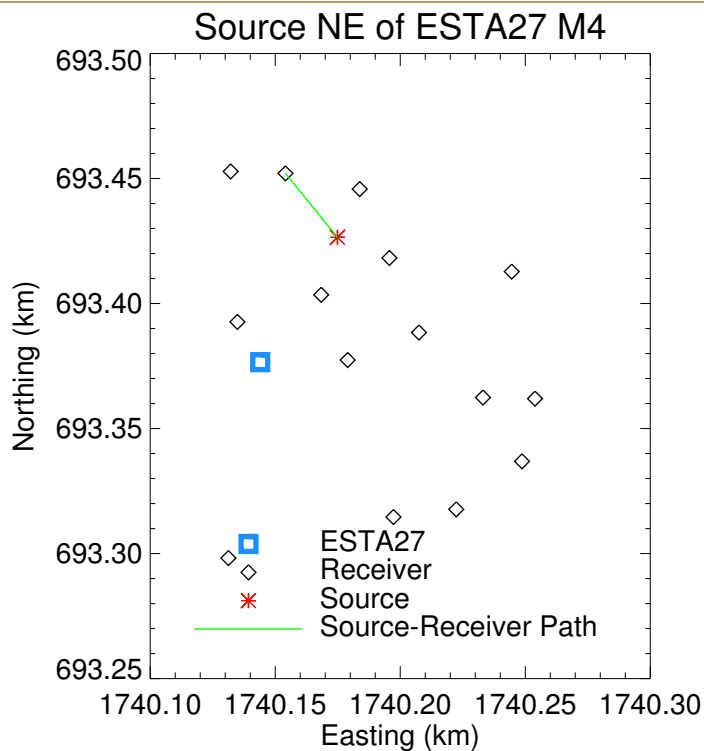
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 1 OFFSET = 135 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



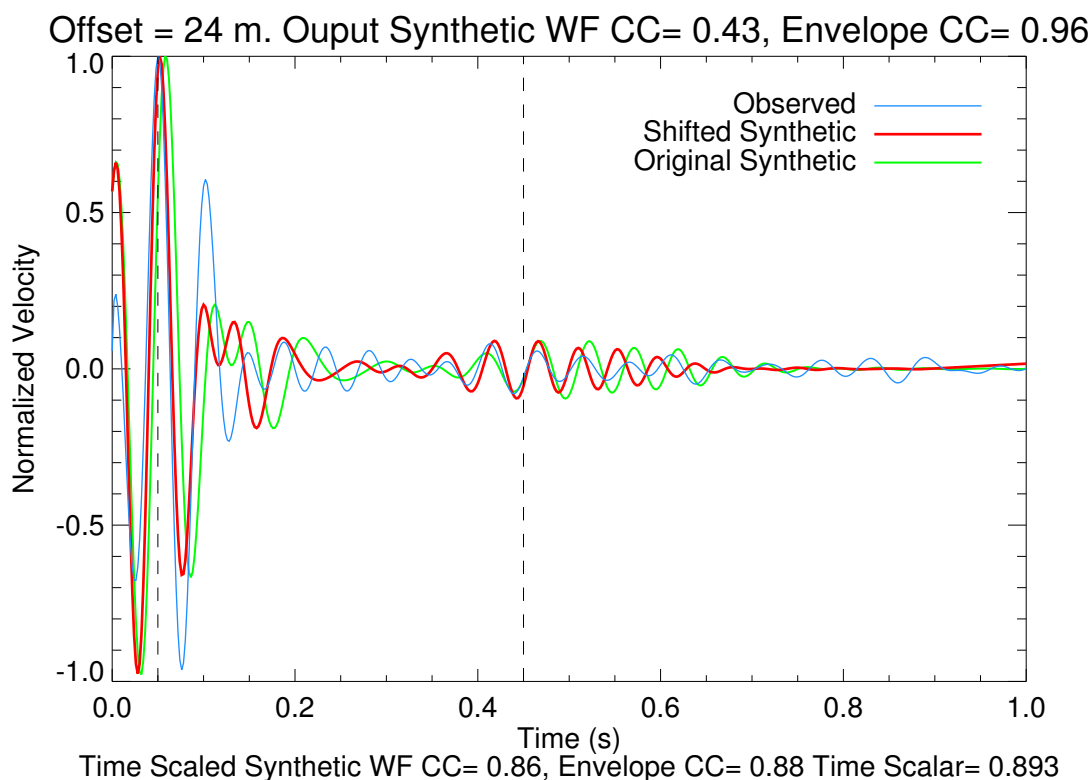
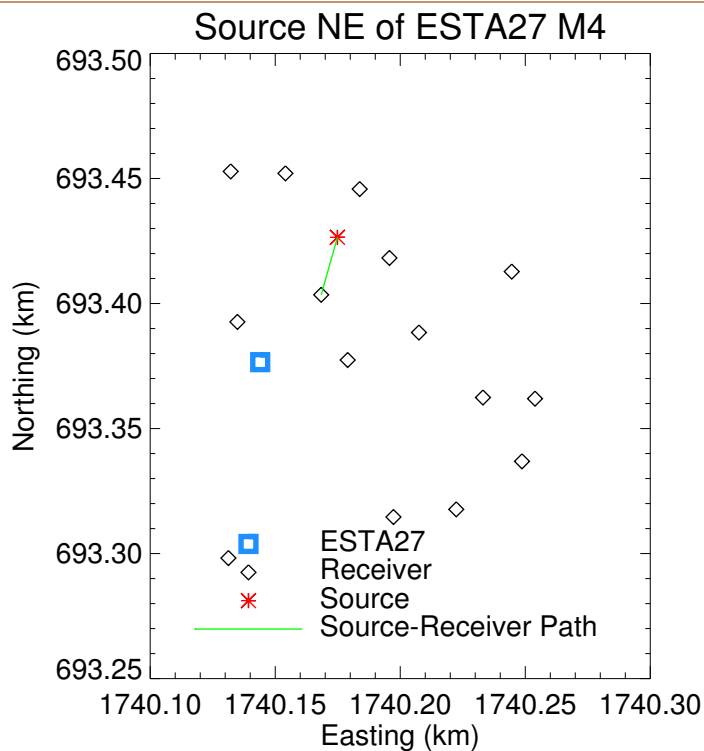
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 2 OFFSET = 50 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



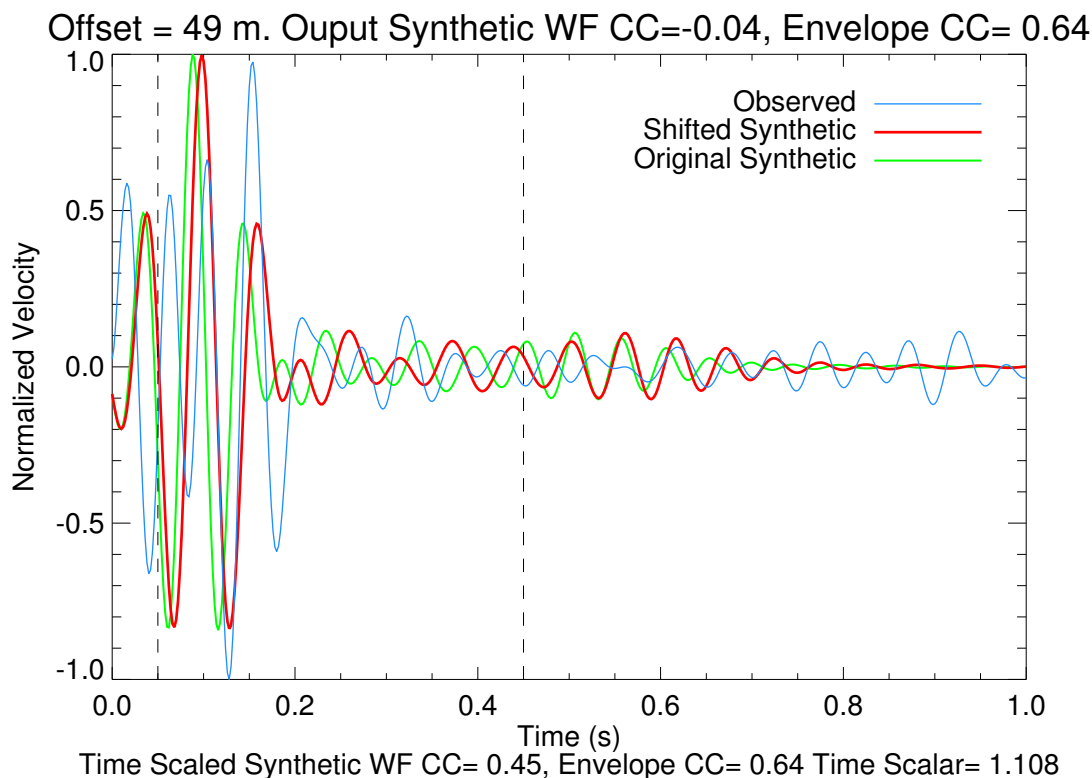
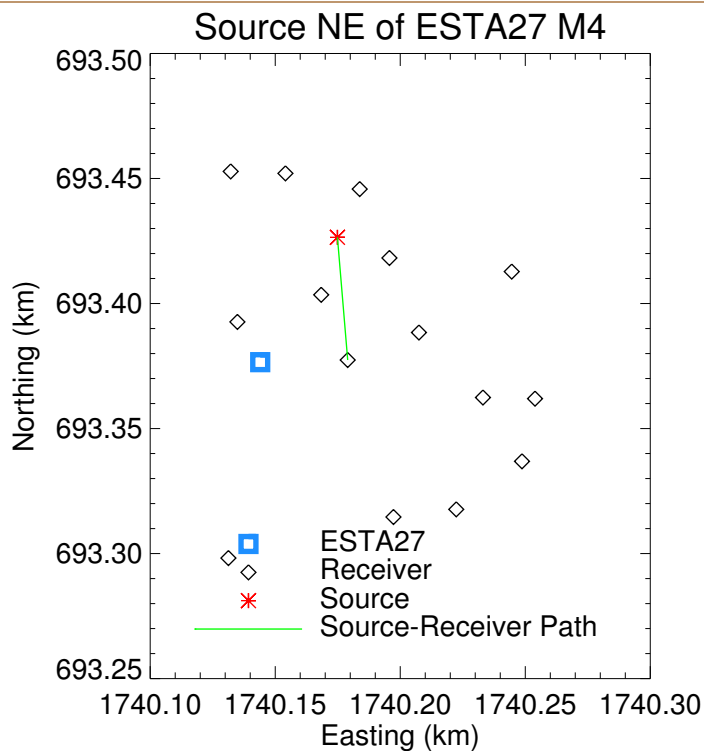
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 3 OFFSET = 52 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



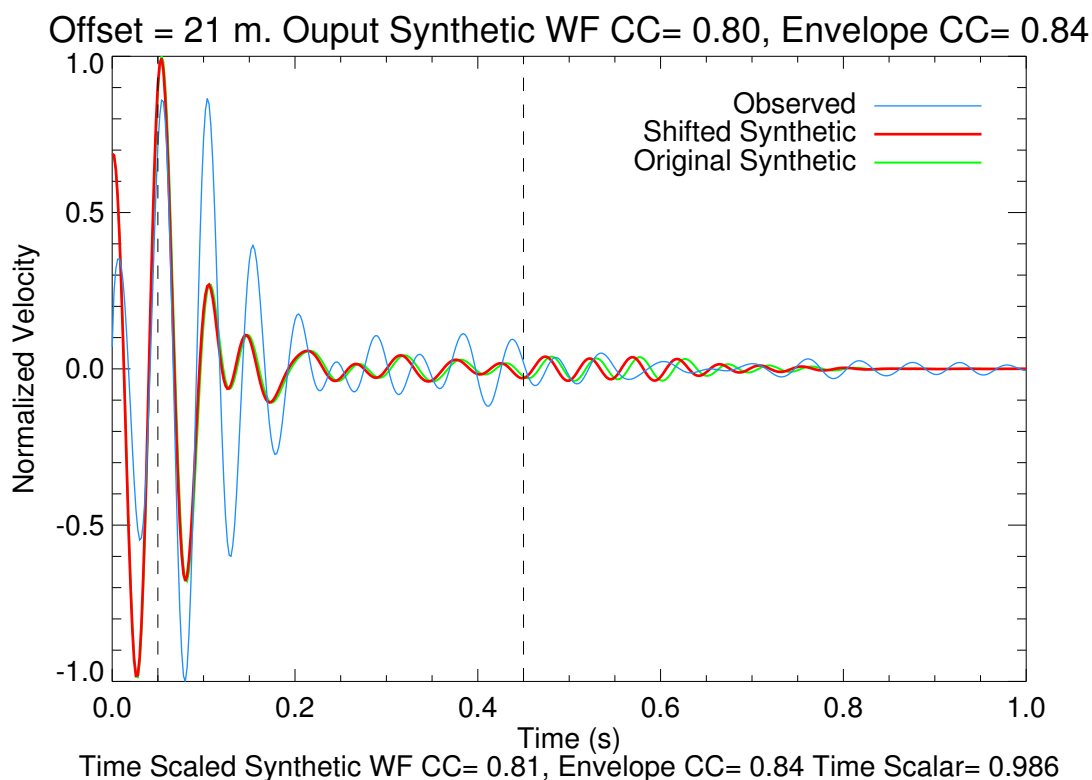
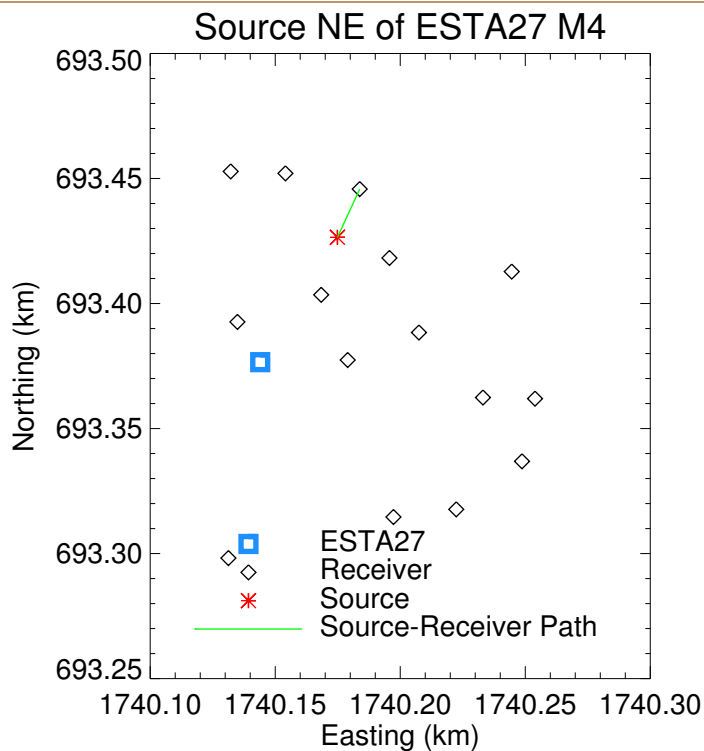
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 4 OFFSET = 33 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



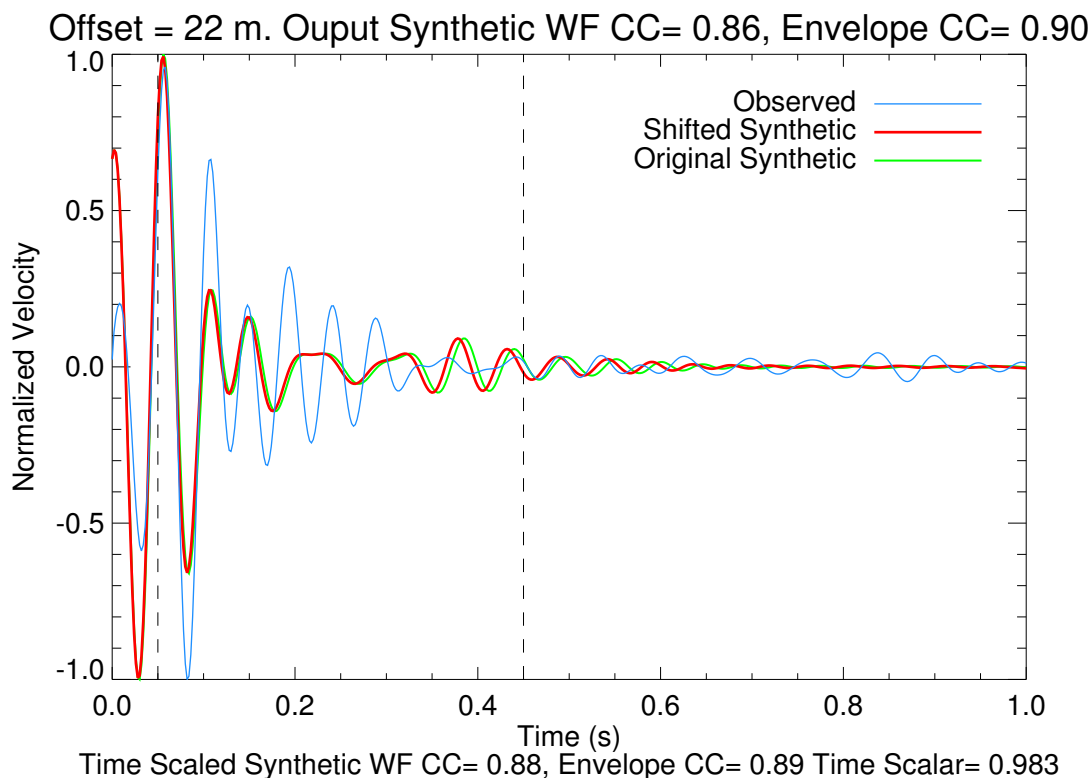
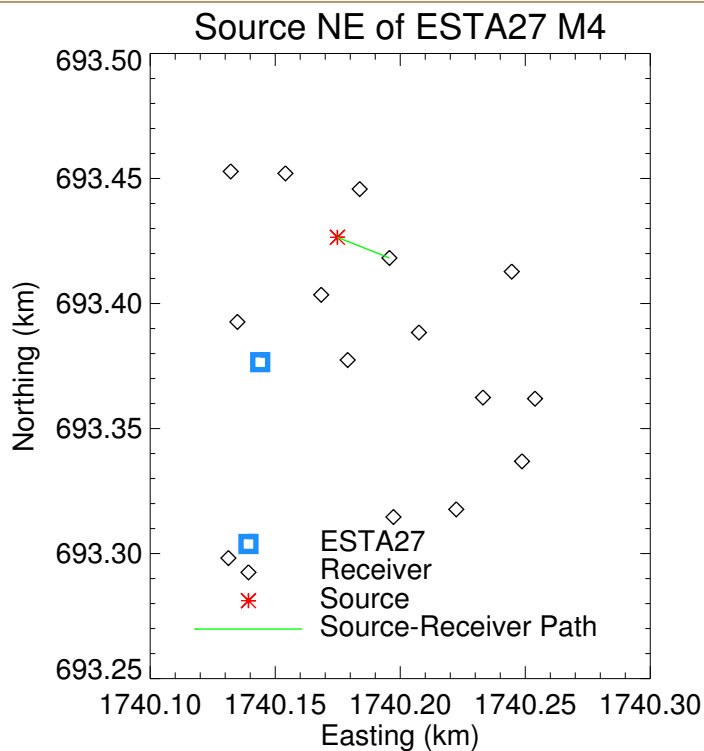
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 5 OFFSET = 24 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



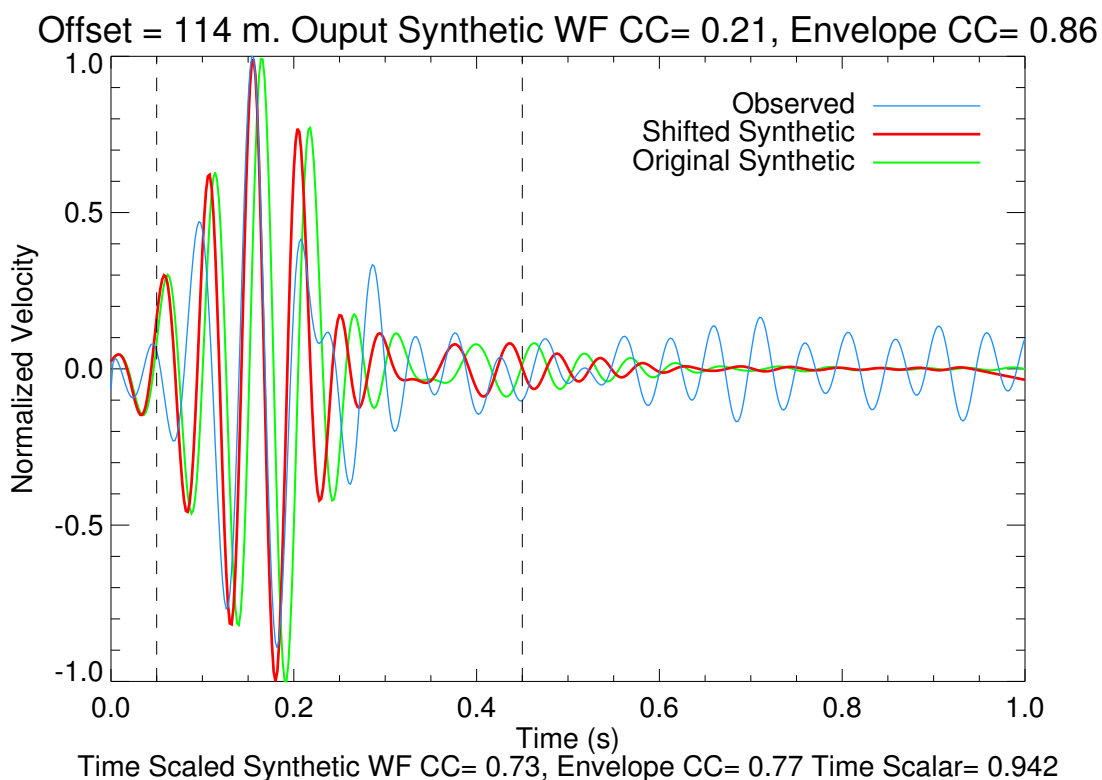
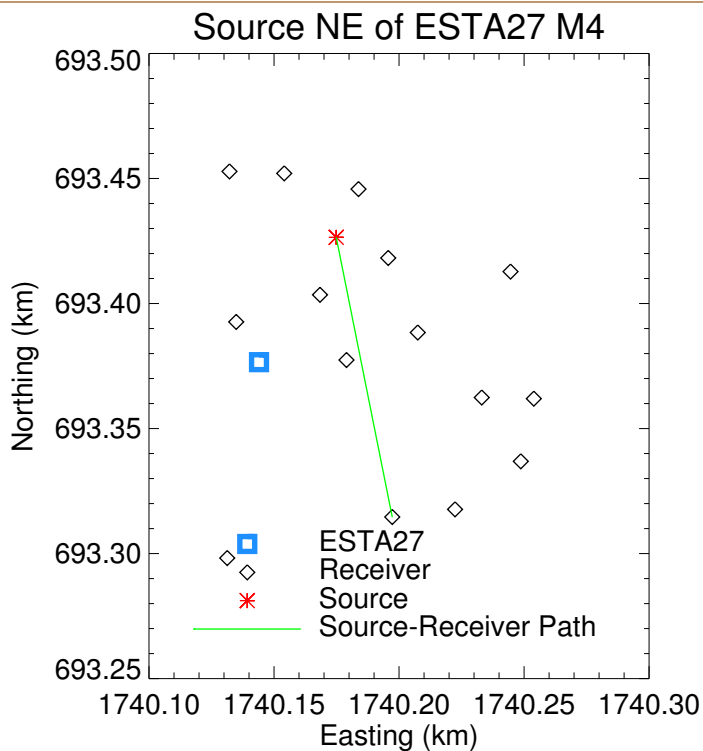
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 6 OFFSET = 49 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



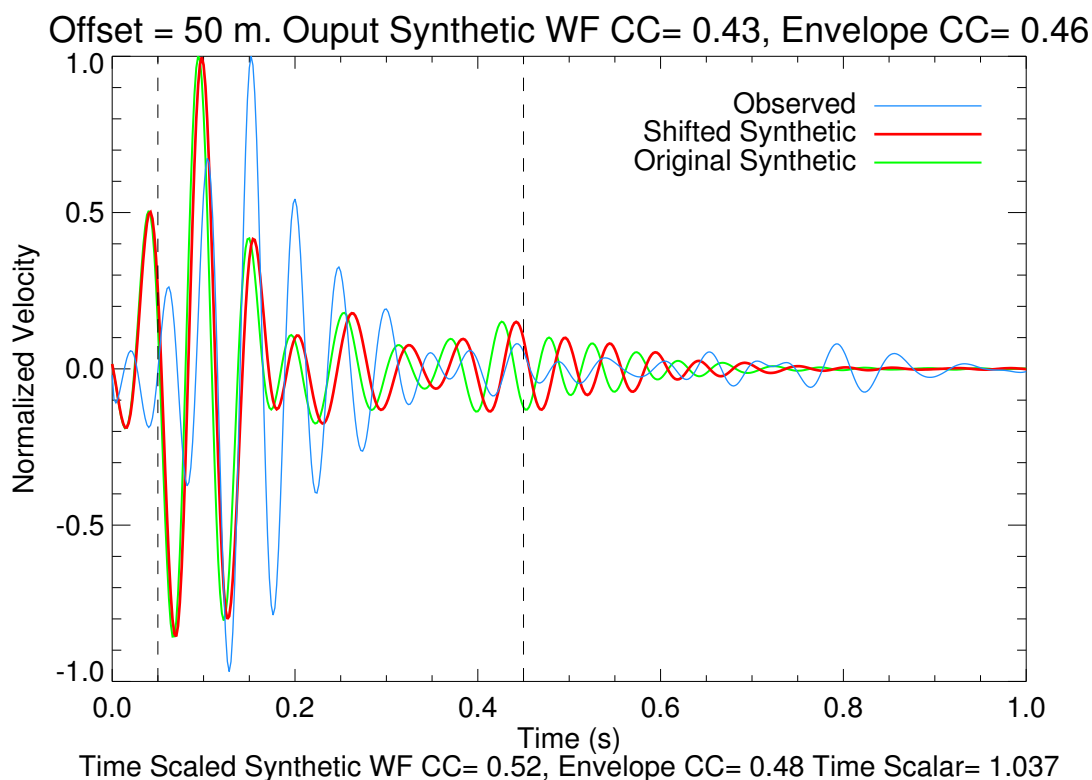
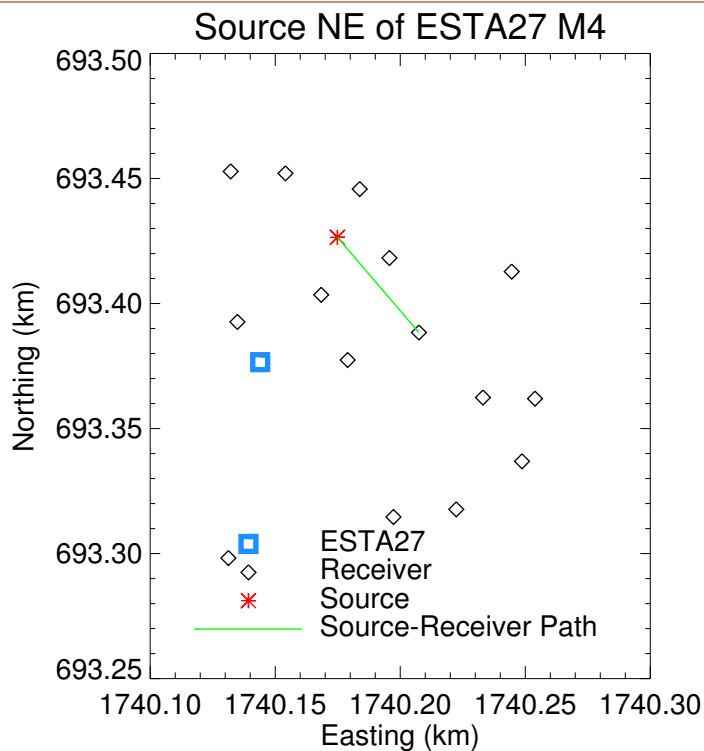
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 7 OFFSET = 21 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



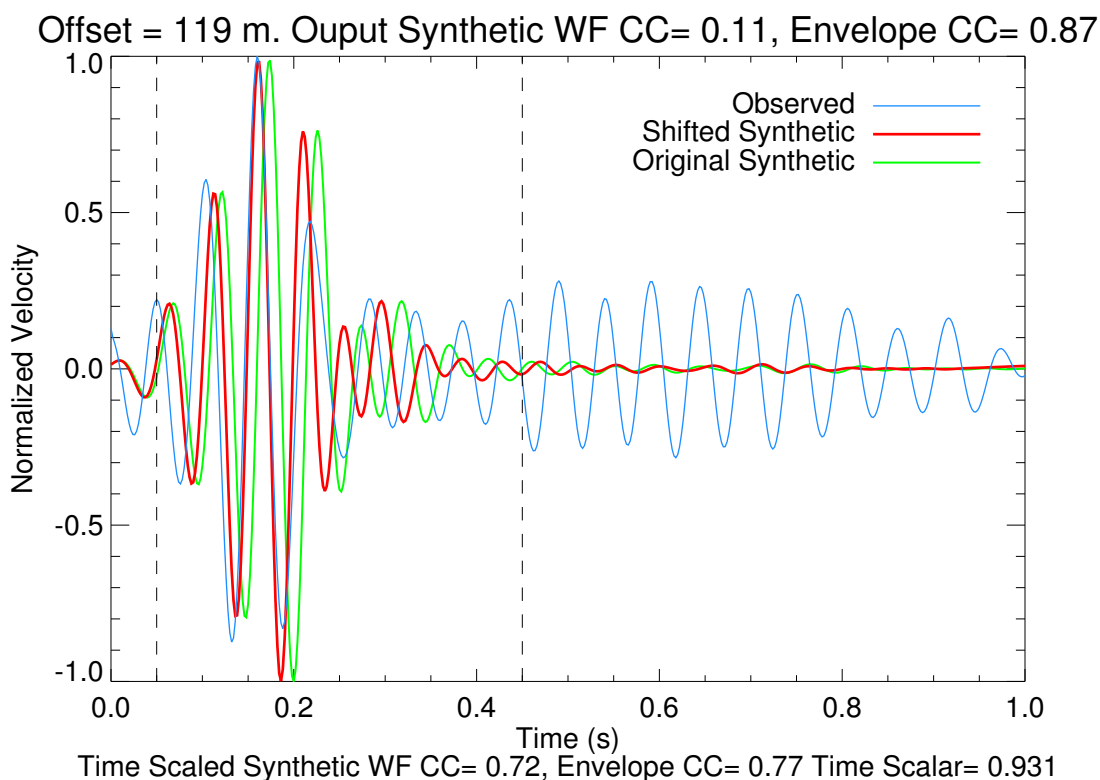
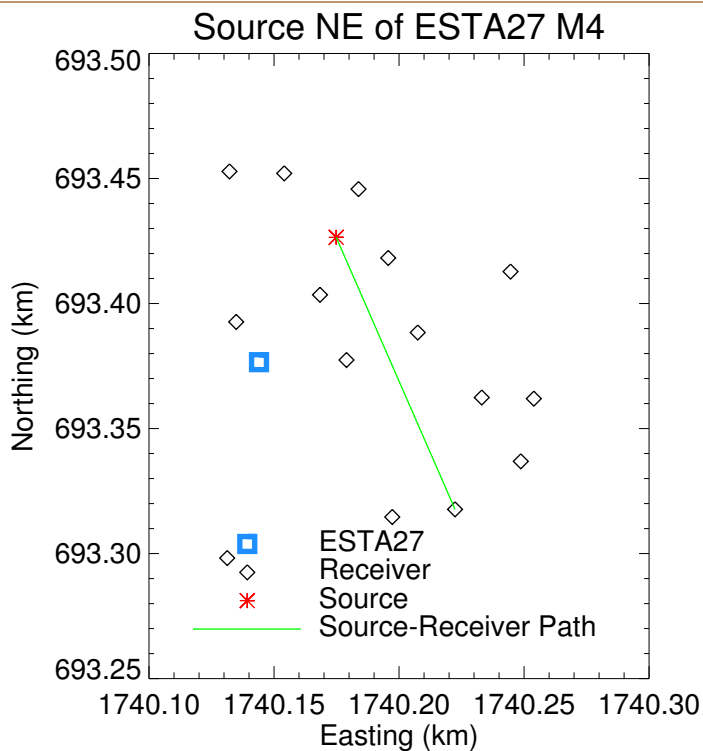
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 8 OFFSET = 22 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



