Southern California Earthquake Center

SCEC's Unified Community Velocity Model (UCVM) Software: Development Goals and Current Status

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Recent Contributors: David Gill (SCEC/USC), Patrick Small (USC), Geoffrey Ely (Argonne National Laboratory), Ricardo Taborda (Carnegie Mellon University), Andreas Plesch (Harvard University), Thomas Jordan (SCEC/USC)

SCEC

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Overview

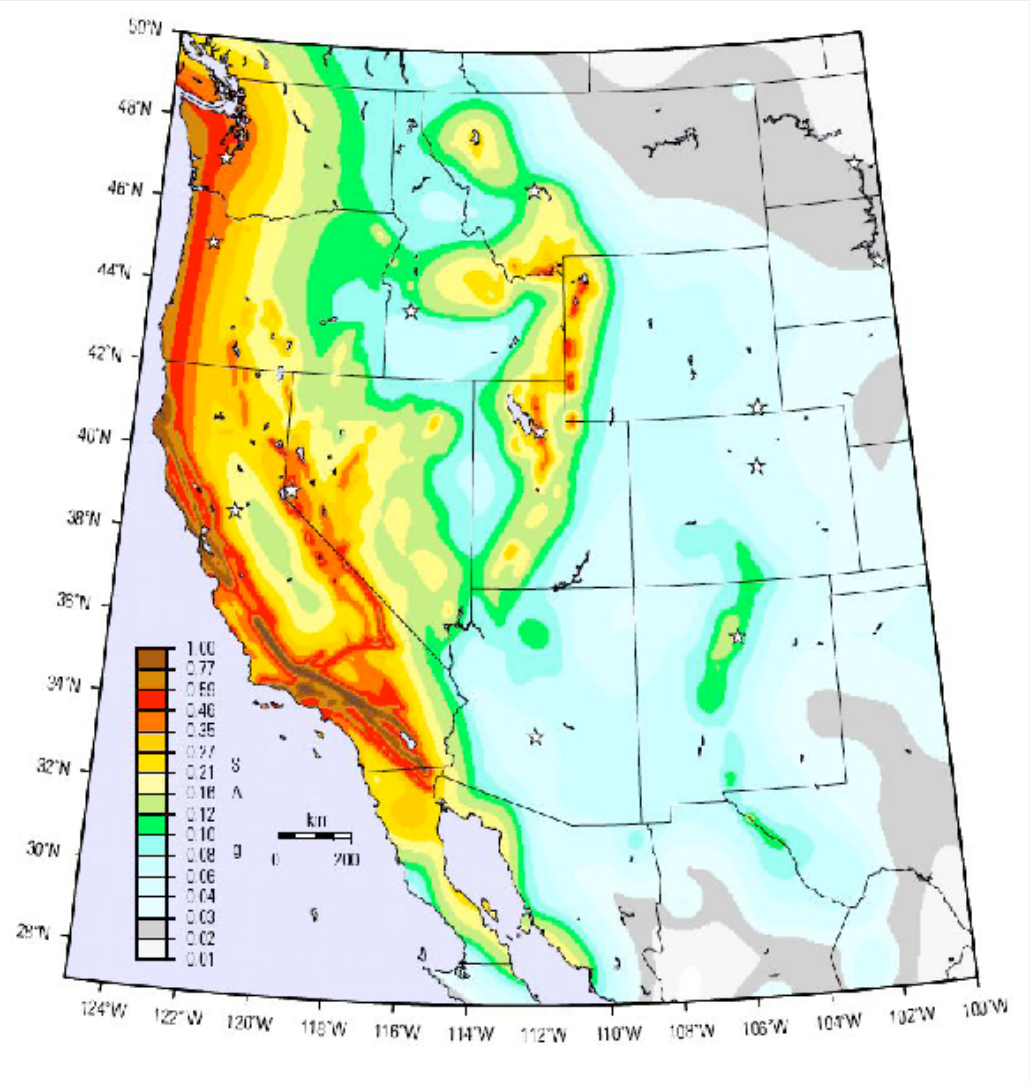
SCEC's Unified Community Velocity Model (UCVM) Software provides a way to interface to various 3D velocity Models (with about 9 models "registered" and accessible through UCVM)

UCVM provides additional utilities for using CVMs in wave propagation simulations including
(a) code to build regular and Etree meshes,
(b) ability to combine or "tile" multiple small models
(c) MPI-codes to build very large meshes, and
(d) export file formatting tools

Outline

- Motivation for Building UCVM
- UCVM Development Status
- Future UCVM Plans
- Conclusions

New National Seismic Hazard Map



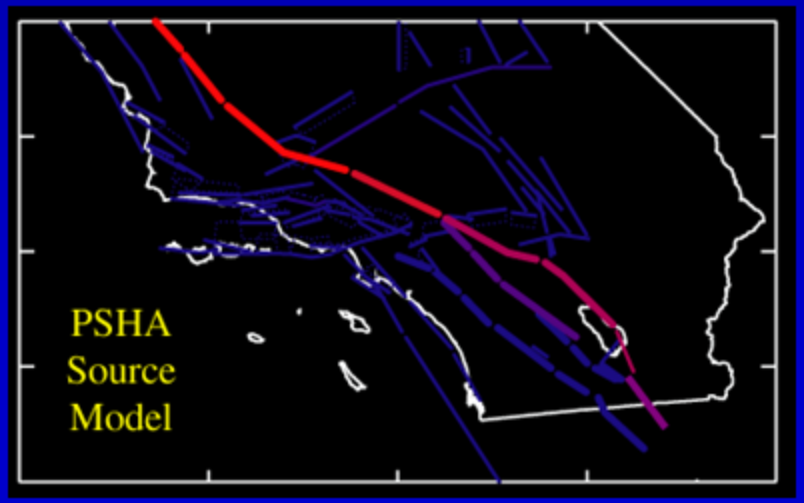
Ground Motion Intensity

(1 s Spectral Acceleration with 2% P_{exc} in 50 yrs)

SHA has two model components:

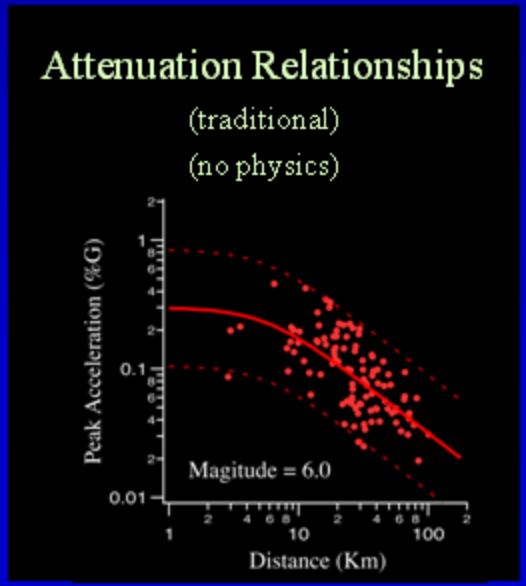
(1) Earthquake-Rupture Forecast (ERF)

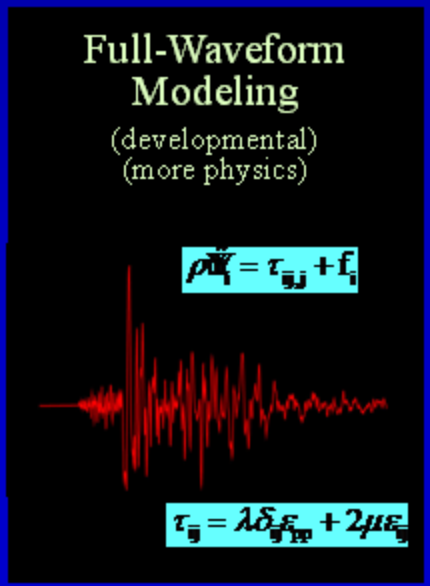
Probability of all possible fault-rupture events (M≥~5) for region & time span



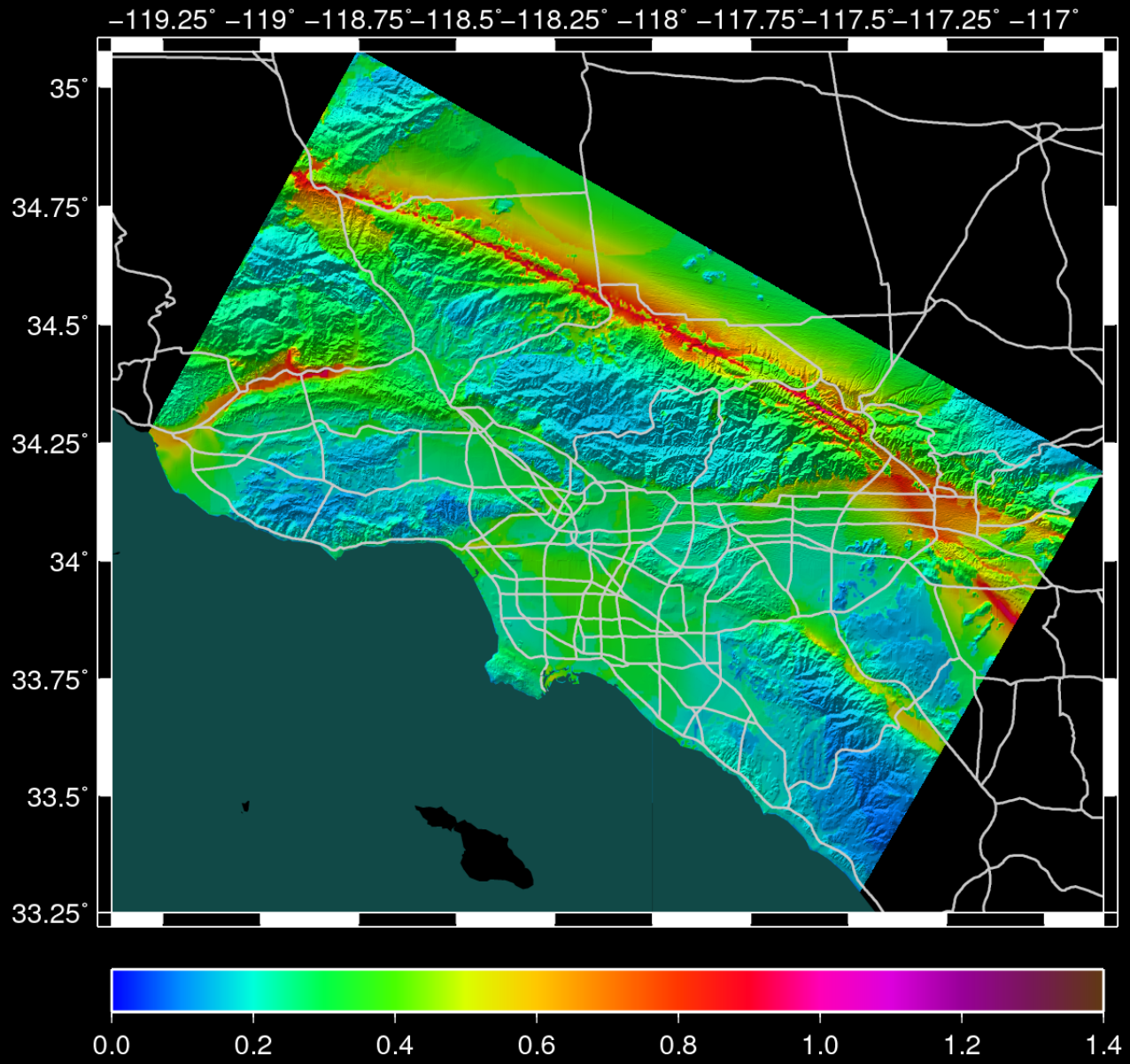
(2) Intensity-Measure Relationship (IMR)

Gives Prob(IMT≥IML) for a given site and fault-rupture event





Boore & Atkinson (2008) Attenuation Relation



How 3D Models Impact PSHA

- Current USGS Southern California Hazard Maps use average results from 4 GMPEs.

