

User manual for the Southern California Earthquake Center Community Velocity Model: SCEC CVM-H 6.2

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http://structure.harvard.edu/cvm-h/download/cvmh_manual.pdf

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1 Overview

The SCEC CVM-H 6.2 is a 3D model of the elastic structure of southern California. It contains volumetric representations of compressional wave velocity (V_P), shear wave velocity (V_S), and density (ρ). It also contains three primary surfaces: the topological/bathymetric surface, the basement surface, and the Moho surface. The model is constructed from numerous datasets (*Süss and Shaw, 2003*) and has been used within parallel-computing based wavefield simulations of earthquakes within southern California (e.g., *Komatitsch et al., 2004*). See Section 6 for details.

2 Downloading CVM-H 6.2

1. Start at SCEC website:
`http://epicenter.usc.edu/cmeportal/cmodels.html`
2. Click “SCEC CVM-H” to link to Harvard website:
`http://structure.harvard.edu/cvm-h/`
3. Read the description of the model.
4. At the bottom of the page, click to download latest version `vx62.tar.bz2`
NOTE: this file is large (500 MB), so the download make take awhile.
Alternatively, browse the download options here:
`http://structure.harvard.edu/cvm-h/download/`
5. Unzip files:
 - `bunzip2 vx62.tar.bz`
 - `tar xvf vx62.tar`
6. The files you should see are these:

```
cvmh_manual.pdf          -- this file
CMxVM_Model13D_CalMex_BAT0.ts  -- bathymetry/topography as tsurf, version 4
CVMH_CalMex_BAT0.ts         -- bathymetry/topography as tsurf, version 5
CMxVM_Model13D_CM_BASE_Folded.ts -- top of the basement as tsurf
CVMH_Moho.ts               -- Moho surface
ts2gts.awk                 -- script to translate from .ts to .gts
ts2gts.sh                  -- run script for ts2gts.awk
Makefile                   -- for compilation
interpolate                -- directory with routines for
                           inverse distance weighted interpolation
gctpc                       -- projection library
src                         -- directory for source files
bin                         -- directory for RUN
```

3 System requirements and compilation

The system requirements are as follows:

1. UNIX operating system (Linux, Solaris, MacOS)
2. GNU make
3. tar and bunzip2 for opening the compressed files

From the main directory, compile vx:

```
make all
cd bin
ls -ltr
```

You should see the executable vx as the most recent file.

4 Extracting values from CVM-H 6.2

The `vx` code provides output consistent with directly querying the voxel in the Gocad software, and gives the position of the cell centers from which the data are provided. Also, elevation of the topographic, basement and Moho surfaces are provided, at the closest grid point to the input coordinates. Additional details are listed in Tables 1 and 2. For usage details, type `vx -h`.

From the `bin` directory, try feeding the test points into the program. The test file, `test.dat`, contains eight input points:

```
-125 35 -7777
-118.56 32.55 -2450
360061 3750229 -1400
-118.52 34.12 -1400
-116.40 32.34 -1000
376592 3773379 -1770
376592 3773379 -17700
408669 3766189 -3000
```

Note that the input can be either (lon, lat, elevation) or (UTMx-11, UTMMy-11, elevation).

Execute `vx` with the command¹

```
./vx < test.dat
```

The output has 8 rows and 18 columns (Table 1) and should look like this (here the columns are truncated):

```
-125.000000    35.000000   -7777.00  -230844.88  3902223.73  -99999.00  -99999.00  -99999.00  -99999.00  -99999.00  -99999.00  nr  -99999.00  -99999.00  -99999.00  -99999.00
-118.560000    32.550000   -2450.00  353525.18  3602285.14  353625.00  3602375.00  -1114.91  -1150.00  -1327.54  -21571.67  lr  354000.00  3602000.00  -2400.00  2.
360061.000000  3750229.000000  -1400.00  360061.00  3750229.00  360125.00  3750125.00  -56.93  -50.00  -1404.07  -24868.83  lr  360000.00  3750000.00  -1400.00  2.
-118.520000    34.120000   -1400.00  359819.67  3776309.78  359875.00  3776375.00  491.46  450.00  38.42  -28061.40  lr  360000.00  3776000.00  -1400.00  2.
-116.400000    32.340000   -1000.00  556464.74  3578092.46  556375.00  3578125.00  780.43  750.00  616.39  -31413.62  lr  556000.00  3578000.00  -1000.00  2.
376592.000000  3773379.000000  -1770.00  376592.00  3773379.00  376625.00  3773375.00  99.38  100.00  -2374.53  -28165.35  hr  376552.25  3773500.00  -1800.00  3.
376592.000000  3773379.000000  -17700.00  376592.00  3773379.00  376625.00  3773375.00  99.38  100.00  -2374.53  -28165.35  cm  380000.00  3770000.00  -18000.00  2.
408669.000000  3766189.000000  -3000.00  408669.00  3766189.00  408625.00  3766125.00  93.89  50.00  -2820.45  -29799.86  hr  408552.25  3766250.00  -3000.00  2.
```

The values for the eighth row are listed below, in transpose form, and with some annotations:

```
408669.000000
3766189.000000
-3000.00
408669.00
3766189.00
408625.00
3766125.00
93.89    --> elevation of topo/bath surface
50.00    --> elevation of top of model (below which there is data)
-2820.45 --> elevation of basement surface
-29799.86 --> elevation of Moho surface
hr
408552.25
3766250.00
-3000.00
2.00     --> value from tomography model
4997.06  --> Vp
2889.03  --> Vs
2534.30  --> density
```

Note that there is a discrepancy between the top of the model (50.00 m) and the topography (93.89 m). The “real” top of the model is defined by `mtop`, and there may be minor discrepancies between `mtop` and `topo`.

If you wish to extract values from the CVM-H without consideration of topography, please see Appendix B for one possible approach.

¹To output directly to a file, use the format `./vx < test.dat > ofile1.dat`

Table 1: Columns of the output produced by vx. Queries which fall outside of the model area return -99999, the no-data value, for all fields.