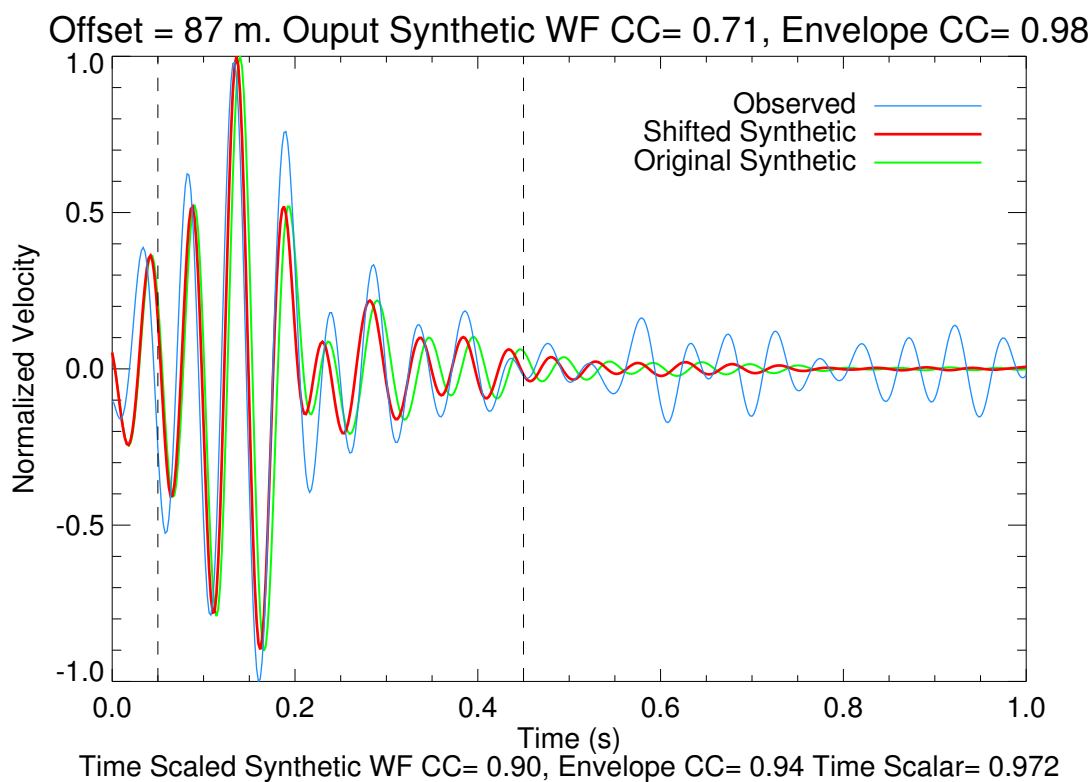
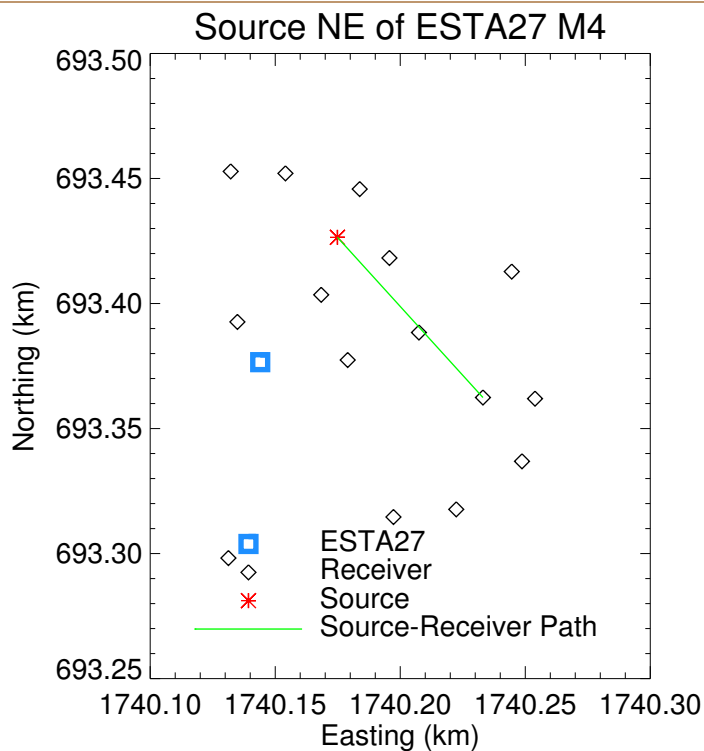
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 9 OFFSET = 114 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



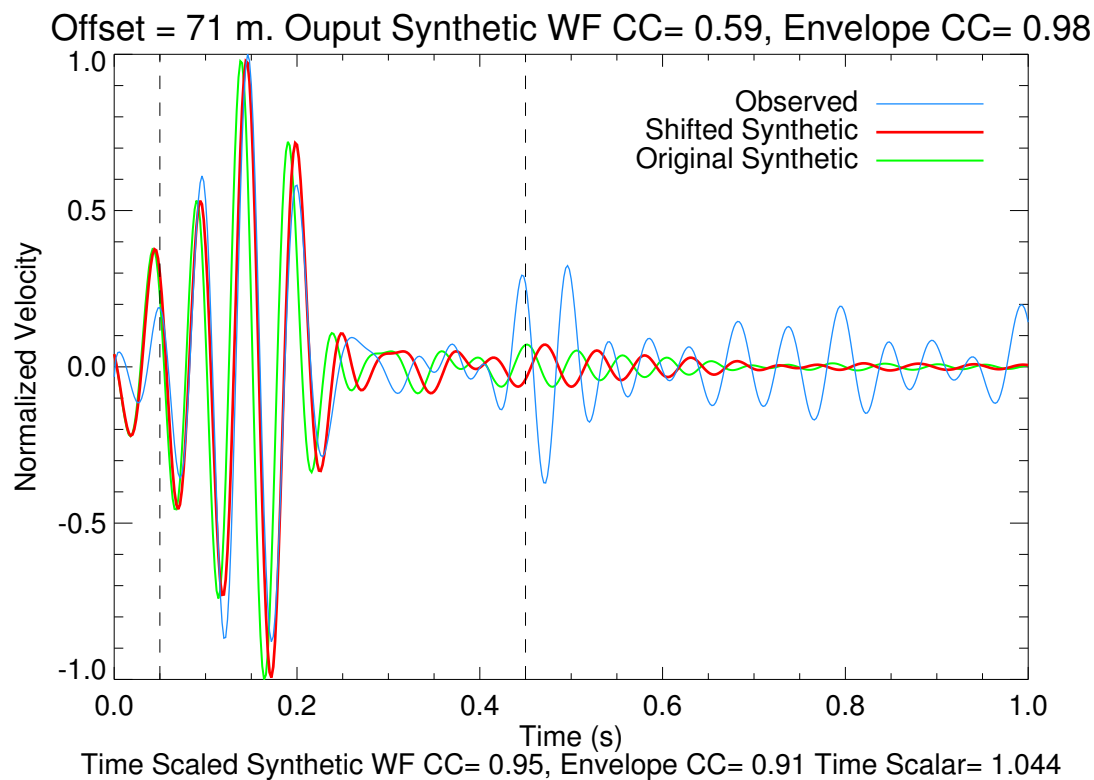
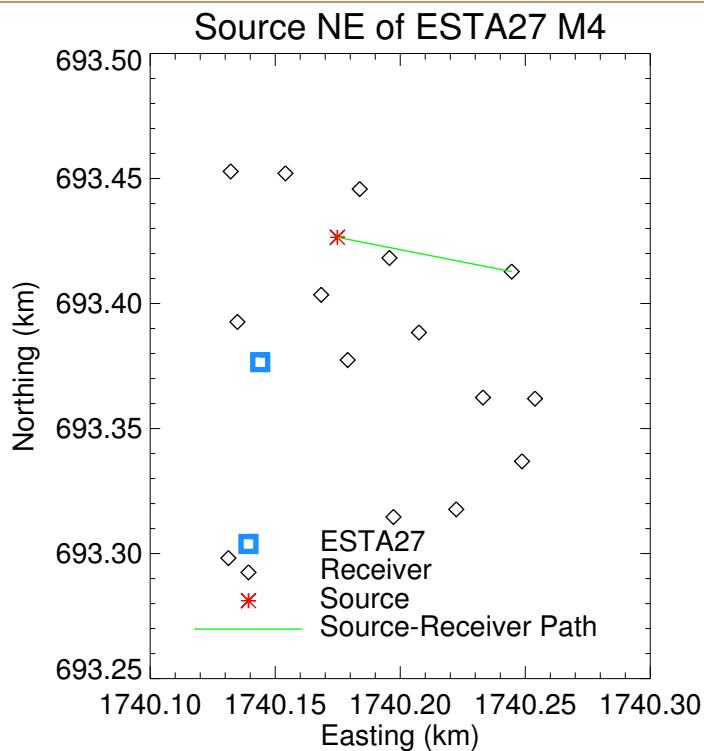
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 10 OFFSET = 50 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



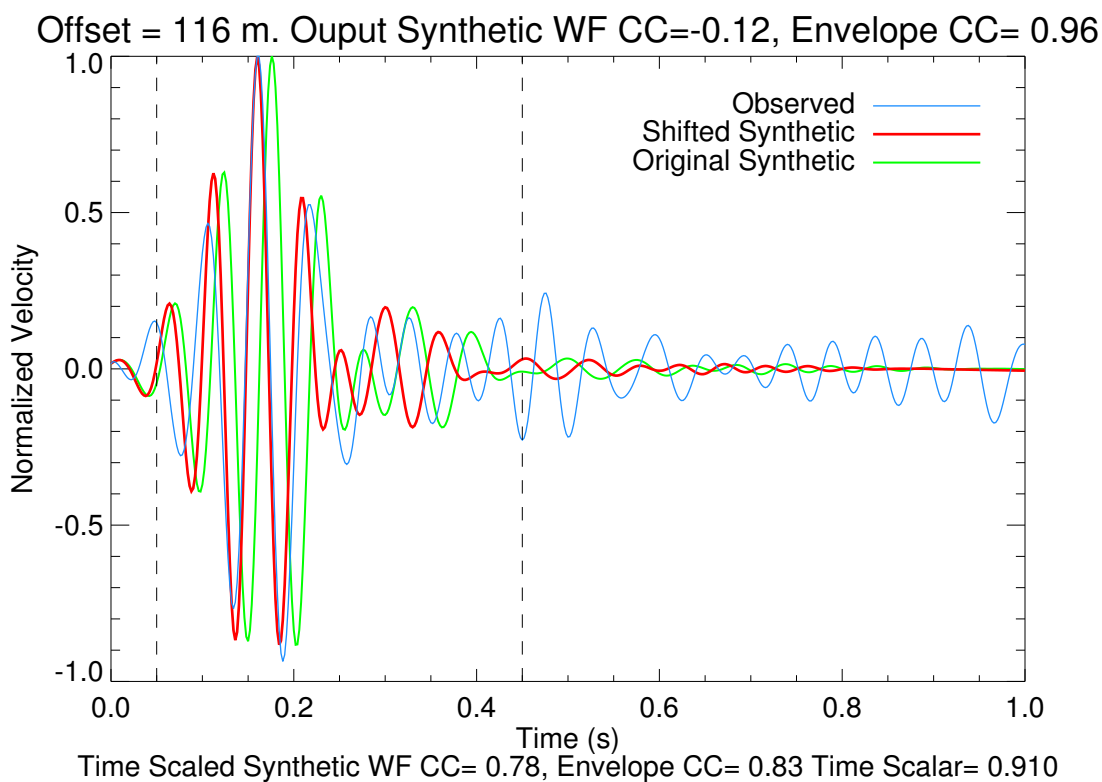
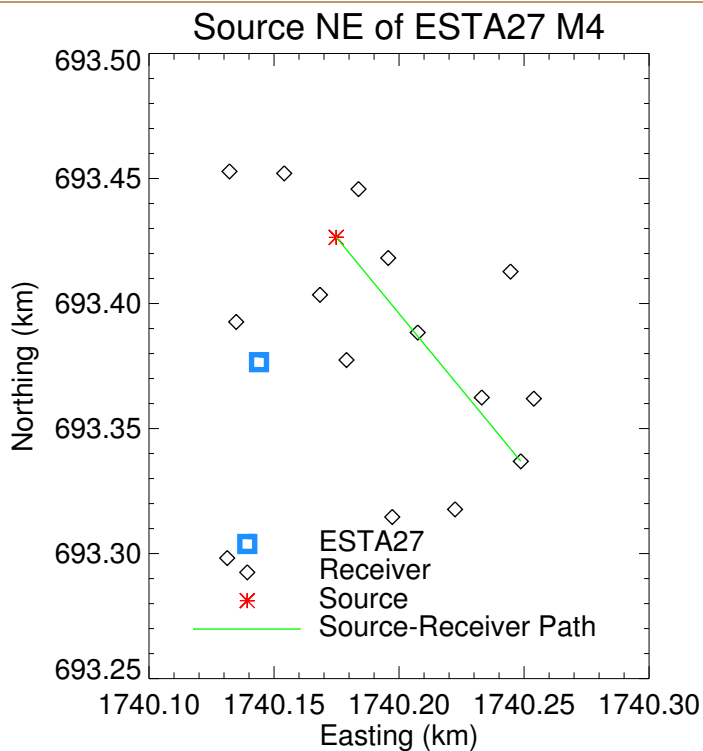
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 11 OFFSET = 119 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



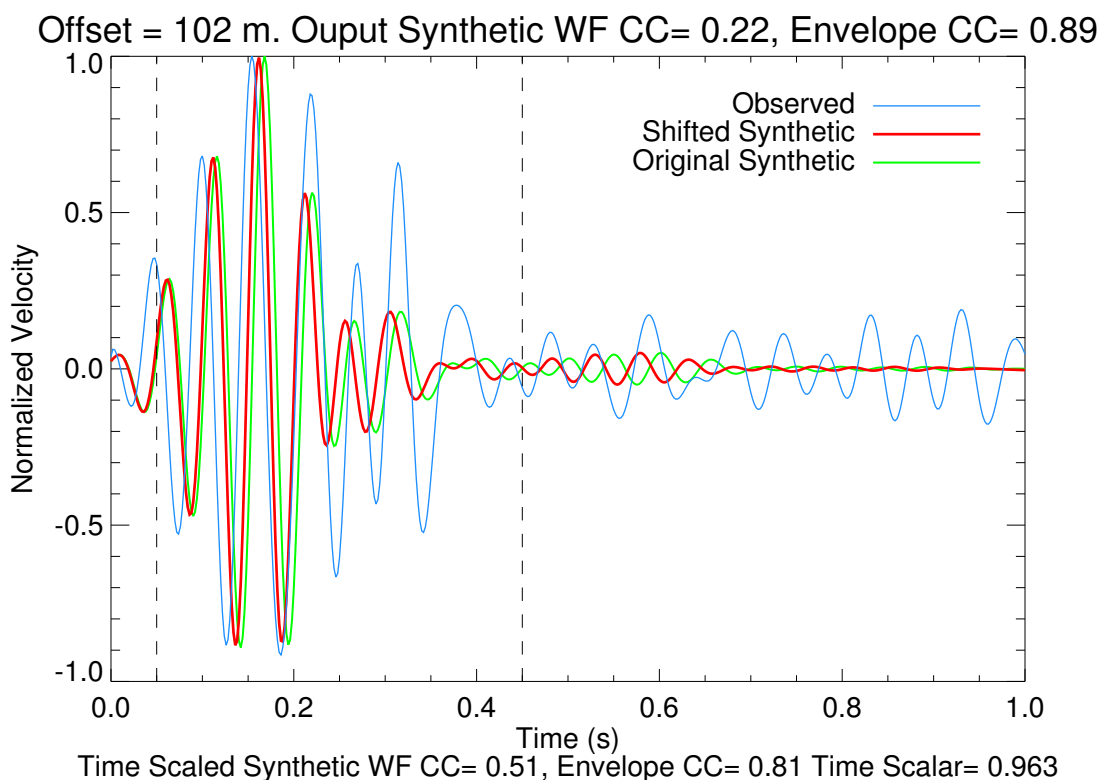
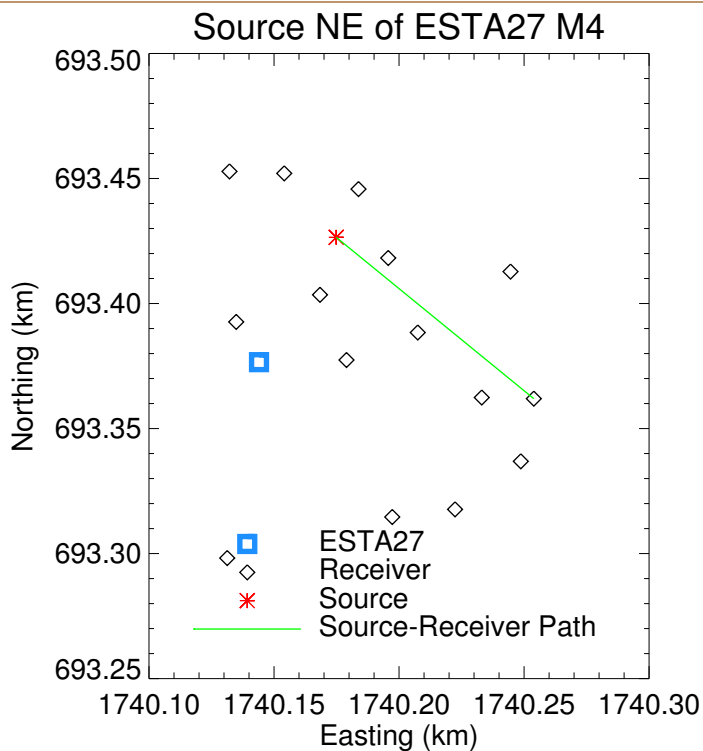
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 12 OFFSET = 87 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



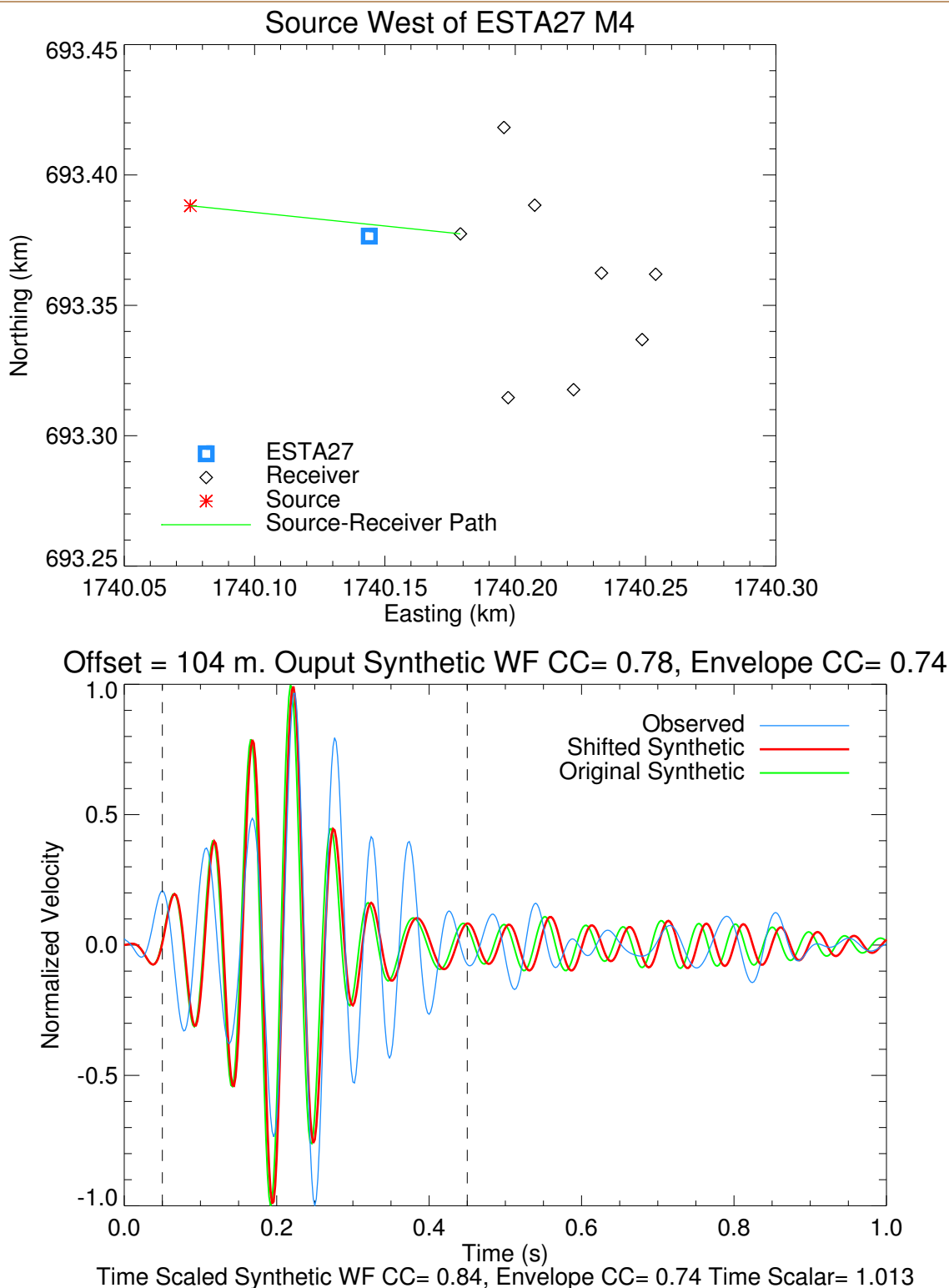
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 13 OFFSET = 71 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



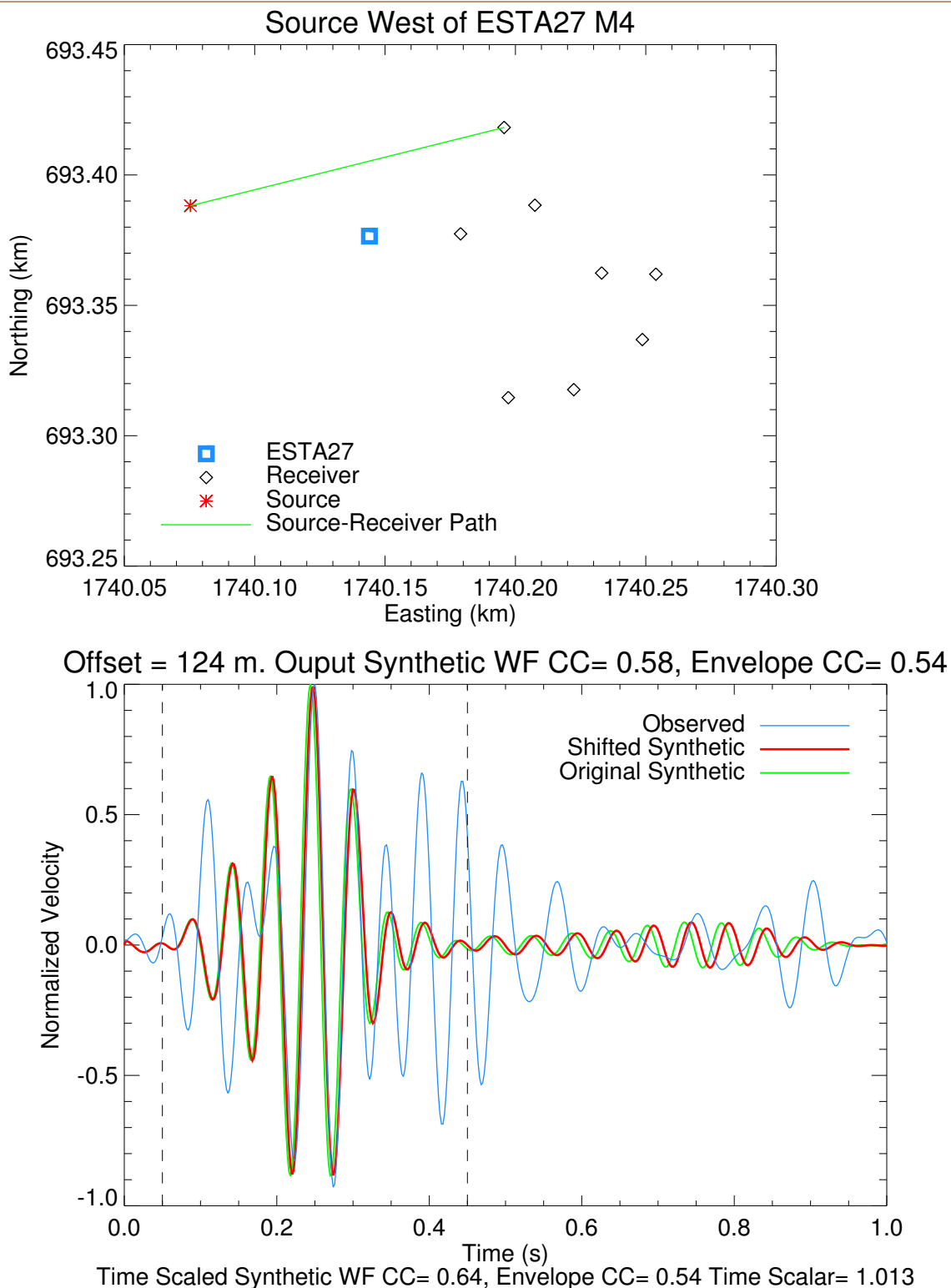
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 14 OFFSET = 116 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



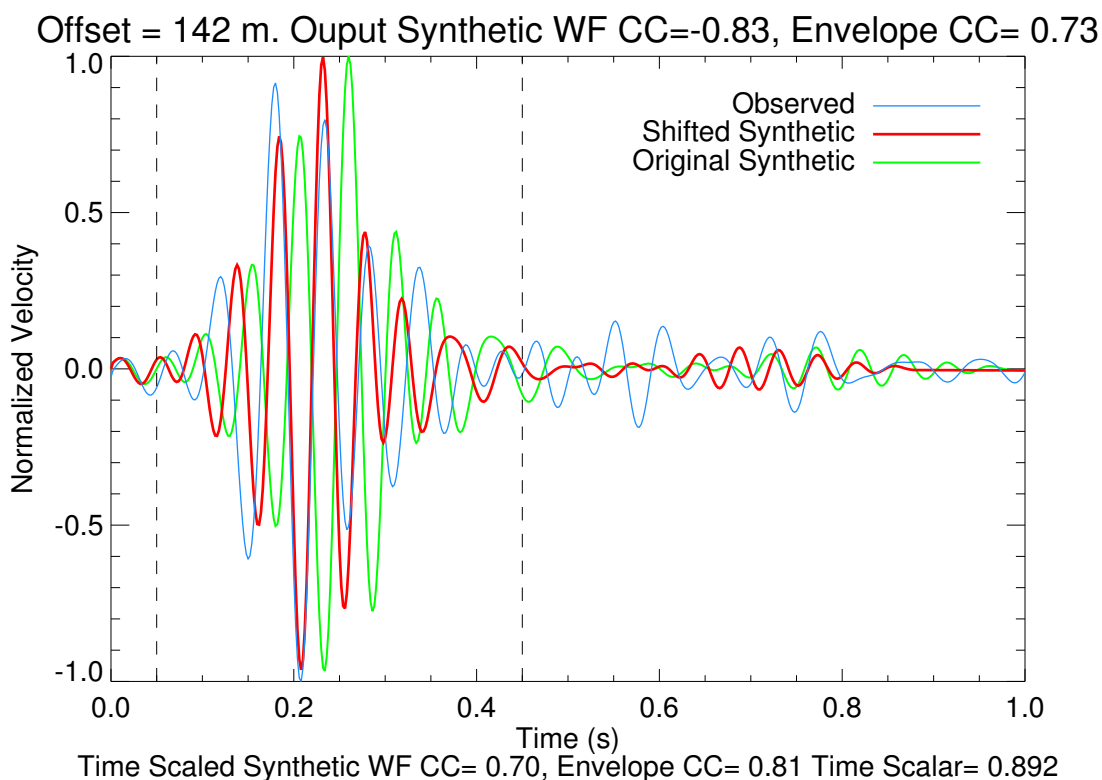
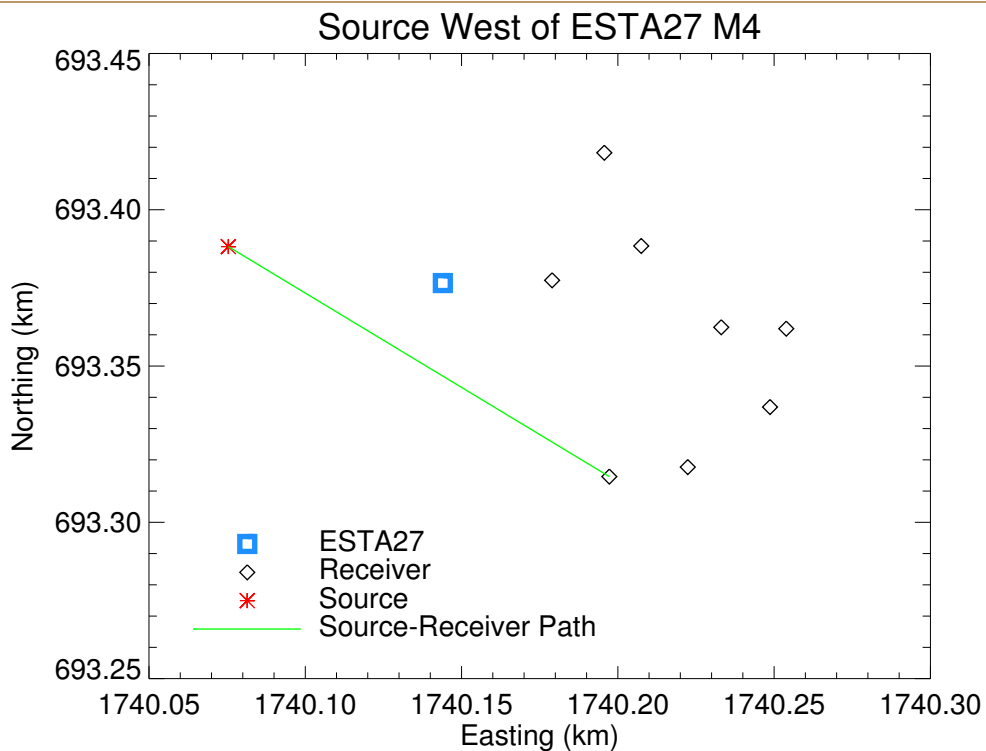
MODEL 4 SOURCE NE OF ESTA27
SOURCE-RECEIVER PAIR 15 OFFSET = 102 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



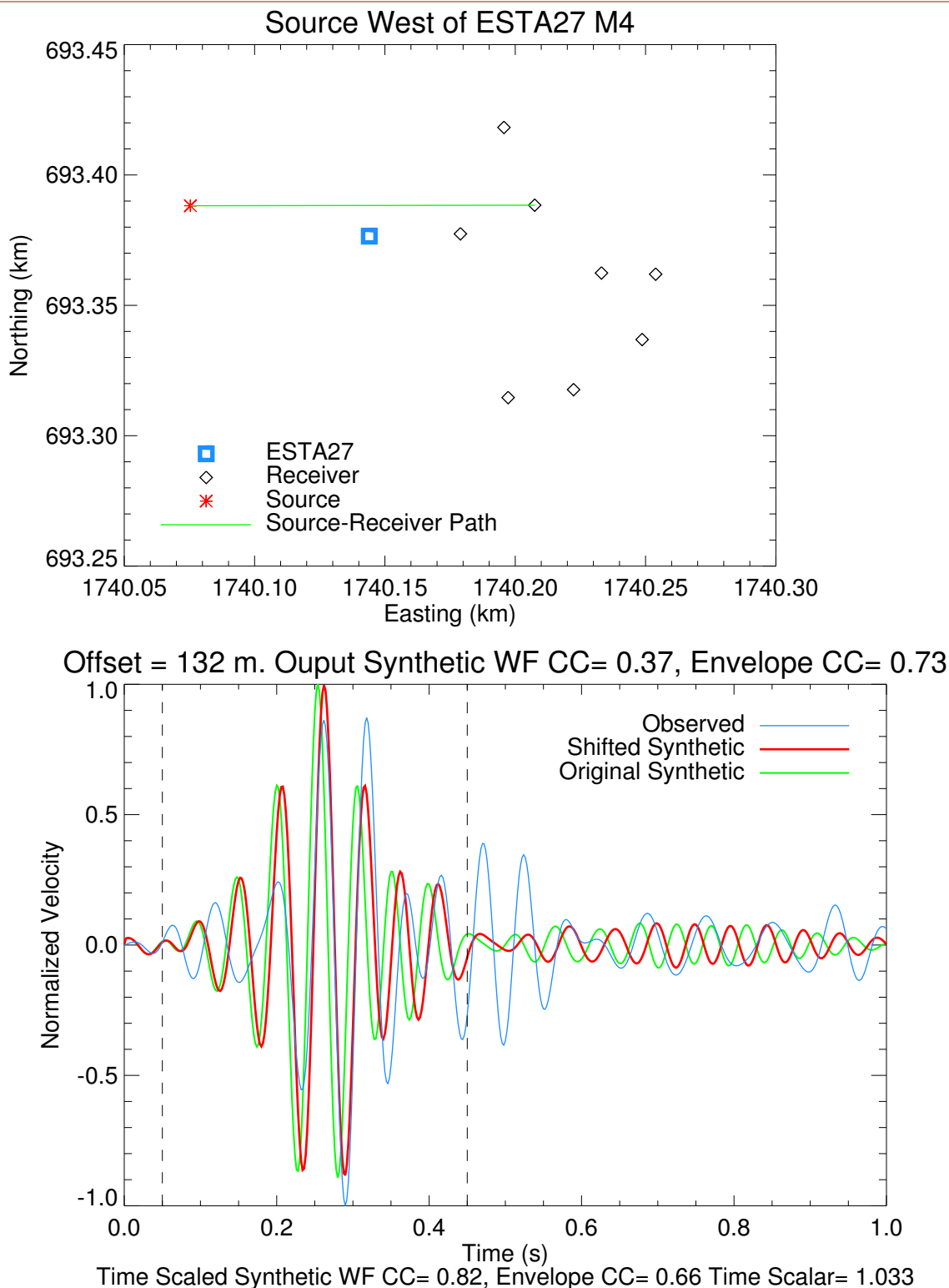
MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 1 OFFSET = 104 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