- Some of these 4 GMPEs (e.g. Abrahamson and Silva) use information (Z1.0 and Z2.5) derived from 3D earth models. (Z1.0 is depth to Vs of 1000m/s)

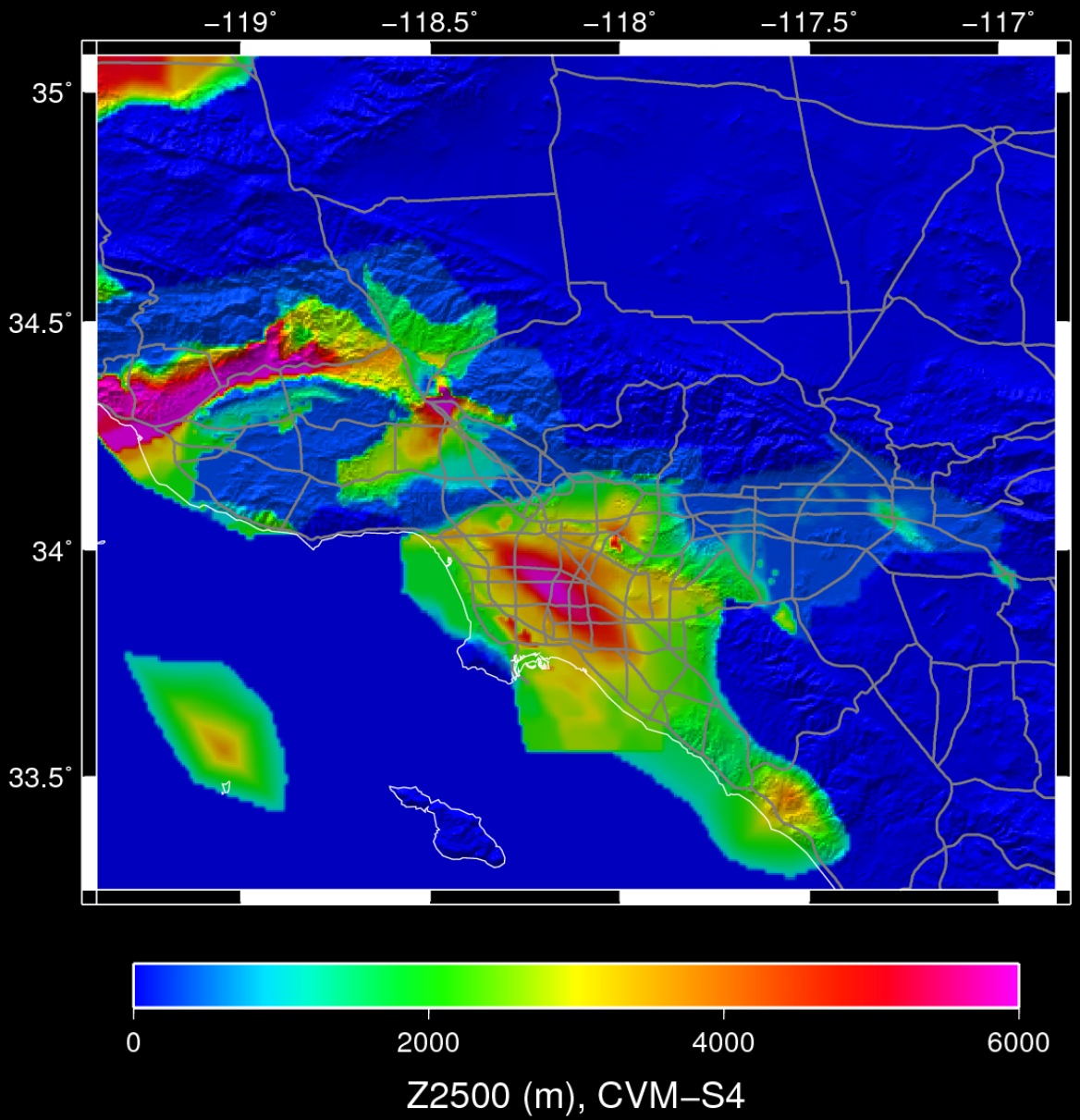
- 3D models are queried to determine Z1.0 and Z2.5 values which are then used in the GMPE

Southern California 3D CVM

In SCEC terms, a Community Velocity Model (CVM) refers to any 3D seismic velocity model shared within a community.

SCEC's seismic hazard and wave propagation modeling groups currently support two Southern California 3D Velocity Model Codes:

(1) CVM-S4 (Kohler, Magistrale et al ~2006)
(2) CVM-H11.9 (Shaw, Plesch et al ~2011)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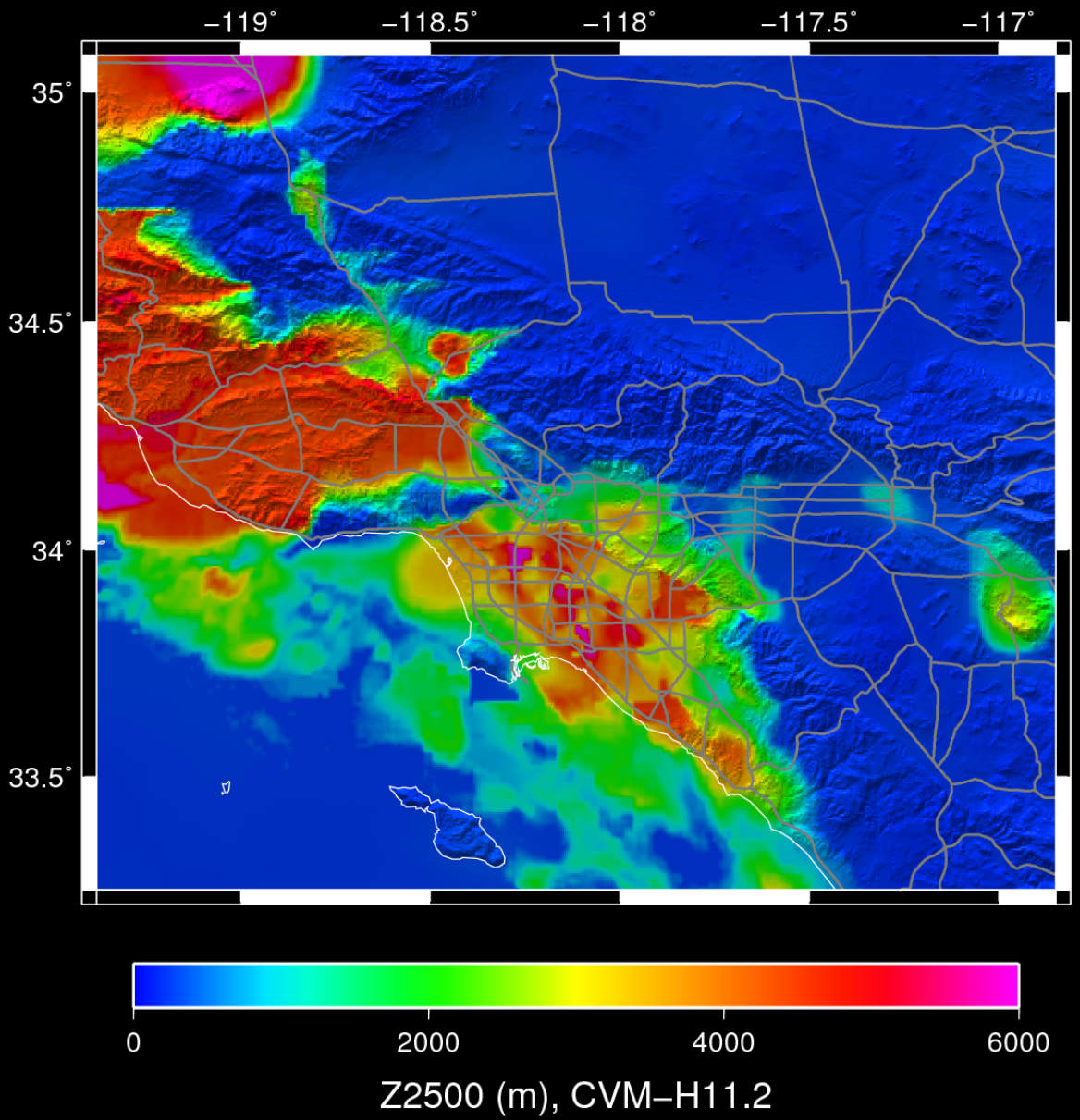
2000
4000
6000
Z2500 (m), CVM−S4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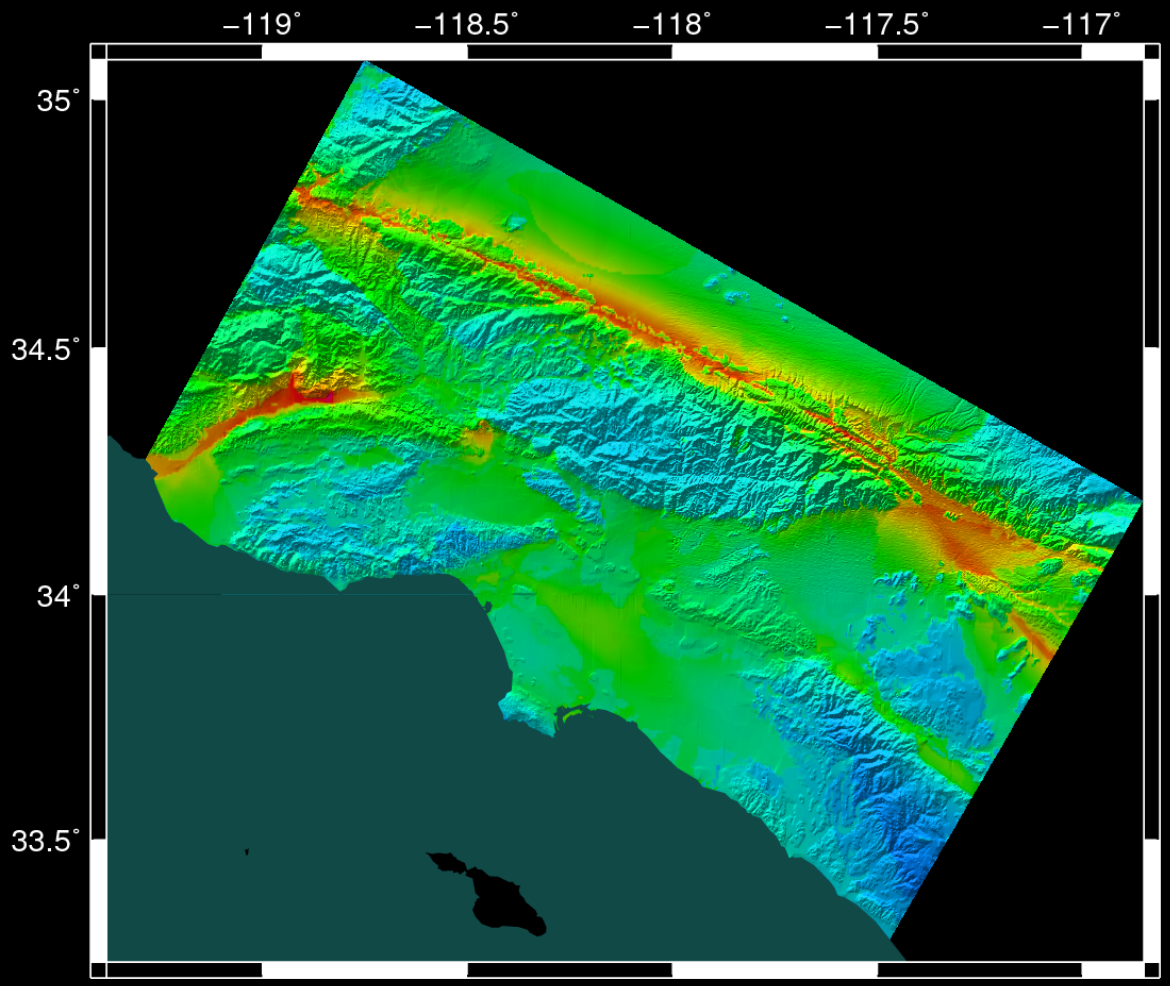
Z2500 (m), CVM−H11.2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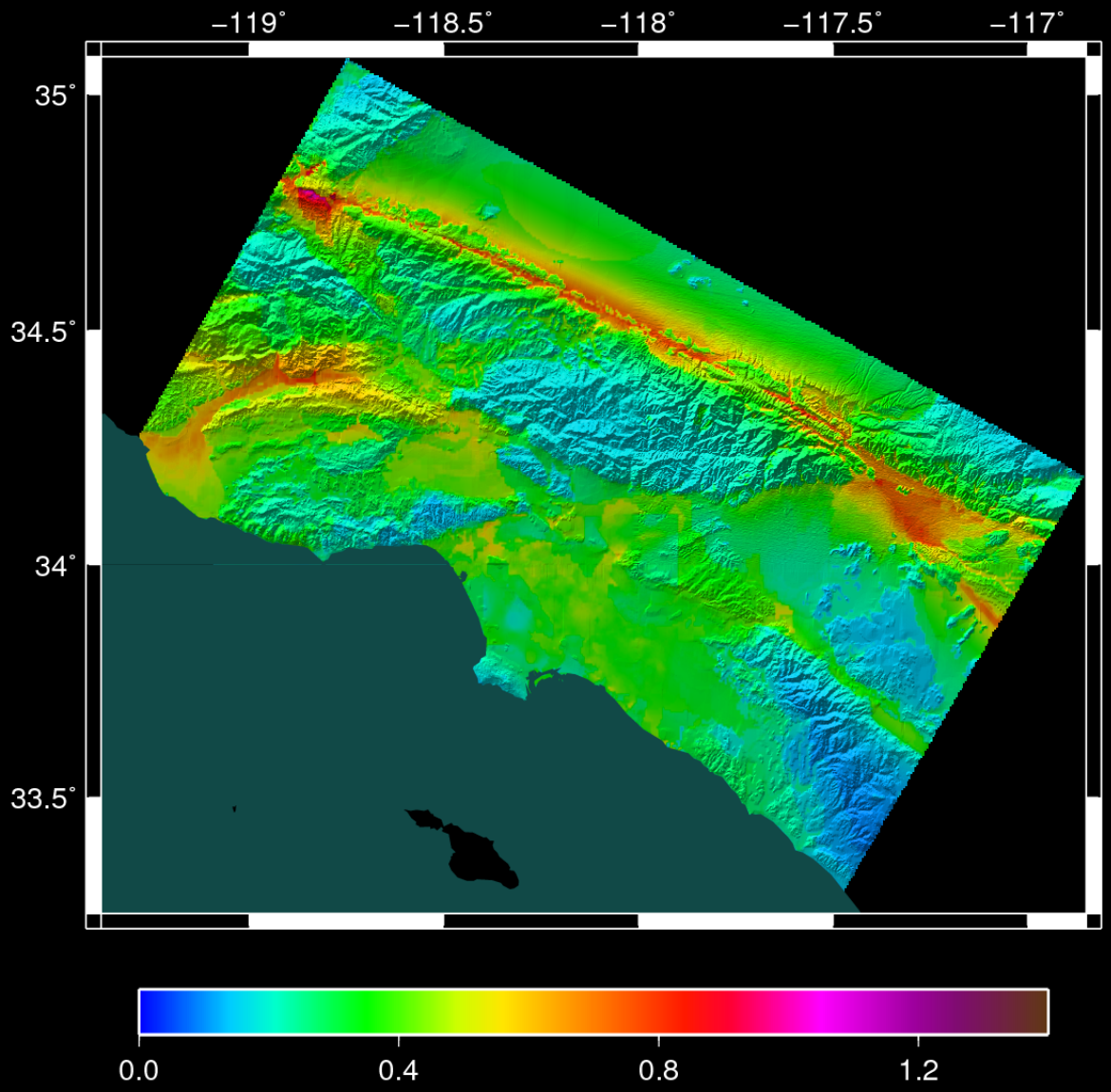
GMPE Basemap, RWG CVM−S 3sec SA, 2% in 50 yrs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GMPE Basemap, RWG CVM−H 3sec SA, 2% in 50 yrs