Column Index	Variable	Description
1	X	input X (longitude or UTM coordinate)
2	Y	input Y (latitude or UTM coordinate)
3	Z	input Z (elevation, meters above sea level, i.e., positive up)
4	utmX	UTM coordinate (zone 11), easting
5	utmY	UTM coordinate (zone 11), northing
6	elevX	X coordinate of center of the cell which provided data value for elevations
7	elevY	Y coordinate of center of the cell which provided data value for elevations
8	topo	topographic/bathymetric elevation in m
9	mtop	top of model in m, below this depth there are data
10	base	basement elevation in m (generally negative)
11	moho	Moho elevation in m (always negative)
12	hr/lr/cm	flag to indicate whether high- (hr), low-resolution (lr) or lower crust/mantle voxet was used; nr if no data available
13	cellX	X coordinate of center of cell which provided velocity data value
14	cellY	Y coordinate of center of cell which provided velocity data value
15	cellZ	Z coordinate of center of cell which provided velocity data value
16	tag	tag: provenance of data point (see Table 2)
17	vp	compressional wave velocity in m/s
18	vs	shear wave velocity in m/s
19	rho	density in kg/m ³

Table 2: Provenance tag: the 16th column of the output file (see Table 1).

Index	Description
1	mantle data
2	tomography
3	basins
4	air
5	basin GTL
6	extrapolated tomography
7	water
8	basement GTL
9	basin-background transition in outer area (no basin model)
10	air in outer area
11	filled-in mantle
12	filled-in crust
13	extrapolated mantle

5 Extracting distances to surfaces in CVM-H 6.2

There is also an additional program, `cvmdst`, to compute the the distance to, and the location, of the closest points on the topographic/bathymetric, top of the basement, and Moho surfaces which are provided with CVM-H. The input file has the same format as the input file to `vx`, the query code to CVM-H.

To use this capability, you need GTS (GNU Triangulated Surface Library), available from <http://gts.sourceforge.net>. (Using a Linux-Ubuntu platform, it may be as simple as installing all “gts” packages from the Synaptic Package Manager.) With GTS installed, you can now compile. From the `vx62` directory, compile:

```
make cvmdst
cd bin
ls -ltr
```

You should see that the executable `cvmdst` is the most recent file.

Try the program with the same test data as before:

```
./cvmdst < test.dat > ofile2.dat
```

The output file `ofile2.dat` has 17 columns described in Table 3. Note that the basement surface is not defined over the entire area of the model.

Table 3: Columns of the output produced by `cvmdst`.

Column Index	Variable	Description
1	X	repeat of input coordinates
2	Y	
3	Z	
4	utmX	UTM coordinates (zone 11)
5	utmY	
6	t_x	location of the closest point on the topographic/bathymetric surface
7	t_y	
8	t_z	
9	t_dst	distance to the closest point on the topographic/bathymetric surface
10	b_x	location of the closest point on the top of the basement surface
11	b_y	
12	b_z	
13	b_dst	distance to the closest point on the basement surface
14	m_x	location of the closest point on the Moho surface
15	m_y	
16	m_z	
17	m_dst	distance to the closest point on the Moho surface

6 History of CVM-H releases

Please reference at least *Süss and Shaw (2003)* if you use this model. The latest model, CVM-H 6.2, contains several components that may warrant referencing, depending on the objectives of a particular study. For example, the background crustal tomography model is from *Tape et al. (2009)*, the upper mantle model is from *Prindle and Tanimoto (2006)*, and the Moho surface is obtained primarily from *Yan and Clayton (2007)*. Additional references for basins within the high-resolution model are within these papers: *Komatitsch et al. (2004)*, *Lovely et al. (2006)*, *Munster (2007)*.

Table 4 documents the references for each release (up to *Plesch et al. (2009)*), as well as references for new components associated with each release. The CVM-H model has also been presented at these SCEC meetings: *Stidham et al. (2001a)*, *Suess and Shaw (2002)*, *Shaw et al. (2004)*.

Table 4: History of CVM-H releases.

Version	Date	Reference	New Components				
			Mantle	Moho	Crust	Basins	GTL
CVM-H 1.0	2003	<i>Süss and Shaw (2003)</i>	—	—	—	SS2003	—
CVM-H 2.0	Sept 2005	<i>Suess et al. (2005)</i>	1D		H2000	K2004 L2006	
CVM-H 4.0	Sept 2006	<i>Suess et al. (2006)</i>					
CVM-H 5.0	Sept 2007	<i>Plesch et al. (2007)</i>	PT2006		L2007	M2007	M2000 M2002
CVM-H 5.5	Sept 2008	<i>Plesch et al. (2008)</i>					BJ1997
CVM-H 6.0	Sept 2009	<i>Plesch et al. (2009)</i>		YC2007	T2009		
CVM-H 6.2	Jan 2010	<i>Plesch et al. (2009)</i>					

REFERENCES: BJ1997 (*Boore and Joyner, 1997*), H2000 (*Hauksson, 2000*), L2007 (*Lin et al., 2007*), L2006 (*Lovely et al., 2006*), K2004 (*Komatitsch et al., 2004*), M2000 (*Magistrale et al., 2000*), M2002 (*Magistrale, 2002*), M2007 (*Munster, 2007*), PT2006 (*Prindle and Tanimoto, 2006*), SS2003 (*Süss and Shaw, 2003*), T2009 (*Tape et al., 2009, 2010*), YC2007 (*Yan and Clayton, 2007*), 1D (*Kanamori and Hadley, 1975; Dreger and Helmberger, 1991; Wald et al., 1995*)

7 Acknowledgments and contact info

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- Contributions to this manual were made by: Andreas Plesch, Carl Tape, John Shaw, Patrick Small.
- Please email andreas_plesch@harvard.edu for help on downloading and using CVM-H 6.2, and for any suggestions for the delivery of the code or for this manual.
- Please reference at least *Süss and Shaw* (2003) if you use this model; other references should be considered, depending on the purpose (see Section 6).