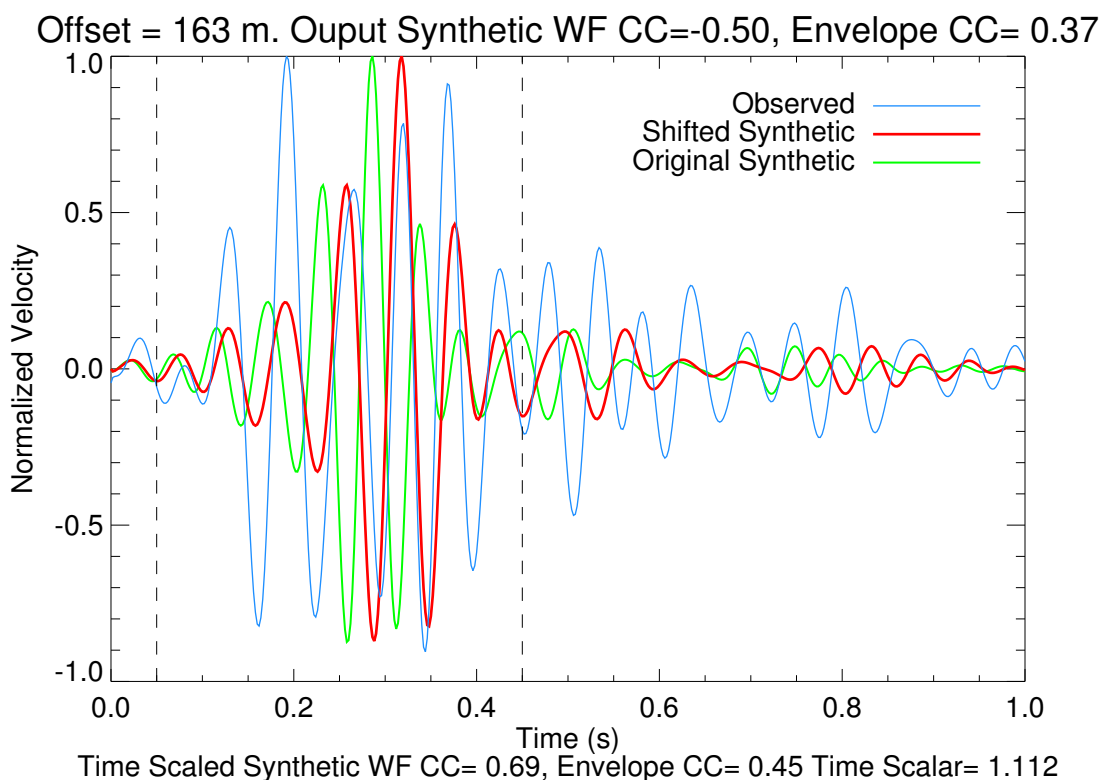
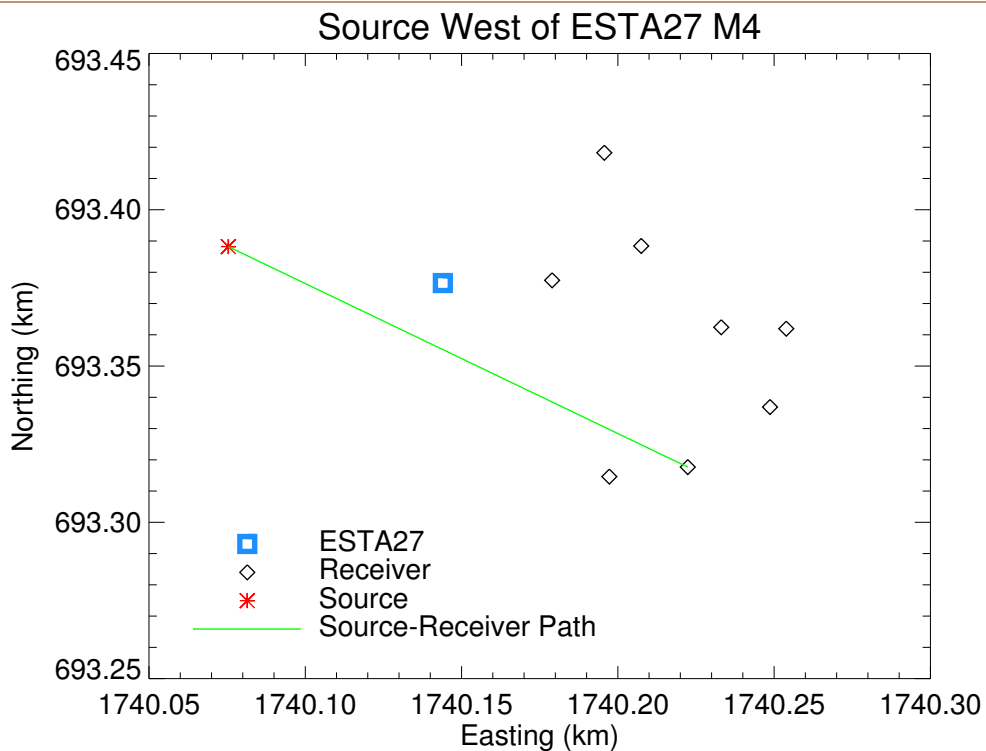
MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 2 OFFSET = 124 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



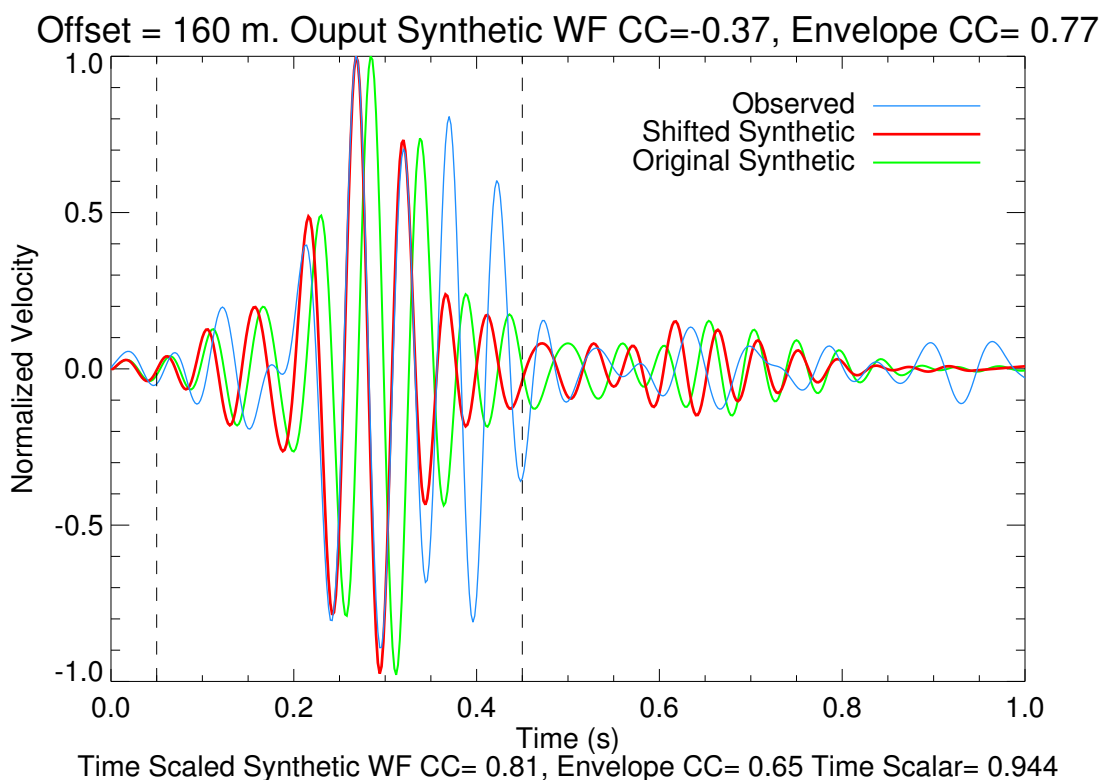
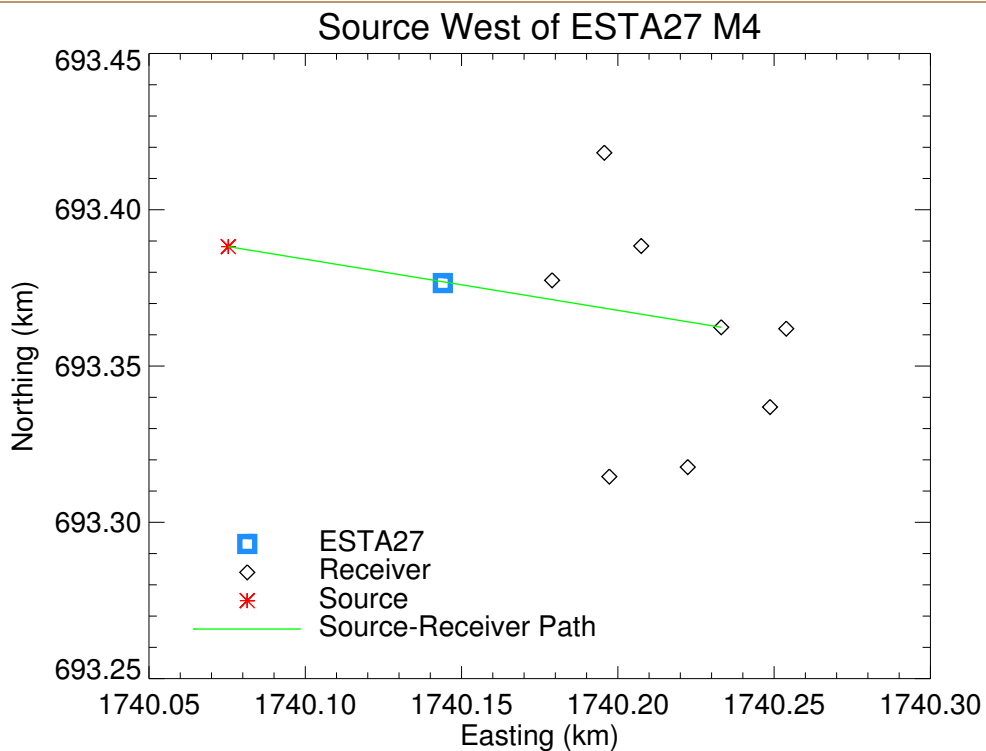
MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 3 OFFSET = 142 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



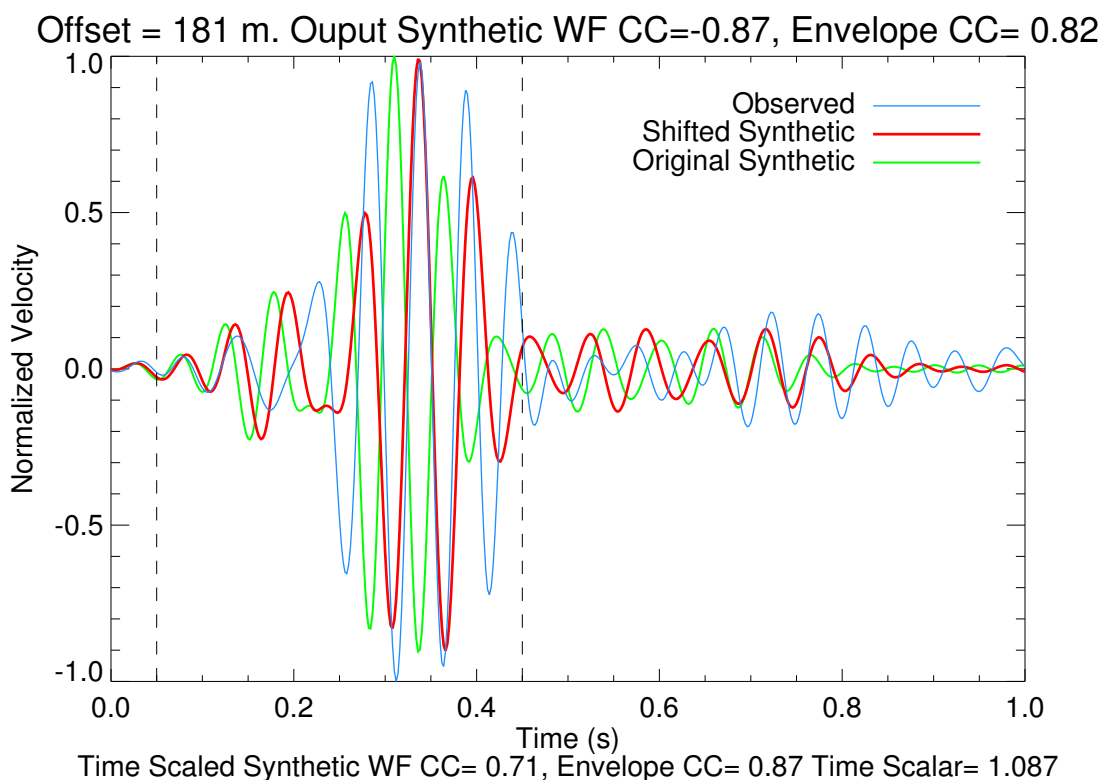
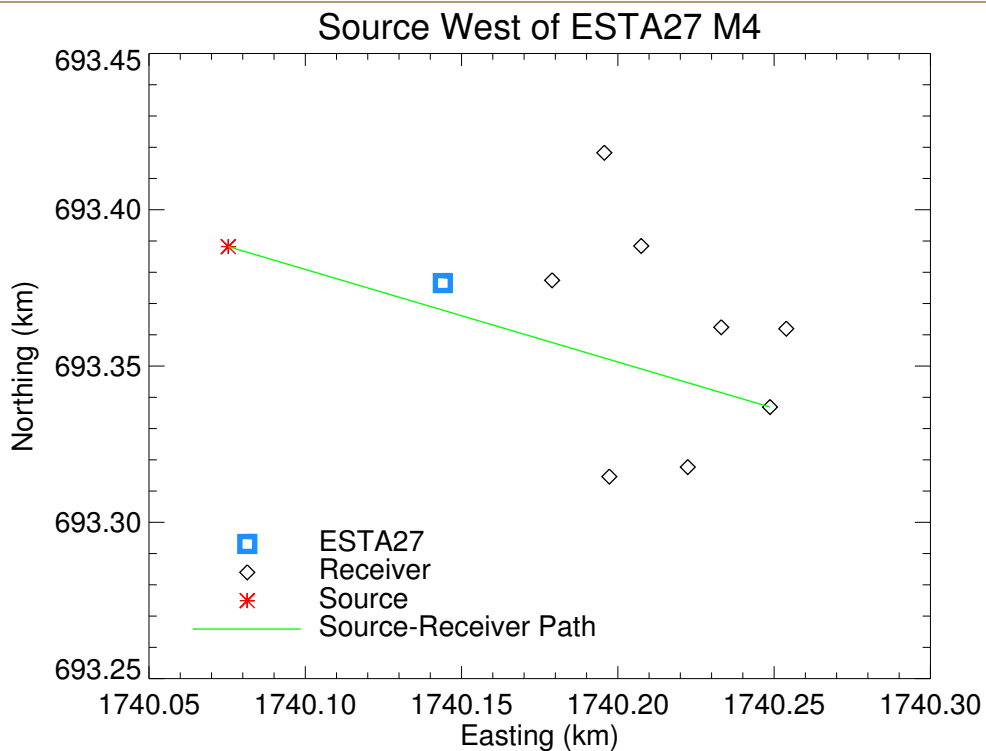
MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 4 OFFSET = 132 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



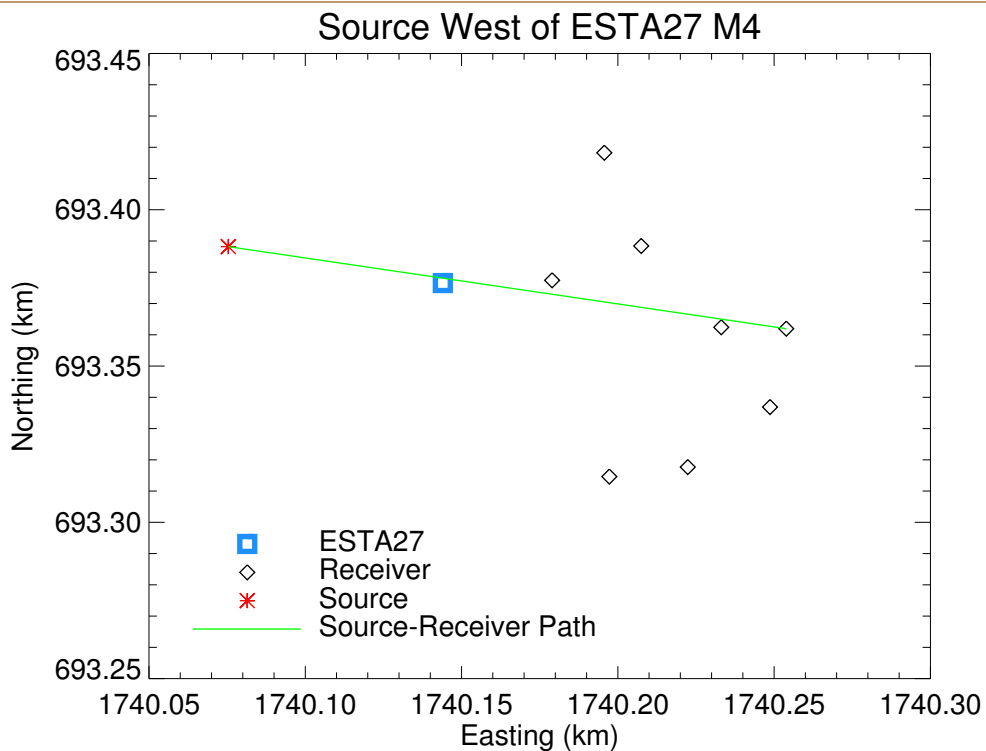
MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 5 OFFSET = 163 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California



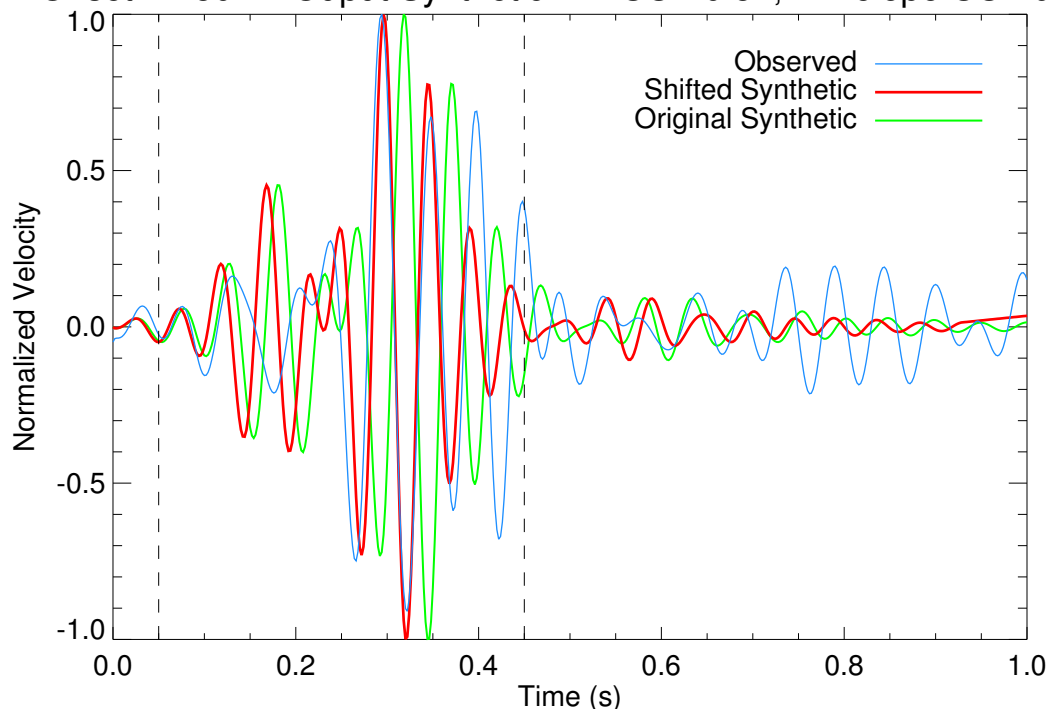
MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 6 OFFSET = 160 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 7 OFFSET = 181 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California

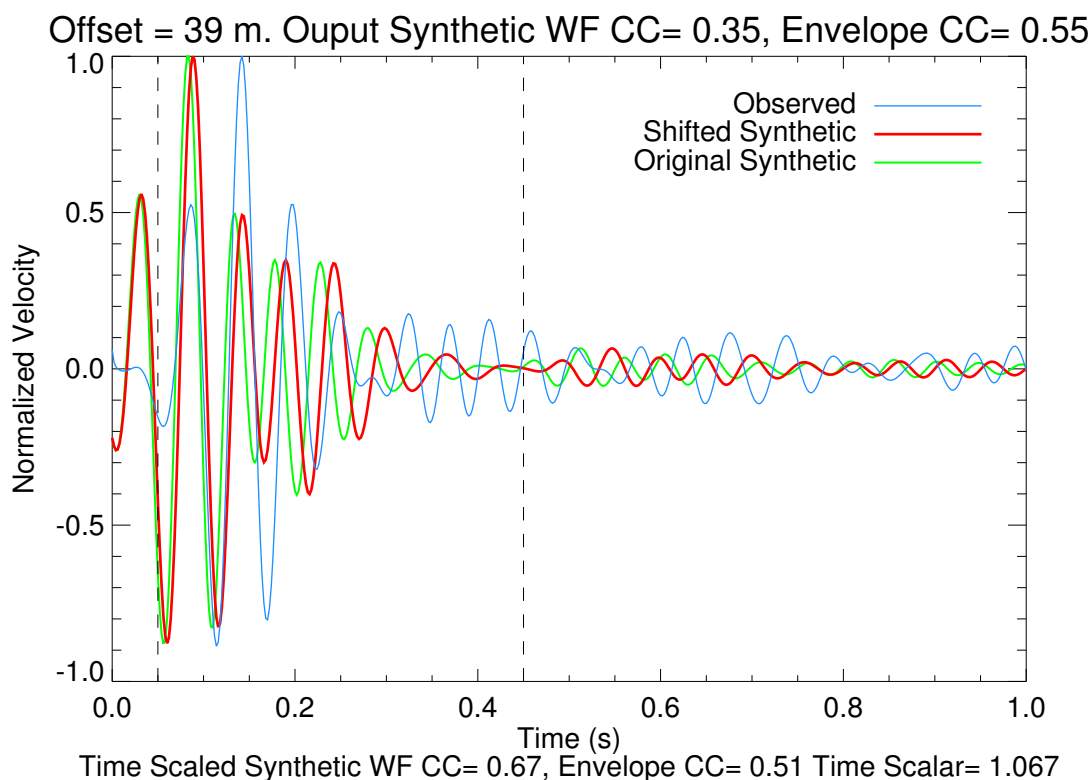
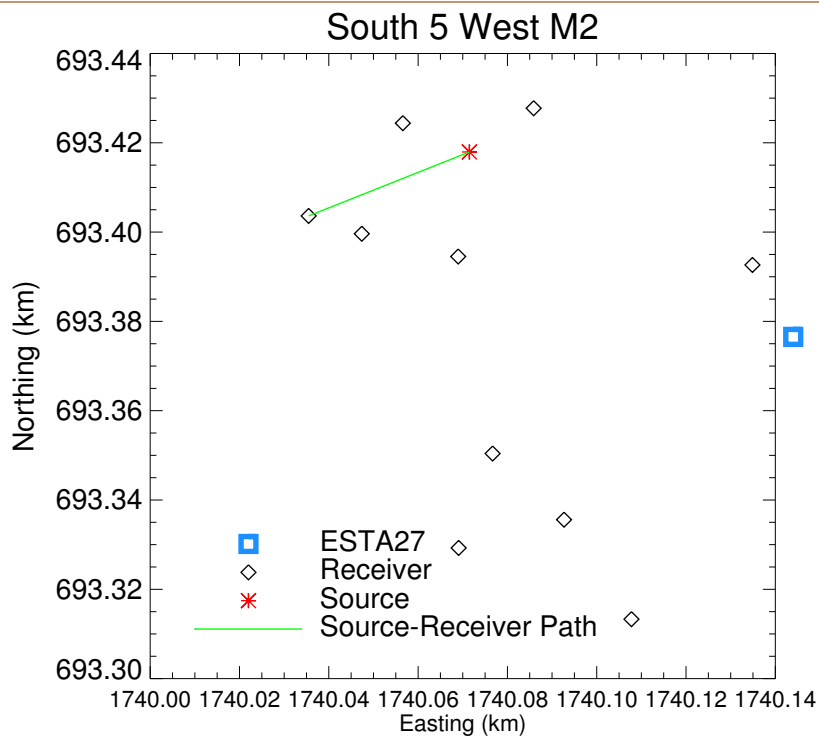


Offset = 180 m. Output Synthetic WF CC=-0.81, Envelope CC= 0.70

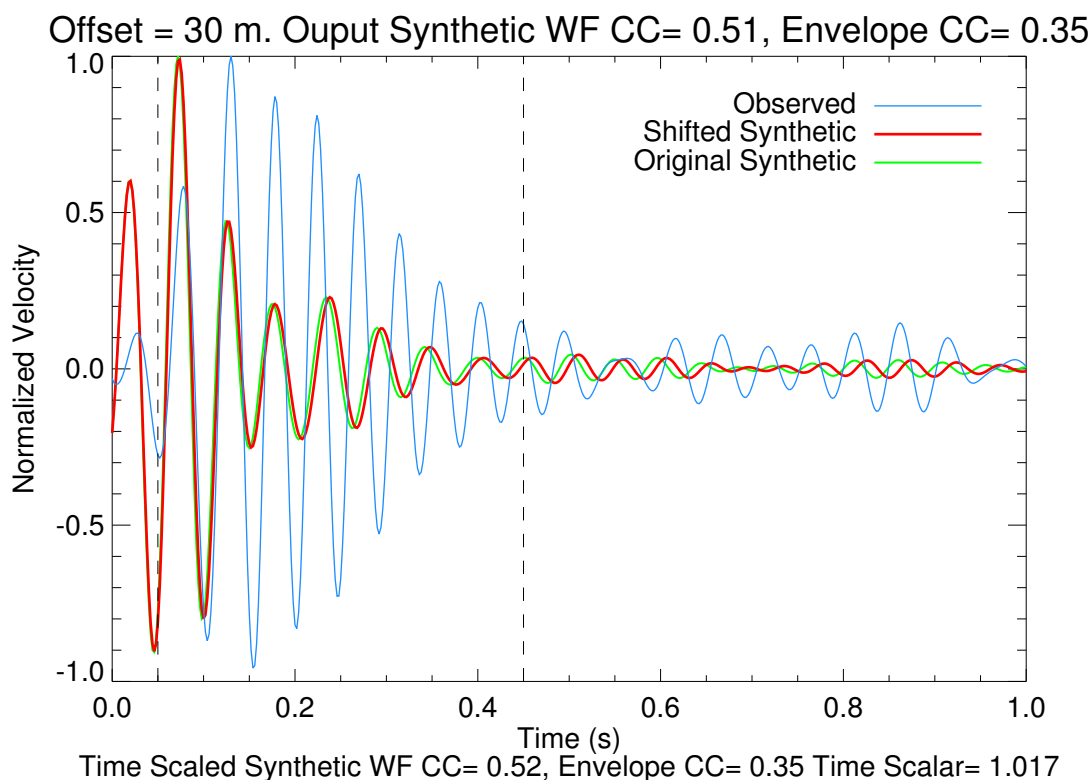
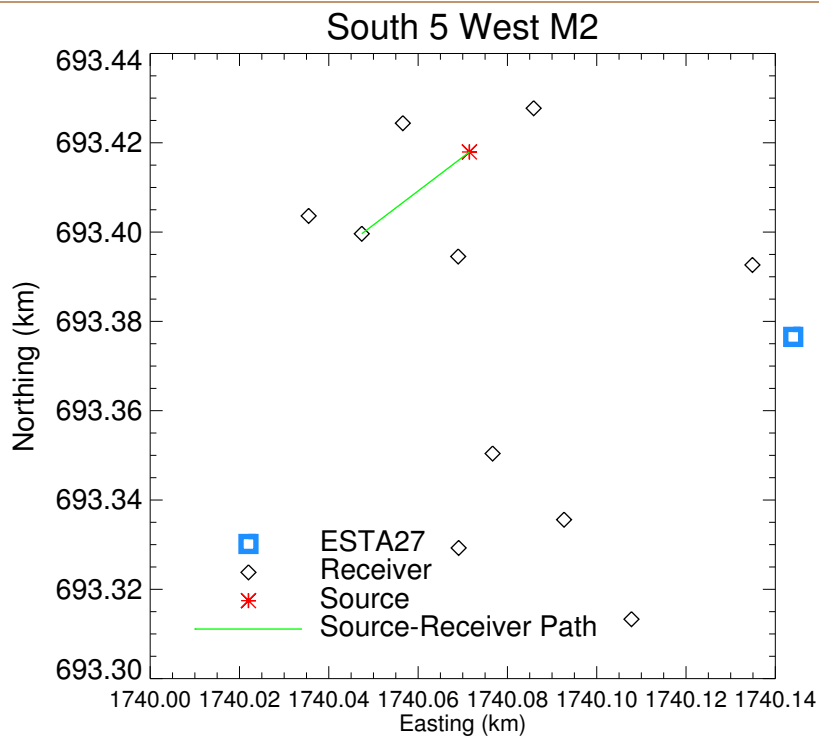


Time Scaled Synthetic WF CC= 0.72, Envelope CC= 0.72 Time Scalar= 0.930

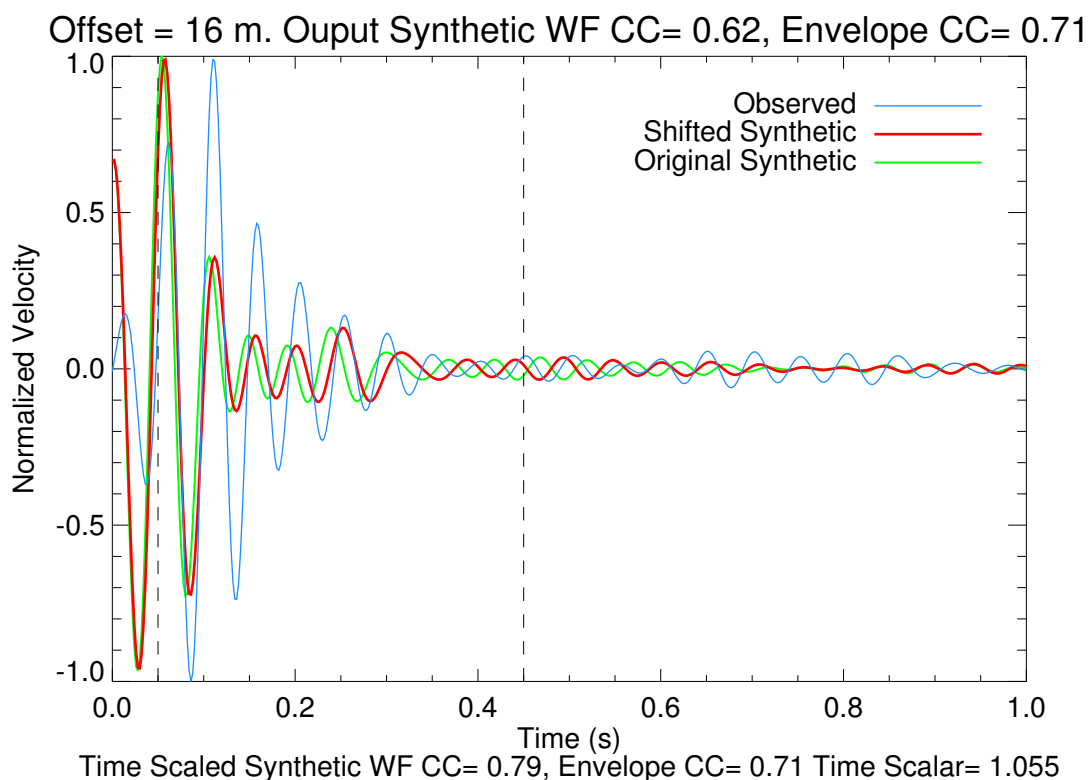
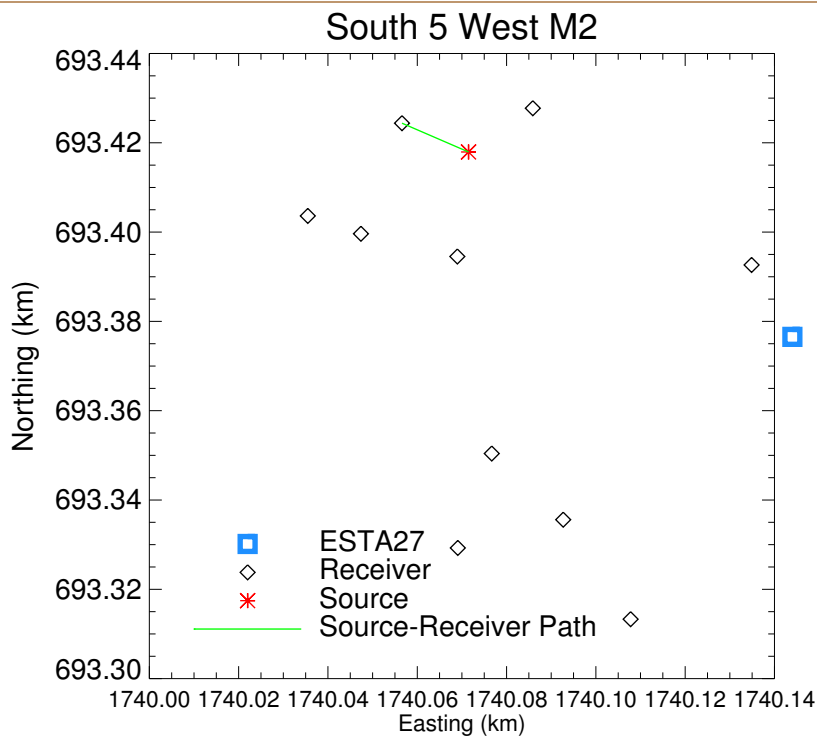
MODEL 4 SOURCE WEST OF ESTA27
SOURCE-RECEIVER PAIR 8 OFFSET = 180 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