UCVM Was Built to Help SCEC Work with Multiple 3D Velocity Models for California

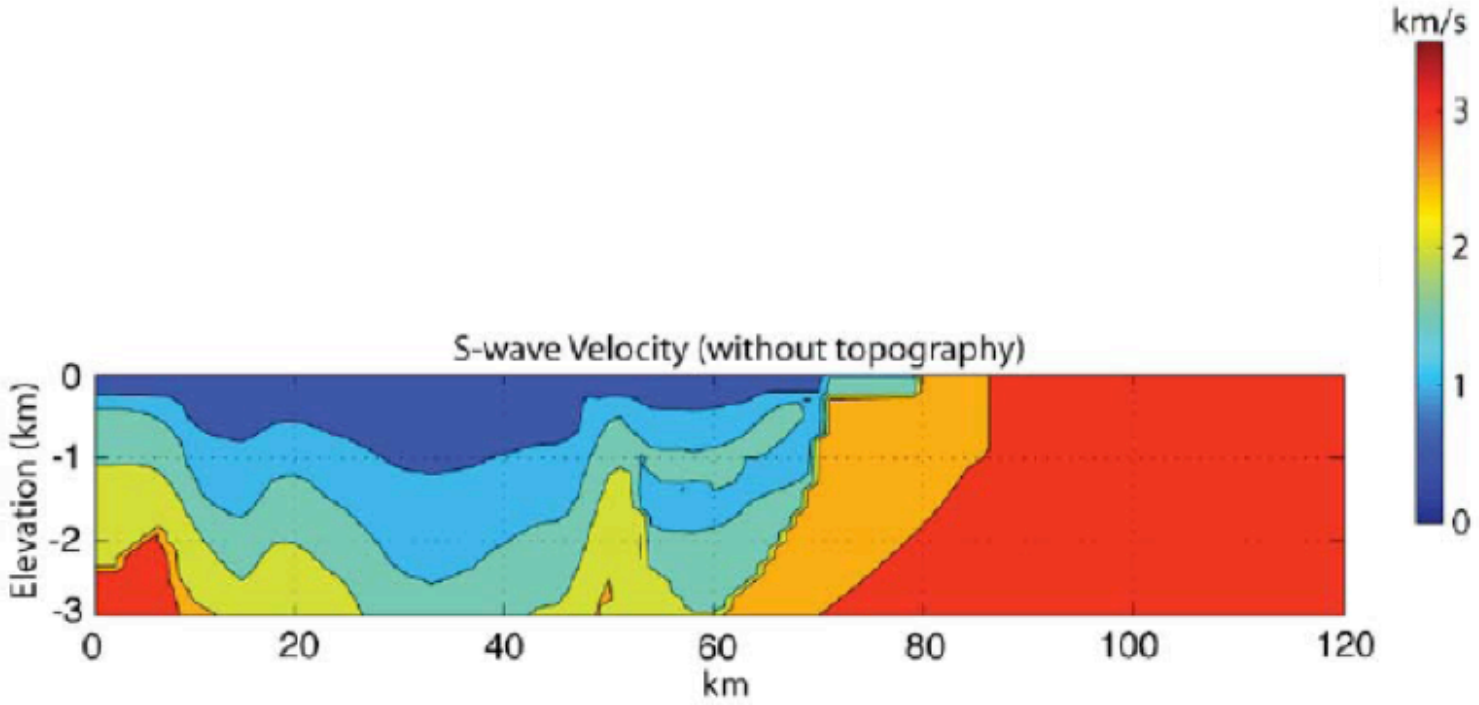
Coverage region for UCVM 2D maps (cyan) overlayed upon regions of various California 3D velocity models CVM-S: red, CVM-H: blue, LinThurber: yellow, Thurber NCal: green, USGS Bay Area: white

SCEC CVM-S4 (No Topography)

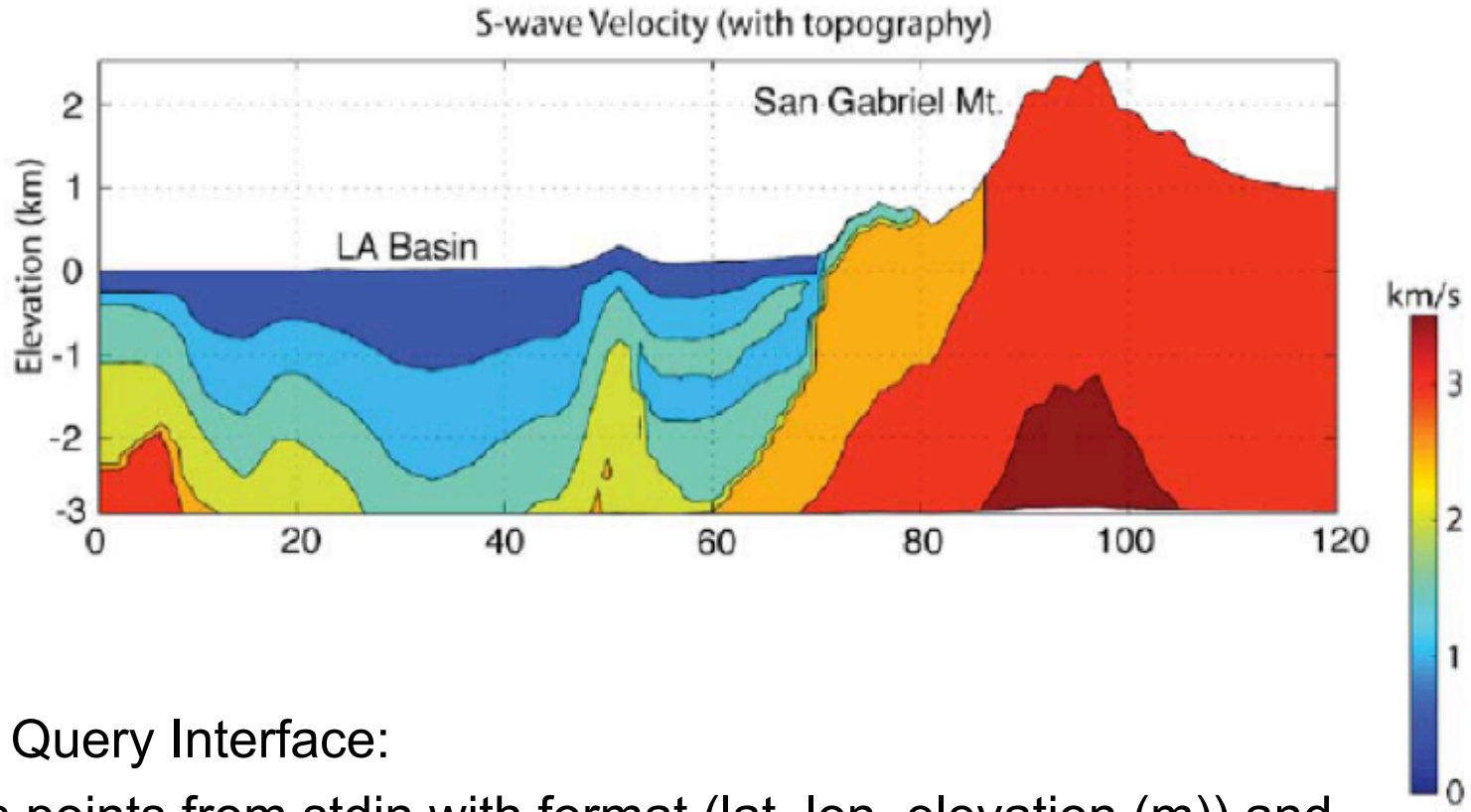
CVM-S4 Query Interface:

Accepts points from stdin with format (lat, lon, depth (m)) and

Accepts points from input file containing list of (lat,lon,depth(m))