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A Miscellaneous technical notes

This section contains notes on previous versions of the CVM-H model. Note that the information here does not necessarily apply to the current model, CVM-H 6.2.

Log file from 6/2007 onward:

- 10/2009 AP: minor update of Moho surface in CM, corresponding update to changed cells, truncated border by one cell in LR, fixed V_P/V_S in interpolation area
- 09/2009 AP: replaced LR and HR data files with *Tape et al. (2009)* \mathbf{m}_{16} model as background, replaced Moho data with update, changed tagging
- 06/2009 AP: returned GTL cells in Salton trough to original CVM-H values, higher coordinate output precision
- 03/2009 AP: changed density scaling to Nafe–Drake (*Brocher, 2005*)
- 09/2008 AP: fixed V_S in buffer zone, used model V_P/V_S , not interpolated V_S , in core zone to be consistent with V_P there
- 08/2008 AP: enlarged area to fit TeraShake box, added model V_S in all voxets, no tt file creation
- 01/2008 AP: replaced striped artifacts offshore San Diego with depth-basin depth-seafloor calibrated model data
- 11/2007 AP: clarified geodetic datum with P. Suess
- 10/2007 AP: added V_S voxel for lower crust/mantle, switched to *Brocher (2005)* V_S in LR/HR, truncated min. V_P at 121 m/s, made HR consistent with LR for nodata points.
- 9/2007 AP: updated lower crustal/mantle voxel to include Socal background V_P
- 9/2007 AP: added lower crustal/mantle voxel, elevation voxets; updated background tomographic model
- 6/2007 Andreas Plesch: modified to be consistent with direct query of voxel in gocad, provide cell center

Additional notes:

- This program originated as a code designed for SCEC-IT to demonstrate the capability of a final interface for the HUSCV-model as described by *Süss and Shaw (2003)*. The code is now available to the community as a simple tool to extract data from the HUSCV-model. In this new version also the High Resolution velocity volume is supported by the code.

The Harvard University Southern California Velocity Model (HUSCV_1.0) describes the seismic P-wave velocity structure in the Los Angeles basin and surrounding areas. The model is defined by gridded volumes with higher and lower resolutions, as well as two surfaces used to define the volume of sediments (the top pre-Cretaceous basement and topography/bathymetry). A water-layer with a V_P velocity of 1480 m/s is included. No V_S is defined for water, and density is 1000 kg/m³.

- The model was designed in a UTM Zone-11 projection with the following coordinates, for the lower resolution model and lower crustal/mantle model:

Origin(SW) : 131000 3431000 (120d51'43.301''W 30d57'23.387''N)
NE-Corner : 828000 4058000 (113d19'58.583''W 36d36'46.622''N)

With grid resolutions of:

1000m x 1000m x 100m (low res.)
670 x 400 x 200 grid cells

and

10000m x 10000m x 1000m (mantle)
71 x 64 x 186 grid cells

For the high resolution model:

Origin(NW) : 371053.25 3774000 (-119.322991 / 33.013591)
NE-Corner : 417052.25 3774000 (-117.257011 / 33.034954)
SW-Corner : 371053.25 3725250 (-119.371155 / 34.770882)

With a grid resolution of:

250m x 250m x 100m
185 x 196 x 100 grid cells

The velocity volumes are stored in the GoCAD voxet format.

The program accepts geographic coordinates and UTM zone 11 (NAD27) coordinates. Coordinate transformation is performed by GCTPC2.0, a free projection library by the USGS. Sources for the library are included.

- V_S is calculated from V_P using the “mudline” relation and “Brocher’s regression line” (*Brocher, 2005*):

$$V_S = (V_P - 1360)/1.16 .$$

For $V_P < 1500$ m/s, V_S is fixed at 121 m/s which corresponds to $V_P = 1500$ m/s.

CVM-H 5.1 and earlier versions used this relation:

V_P/V_S varies linearly from 1.732 in the deepest part of the basin (Poisson’s ratio of 0.25 at a depth of 8.5 km) to 2.0 in the shallow sediments near the surface (Poisson’s ratio of 0.3 at the surface).

The overall effect of the switch to *Brocher (2005)* relations are higher V_S .

- The CVM-H 6.2 contains a geotechnical layer (GTL) that describes the velocity structure in the shallow subsurface, where low shear wave speeds, in particular, can have a significant impact on strong ground motions. The GTL velocity values (both V_P and V_S) are parameterized in most of the sedimentary basins after *Magistrale et al. (2000)*; *Magistrale (2002)*, which specified these properties to a depth of 1000 ft as a function of soil type and measurements from shallow geotechnical boreholes. The GTL in the Salton Trough was specified in CVM-H 6.2 following this approach. The basement GTL is derived using the gradient of the depth- V_P relation of *Boore and Joyner (1997)* to extend the tomographic velocities into the shallow subsurface.

- Extrapolation.

vx60b and later: The models are extrapolated from their data limits to the model boundaries.

Up to vx60: Overall the models (tomography and basins) are embedded into the SoCal 1D velocity model provided by *Dreger and Helmberger (1991)*. Beneath the lowest layer of the 1D model at 35 km depth, the background V_P and V_S is simply kept constant at the velocity of the lowest layer, e.g., 7800 m/s for V_P and 4500 m/s for V_S . The boundaries between areas defined by tomography and the 1D model are smoothed.

- Mantle data were provided by Toshiro Tanimoto (personal communication) and are derived from waveform matching of teleseismic surface waves (*Prindle and Tanimoto, 2006*).
- We adopt the Nafe–Drake scaling relationship to compute density from V_P (*Ludwig et al., 1970; Brocher, 2005*):

$$\rho = 1.6612 V_P - 0.4721 V_P^2 + 0.0671 V_P^3 - 0.0043 V_P^4 + 0.000106 V_P^5 ,$$

where ρ is in g/cm^3 and V_P is in km/s .