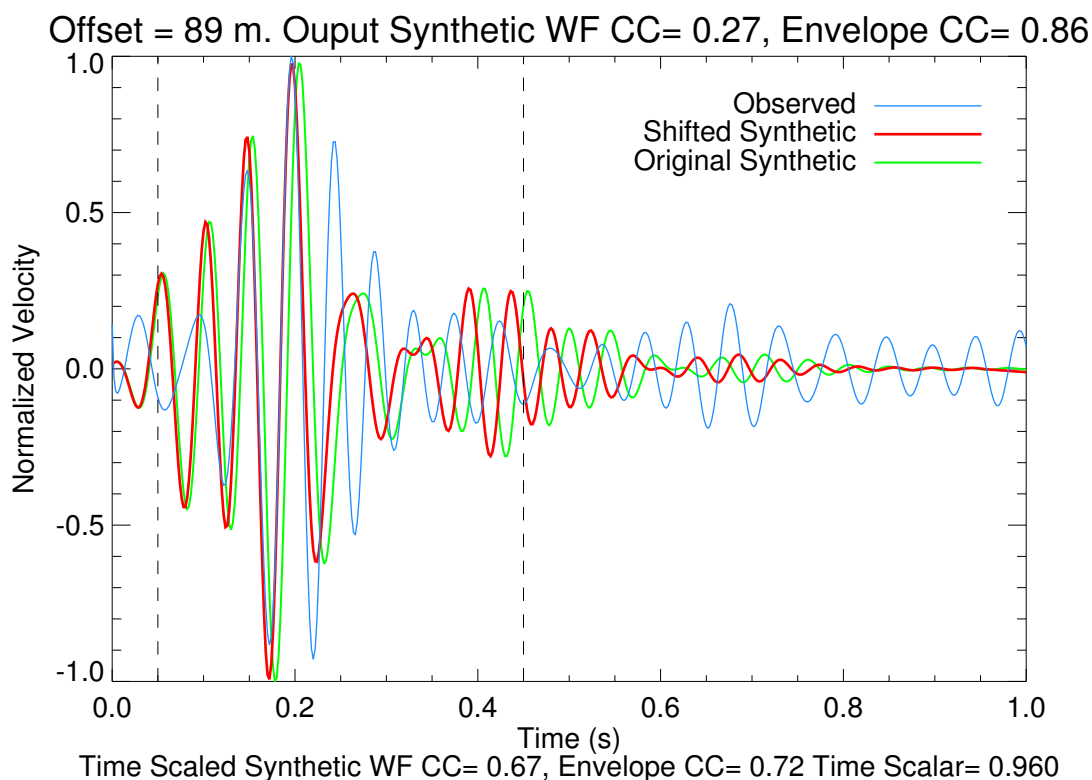
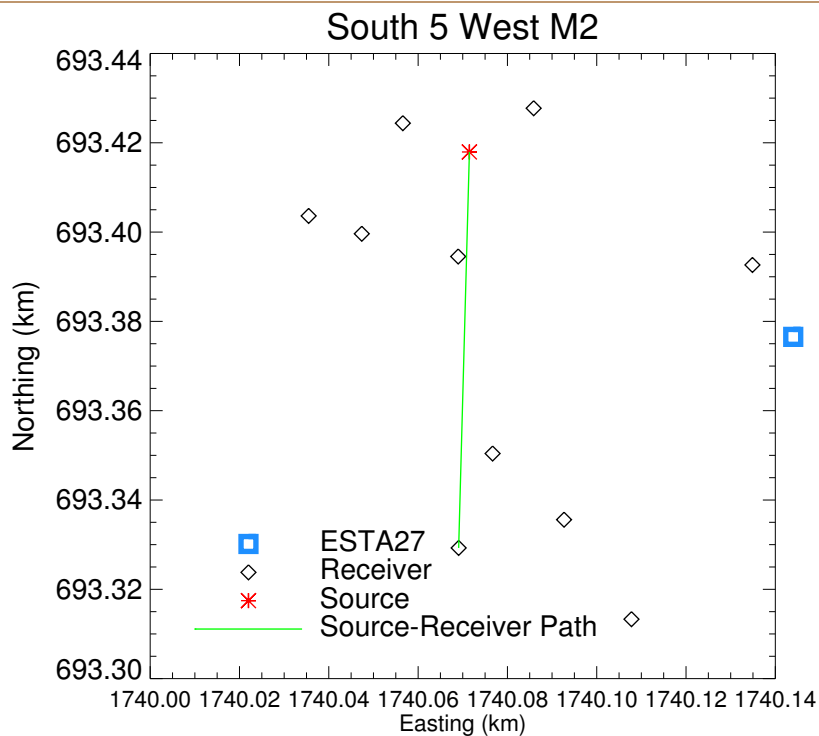
MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 1 OFFSET = 39 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



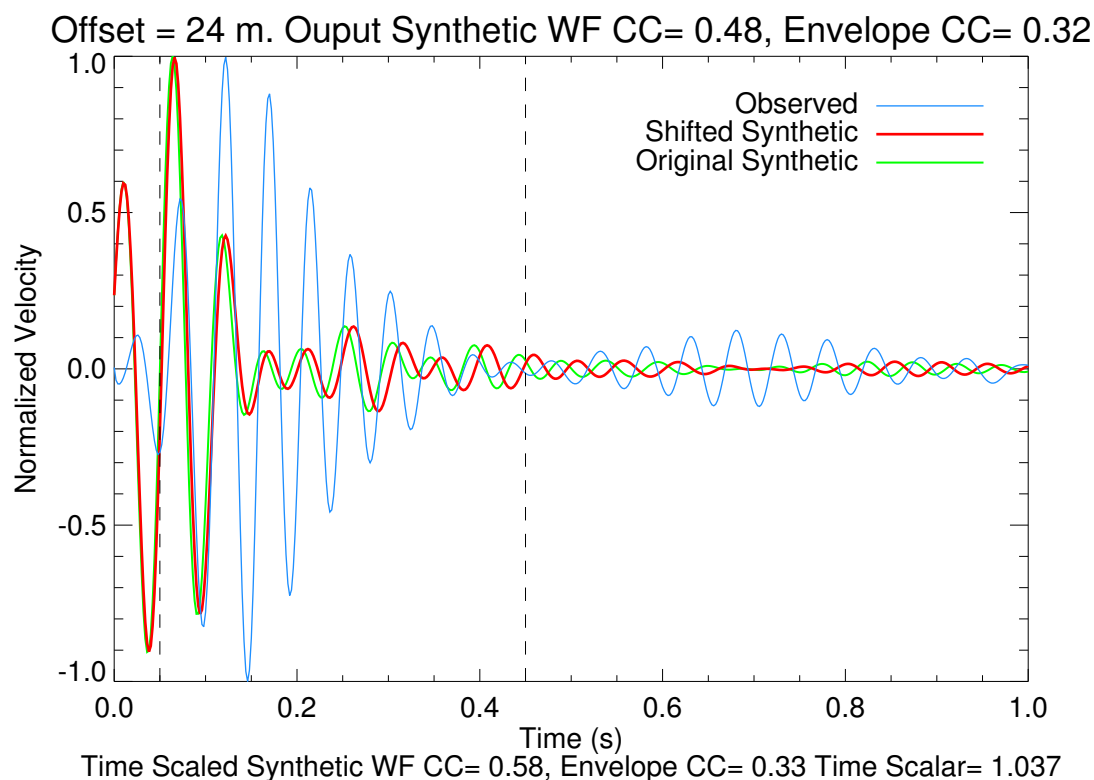
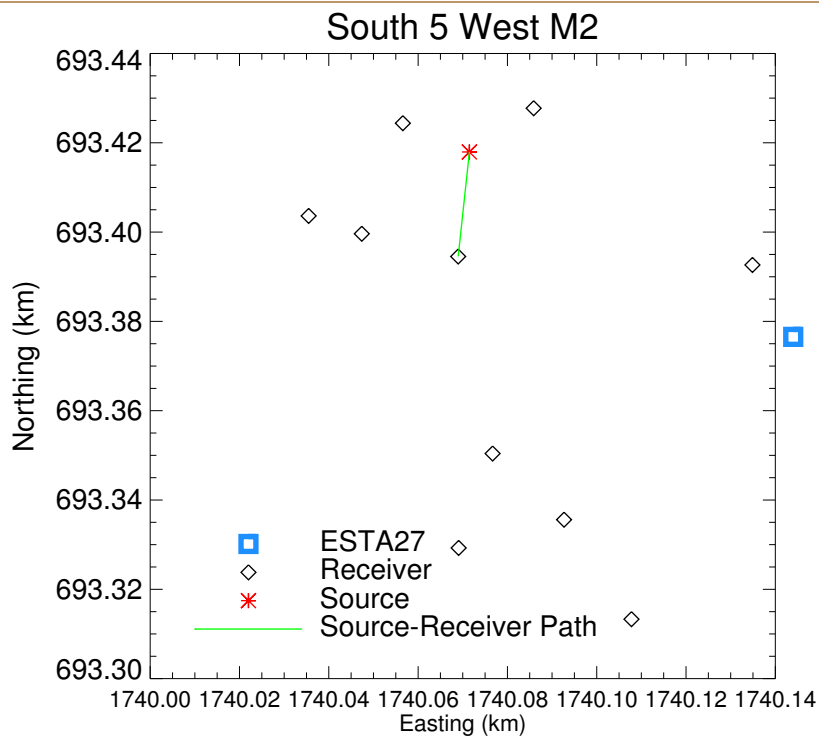
MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 2 OFFSET = 30 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



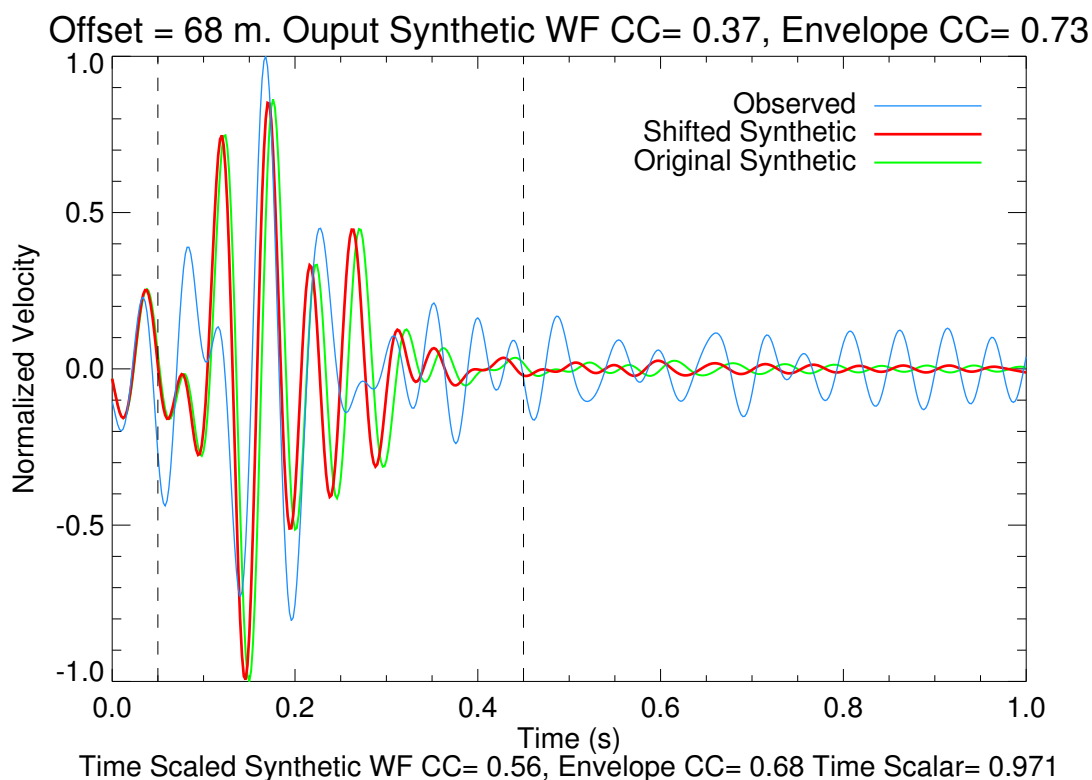
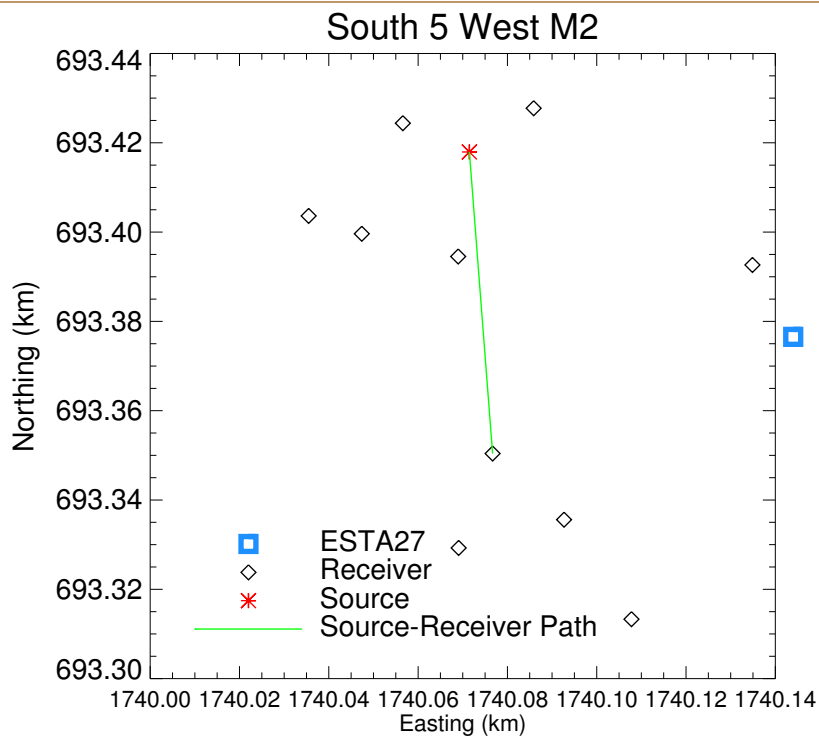
MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 3 OFFSET = 16 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



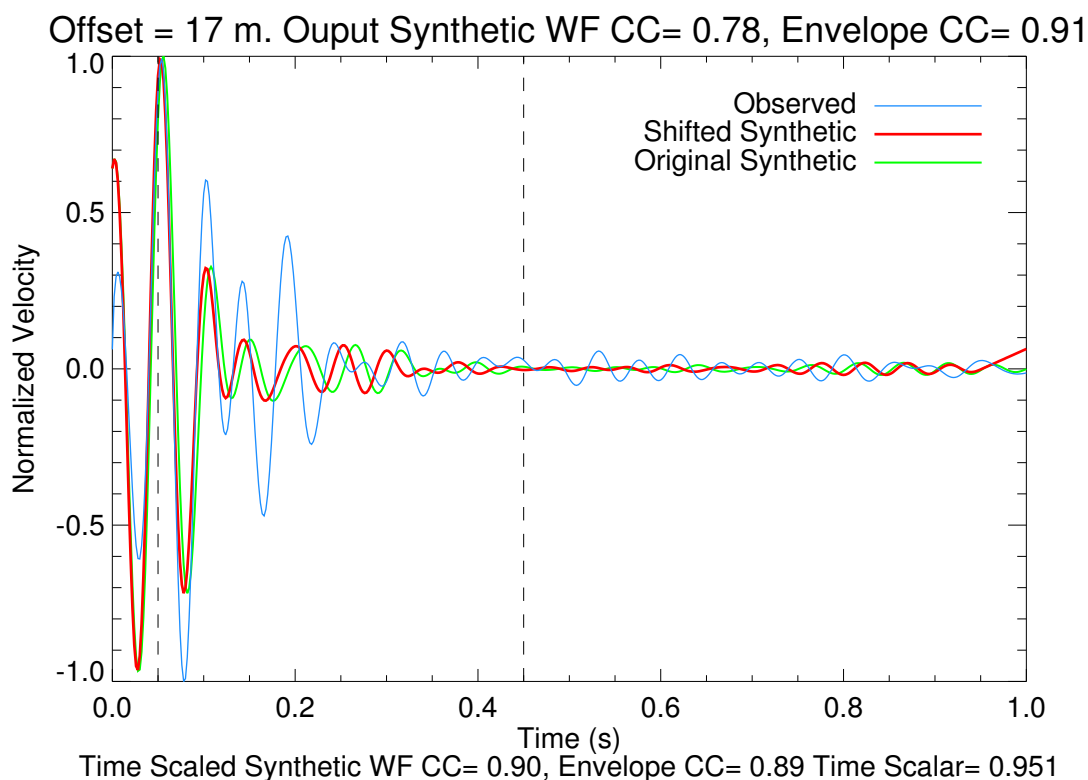
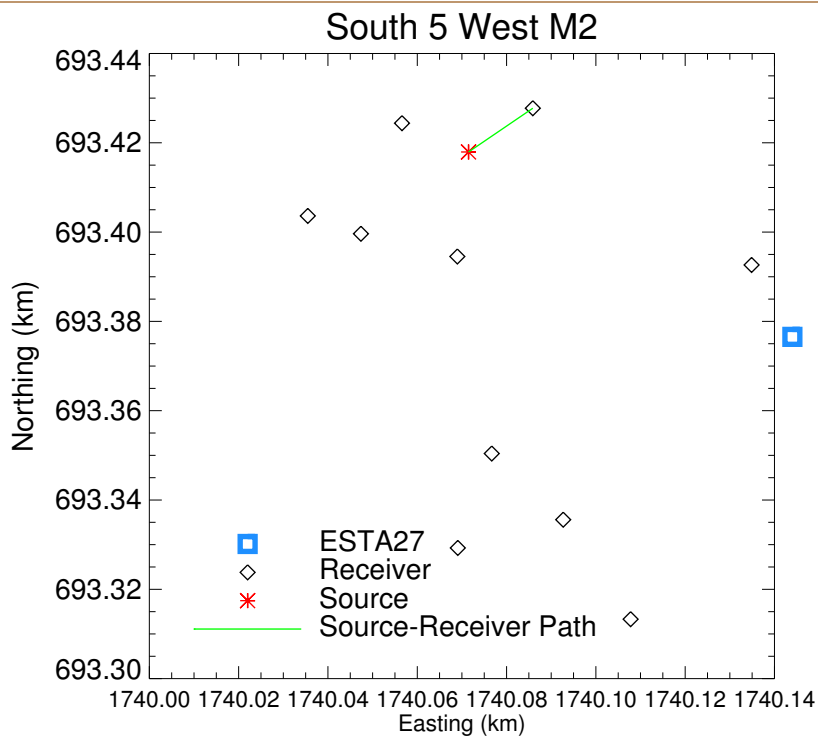
MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 4 OFFSET = 89 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California



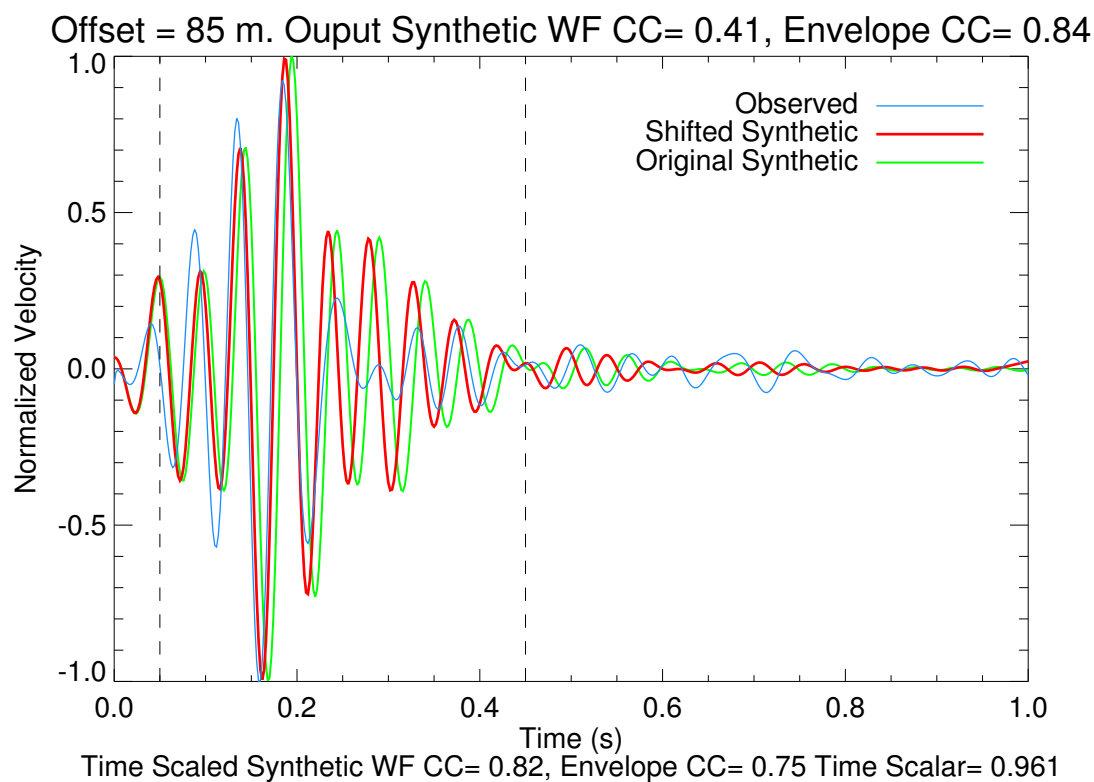
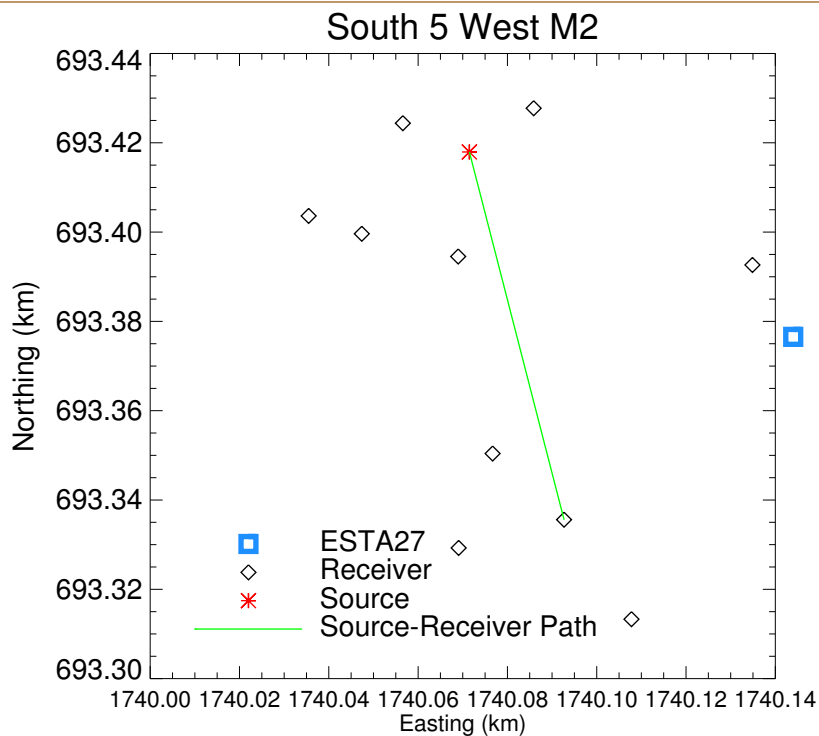
MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 5 OFFSET = 24 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



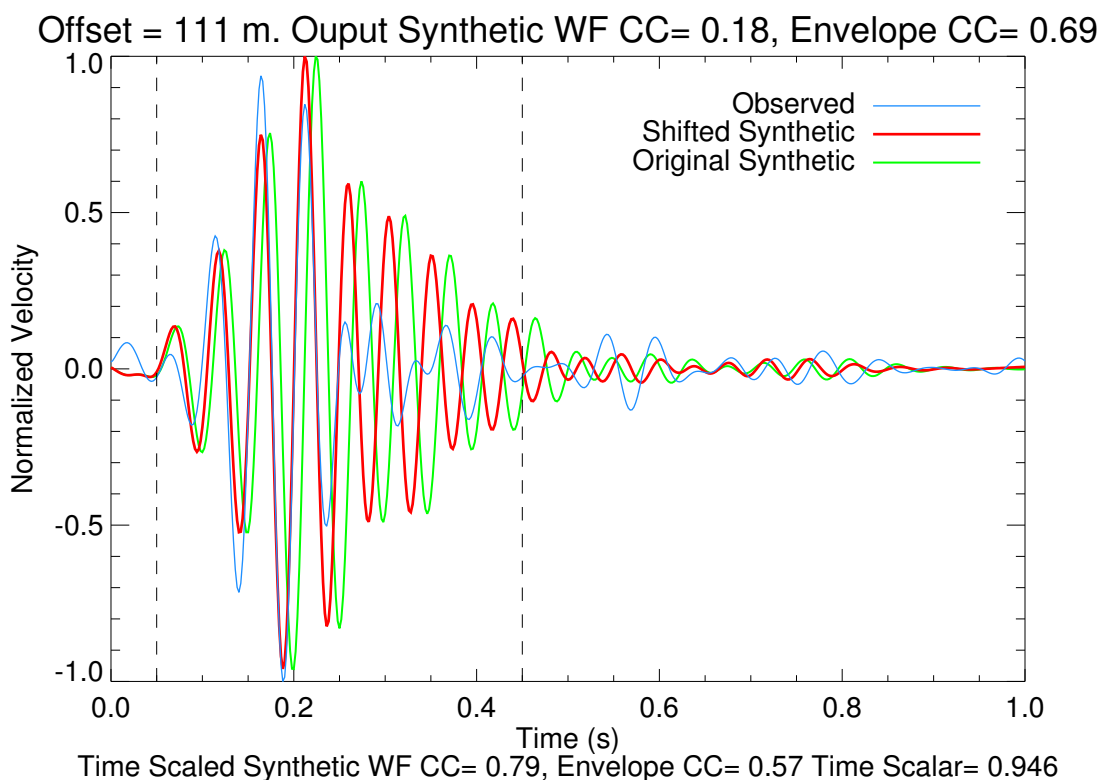
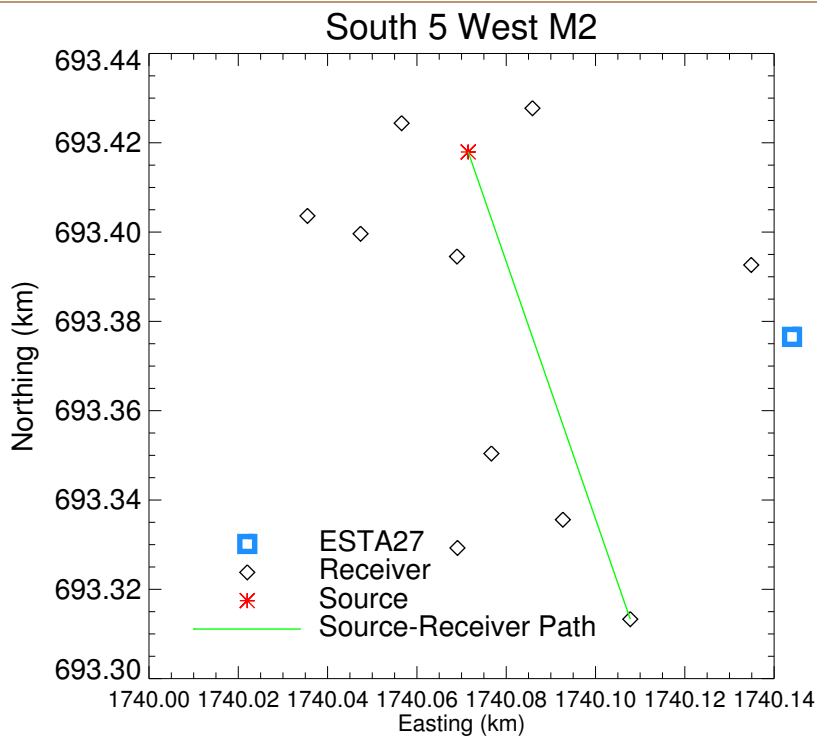
MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 6 OFFSET = 68 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



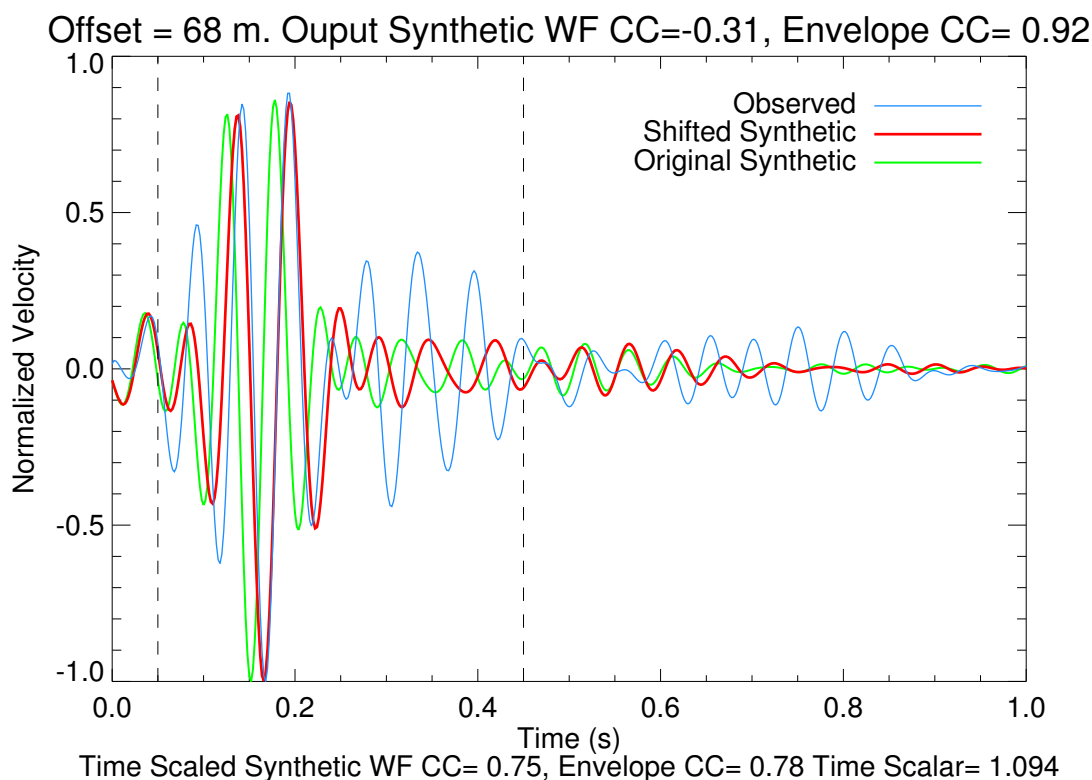
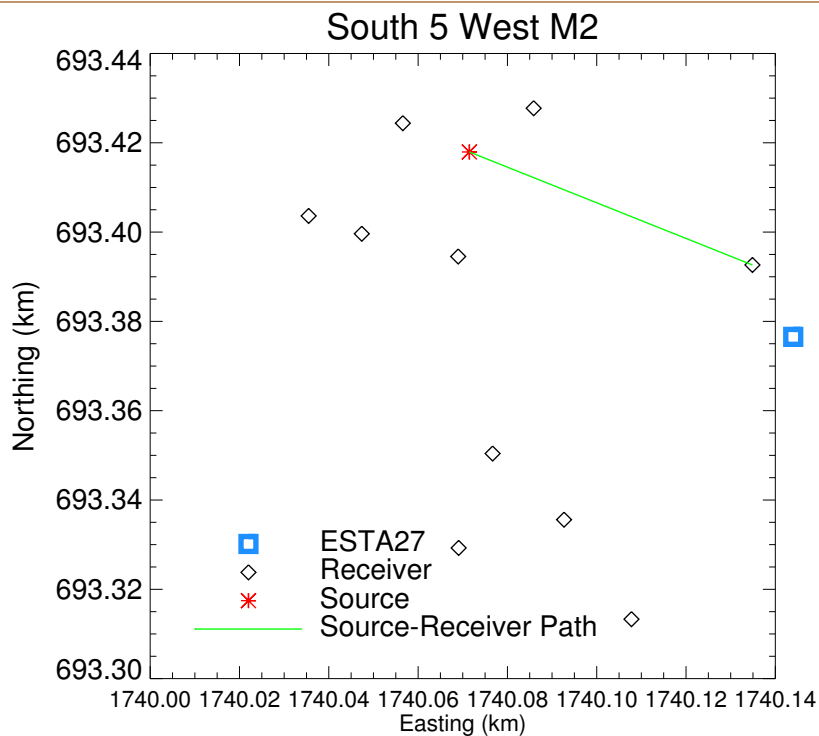
MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 7 OFFSET = 17 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 8 OFFSET = 85 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California