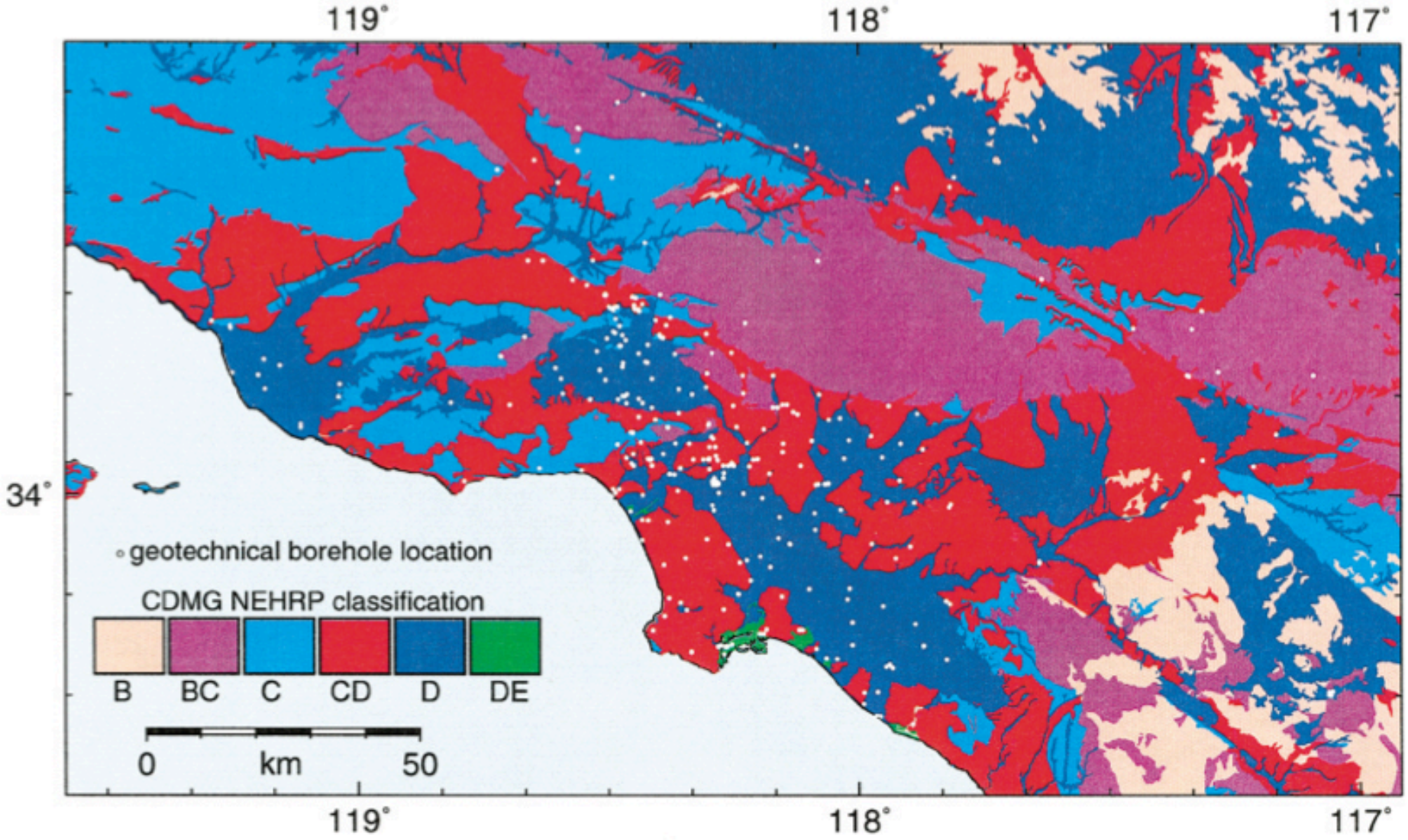
SCEC CVM-H (Topography)



CVM-H Query Interface:

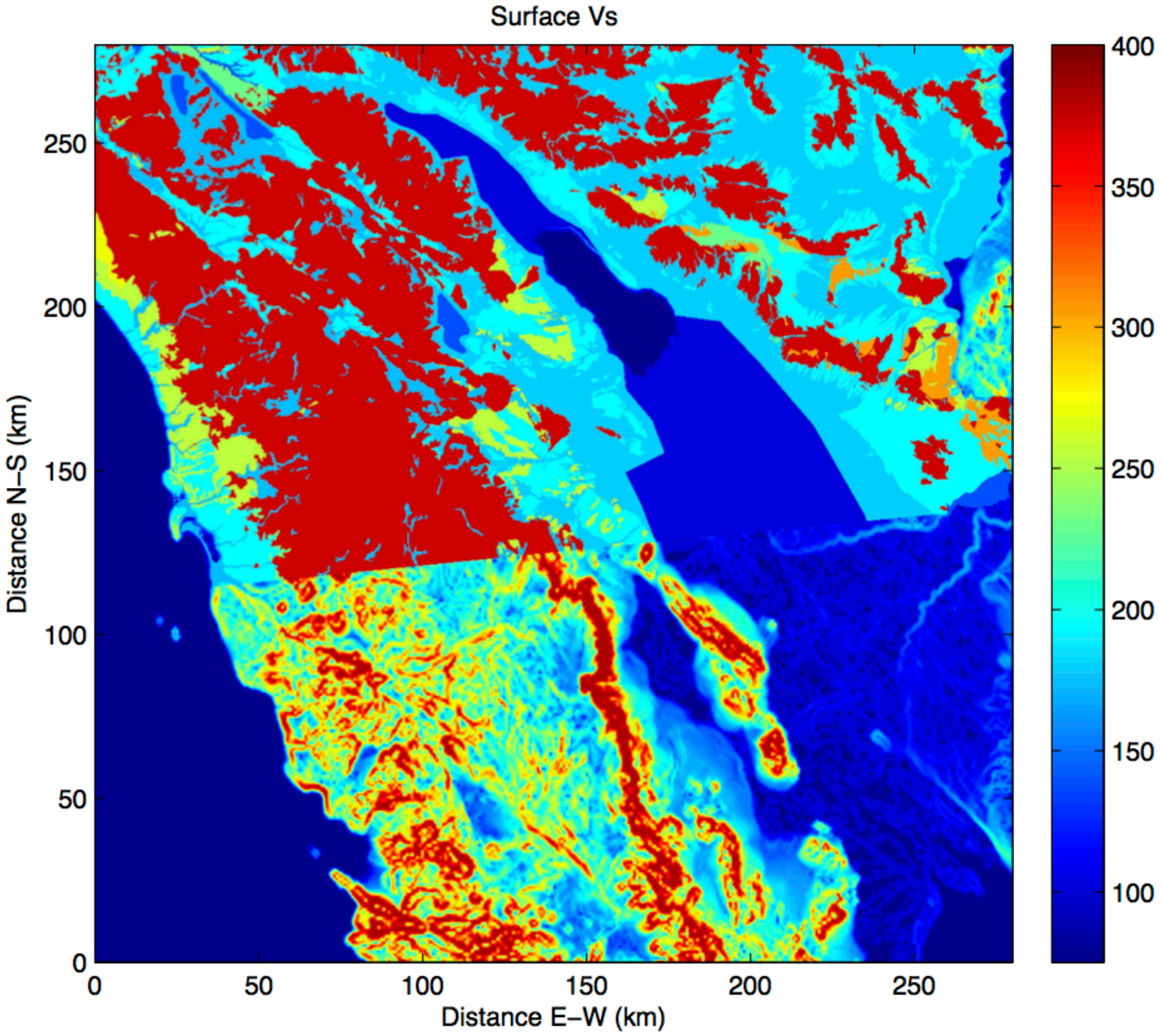
Accepts points from stdin with format (lat, lon, elevation (m)) and

Accepts points from input file containing list of (lat,lon,elevation(m))



Geotechnical borehole locations (white circles; W. Silva, personal comm.) and the CDMG NEHRP site classifications (Wills et al., 2000) for the Los Angeles region.

CVM-H v11.9


Surface Vs
Distance N–S (km)
Distance E–W (km)
0
50
100
150
200
250
400
350
300
250
200
150
100

CVM-S4 Output Information

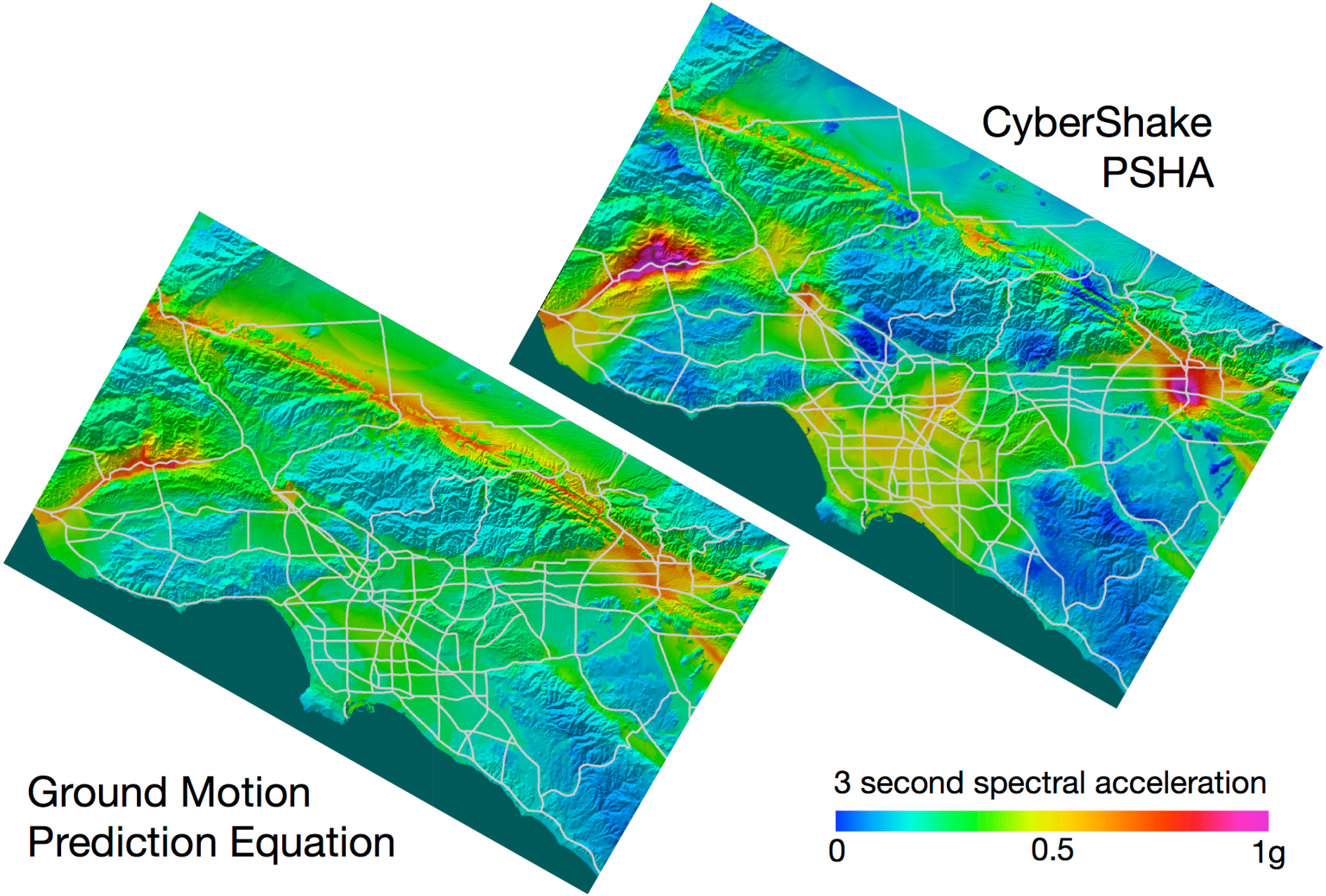
- In command line mode, the code writes data material properties to std out with format (lat, lon, dep, vp, vs, density).
- Input file with list of entries in 3 columns (list of lat,lon,depth) the output file contains entries with (lat, lon, dep, vp, vs, density).
- If Qp, and Qs are needed, they are calculated externally.

CVM-H Output Information

Table 5: Columns of the output produced by vx. Queries which fall outside of the model area return -99999, the no-data value, for all fields.