In CVM-H versions 5.6 and prior we used well-log calibrated density scaling defined by (*McCulloh, 1960; Stidham et al., 2001b*)

$$\rho = V_P/3 + 1280 ,$$

where ρ is in kg/m^3 ; we also impose a water-level minimum of 2000 kg/m^3 .

- No specific shear quality factor is predicted by the model. A Q_μ of 90 has been used in the sediments by *Komatitsch et al. (2004)*.

B “Flattening” of topography using vx_lite

The user may wish to generate a model without topography, for example, for finite-difference numerical simulations. Here we provide instructions for one approach that has been used in the past (*Mayhew and Olsen, 2010*). In this approach, all “columns” of points for which $z_{\text{topo}} > 0$ are “pushed down” to sea level, while all “columns” of points for which $z_{\text{topo}} < 0$ are “pulled up” to sea level. The effect is to generate an upper surface of points with $z = 0$.

The topographic flattening procedure is achieved using the SCEC utility `vx_lite`. To install this package, you will need to have `svn` installed on your computer (type `which svn` to check). To check-out the package, execute the following command:

```
svn --[scec.org username] export http://intensity.usc.edu/svn/cvmh/trunk cvmh
```

At the prompt, enter your `scec.org` password.

Enter the directory (`cd cvmh`) and read the file `README` for details. Then compile:

```
make vx
```

Querying CVM-H is then easily accomplished with the following command:

```
cd bin
vx_lite < test.dat
```

The output should look like this (here the columns are truncated):

```
-125.000000    35.000000    7777.00      0.00      0.00   -99999.00   -99999.00 -99999.00 -99999.00 -99999.00 -99999.00 nr -99999.00   -99999.00 -99999.00 -99999.00
-118.560000    32.550000    2450.00    353525.18  3602285.14  353625.00  3602375.00 -1114.91 -1150.00 -1327.54 -21571.67 lr 354000.00 3602000.00 -3600.00 2.
360061.000000 3750229.000000 1400.00 360061.00 3750229.00 360125.00 3750125.00 -56.93 -50.00 -1404.07 -24868.83 lr 360000.00 3750000.00 -1500.00 2.
-118.520000    34.120000    1400.00    359819.67  3776309.78  359875.00  3776375.00  491.46  450.00  38.42 -28061.40 lr 360000.00 3776000.00 -1000.00 2.
-116.400000    32.340000    1000.00    556464.74  3578092.46  556375.00  3578125.00  780.43  750.00  616.39 -31413.62 lr 556000.00 3578000.00 -300.00 2.
376592.000000 3773379.000000 1770.00 376592.00 3773379.00 376625.00 3773375.00  99.38 100.00 -2374.53 -28165.35 hr 376552.25 3773500.00 -1700.00 3.
376592.000000 3773379.000000 1770.00 376592.00 3773379.00 376625.00 3773375.00  99.38 100.00 -2374.53 -28165.35 cm 380000.00 3770000.00 -18000.00 2.
408669.000000 3766189.000000 3000.00 408669.00 3766189.00 408625.00 3766125.00  93.89  50.00 -2820.45 -29799.86 hr 408552.25 3766250.00 -3000.00 2.
```

This should be compared with the output in Section 4 for the case without topography flattening. To summarize, we list the V_P , V_S , and ρ values (final three columns) for the two cases:

Test Point	Default (Vp,Vs,rho)			Topo filtering (Vp,Vs,rho)		
1	-99999.00	-99999.00	-99999.00	-99999.00	-99999.00	-99999.00
2	5575.15	3132.10	2631.81	5749.17	3229.70	2665.08
3	4554.52	2313.56	2469.78	4558.41	2317.10	2470.32
4	5066.61	2916.30	2545.10	4914.69	2843.58	2521.77
5	5372.79	3024.30	2595.55	5289.65	2973.20	2581.35
6	4181.37	2432.22	2418.45	4184.09	2434.56	2418.82
7	6533.31	3776.40	2841.47	6533.31	3776.40	2841.47
8	4997.06	2889.03	2534.30	4997.06	2889.03	2534.30

There are two other modes for running `vx_lite`. The three options are summarized here:

1. `vx_lite < test.dat`

Default mode, reads in a list of (x, y, z) , where z is elevation.

2. `vx_lite -d < test.dat`

Reads in a list of (x, y, d) , where $d = -z$ is depth.

3. `vx_lite -v < test.dat`

`vx` emulation mode, reads in a list of (x, y, z) , where z is elevation.

Five test profiles (Figures 1–6)

In Figure 1 we show five test points used to generate five profiles of data. Each profile is spaced from $z = -45$ km to $z = 5$ km with an increment of $\Delta z = 0.5$ km. The five input files for these profiles can be found in `test_profiles.tar` (`tar -xvf test_profiles.tar`) within the `bin` directory. For each profile, the model values can be obtained following the instructions in Section 4. For example, for the first test profile (Figure 2), the commands are

```
vx < column_1_lonlat_xyz.dat
vx_lite < column_1_lonlat_xyz.dat
```

In Figures 2–6 we show the profiles of V_P and V_S , with and without topographic flattening. It is clear that the largest discrepancies exist for locations whose surface value is farthest from sea level ($|z_{\text{topo}}| > 0$), such as Mt. Whitney (Figure 5) and oceanic crust (Figure 6).