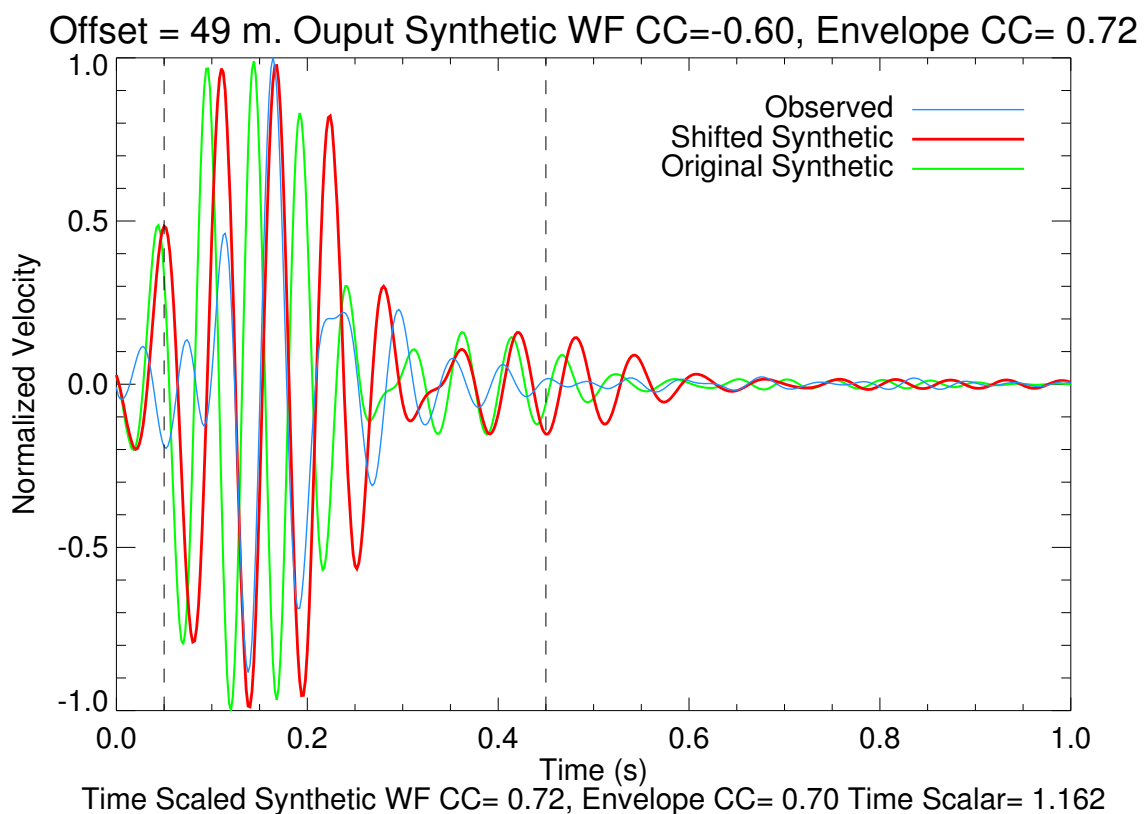
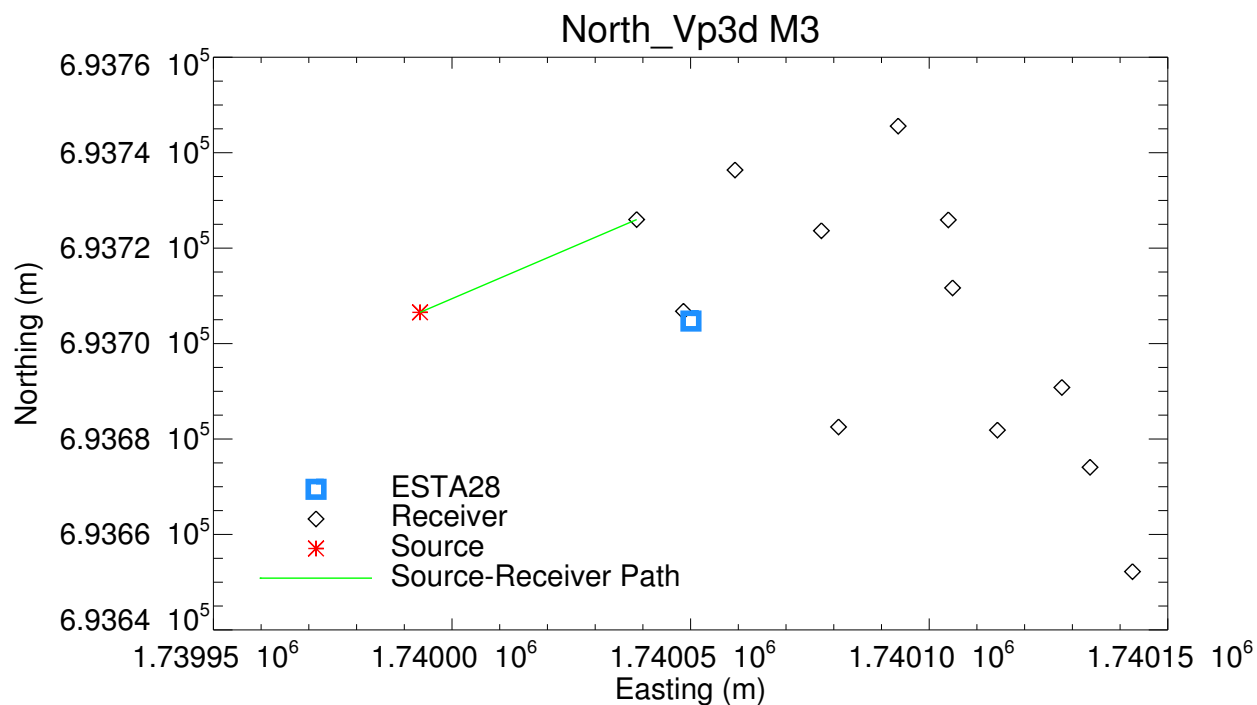


MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 9 OFFSET = 111 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California

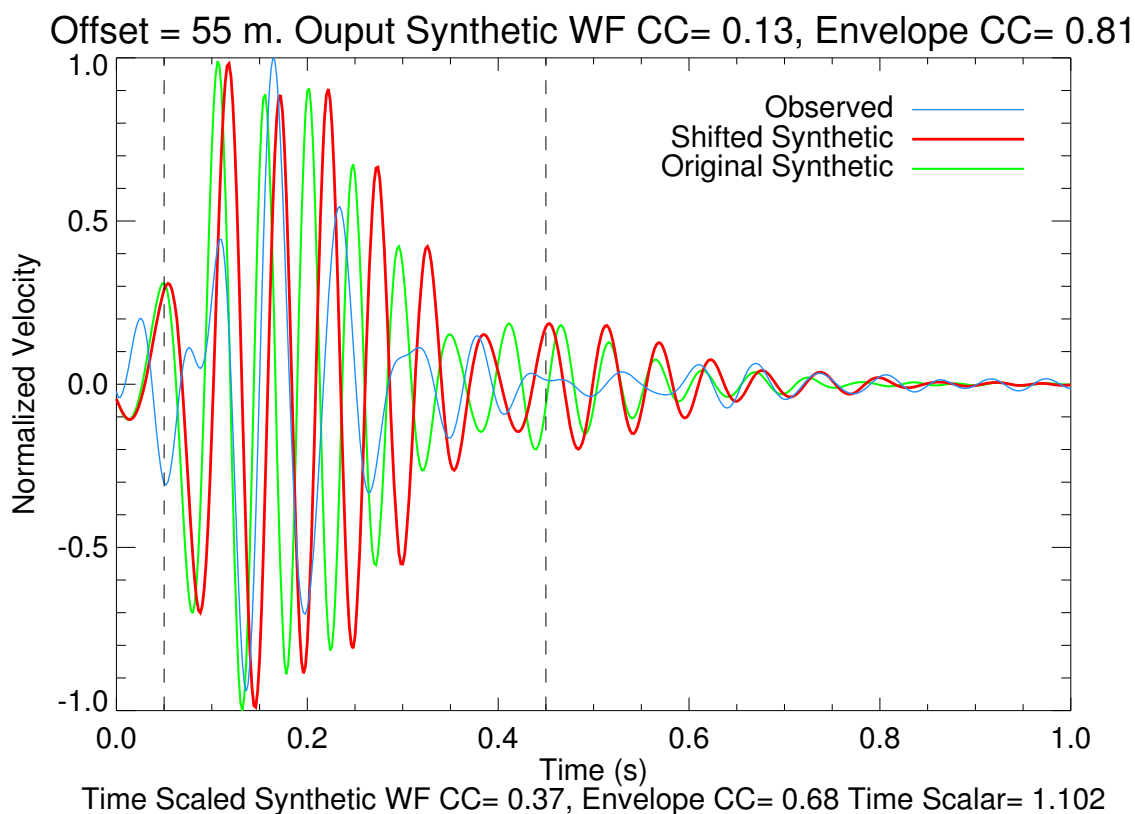
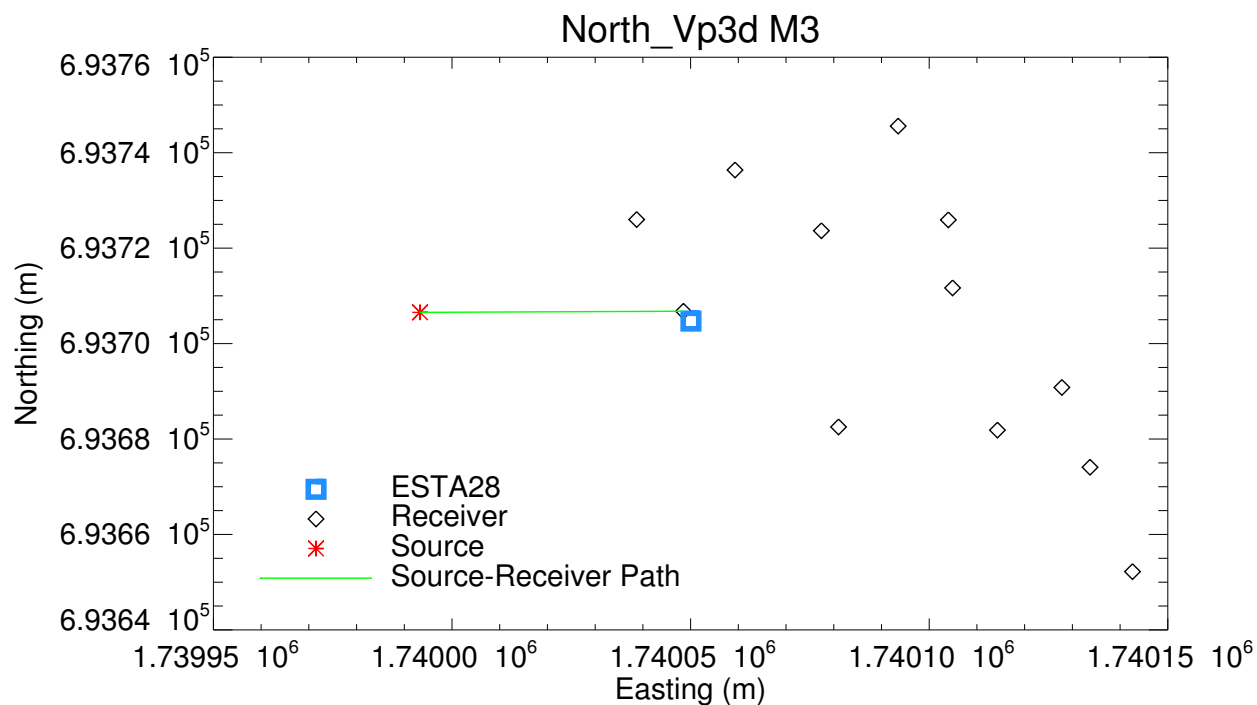


MODEL 4 SOURCE NW OF ESTA27
SOURCE-RECEIVER PAIR 10 OFFSET = 68 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California

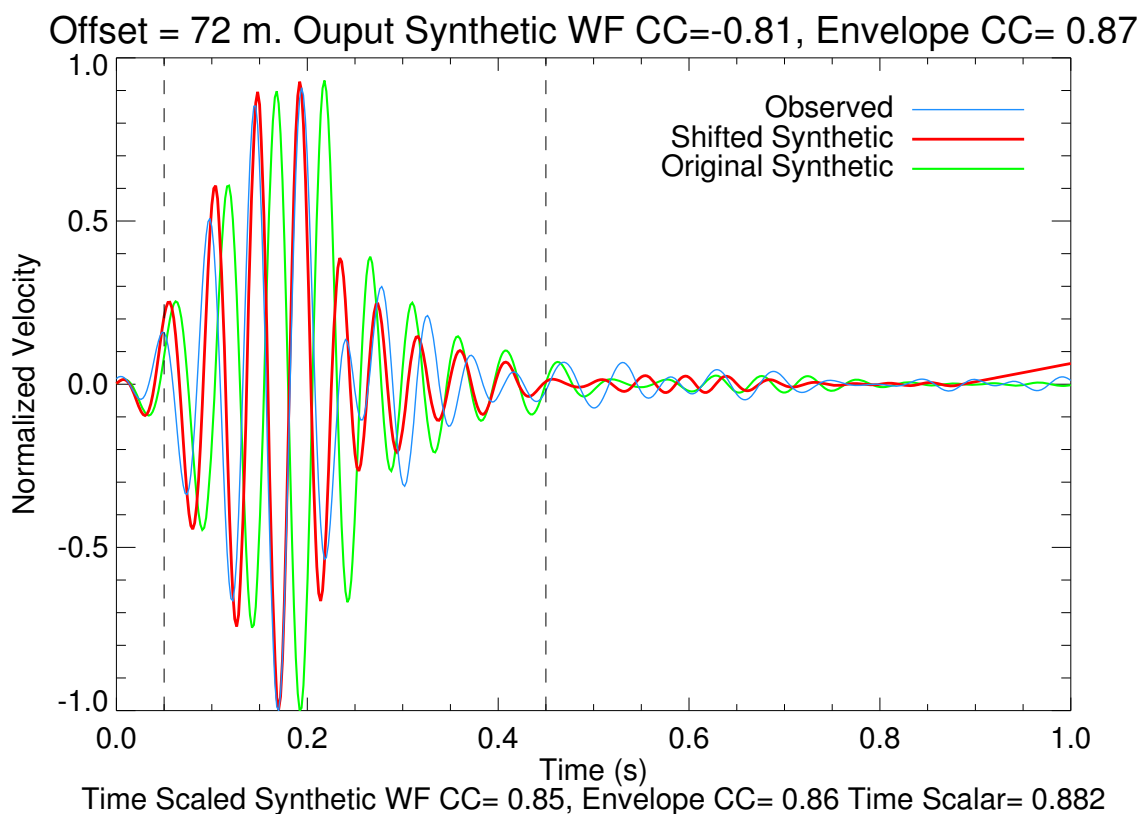
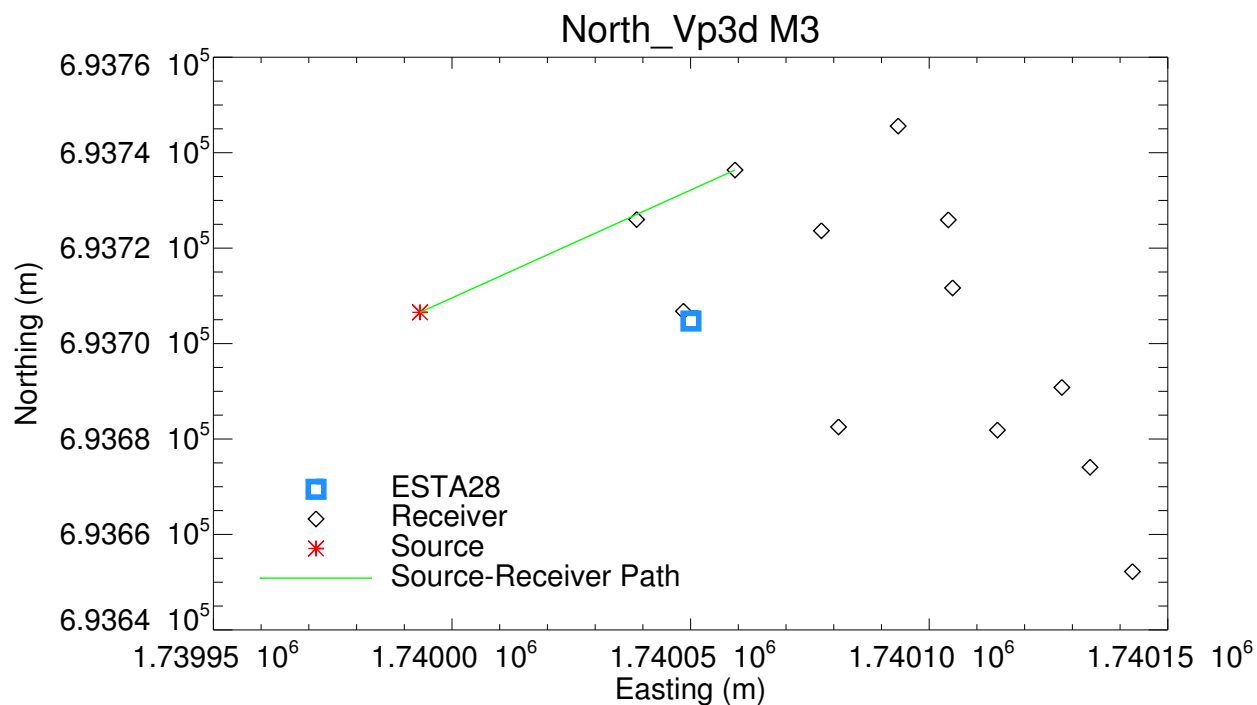
APPENDIX D



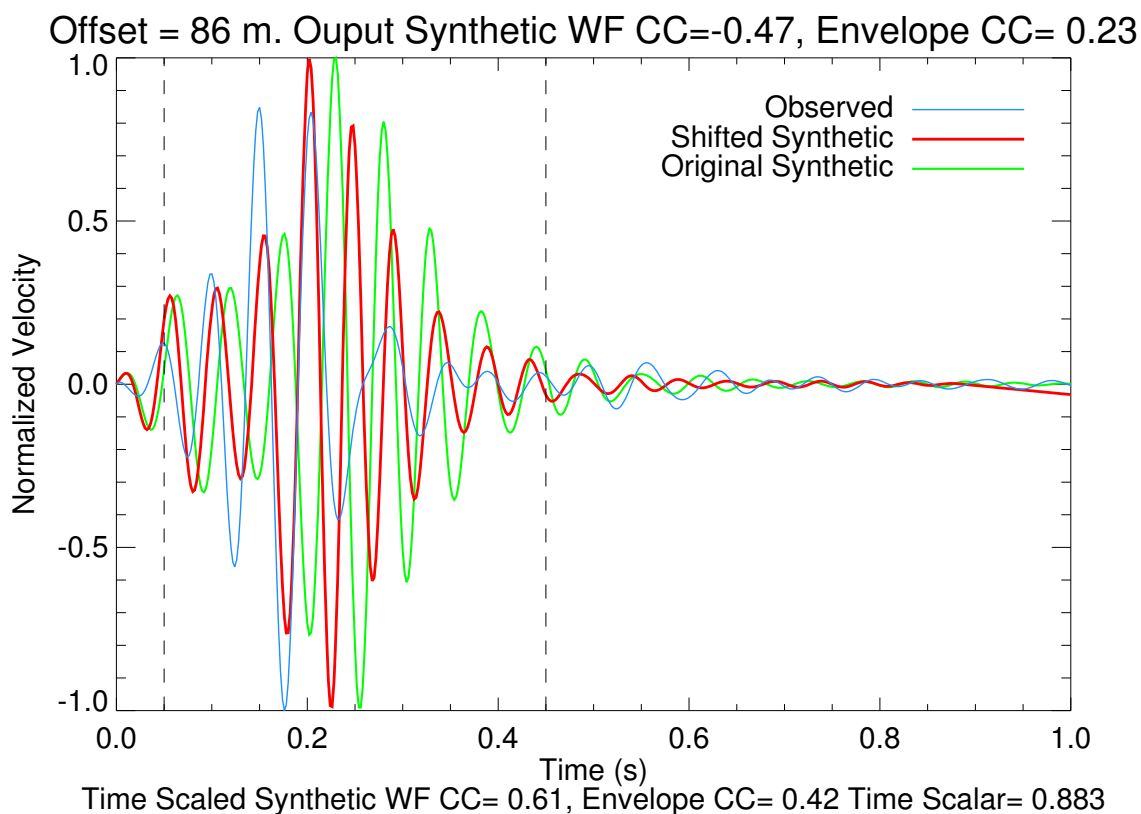
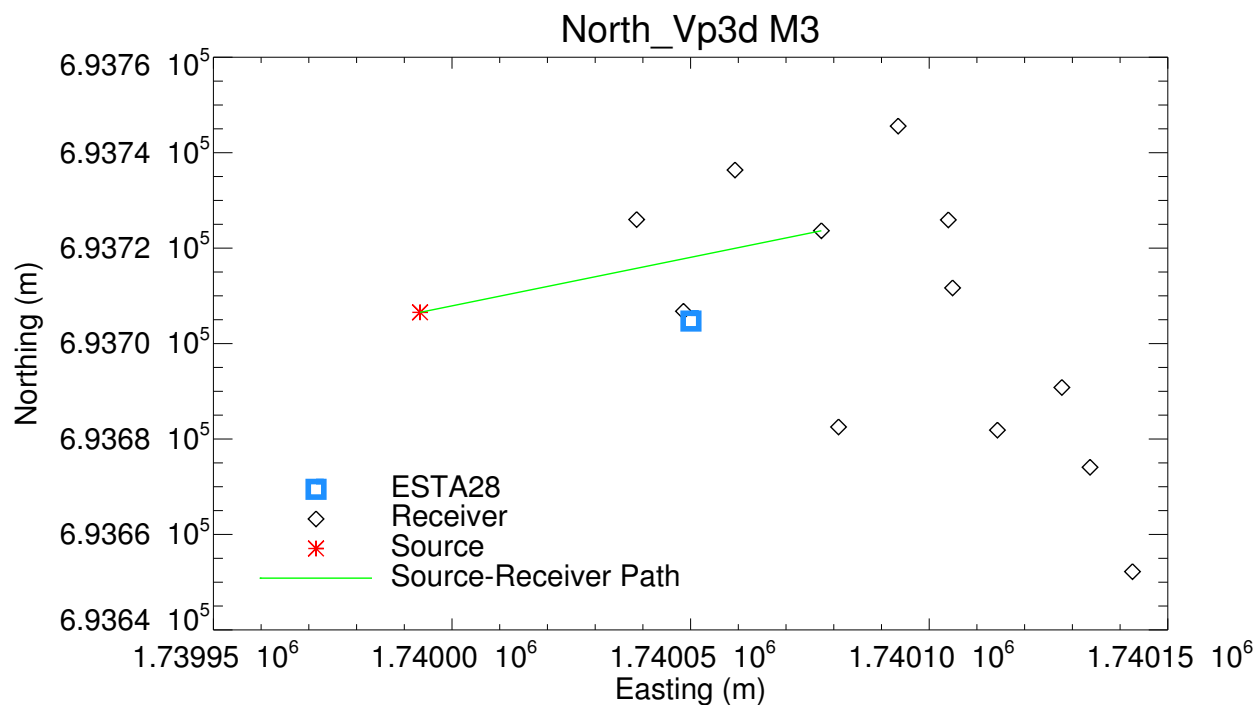
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 1 OFFSET = 49 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



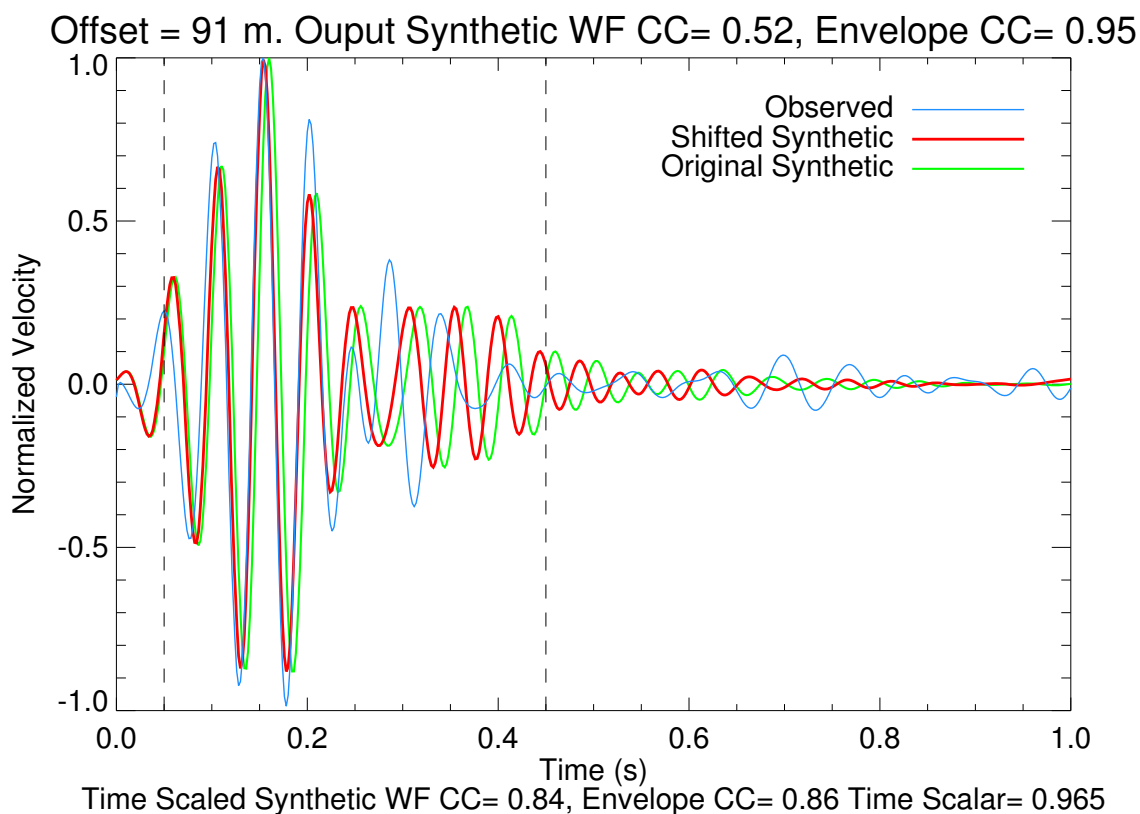
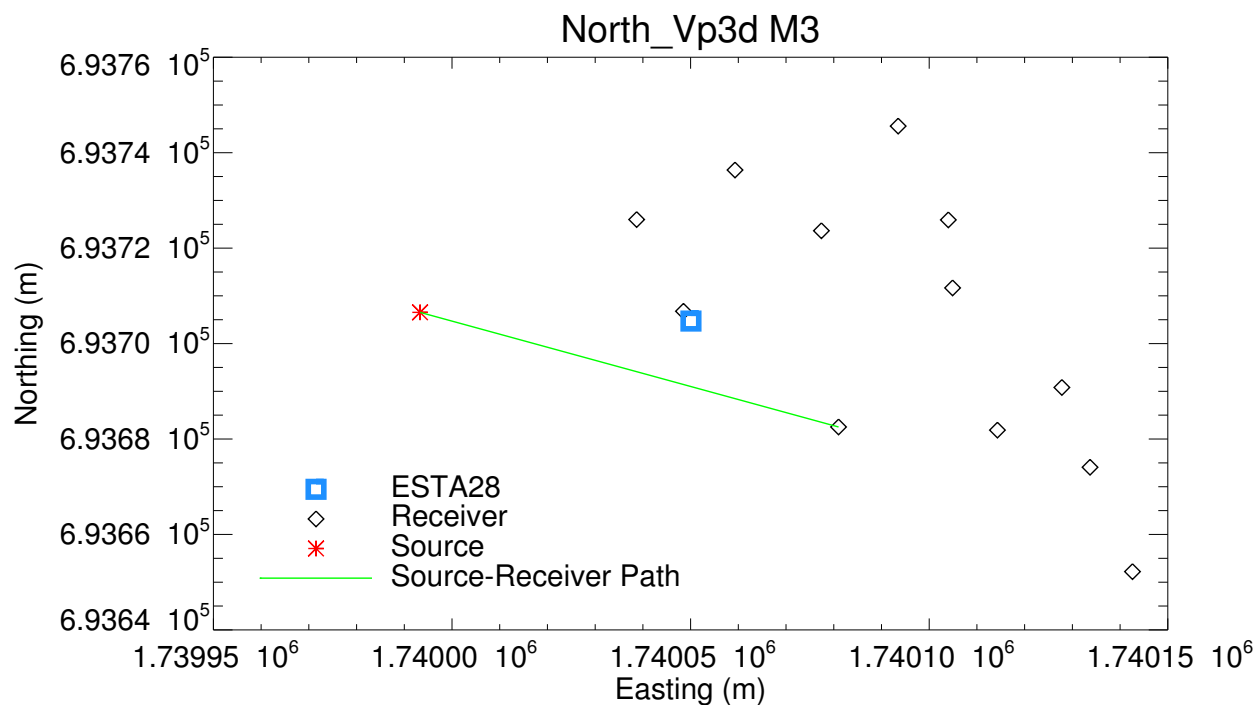
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 2 OFFSET = 55 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



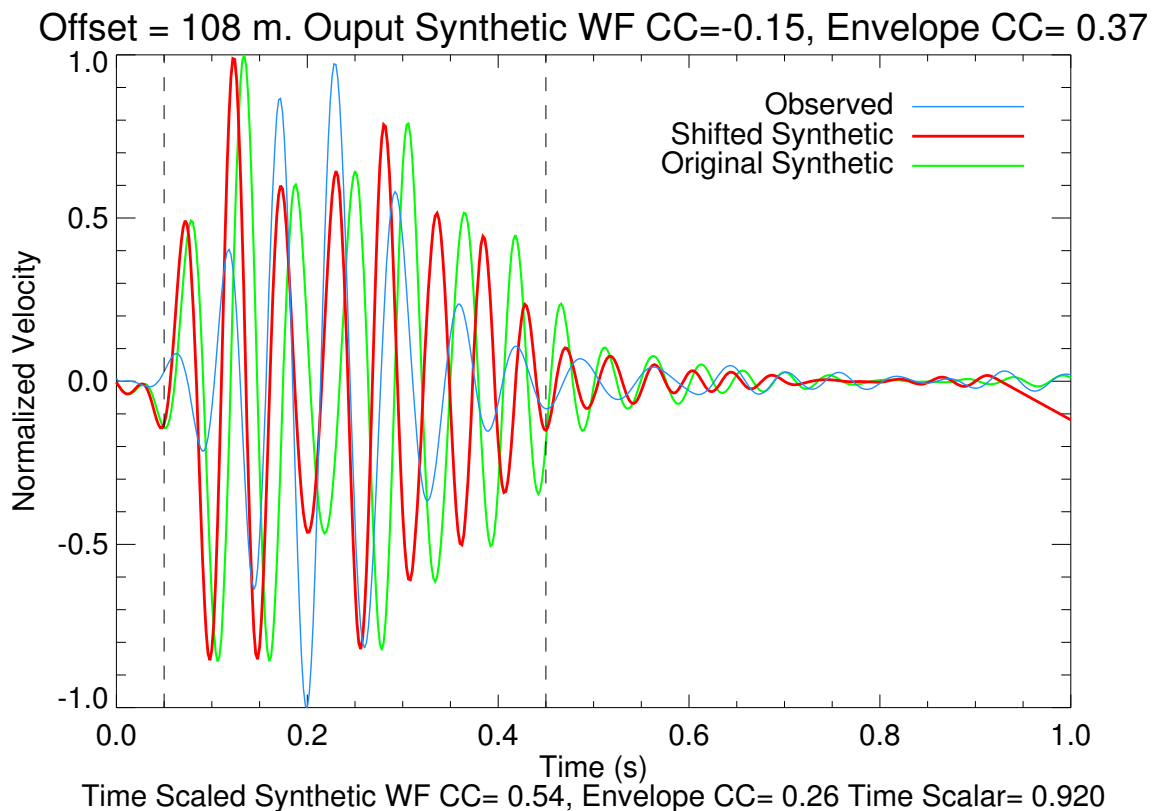
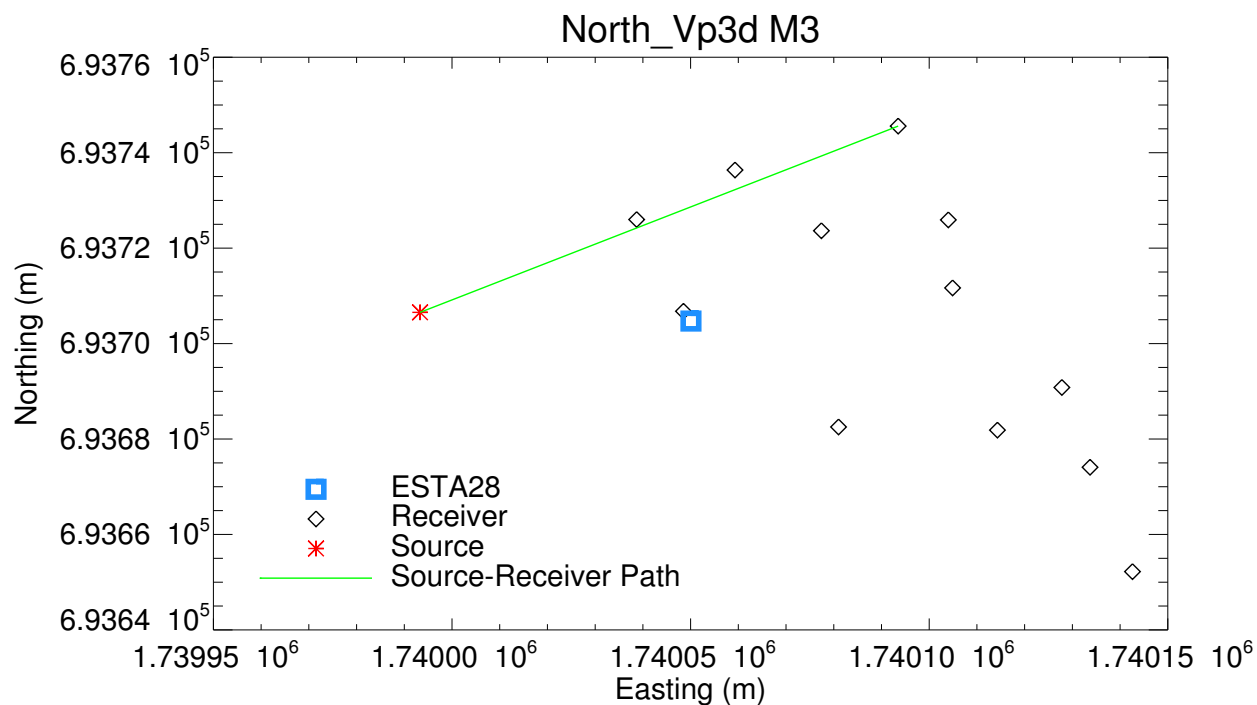
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 3 OFFSET = 72 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