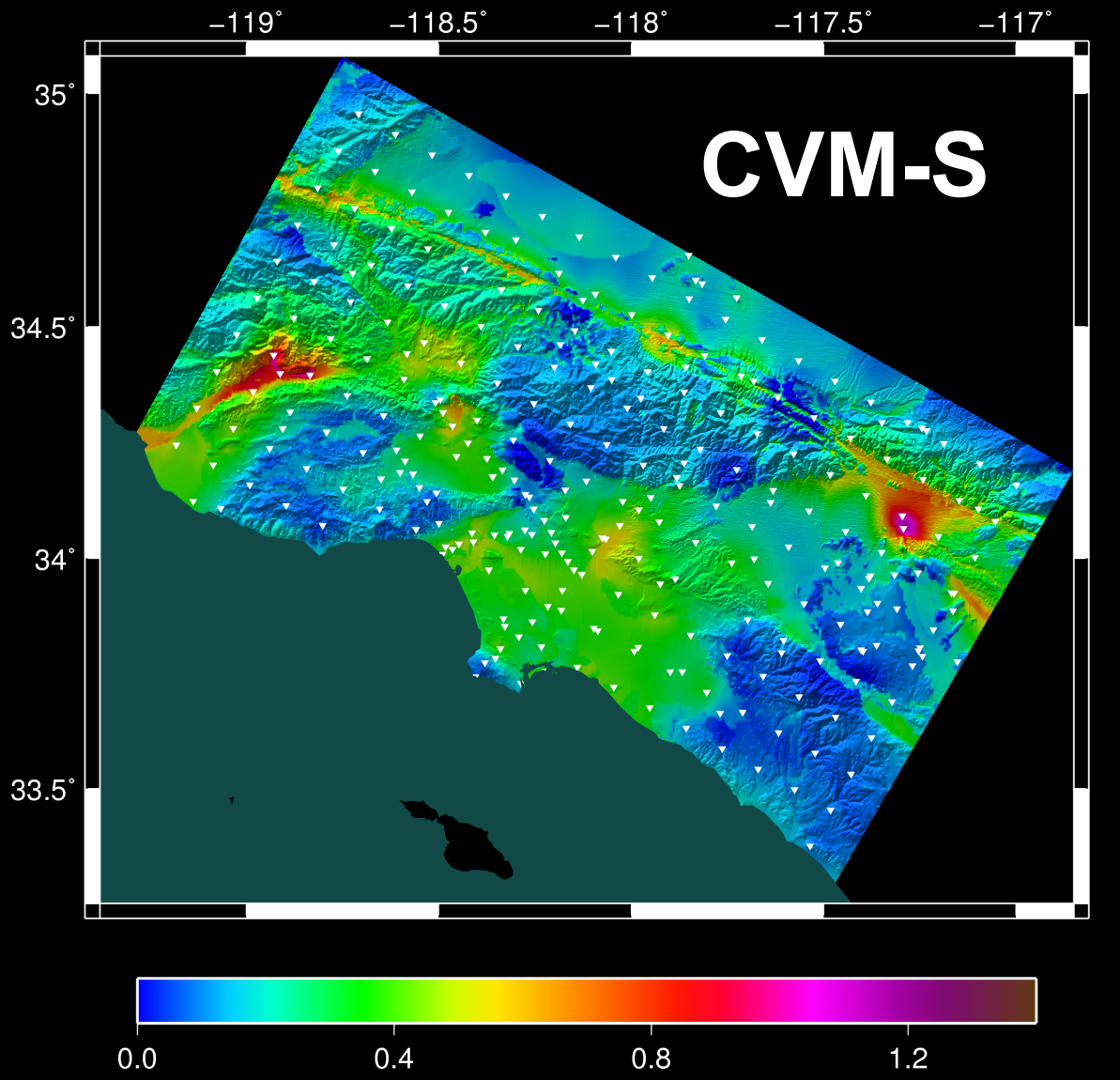
Column Index	Variable	Description
1	X	Input X (longitude or UTM coordinate)
2	Y	input Y (latitude or UTM coordinate)
3	Z	input Z (elevation, meters above sea level, i.e., positive up)
4	utmX	UTM coordinate (zone 11), easting
5	utmY	UTM coordinate (zone 11), northing
6	elevX	X coordinate of center of 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	provenance of data point (see Table 6)
17	vp	compressional wave velocity in m/s
18	vs	shear wave velocity in m/s
19	rho	density in kg/m3

Physics-Based Probabilistic Seismic Hazard Analysis



Impact of Alternative CVMs in PSHA

- These two maps differ by Velocity Model used (CVM-S4 or CVM-H 11.9.1)
- Maps are PSA3.0 at POE of 2% in 50 years
- Background maps are average GMPE hazard values from the 4 GMPEs used in current USGS maps.
- GMPE maps for CVM-S use Z1.0 and Z2.5 values extracted from CVM-S, and CVM-H maps use Z1.0 and Z2.5 values extracted from CVM-H v11.9.0
- Vs30 values in GMPEs are from most recent California Wills map.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CVM-S
0.0
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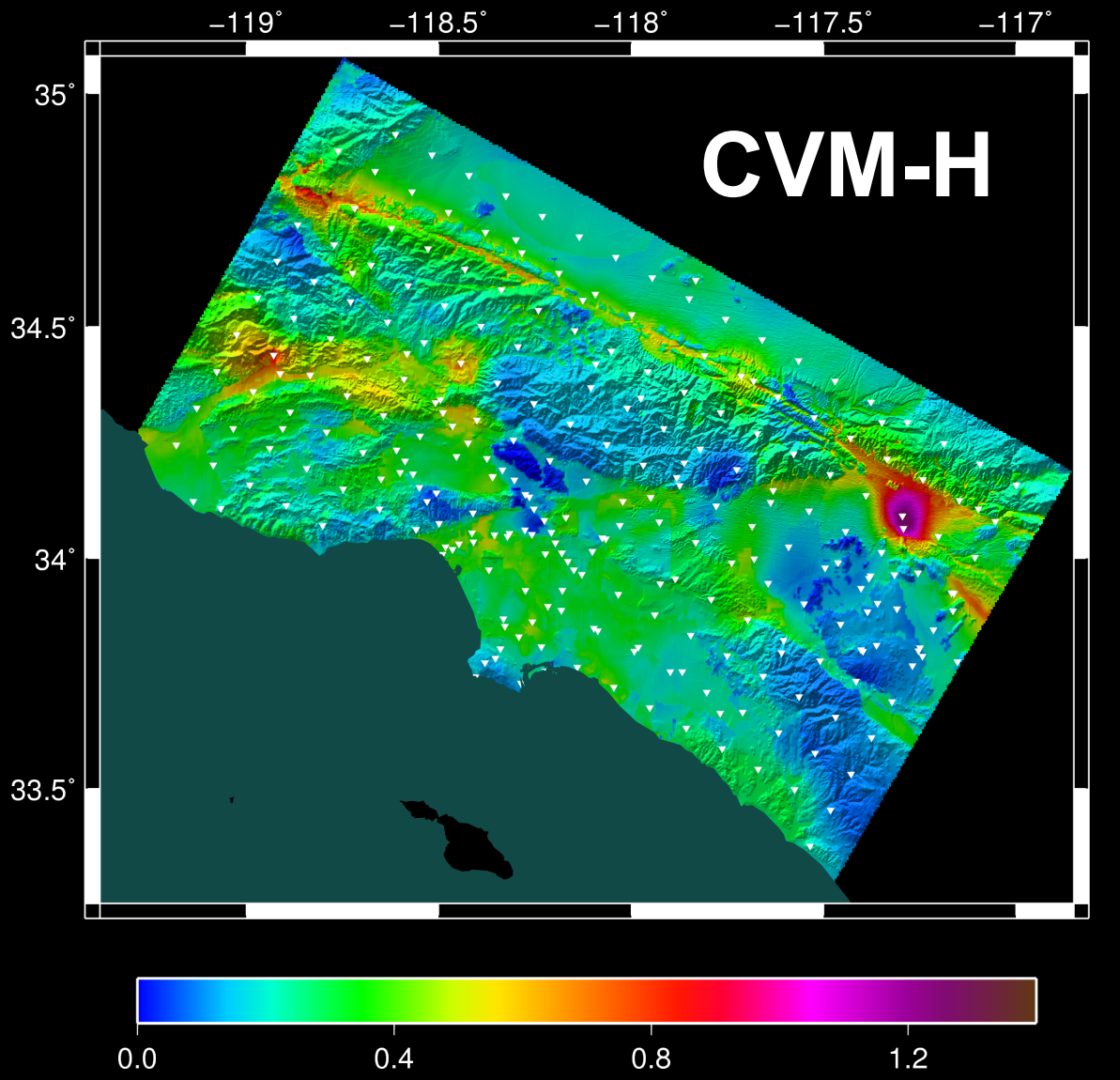
1.2
CyberShake Hazard Map, RWG CVM−S 3sec SA, 2% in 50 yrs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CyberShake Hazard Map, RWG CVM−H 3sec SA, 2% in 50 yrs

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- Motivation for Building UCVM
- UCVM Development Status
- Future UCVM Plans
- Conclusions

CVM Software Overview

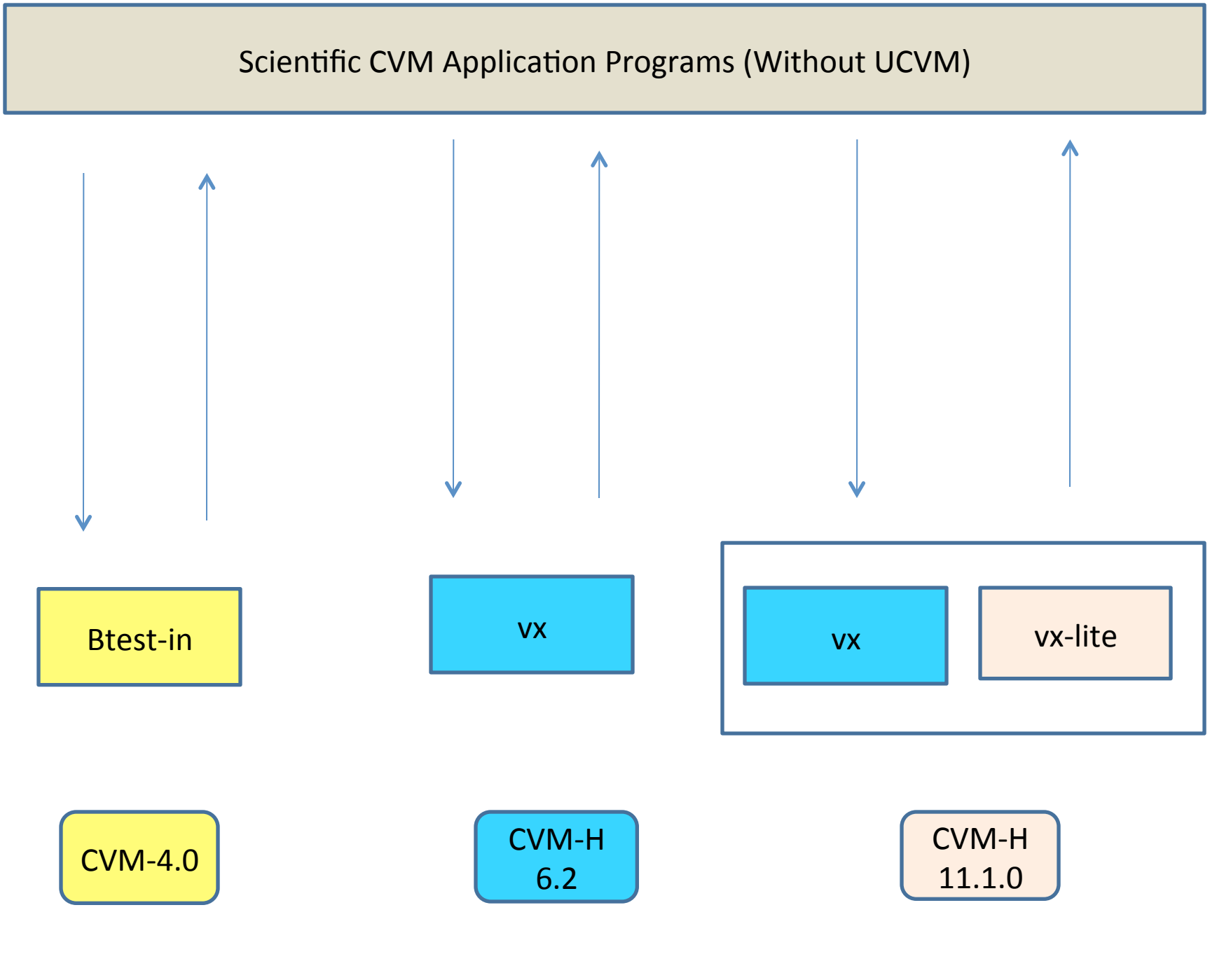
Standard information needed for every new CVM:

1. Coverage Region:
2. Elevation Model
3. Basin Model
4. Geotechnical Layer (0-350m):

5. How to query the model:
6. What material properties the model returns:
7. What file format is used to store the material properties:
8. Where to get Latest/Best version:

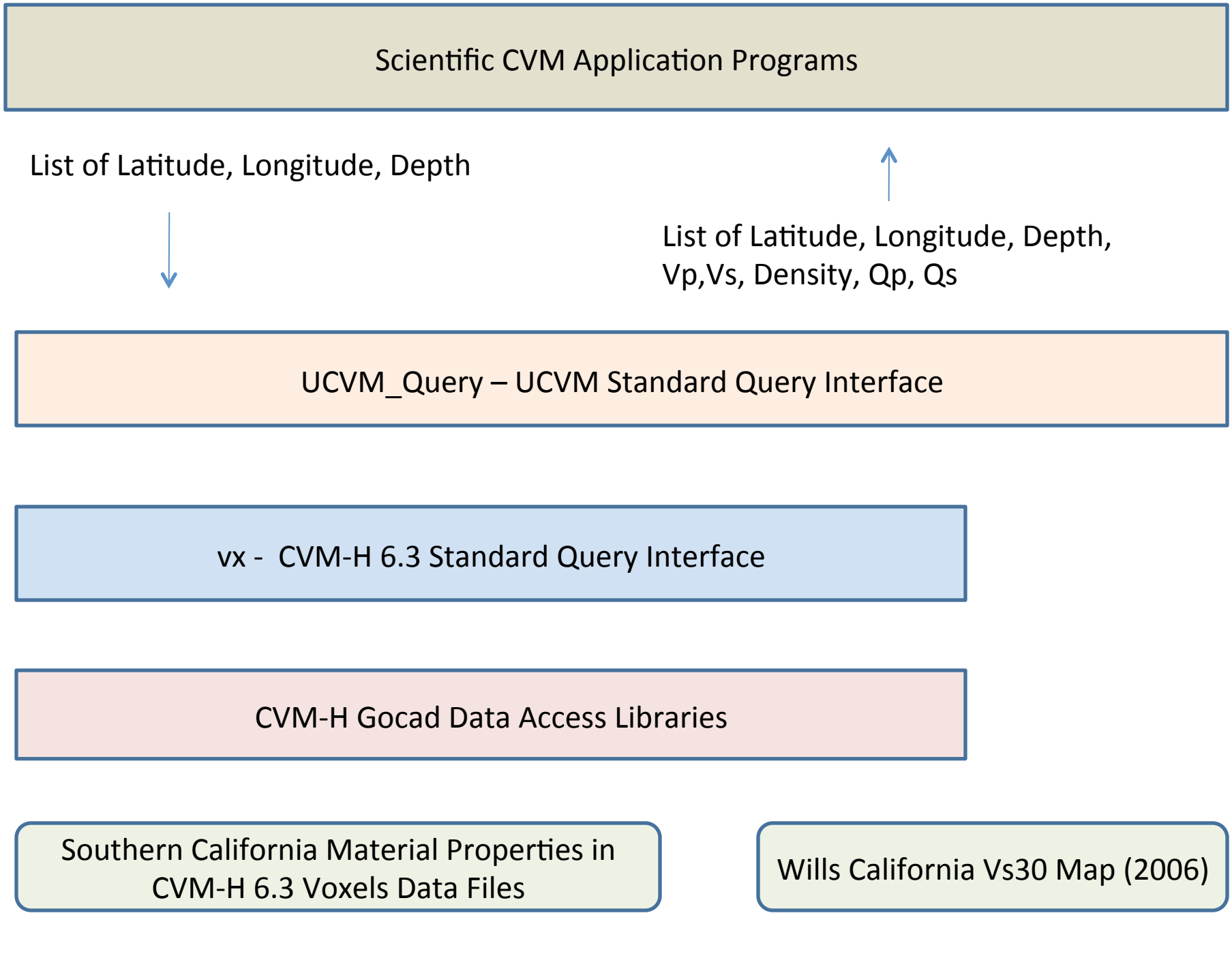
UCVM Development Approach

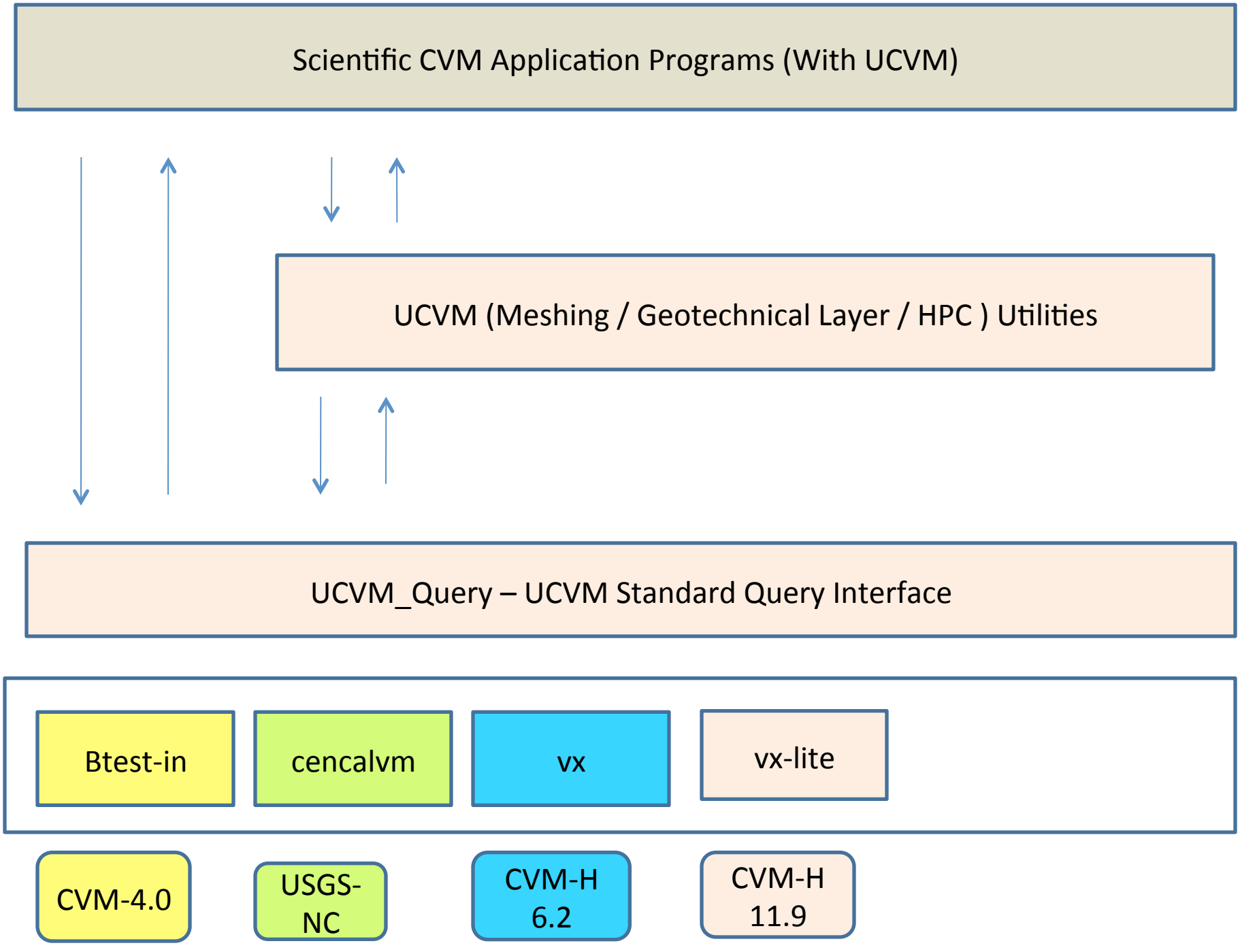
- Not practical to re-write all CVMs.
  - We designed UCVM to require minimal changes to existing CVMs.
- We want to avoid changing our application software to query each model in its own way.
  - We implemented standardized query and projection conversion methods so results a repeatable and comparable


Scientific CVM Application Programs (Without UCVM)
Btest-in
vx
vx
vx-lite
CVM-4.0
CVM-H
6.2
CVM-H
11.1.0

Summary of UCVM Software

- **UCVM provides a uniform query interface to several California velocity models. Models may be queried by (lon,lat,depth) or (lon,lat,elev).**
  - **ucvm_query: Linux command-line query tool**
  - **API: C interface to UCVM**
- **UCVM easily combine two or more regional velocity models together into one meta-model. Models are tiled in specified order.**
- **Read and write CMU/SCEC-formatted Etrees with Vs and frequency dependent resolution**


Scientific CVM Application Programs
List of Latitude, Longitude, Depth
List of Latitude, Longitude, Depth,
Vp,Vs, Density, Qp, Qs
UCVM_Query – UCVM Standard Query Interface
vx - CVM-H 6.3 Standard Query Interface
CVM-H Gocad Data Access Libraries
Southern California Material Properties in
CVM-H 6.3 Voxels Data Files
Wills California Vs30 Map (2006)

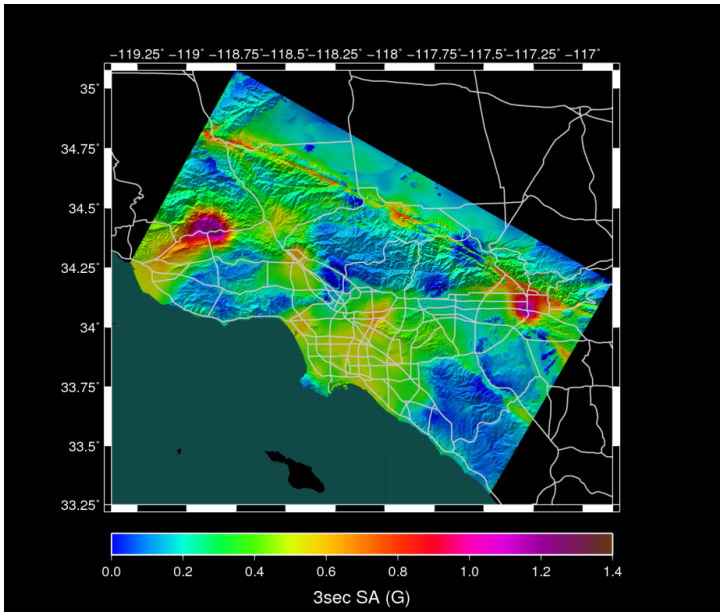

Scientific CVM Application Programs (With UCVM)
UCVM (Meshing / Geotechnical Layer / HPC) Utilities
UCVM_Query – UCVM Standard Query Interface
Btest-in
cencalvm
vx
vx-lite
CVM-4.0
USGS-NC
CVM-H 6.2
CVM-H 11.9

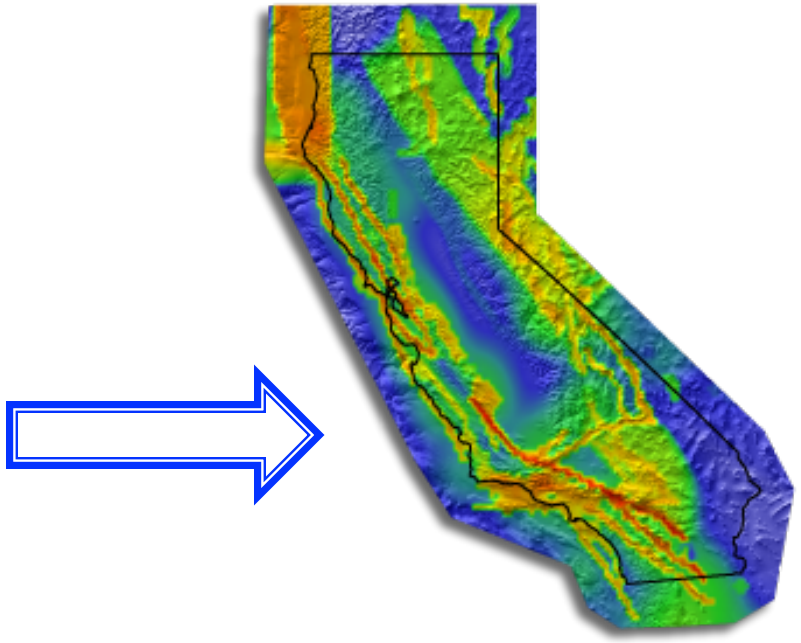
Supported Models

- These regional crustal models are currently registered into UCVM:
  - SCEC CVM-H 11.2.0/11.9.1
  - SCEC CVM-S4
  - USGS Central California (cencalvm)
  - Chen's SoCal and NoCal iterates (CVM-S4.23, CVM-NCI)
  - User-defined 1D (default is Hadley-Kanamori 1D)
  - Any CMU/SCEC formatted CVM Etree
  - Various other models such as Lin-Thurber, Graves Cape Mendocino
- Statewide support for the Ely Vs30-derived geotechnical layer (w/ interpolation)
- Adding a new CVM requires writing a code that converts UCVM interface into native interface of CVM

CyberShake 1.0
Los Angeles Region Wave Propagation-based PSHA Map up to 0.5Hz will increase in range and frequencies.