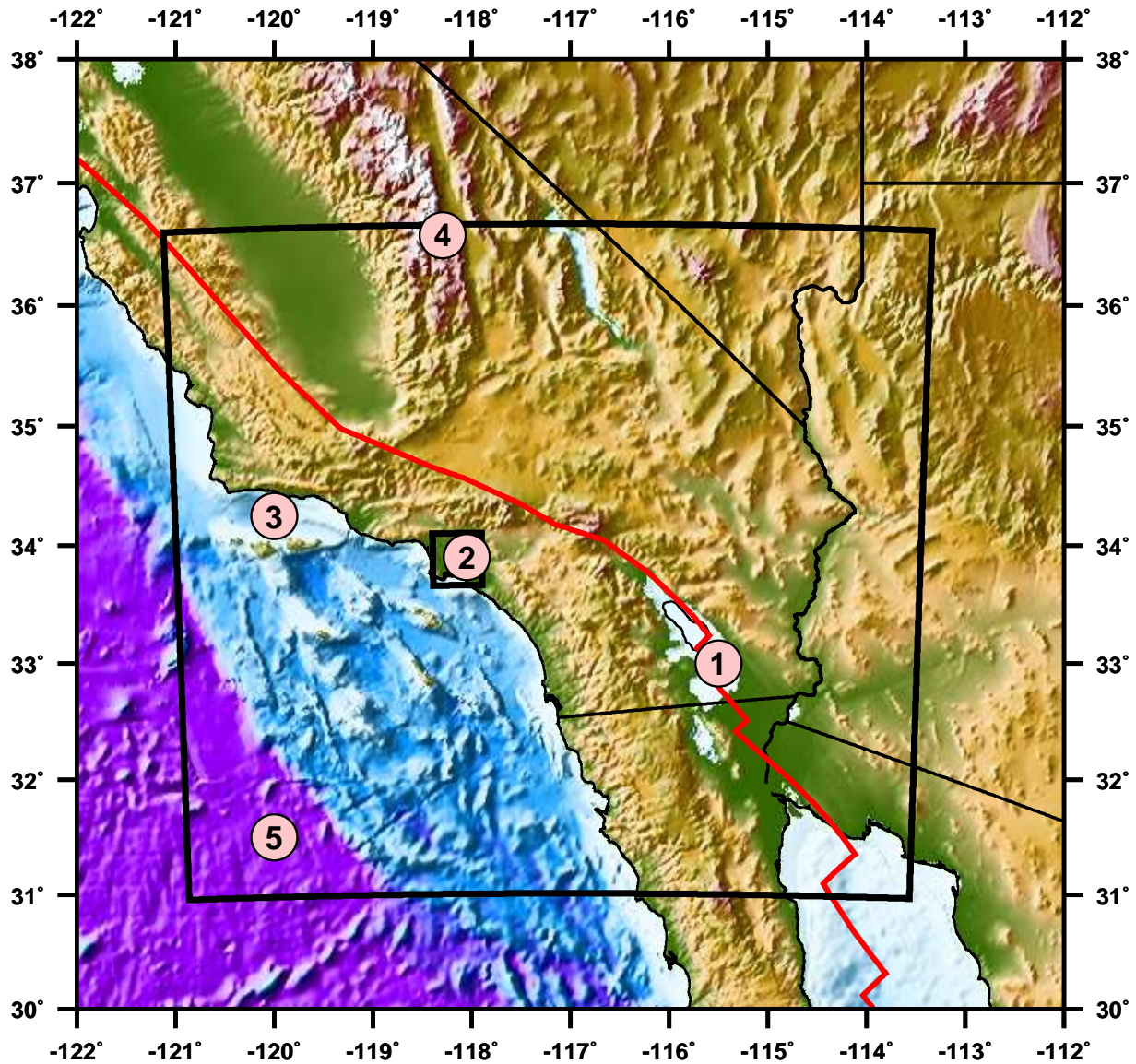


Figure 1: Locations of five test points of the profiles shown in Figures 2–6. Outer box is the full model region; inner box is the high-resolution domain of the Los Angeles basin model. See Appendix B for details.