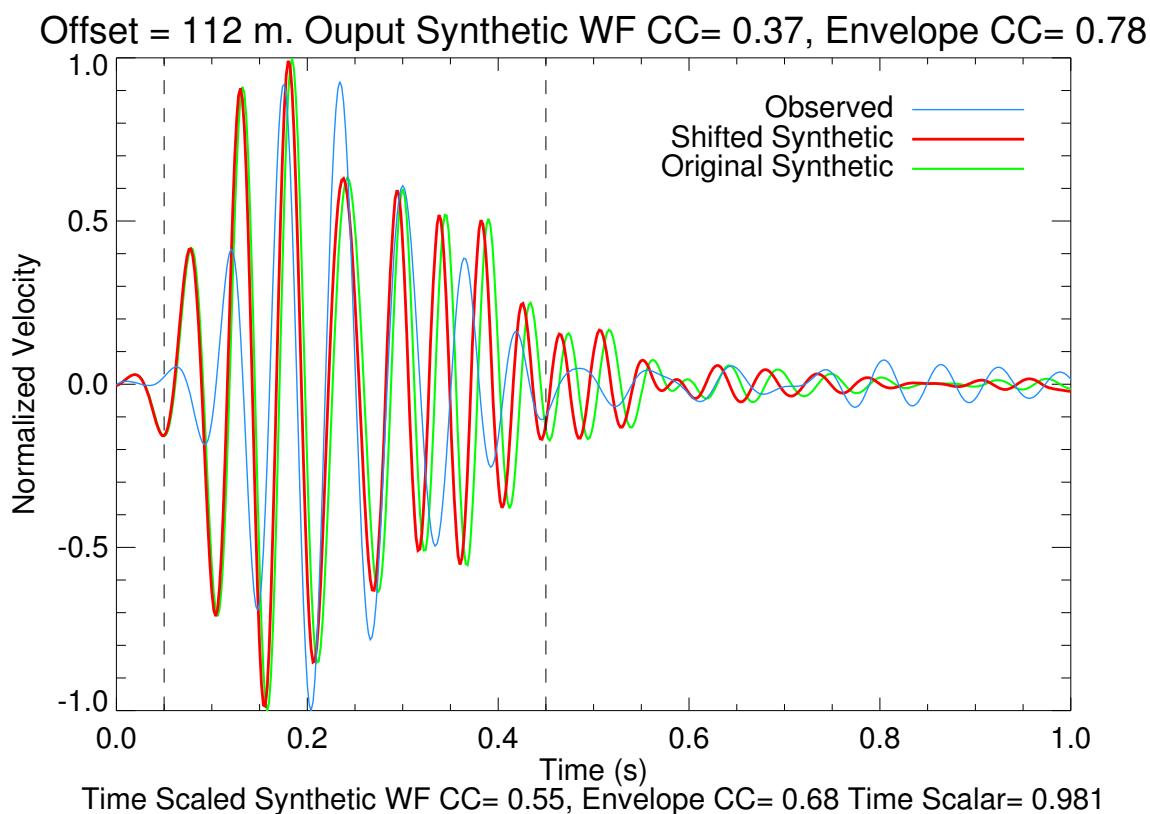
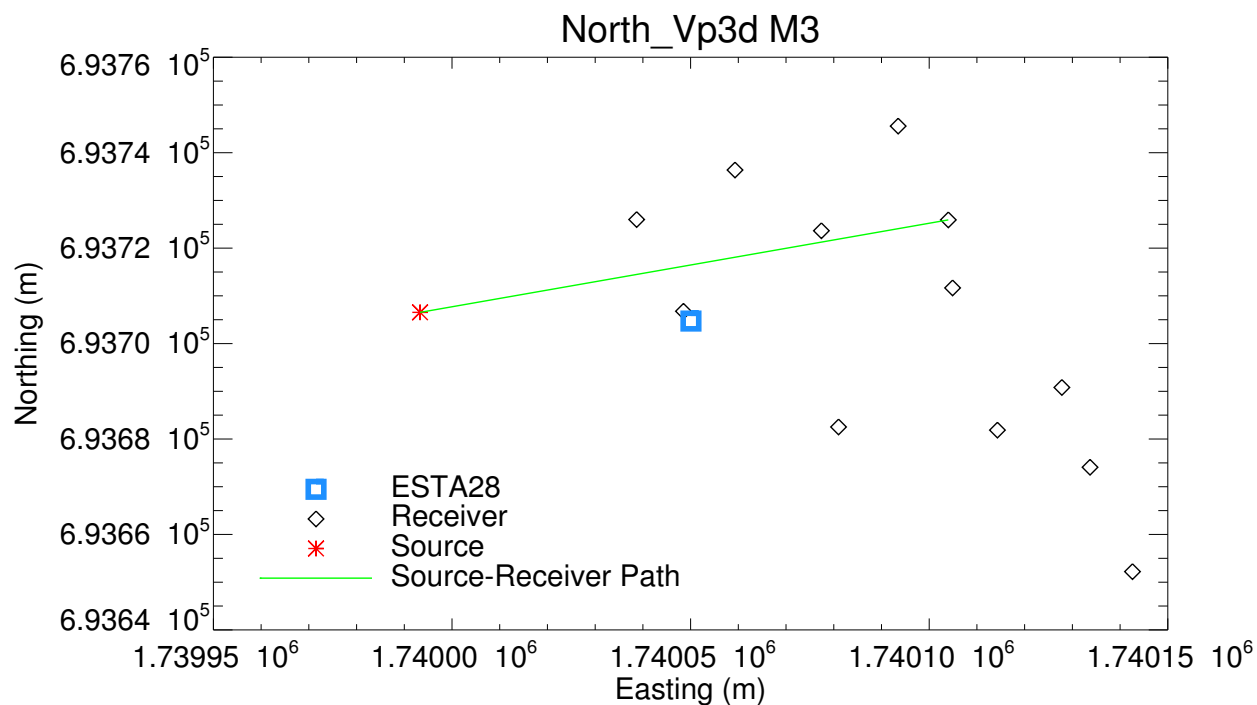
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 4 OFFSET = 86 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



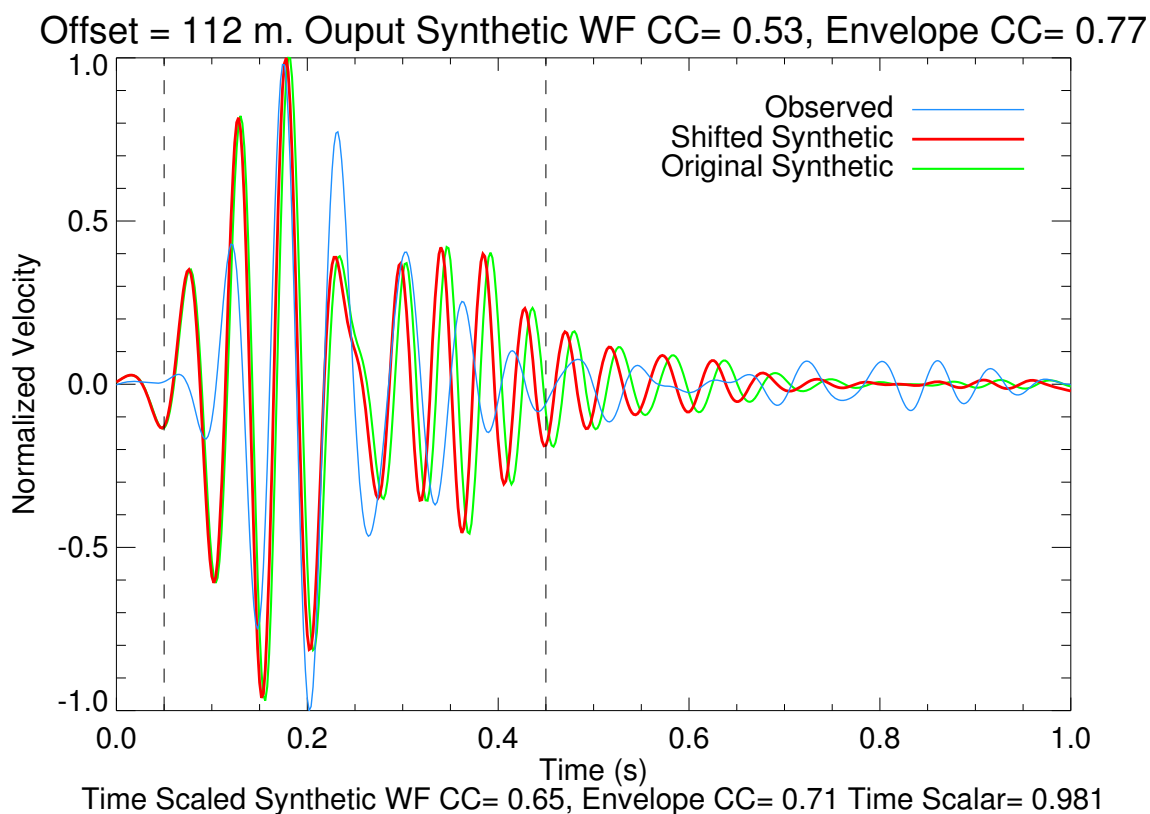
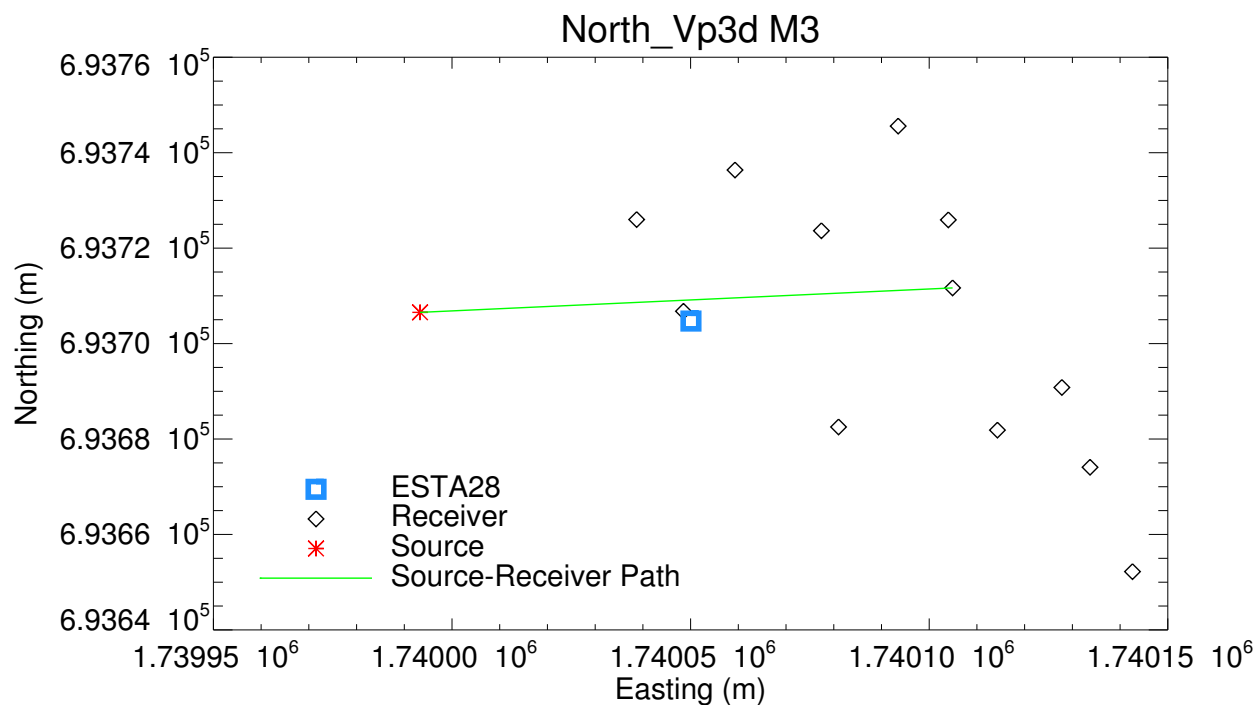
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 5 OFFSET = 91 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California



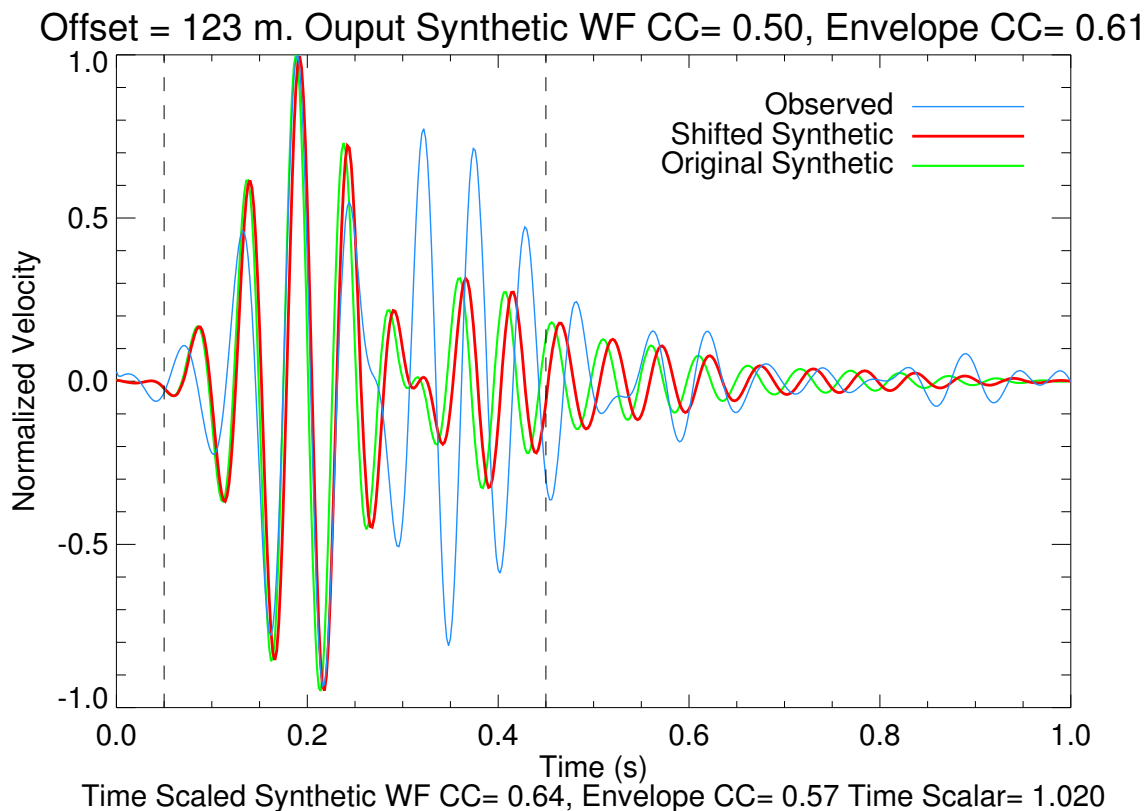
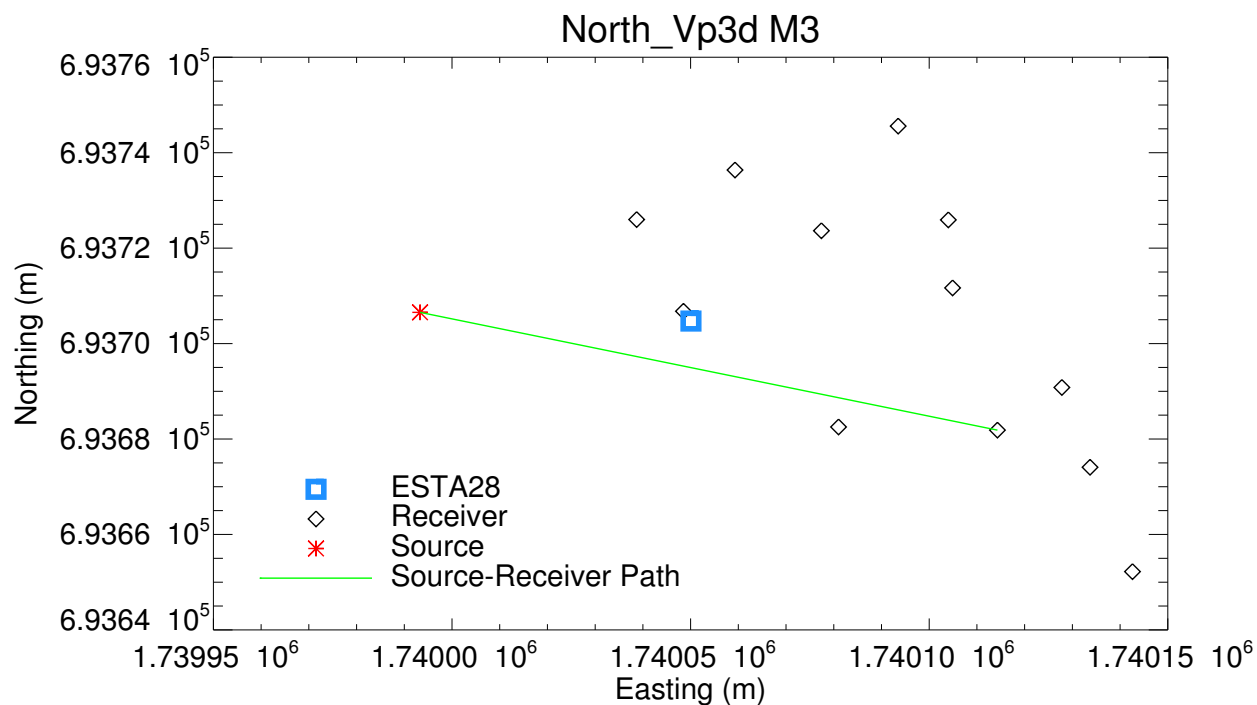
MODEL 4 SOURCE NW OF ESTA28
SOURCE-RECEIVER PAIR 6 OFFSET = 108 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



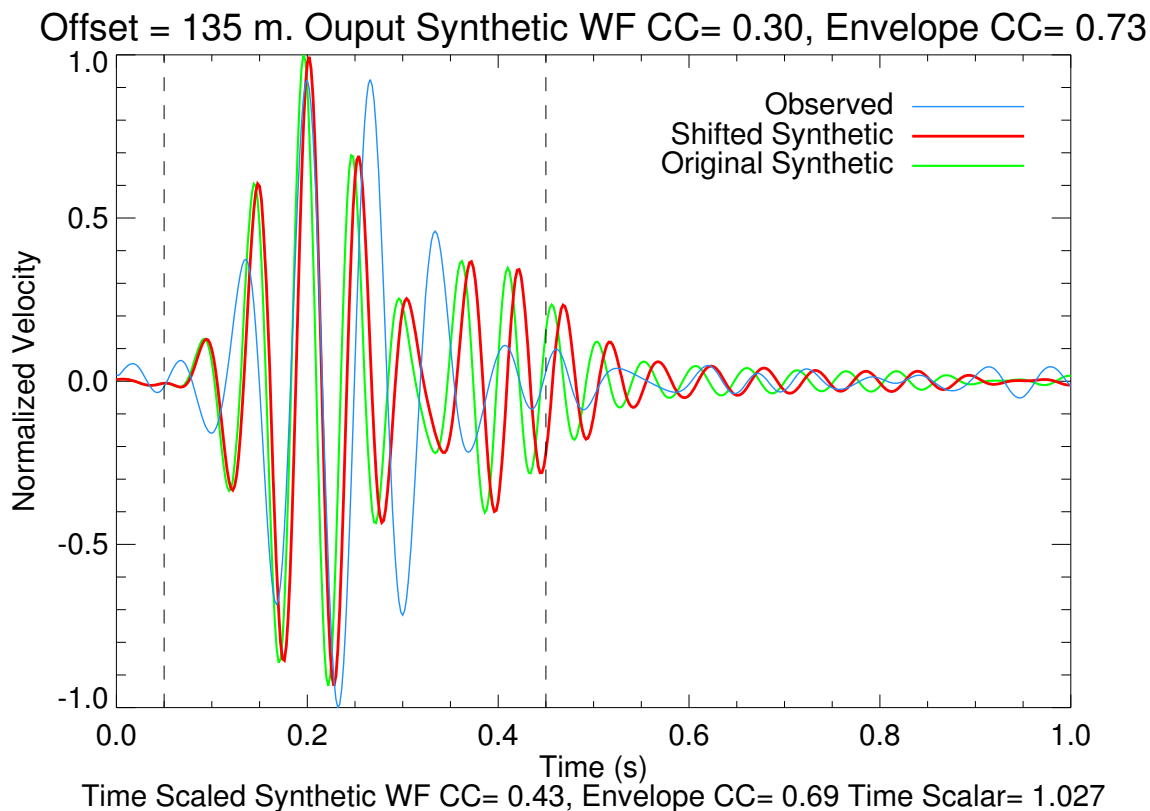
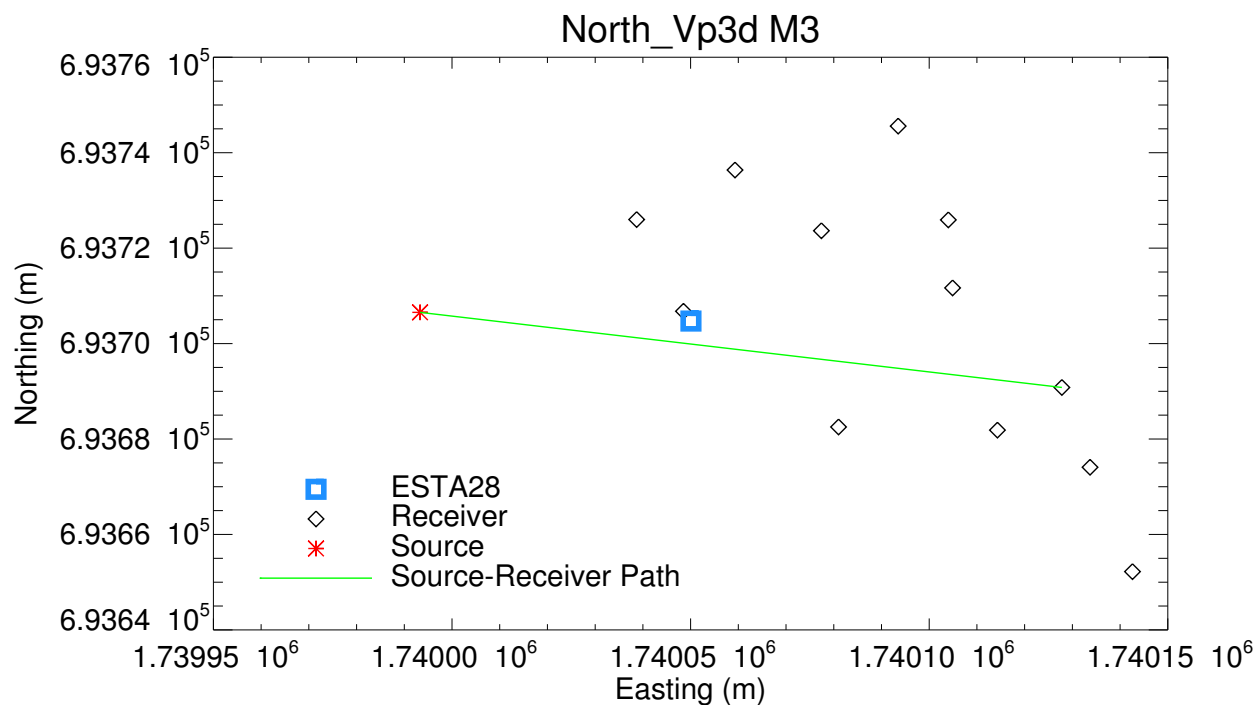
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 7 OFFSET = 112 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



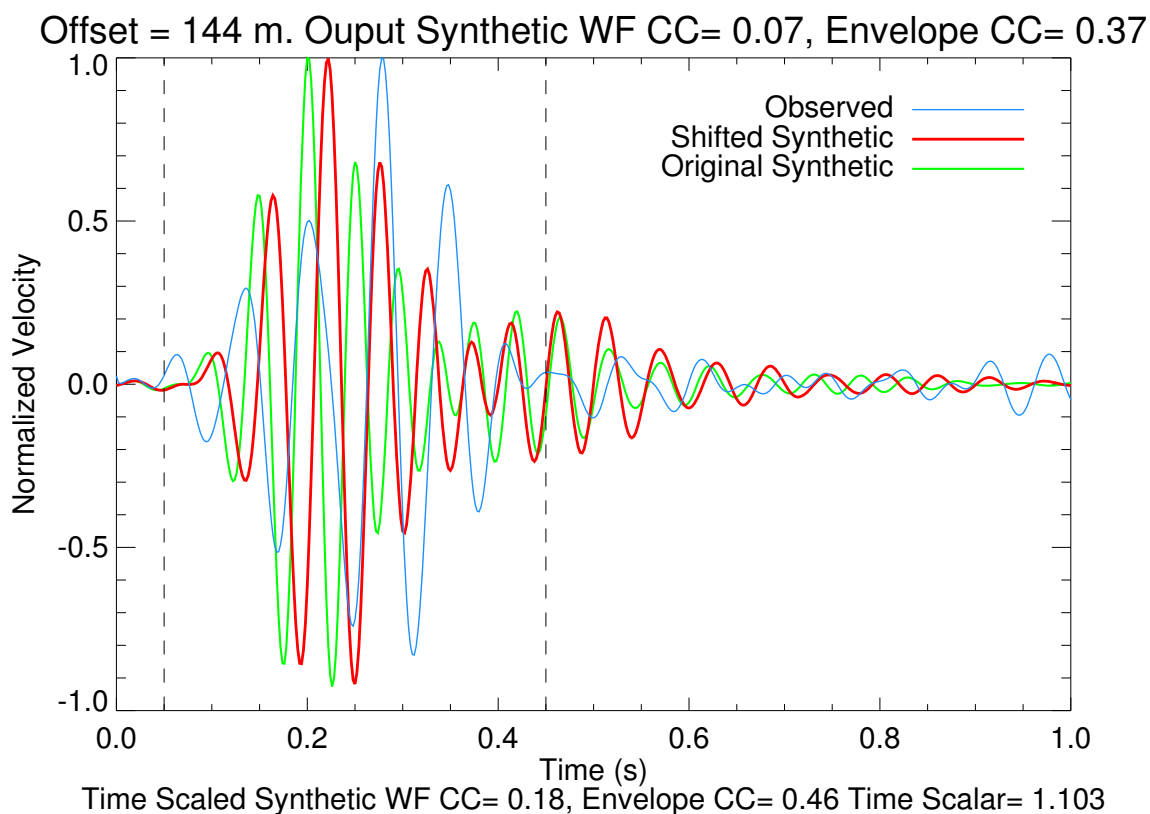
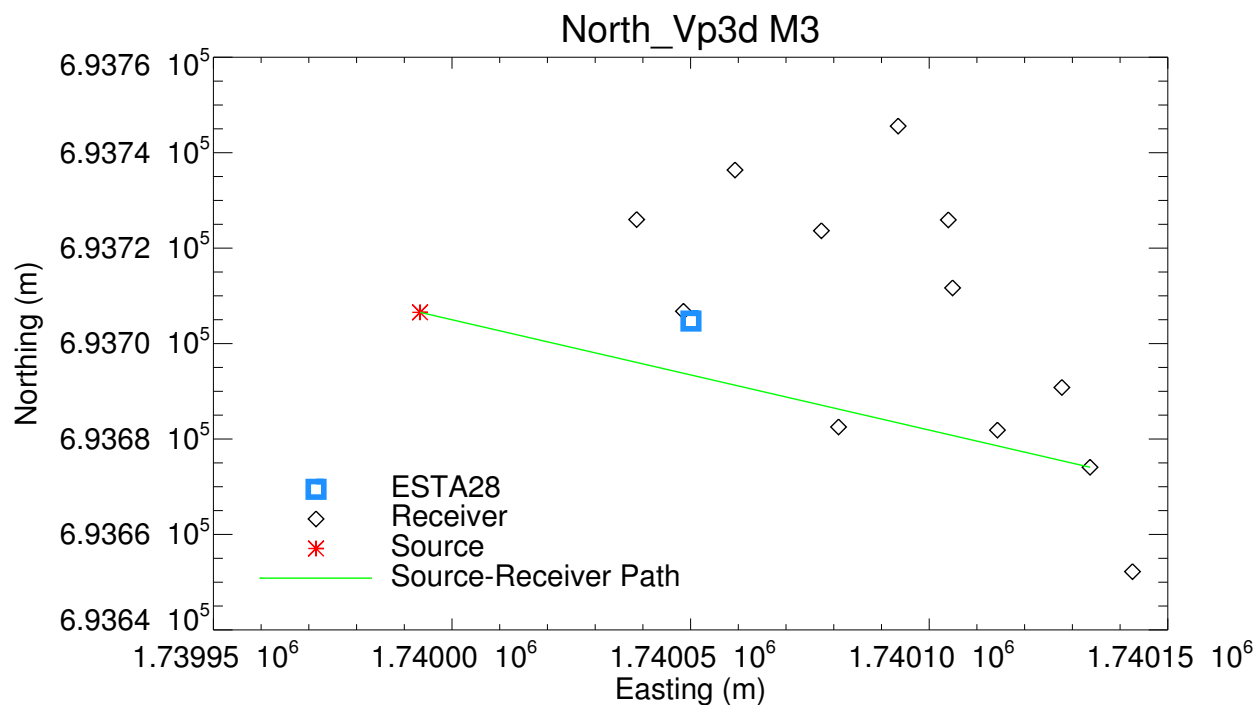
MODEL 4 SOURCE NW OF ESTA28
SOURCE-RECEIVER PAIR 8 OFFSET = 112 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



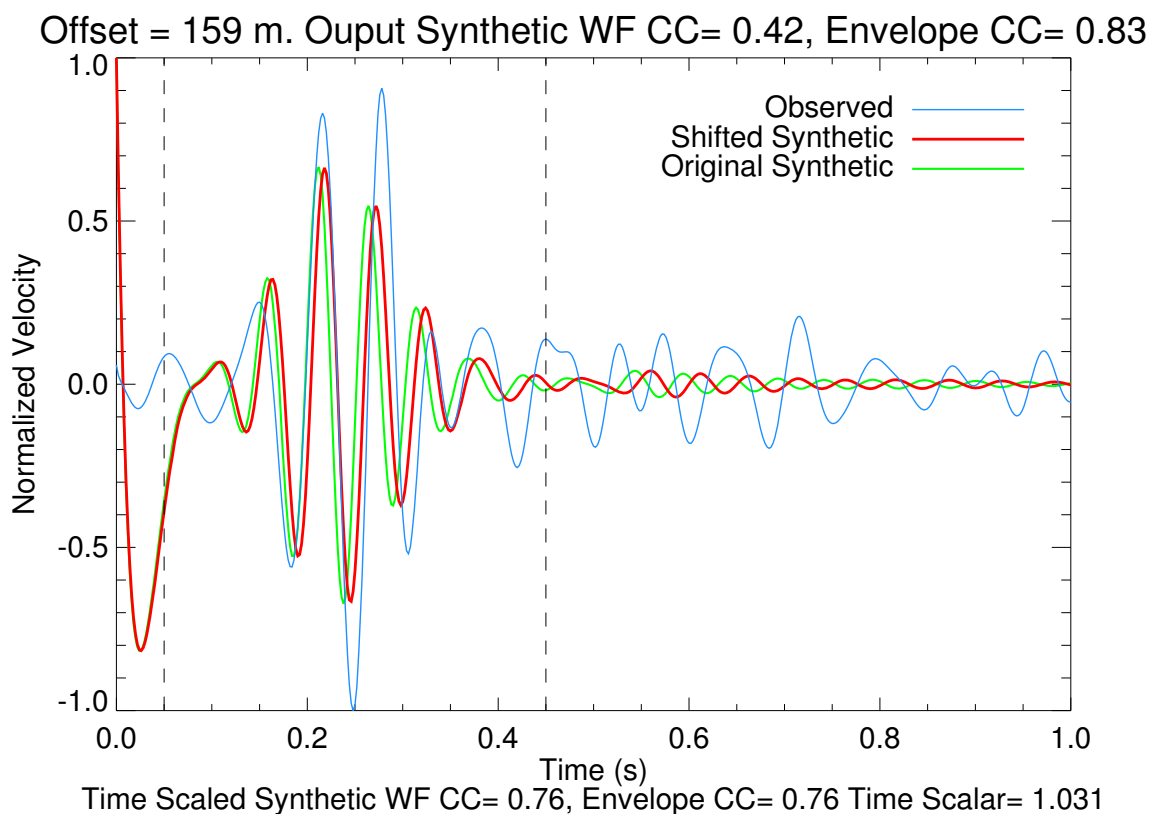
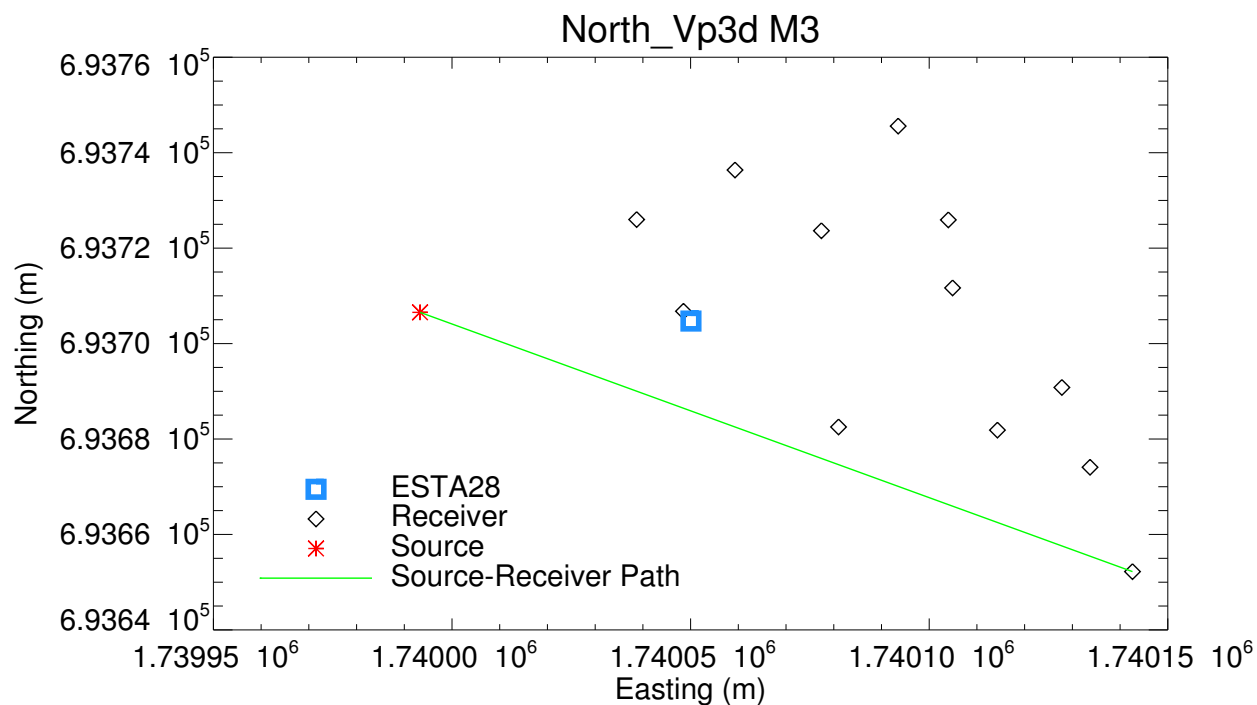
MODEL 4 SOURCE NW OF ESTA28
SOURCE-RECEIVER PAIR 9 OFFSET = 123 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCPD Foundation Area
 San Luis Obispo, California