CyberShake 3.0
California Wave Propagation-based PSHA Map up to 10Hz

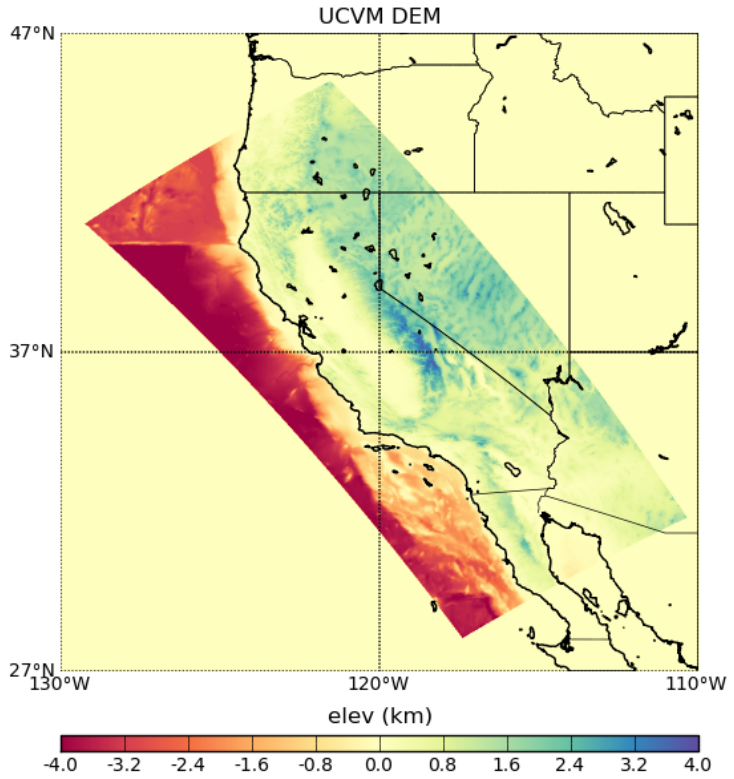




CME CyberShake 3.0 calculation will build on UCERF3.0 in order to calculate a “physics-based” California PSHA Map

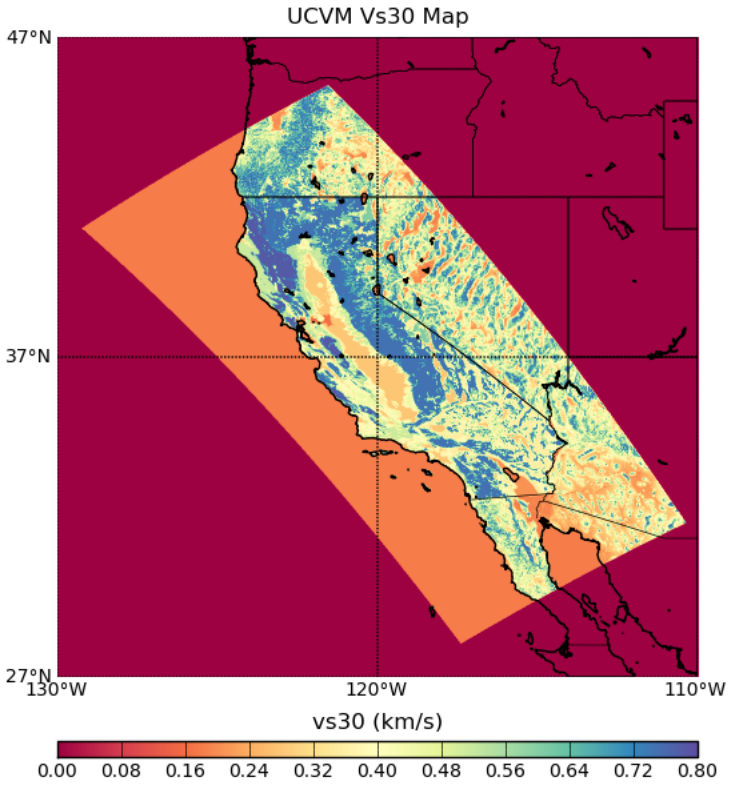
UCVM DEM

Sourced from USGS NED 1 arcsec and ETOPO1 datasets



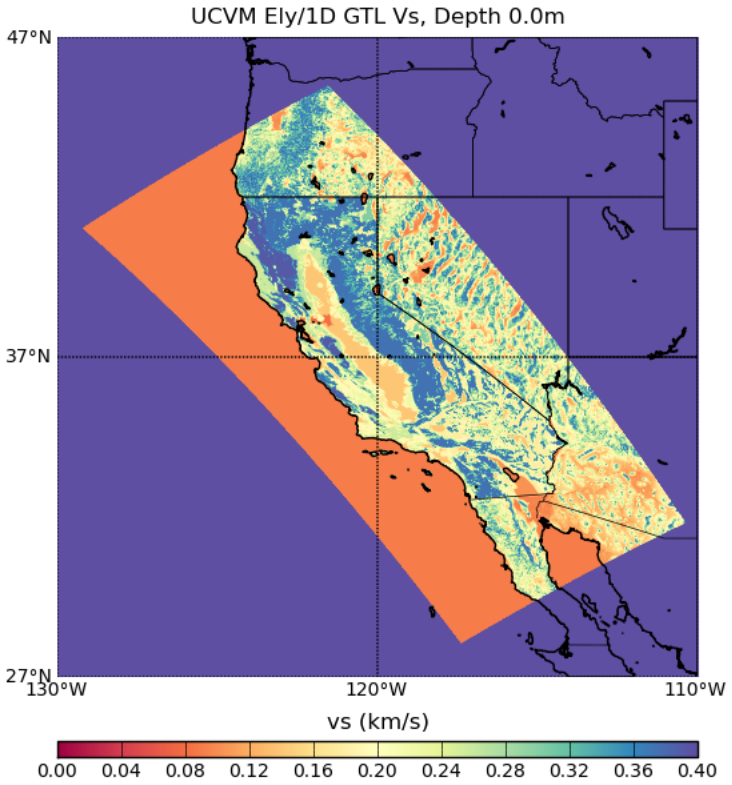
UCVM Vs30

Sourced from Wills 2006 and Wald 2007 Vs30 data



UCVM GTL

Ely Vs30-derived GTL, using Wills/Wald Vs30 map

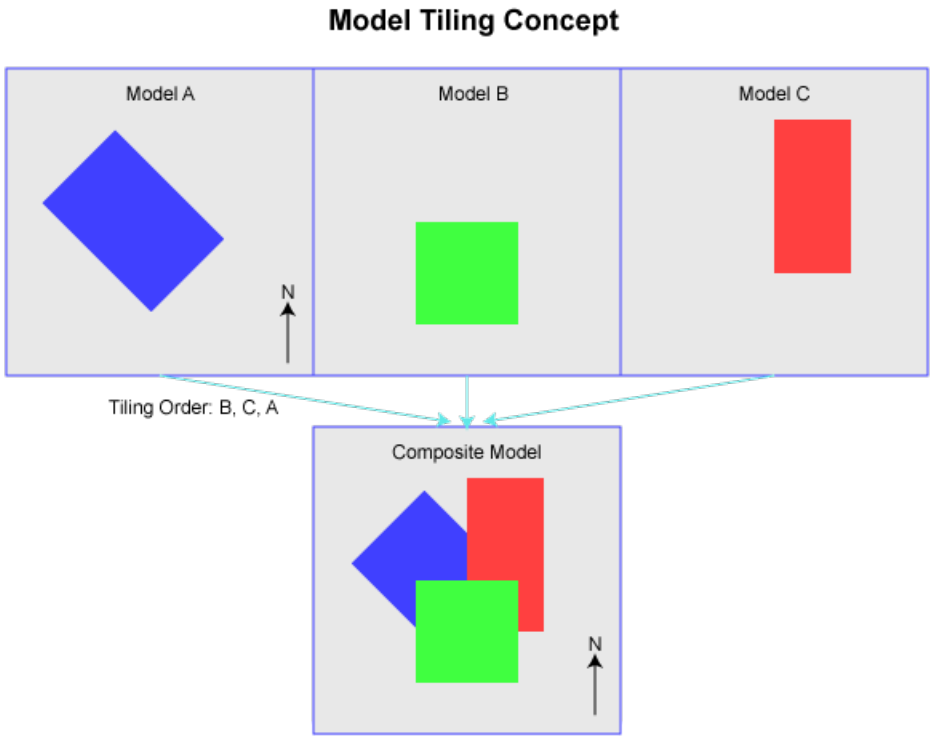


UCVM Tools/Utilities

- Query Tool: Retrieve Vp, Vs, and density for any model or combination of models. Elevation and Vs30 are also provided from the 2D maps.
- Mesh Generator: Supports 3D AWP and SORD meshes.
- Etree Generator: Supports SCEC and CMU formatted etrees with variable resolution. Employs this mininum Vs and max frequency relation:
  local resolution = local Vs / (fmax * ppwl)
- netCDF Support: Export of 3D meshes to netCDF format
- Numerical smoothing of overlapping models: Remove sharp discontinuities in 3D interfaces between overlapping velocity models (using an inverse distance weighting function).
- Large-scale parallel meshes (400B+ mesh points) extracted from slow CVM using MPI

Combining Models

When the researcher selects two or more models to query, the models are tiled in three dimensions so that for a particular point, each model is queried in sequence until valid material properties are found.

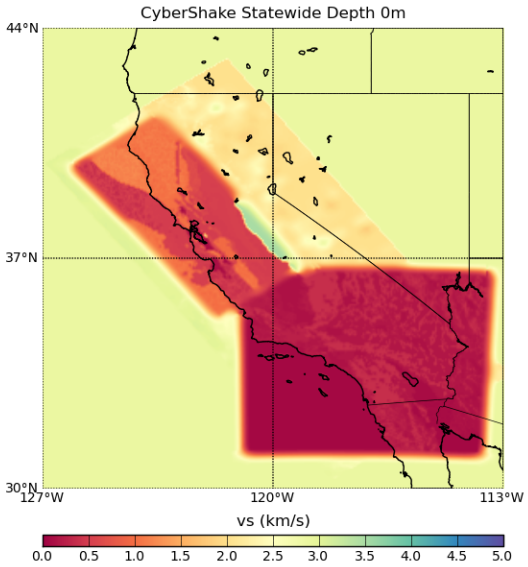


Composite Statewide Example

Plot on the right illustrates a Vs slice at depth 0 m taken from a composite statewide velocity model produced from UCVM

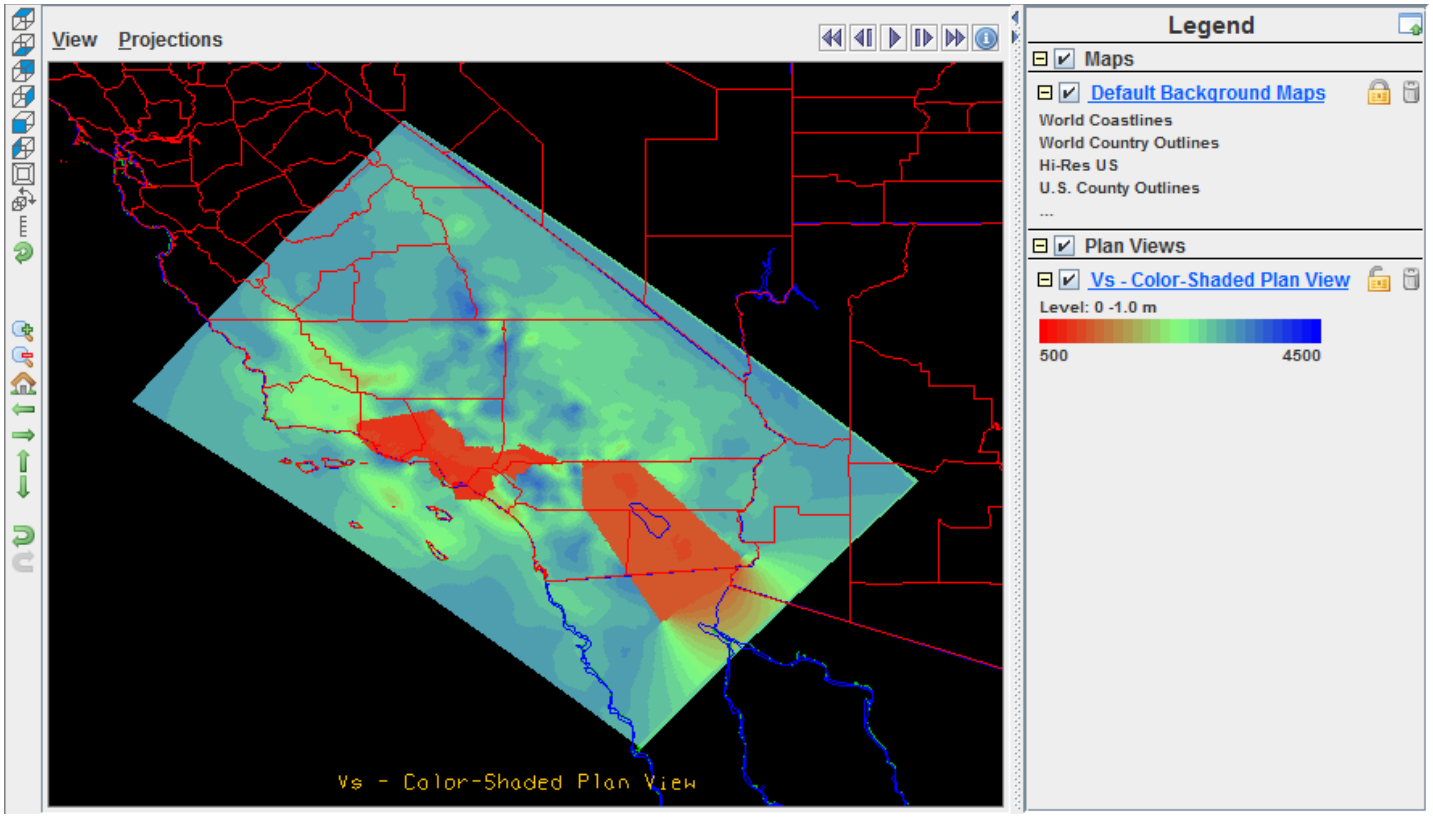
The USGS Central California, CVM-H, Lin-Thurber Statewide, and 1D bkg models have been overlaid