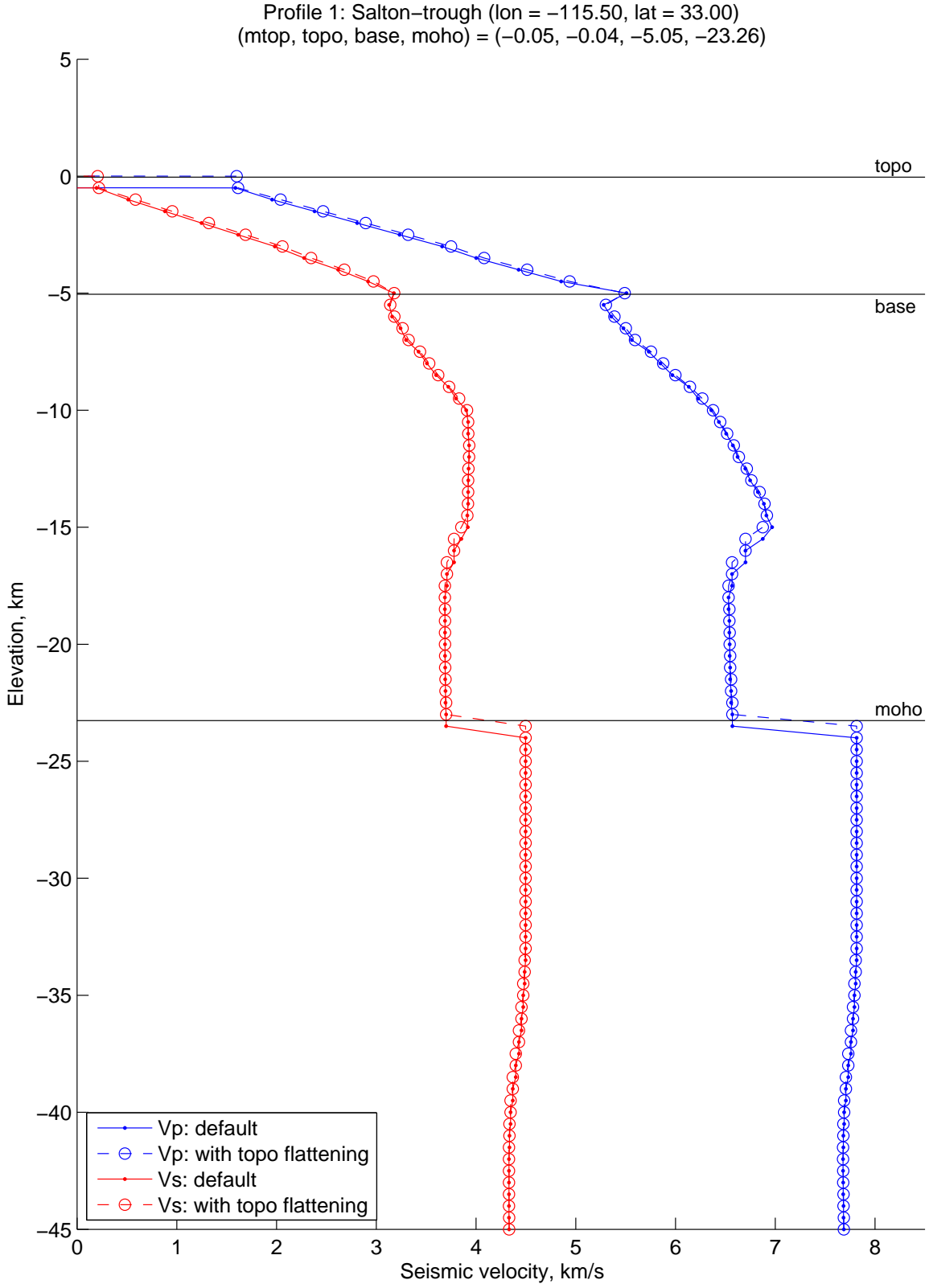


Figure 2: Profile 1: Salton trough. V_P and V_S , with and without topographic flattening. See Appendix B for details.

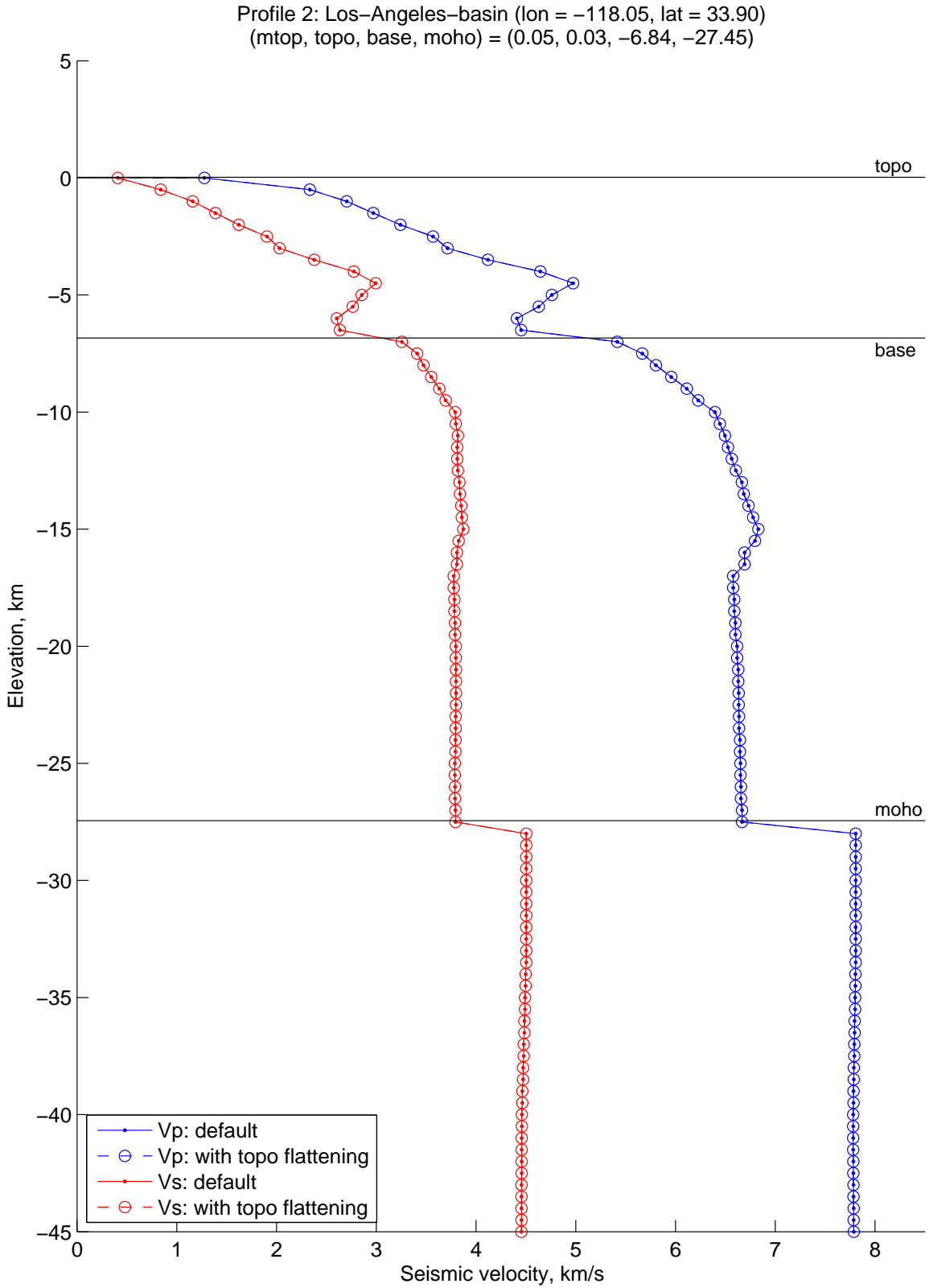


Figure 3: Profile 2: Los Angeles basin. V_P and V_S , with and without topographic flattening. See Appendix B for details.