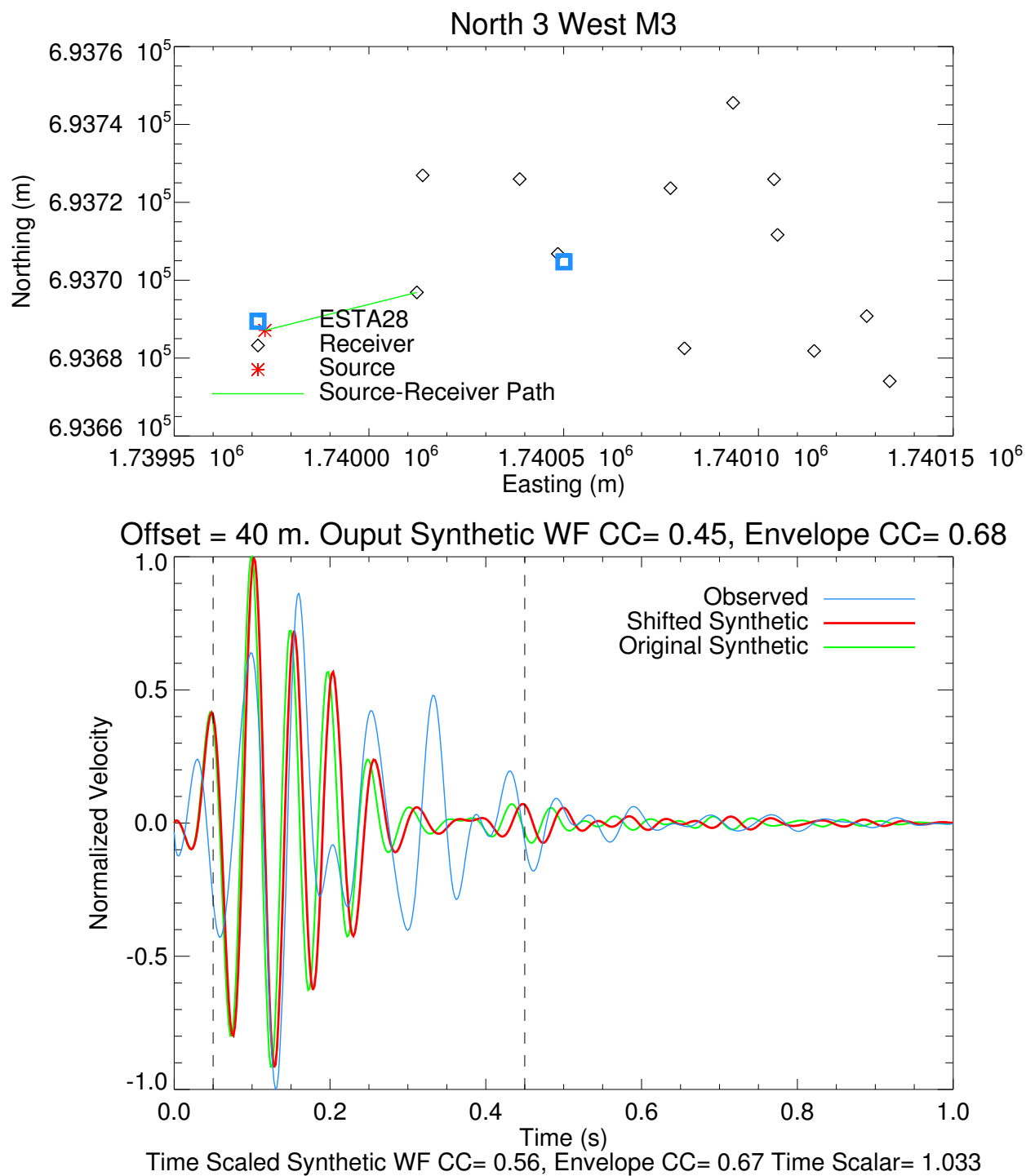
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 10 OFFSET = 135 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



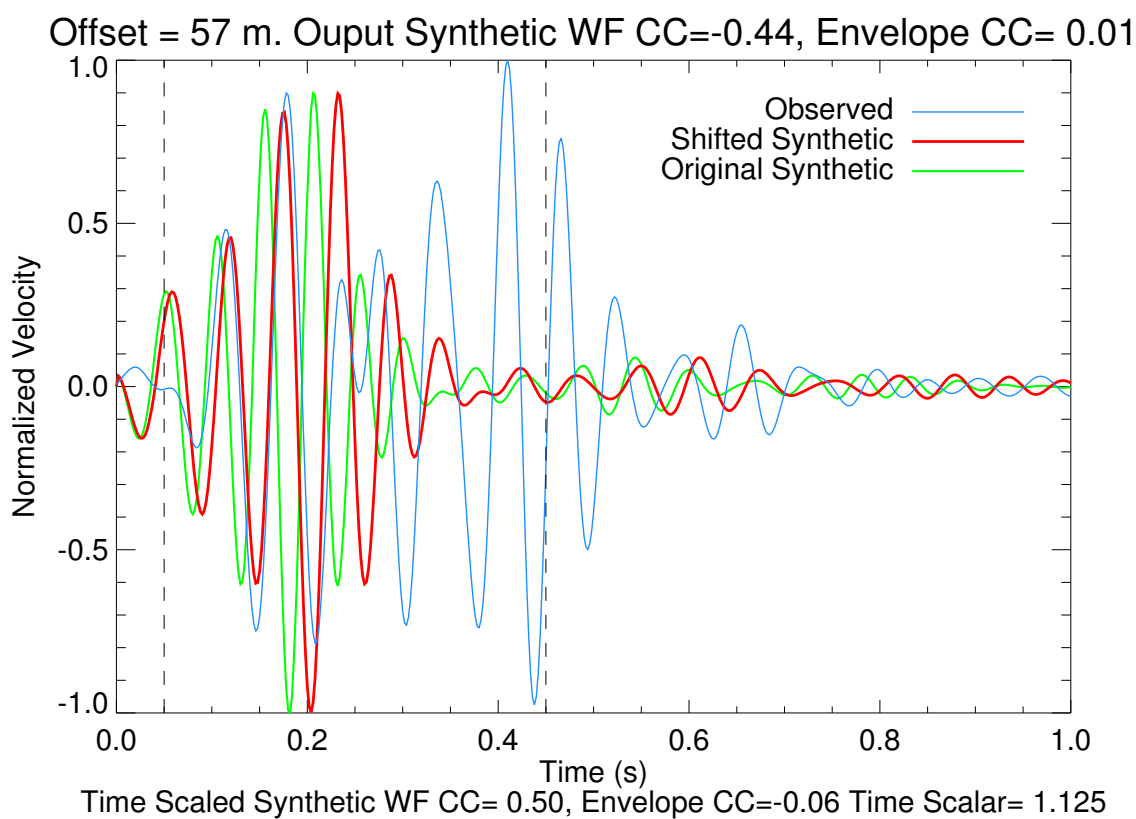
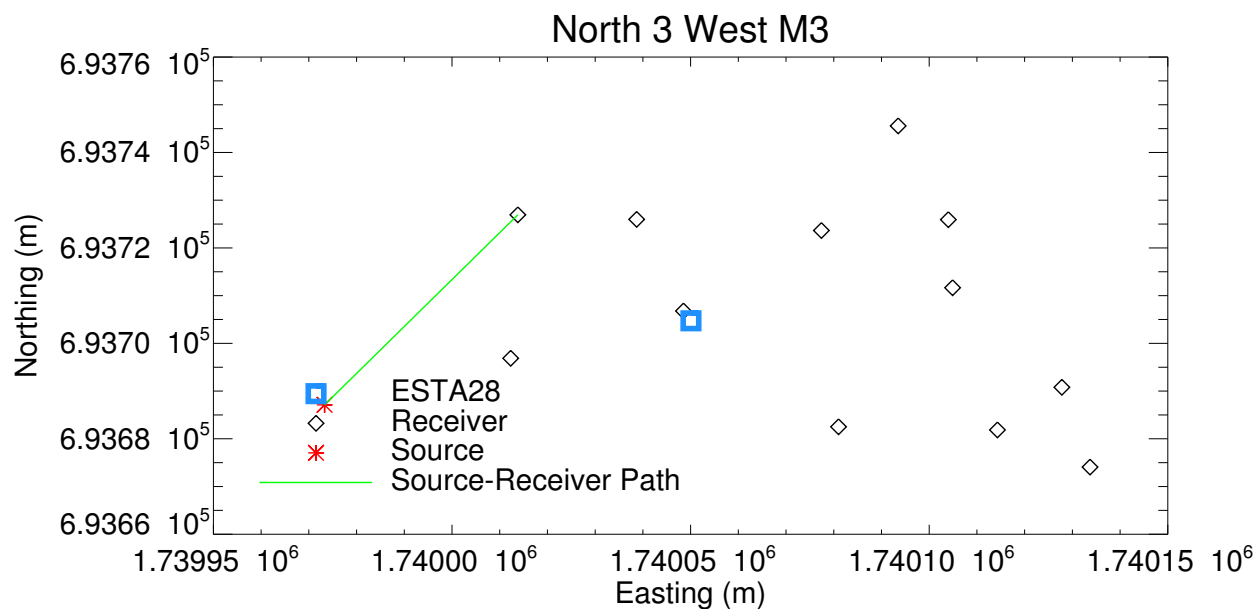
MODEL 4 SOURCE NW OF EST A28
SOURCE-RECEIVER PAIR 11 OFFSET = 144 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



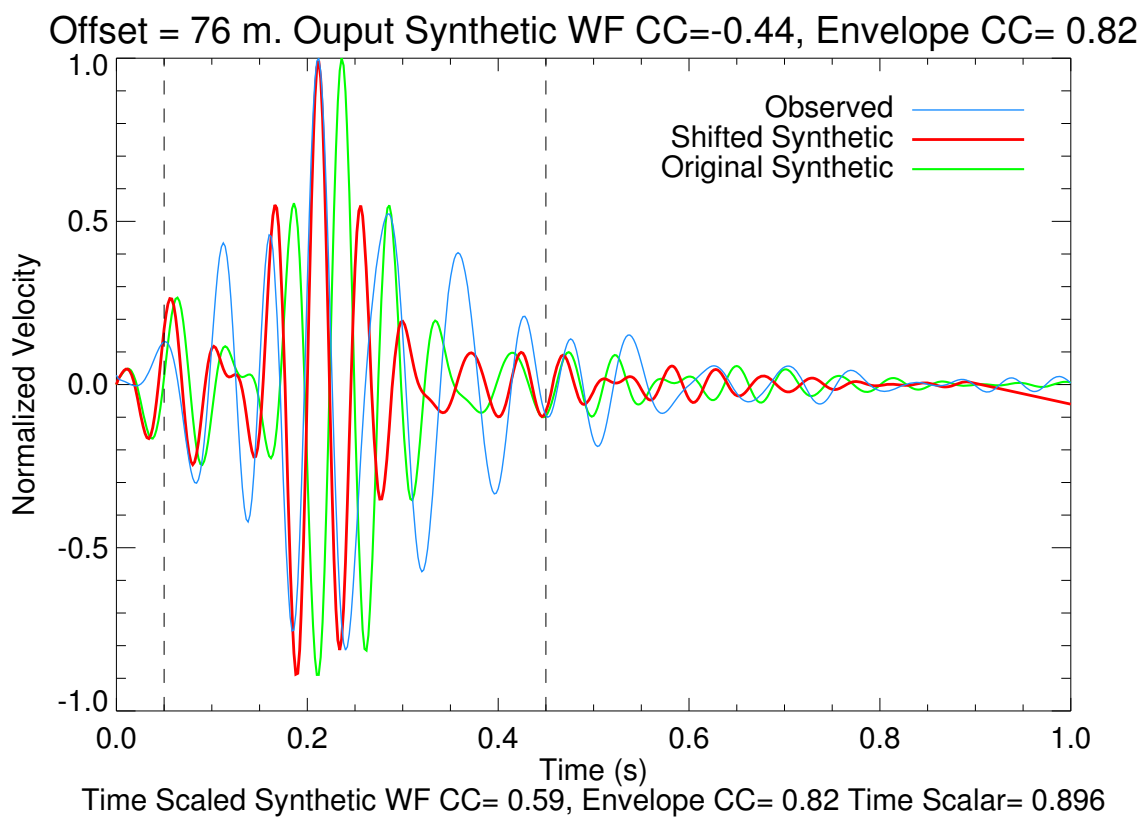
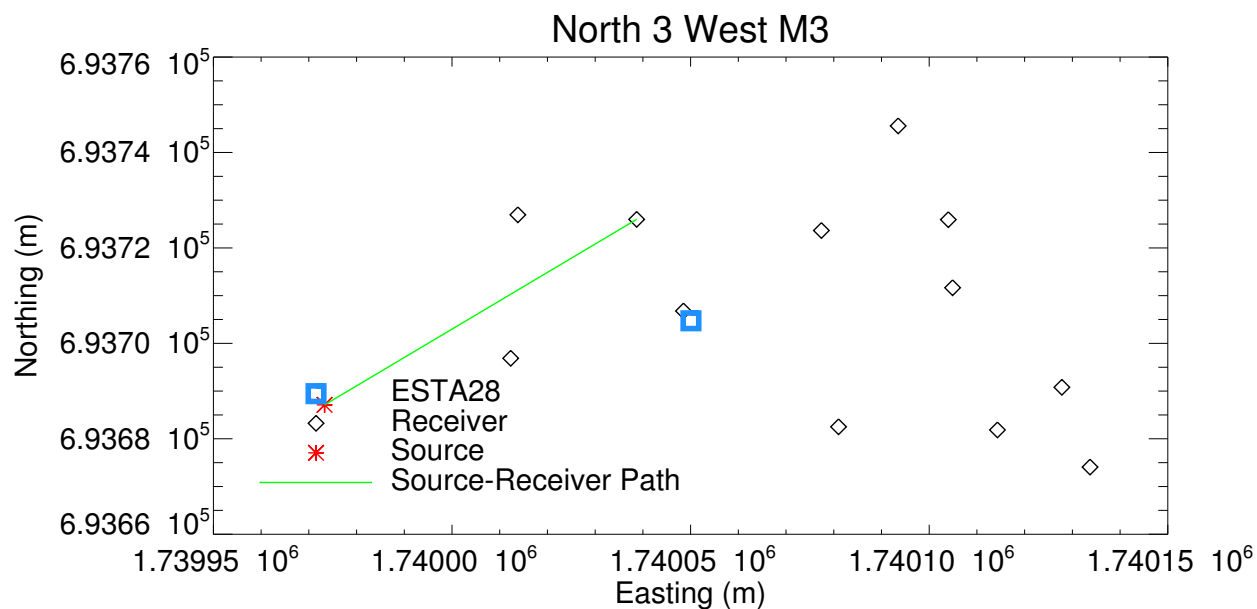
MODEL 4 SOURCE NW OF ESTA28
SOURCE-RECEIVER PAIR 12 OFFSET = 159 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



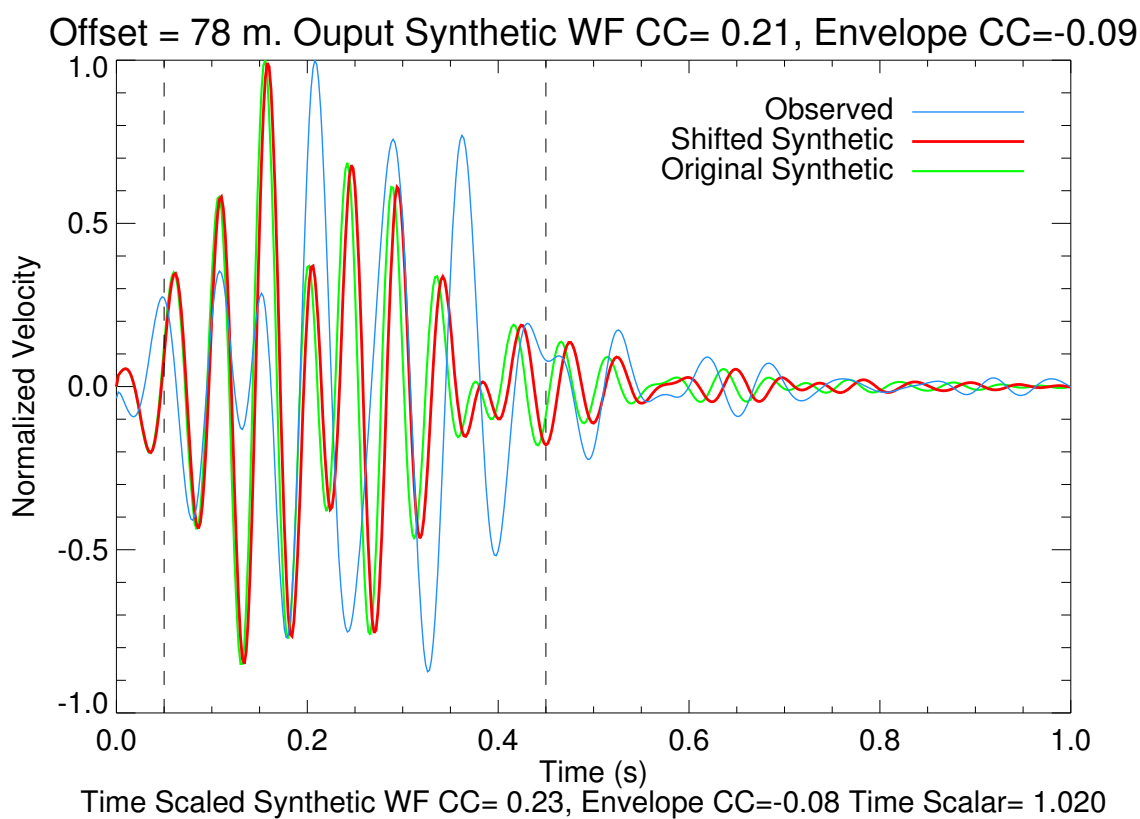
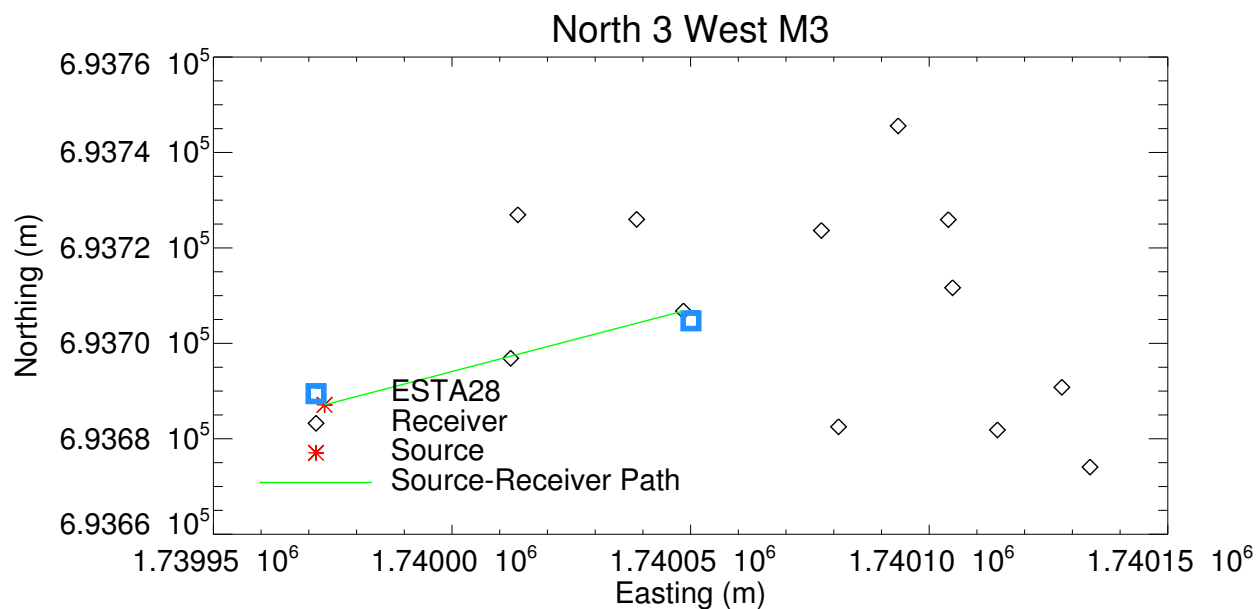
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 1 OFFSET = 40 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



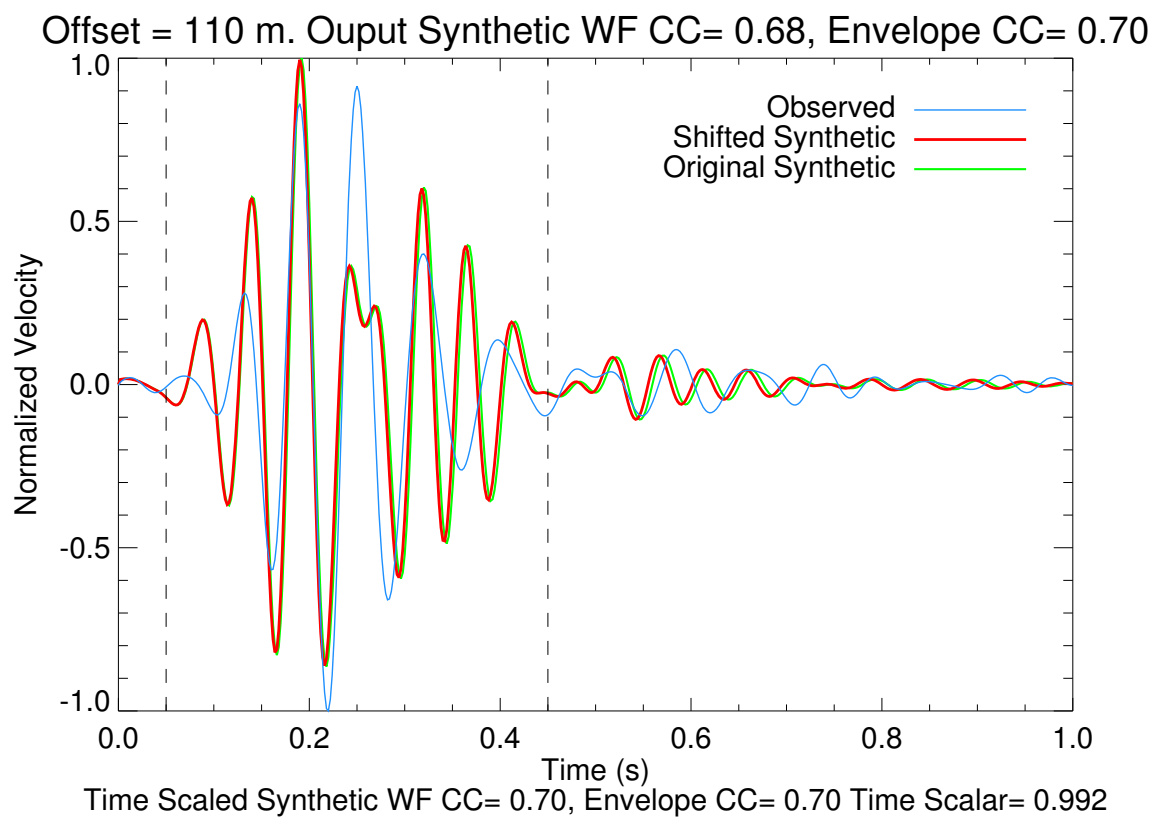
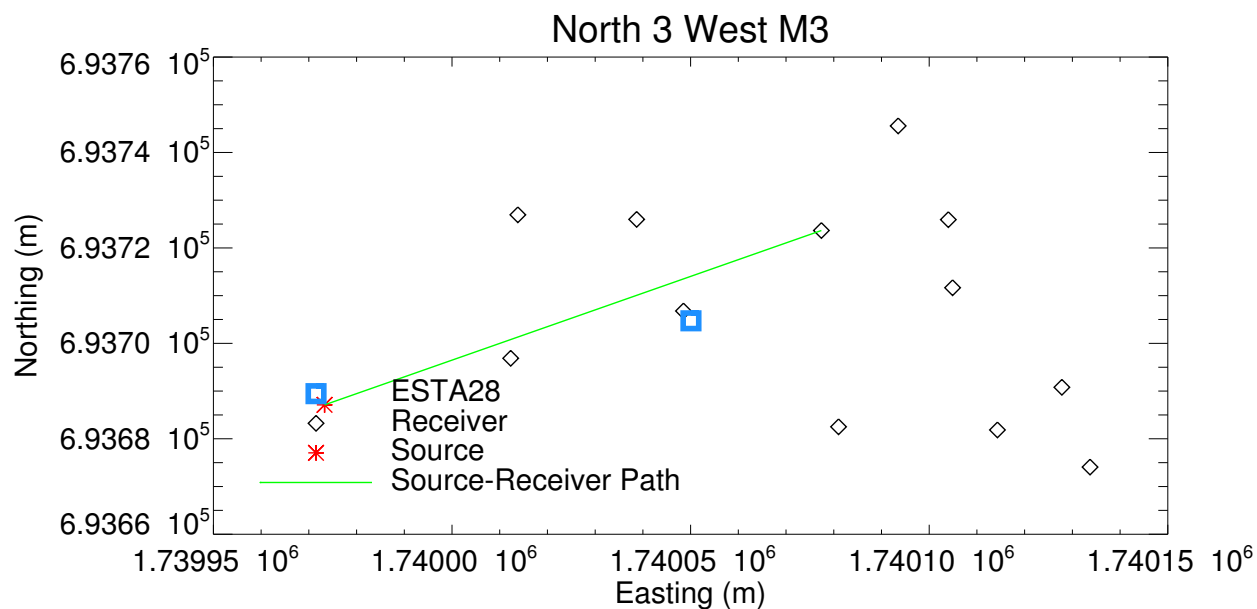
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 2 OFFSET = 57 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



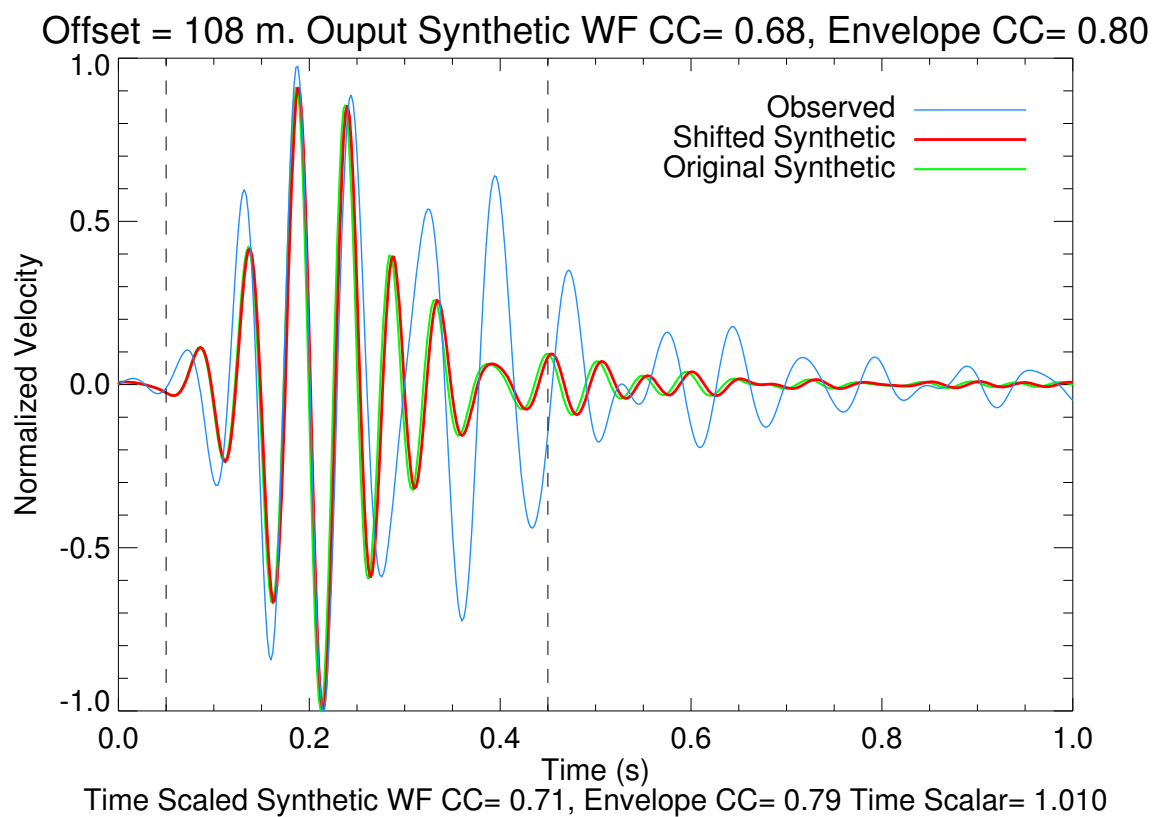
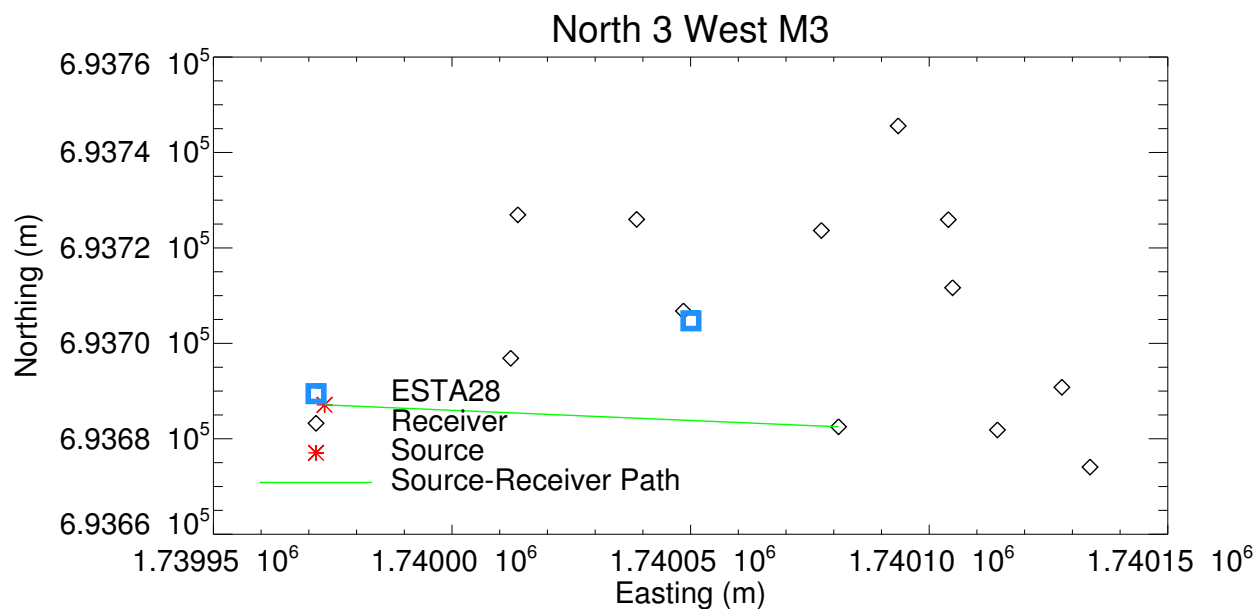
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 3 OFFSET = 76 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



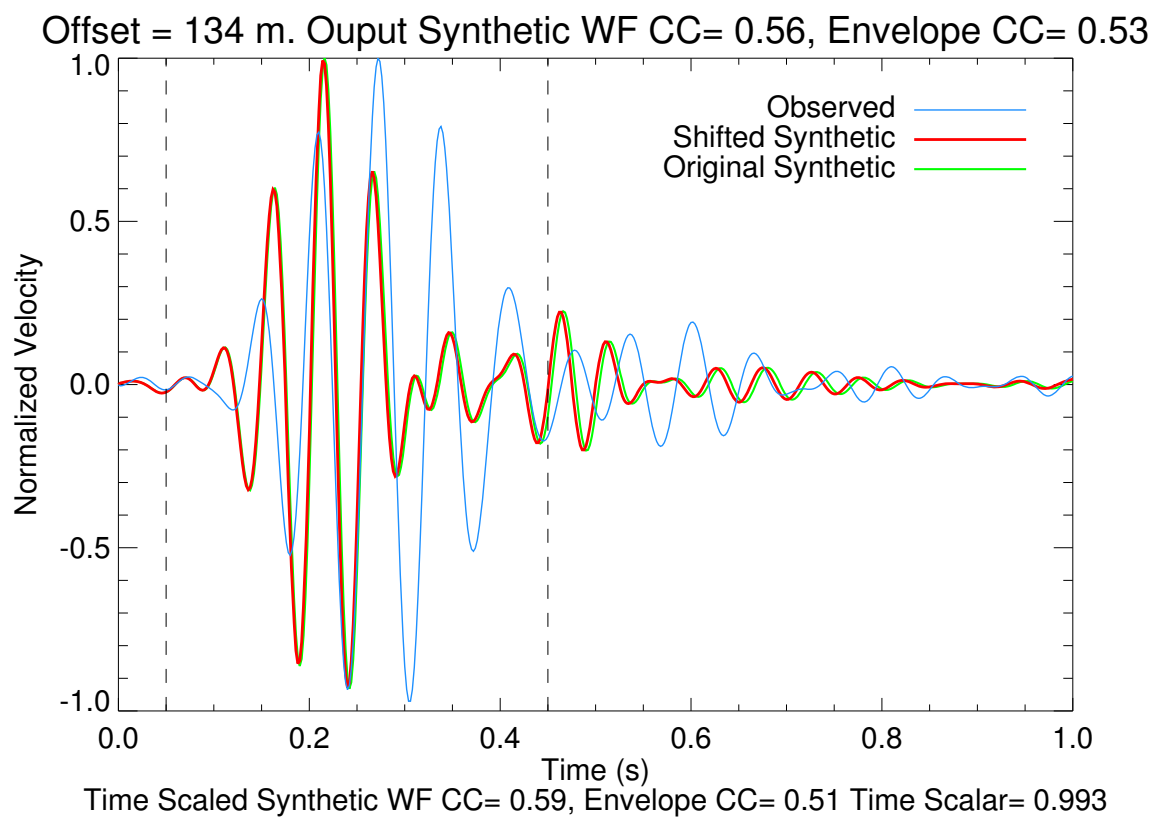
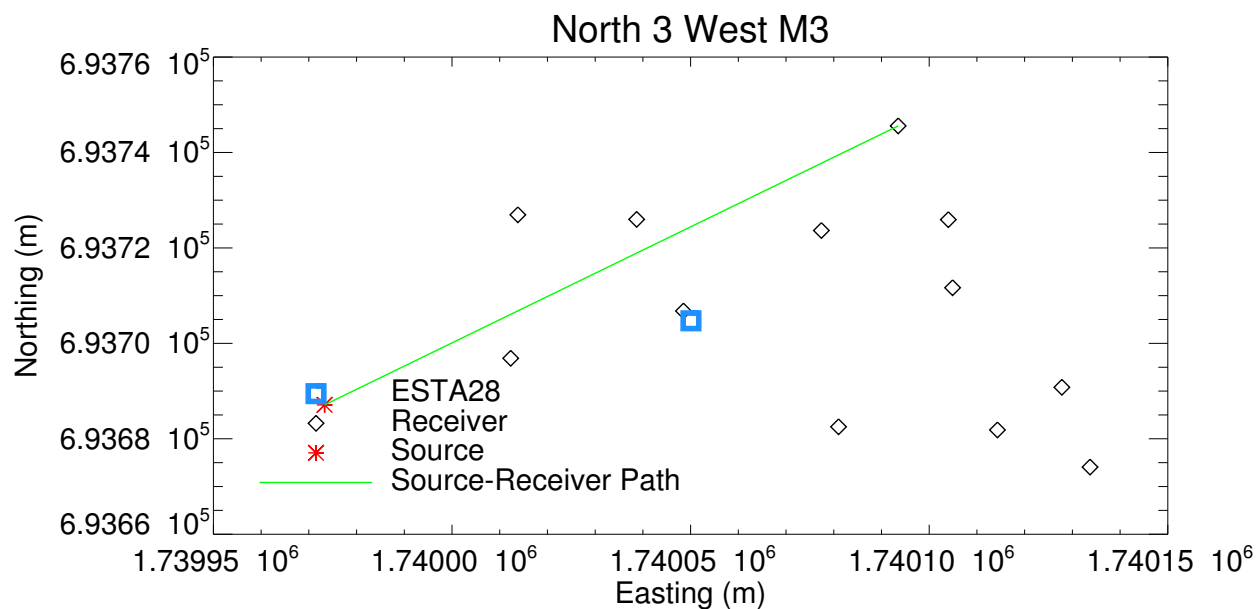
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 4 OFFSET = 78 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



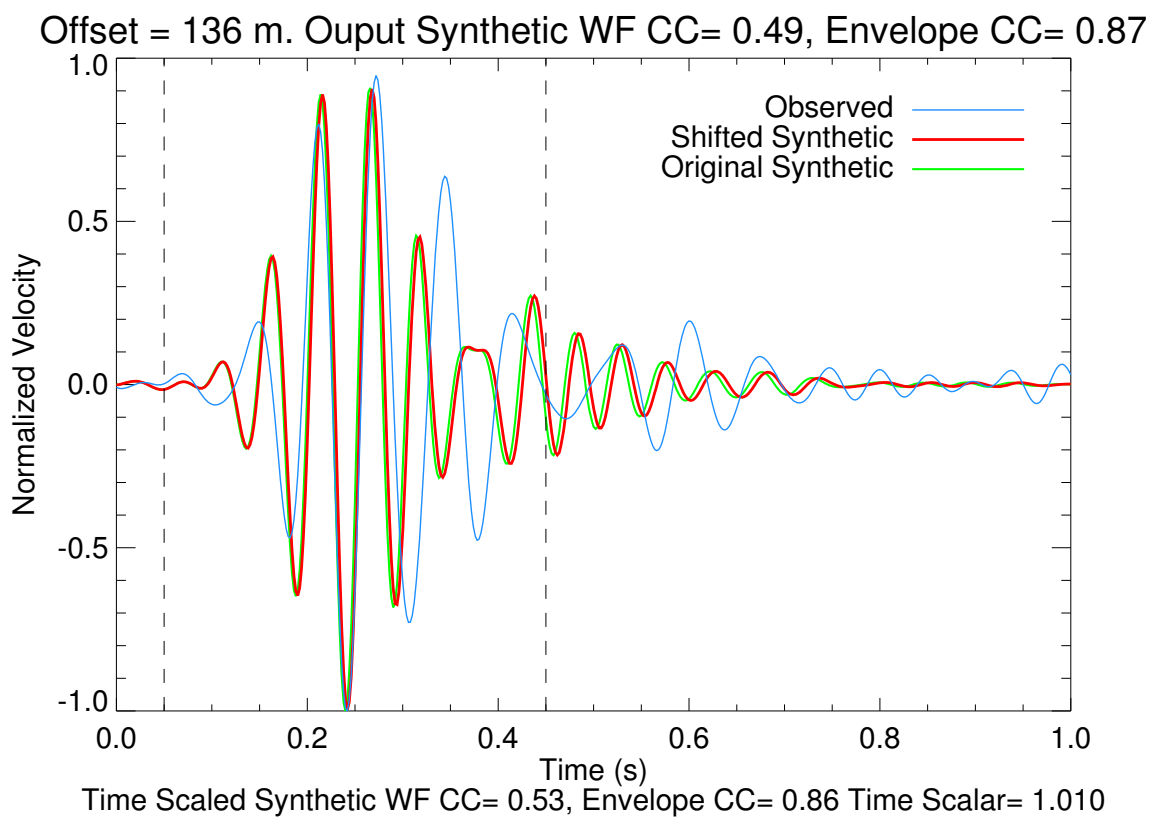
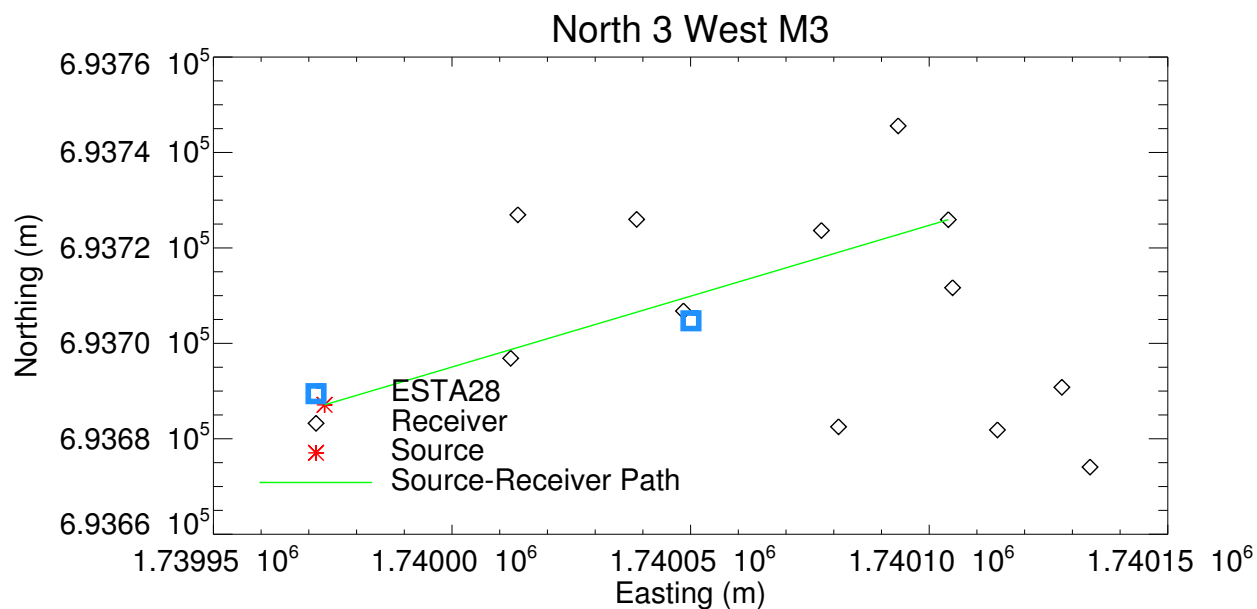
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 5 OFFSET = 110 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



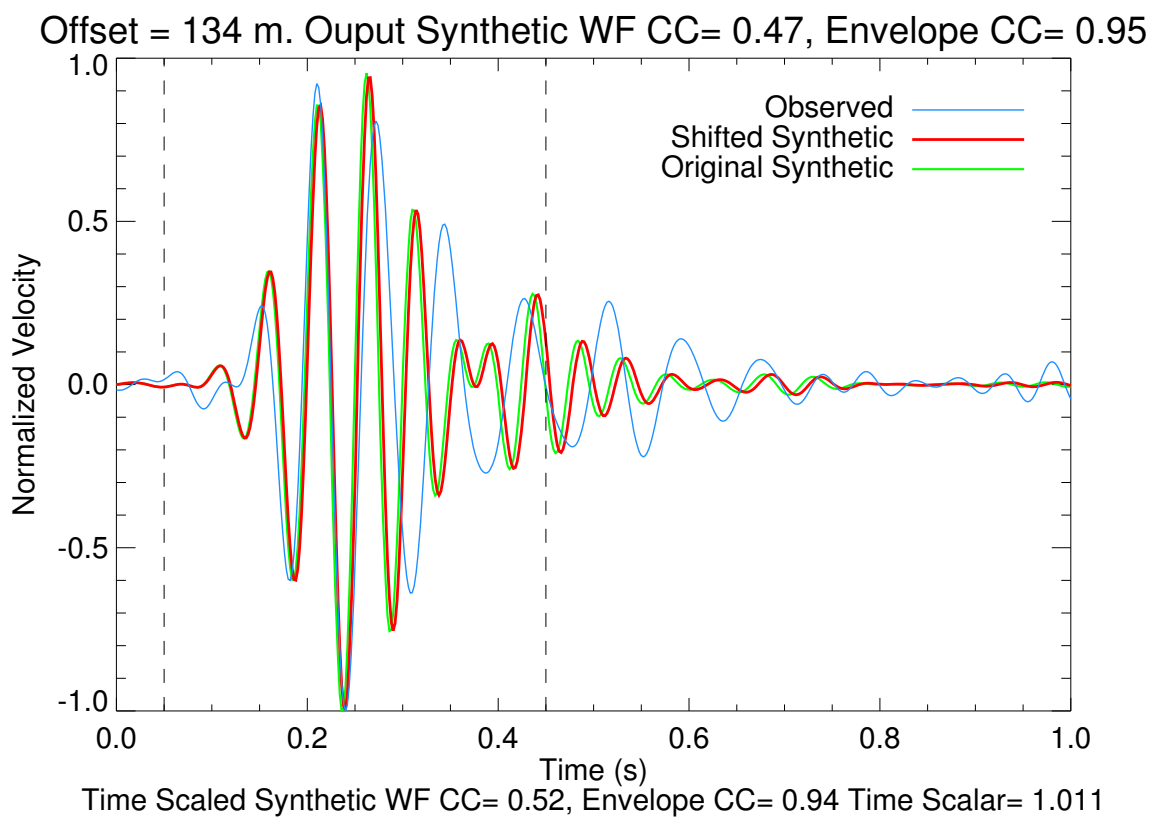
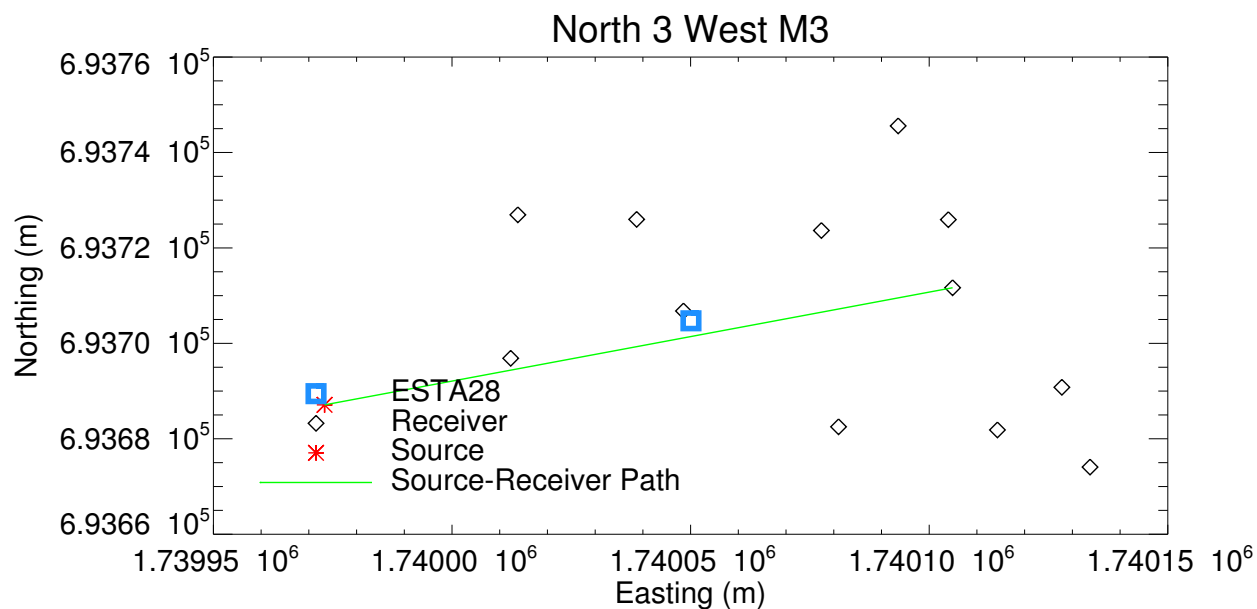
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 6 OFFSET = 108 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



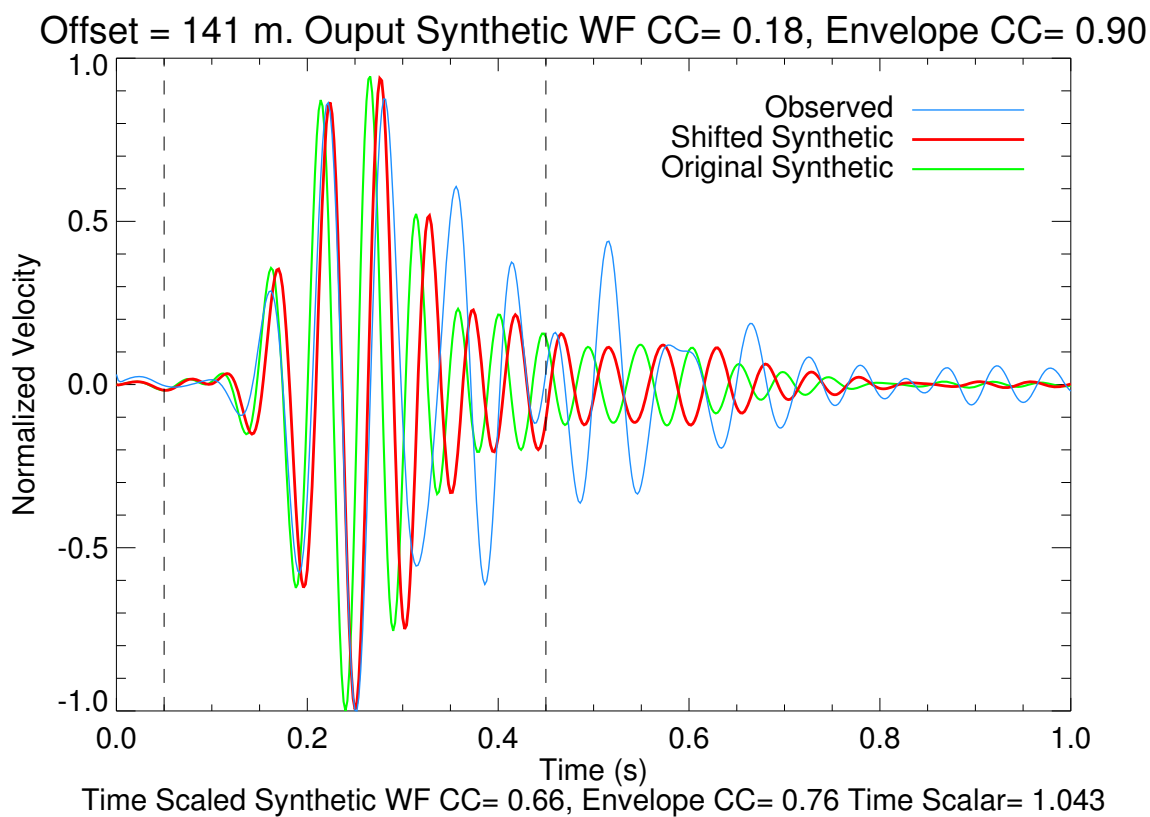
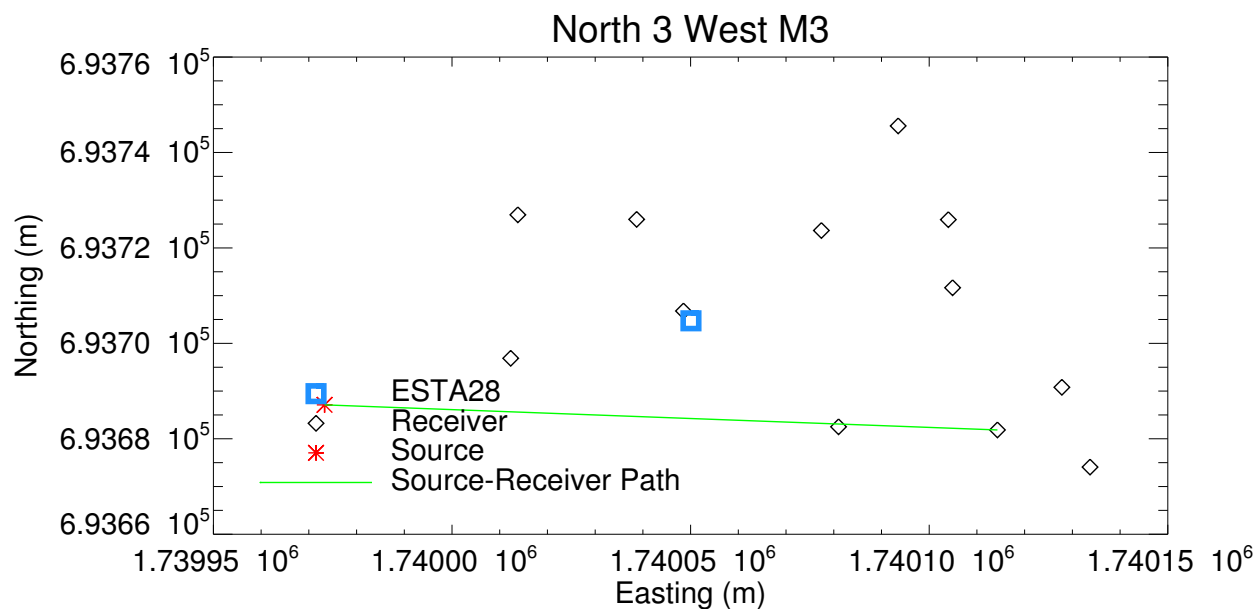
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 7 OFFSET = 134 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



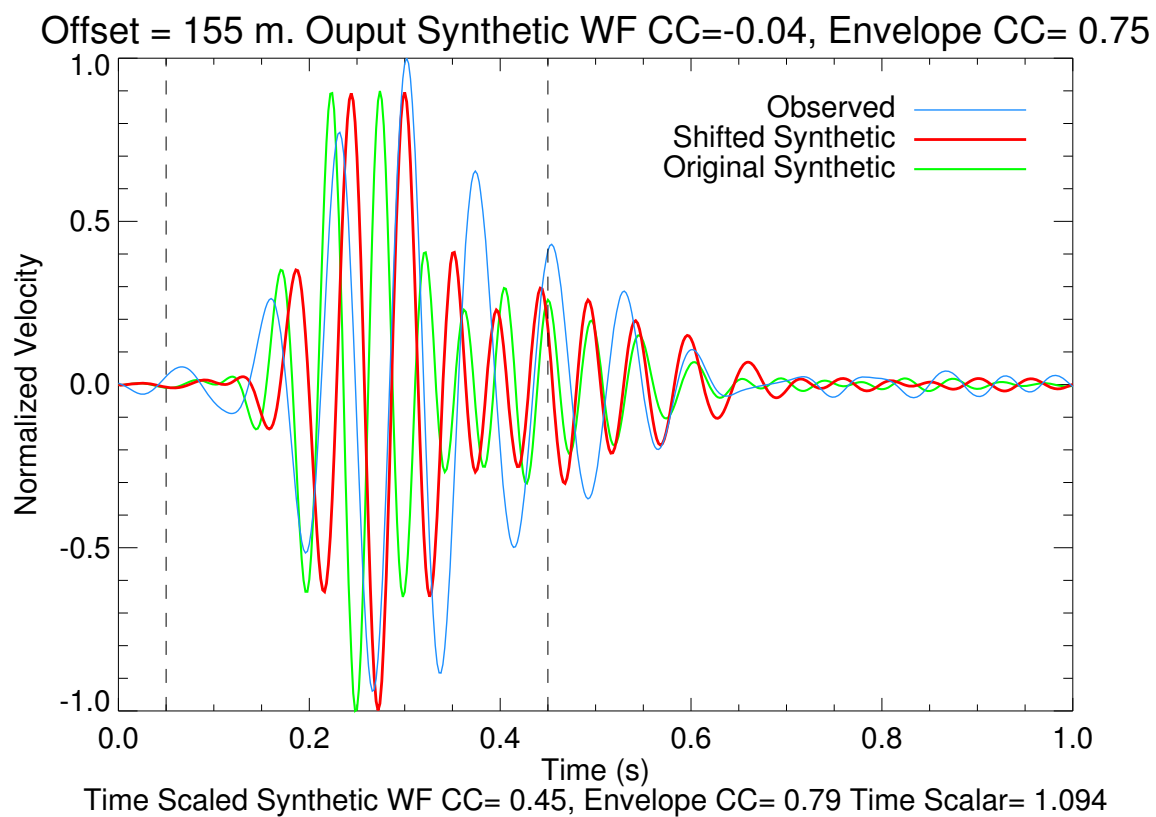
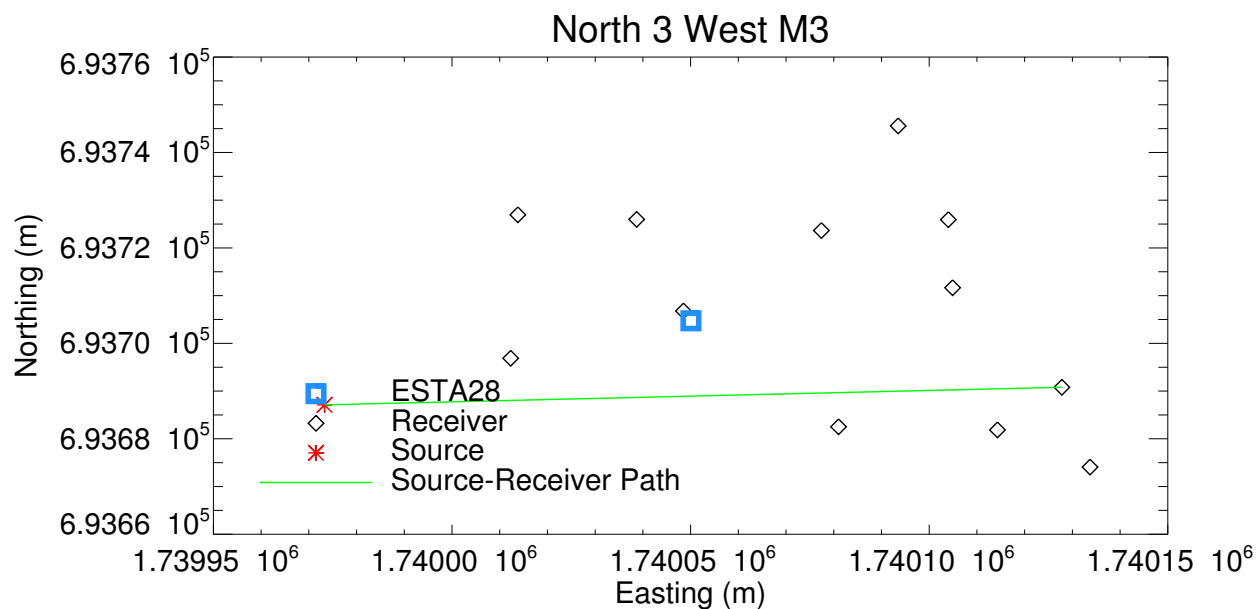
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 8 OFFSET = 136 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



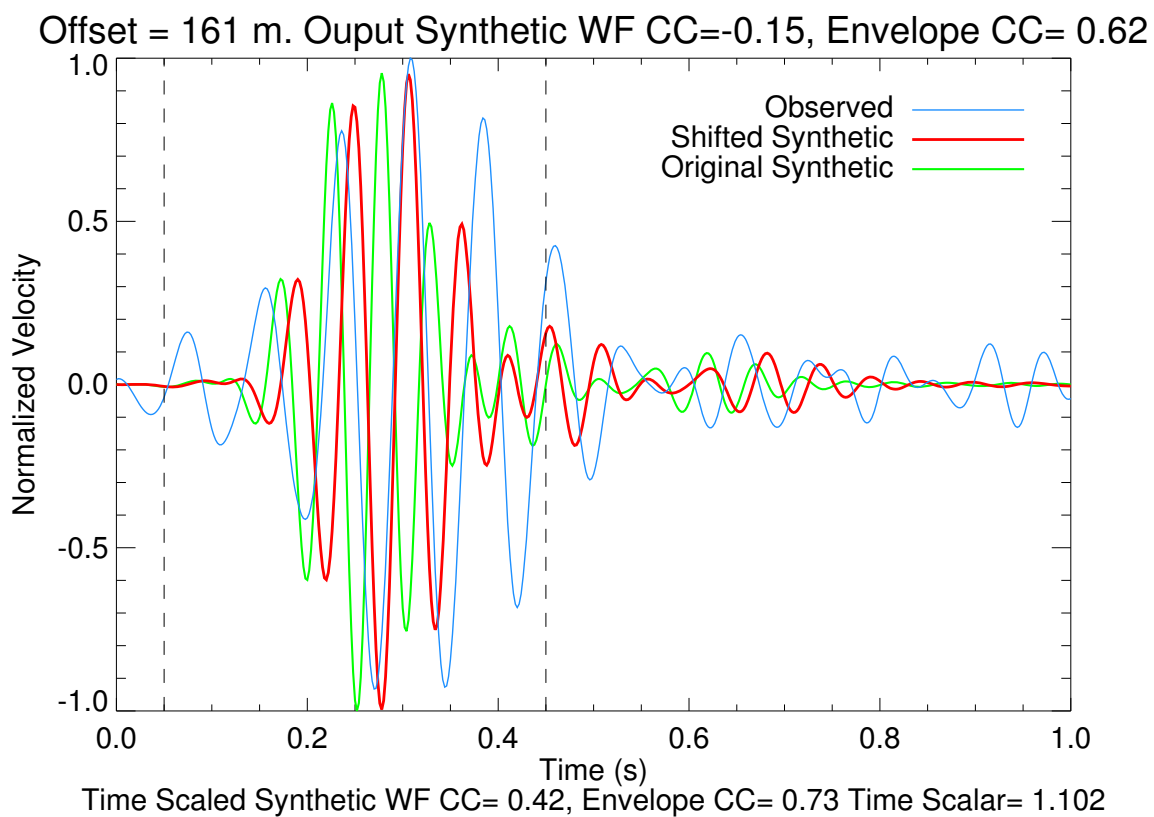
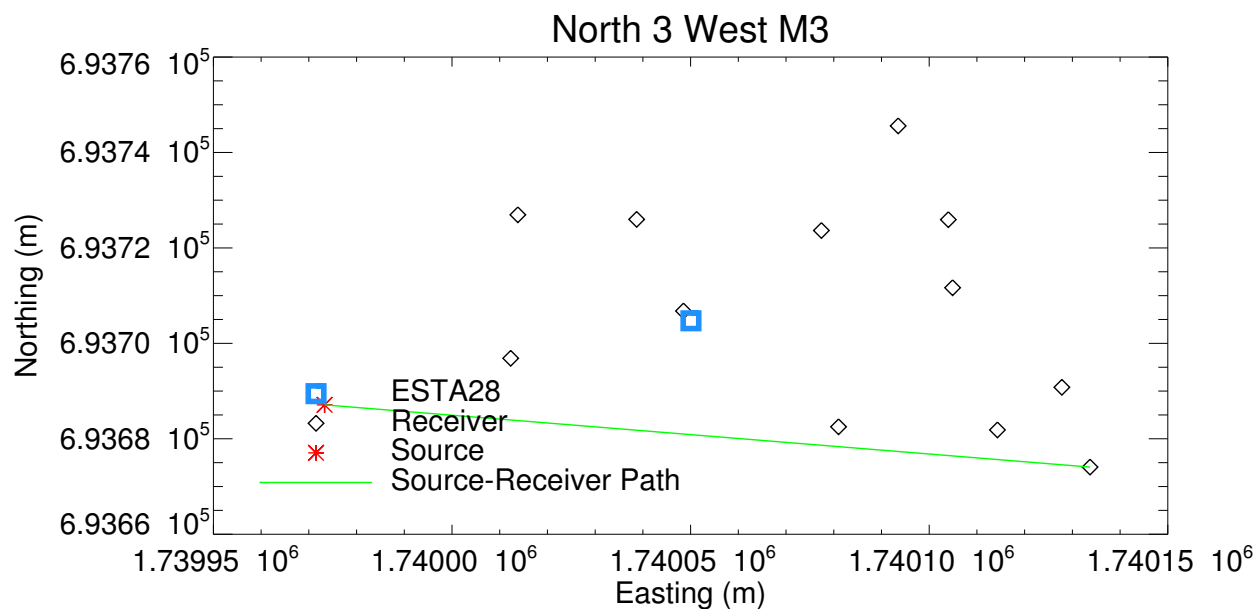
MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 9 OFFSET = 134 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCPD Foundation Area
San Luis Obispo, California



MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 10 OFFSET = 141 M GROUND MOTIONS
Update of the 3-D Velocity Model for the DCP Foundation Area
San Luis Obispo, California



MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 11 OFFSET = 155 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California



MODEL 4 SOURCE SW OF ESTA28
SOURCE-RECEIVER PAIR 12 OFFSET = 161 M GROUND MOTIONS
 Update of the 3-D Velocity Model for the DCP Foundation Area
 San Luis Obispo, California

APPENDIX E

APPENDIX E ELECTRONIC FILES

DCPP 3-D VELOCITY UPDATED MODEL

The updated DCPD 3-D velocity model is provided in a text format to ensure that the files can be inspected with a standard text editor. The files contain all the geographic and velocity information as ASCII text. Coordinates are in North American Datum of 1983 (NAD 83) State Plane Zone 5 meters. Coordinates and velocities are provided in meters and meters/second. The text file with the updated 3-D velocity model is named: dh_1p905m_120m_s-wave_consistent_GeoTomo_vp_rev11_dcpp_3dvgrid.txt. This file is provided in this appendix in compressed .7z format (www.7-zip.org).

This file uses header lines to document the data. In order to facilitate the inspection of these header lines, a text file named dh_1p905m_120m_s-wave_consistent_GeoTomo_vp_rev11_dcpp_3dvgrid_header.txt is also provided in this appendix. An example of the first 15 lines are given below:

- Line 1: Cell-centered draft DCPD Vp and Vs velocity grid with units in meters and meters/second
- Line 2: Cell-centered NAD 83 State Plane Zone 5 lower-left origin in meters
- Line 3: 1739465.1 693147.60
- Line 4: Horizontal constant-velocity cell size in meters
- Line 5: 1.905
- Line 6: Vertical constant-velocity cell size in meters
- Line 7: 0.508
- Line 8: Number of vertical velocity profiles
- Line 9: 256372
- Line 10 number of x cell-center positions on the grid
- Line 11 599
- Line 12 Number of y cell-center positions on the grid
- Line 13 428
- Line 14 Number of elevation points in each velocity profile
- Line 15 589

The entire sequential lists of text lines without the intervening data are produced below:

- Cell-centered draft DCPD Vp and Vs velocity grid with units in meters and meters/second
- Cell-centered NAD 83 State Plane Zone 5 lower-left origin in meters
- Horizontal constant-velocity cell size in meters
- Vertical constant-velocity cell size in meters
- Number of vertical velocity profiles
- Number of x cell-center positions on the grid
- Number of y cell-center positions on the grid

- Number of elevation points in each velocity profile
- Elevation values in meters (positive above sea level) of velocity cell tops (589 points)
- Distance east from lower-left cell center to each x,y cell center in meters (256,372 points)
- Distance north from lower-left cell center to each x,y cell center in meters (256,372 points)
- Vp value that indicates an elevation sample is above topography
- Vs value that indicates an elevation sample is above topography
- Vp elevations profiles in meters/second (256,372 lines with 589 velocity values per line)
- Vs elevations profiles in meters/second (256,372 lines with 589 velocity values per line)

The example Interactive Display Language (IDL) command set below illustrates an approach to read the DCPD 3-D velocity model file:

```
str=''
ifile='dh_1p905m_120m_s-wave_consistent_GeoTomo_vp_rev8_dcpp_3dvgrid.txt'
openr,unit1,ifile,/get_lun
readf,unit1,str
readf,unit1,str
xorigm=0d0
yorigm=0d0
readf,unit1,xorigm,yorigm
readf,unit1,str
hcellsize=0d0
readf,unit1,hcellsize
readf,unit1,str
zcellsize=0d0
readf,unit1,zcellsize
readf,unit1,str
nn=0L
readf,unit1,nn
readf,unit1,str
nx=0L
readf,unit1,nx
ny=0L
readf,unit1,ny
nelevs=0L
readf,unit1,nelevs
sizm=fltarr(nelevs)
readf,unit1,str
```

```
readf,unit1,sizm
readf,unit1,str
dxm=fltarr(nn)
readf,unit1,dxm
readf,unit1,str
dym=fltarr(nn)
readf,unit1,dym
vpnull=0.
readf,unit1,str
readf,unit1,vpnull
vsnull=0.
readf,unit1,str
readf,unit1,vsnull
vpn=fltarr(nelevs,nn)
readf,unit1,str
readf,unit1,vpn
readf,unit1,str
vsnull=fltarr(nelevs,nn)
readf,unit1,vsnull
close,unit1
free_lun,unit1
```

1-D VS PROFILES AT ESTA 27 AND ESTA28

Using the updated DCP 3-D velocity model, 1-D Vs profiles at ESTA 27 and ESTA 28 were extracted and provided in text files in this appendix. These files are named `ESTA_27_1-D_Vs.txt` and `ESTA_28_1-D_Vs.txt`. These files contain two columns of data, elevation in meters and Vs in meters per second.