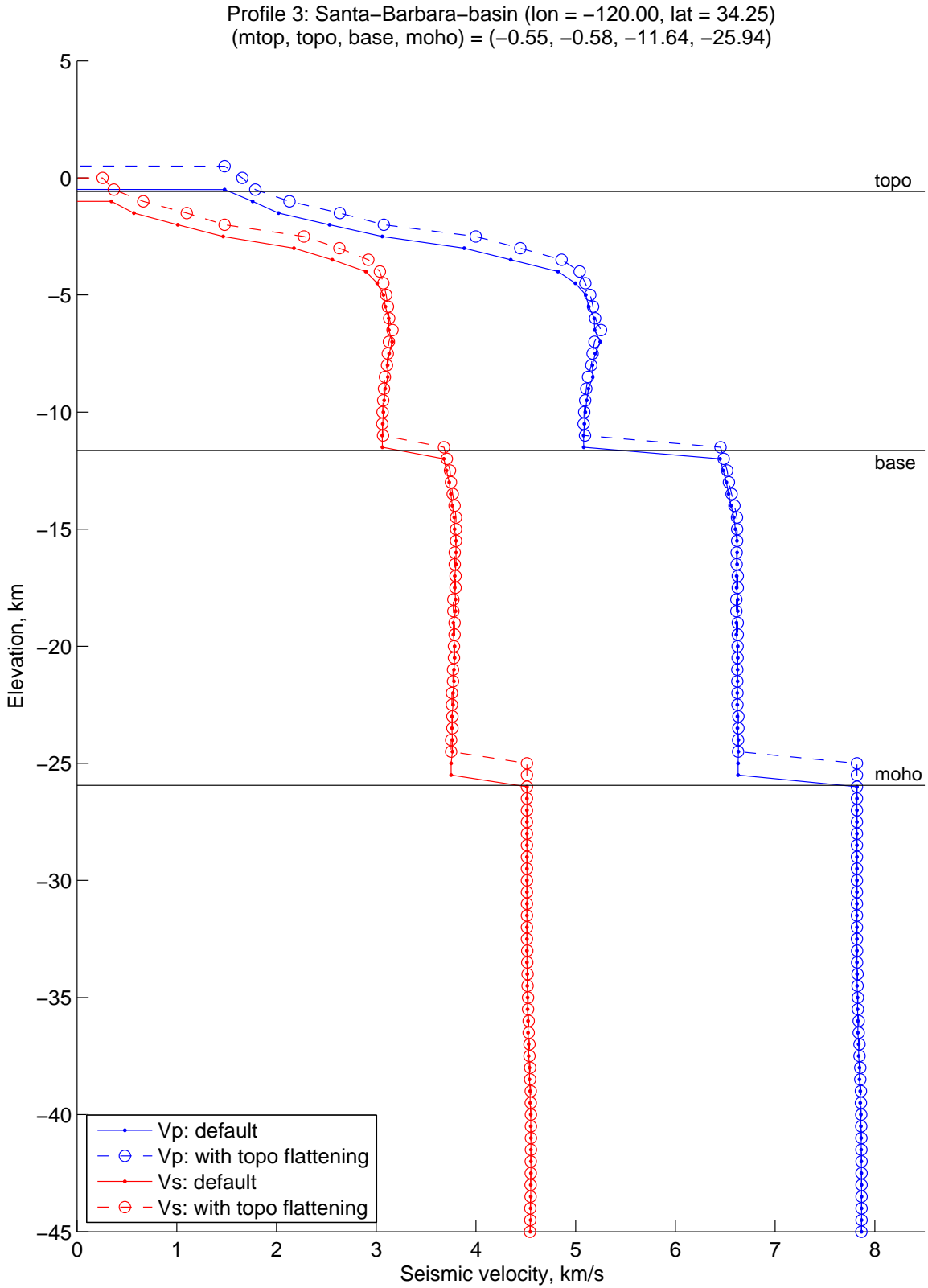


Figure 4: Profile 3: Santa Barbara basin. V_P and V_S , with and without topographic flattening. See Appendix B for details.

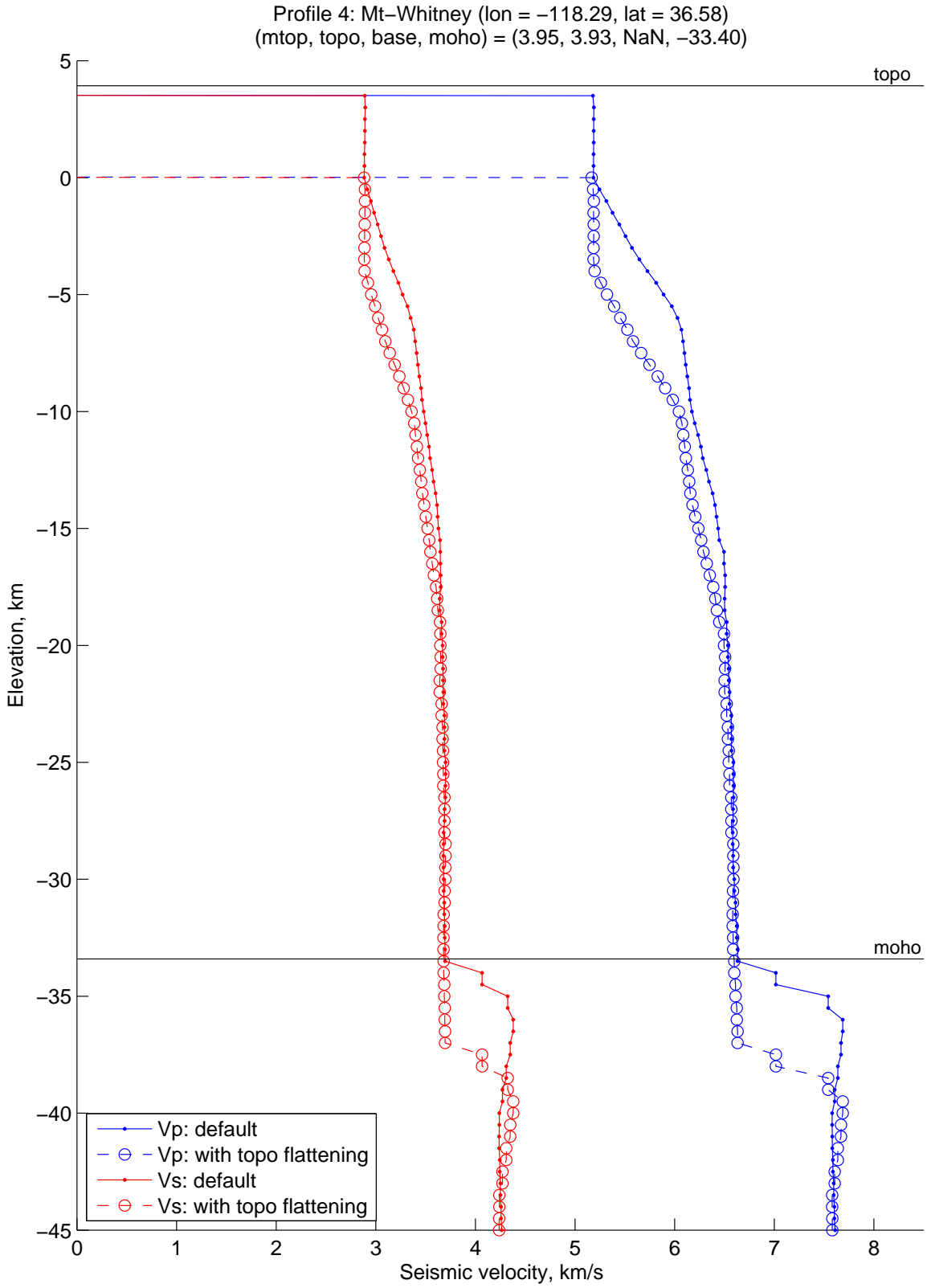


Figure 5: Profile 4: Mount Whitney. V_P and V_S , with and without topographic flattening. See Appendix B for details. Note that the basement surface is not defined this far north, but vx still returns the appropriate V_P and V_S values.

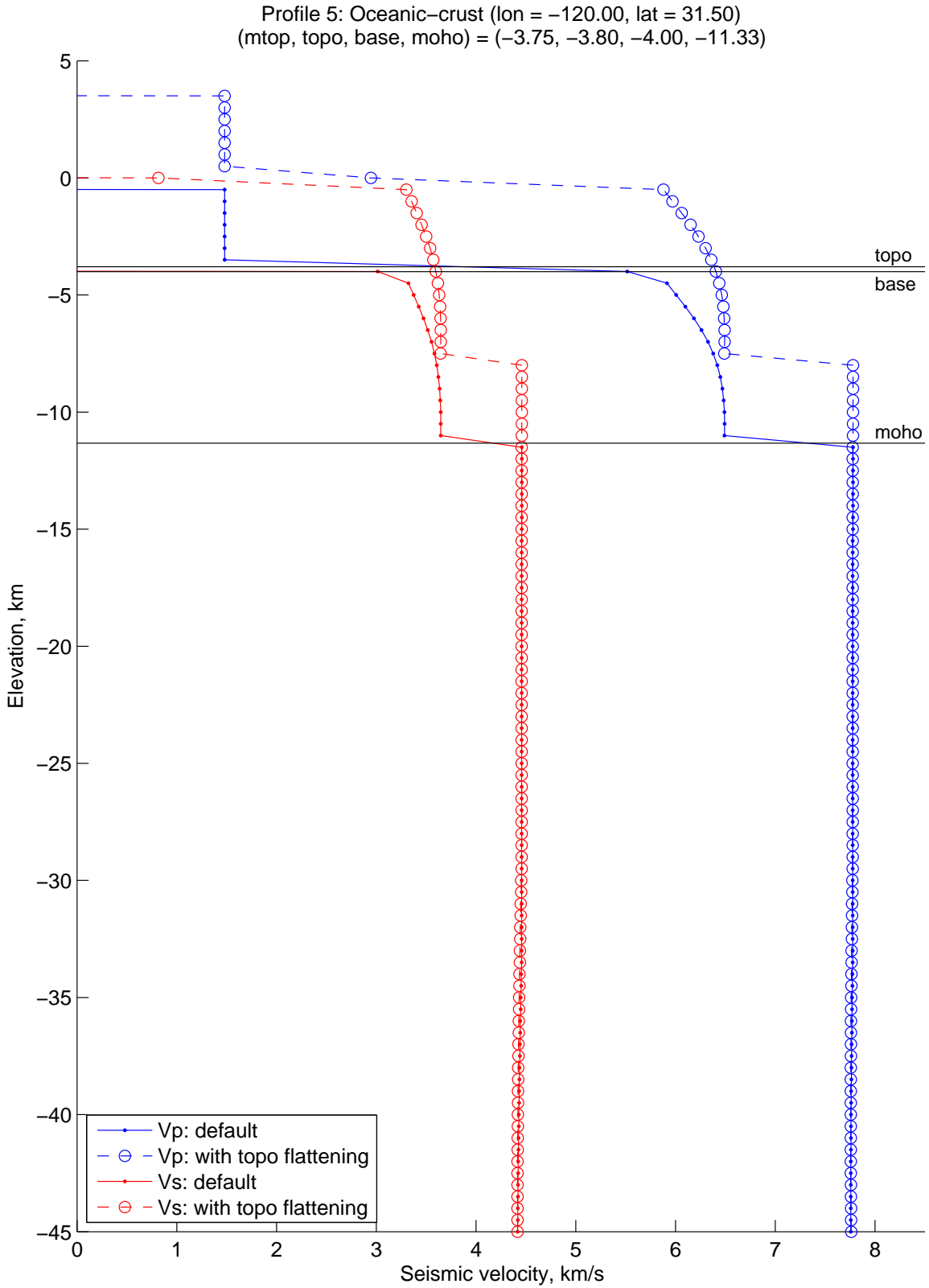


Figure 6: Profile 5: Oceanic crust. V_P and V_S , with and without topographic flattening. See Appendix B for details.