Sharp contrasts at several interfaces have been smoothed with the UCVM numerical smoothing algorithm



3D Visualization Example

- **Screen capture of map view from CVM-SI i5 mesh in IDV:**



Using UCVM to Build Etrees

- The UCVM framework supports the reading and writing of both CMU and SCEC-formatted CVM-Etrees.
- An Etree uses an octree database structure to store large amounts of data with very efficient storage and retrieval operations.
- UCVM can be used to export existing CVMs into CVM-Etree format using the ucvm2etree utility.
- This CVM-Etree can then be queried by UCVM with less memory overhead and generally better run-time performance than the original version.

Extensibility Beyond California

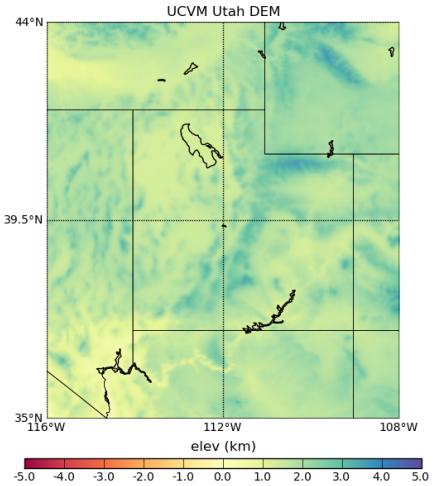
UCVM may be configured for regions outside of California

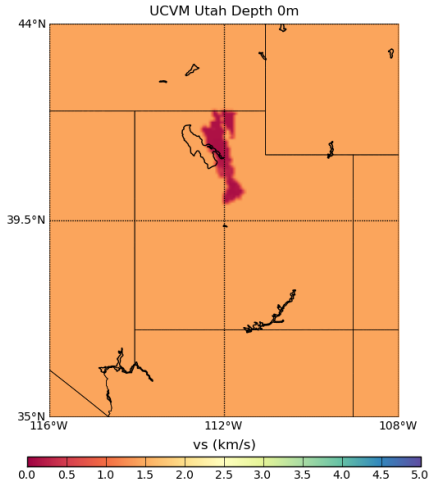
The required data inputs for an arbitrary region are:

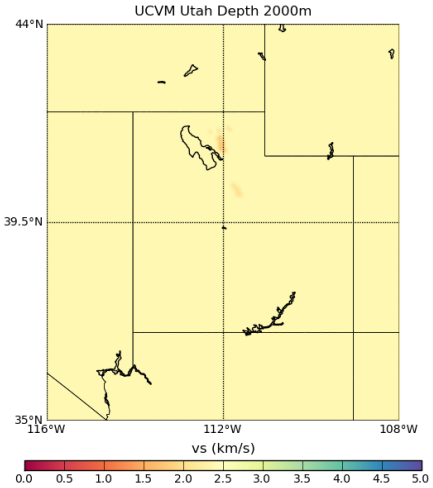
- **Definition of coverage region and projection (any supported Proj.4 proj)**
- **Digital elevation data in ArcGIS gridfloat format**
- **Vs30 data in ArcGIS gridfloat format**
- **A velocity model implemented as C/Fortran code.**

UCVM Utah Example

An example installation of UCVM for northern Utah (with Magistrale's Wasatch Front model):







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UCVM Development Supported on NSF Awards

- **Geoinformatics: Community Computational Platforms for Developing Three-Dimensional Models of Earth Structure (EAR-1226343)** PI: T. H. Jordan (USC) Co-PI: Y. Cui (SDSC) Co-PI: K. Olsen (SDSU) Co-PI: J. Tromp (Princeton) **Project Duration:** Start Date 1 Sept 2012 - End Date: 30 August 2014

- **SI2-SSI: A Sustainable Community Software Framework for Petascale Earthquake Modeling (NSF Award OCI-1148493)** PI: Thomas H. Jordan (USC) co-PI: Jacobo Bielak (CMU) co-PI: Yifeng Cui (SDSC) co-PI: Kim B. Olsen (SDSU) **Project Duration**: Start Date: 1 August 2012 -Date: 31 July 2015

UCVM Development Plans

- Conversion from “Personal Code” to “Community Code”
- Support for High Frequency Simulations
- Delivery of Inversion Results

Software Costs by Program Type

A Programming Product (Generalization, Testing, Documentation, Maintenance make it ready for external use)	A Programming System Component Product (Generalization, Testing, Documentation, Maintenance make components ready for external use)
A Standalone Program	A Programming System Component (Program integrated into a programming system like OpenSHA or CyberShake Workflow- Interfaces, System Integration)

3X Cost

3X Cost

(ref Mythical Man Months – Fred Brooks)

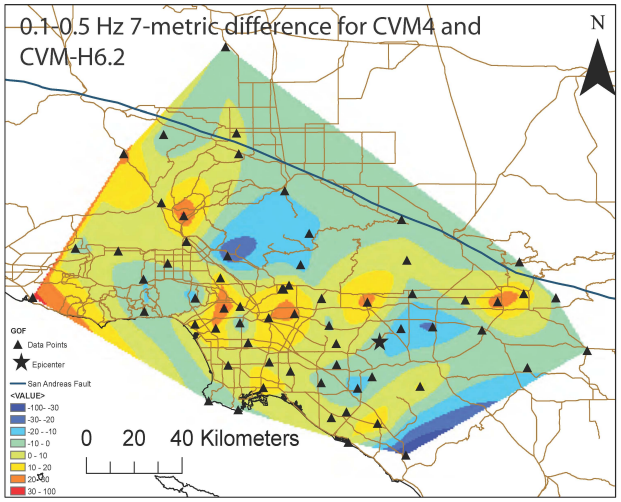
UCVM Software Distributions

- UCVM and utilities are written in GNU C.
- Codes are available for download from SCEC Wiki.
  http://scec.usc.edu/scecpedia/UCVM
- Users guide documentation available.
- UCVM Software designed for use on Linux platform with GNU compilers
- Installation involves building underlying CVMs (e.g. CVM-S4, CVM-H11.9) then configuring UCVM.

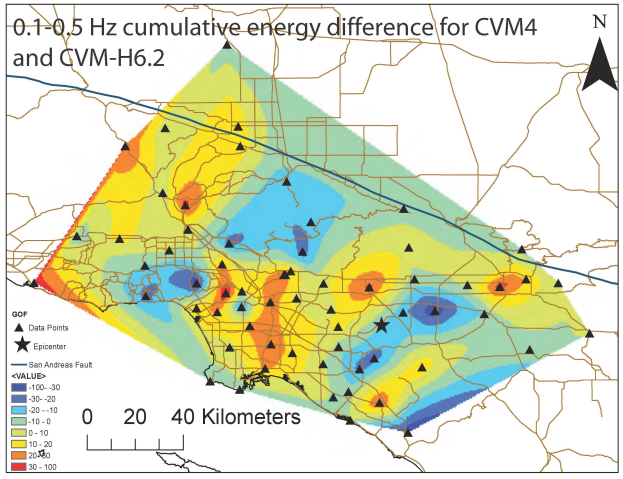
UCVM Development Plans

- Conversion from “Personal Code” to “Public Code”
- Support for High Frequency Simulations
- Delivery of Inversion Results

Validation Using Small Earthquakes at 0.5Hz

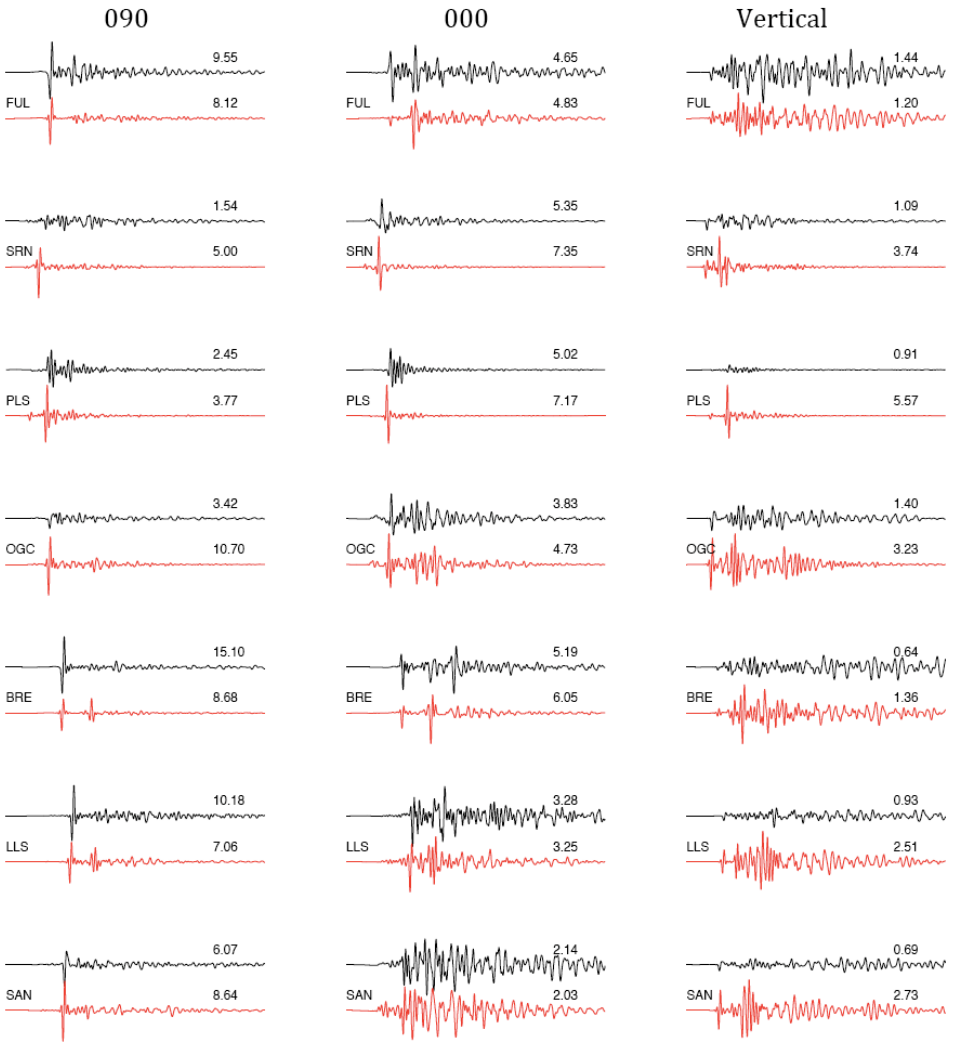


Postive (negative) values depict areas where CVM4 (CVM-H) is more accurate.



Postive (negative) values depict areas where CVM4 (CVM-H) is more accurate.

Chino Hills, M5.4, 07/29/08 (Olsen & Mayhew, 2009)



2.5Hz Chino Hills with and w/o CVM heterogeneities

Simulated Wave Propagation for the Mw5.4 Chino Hills, CA, Earthquake, Including a Statistical Model of Small-Scale Heterogeneities

t=00 seconds

Yellowstone Simulation

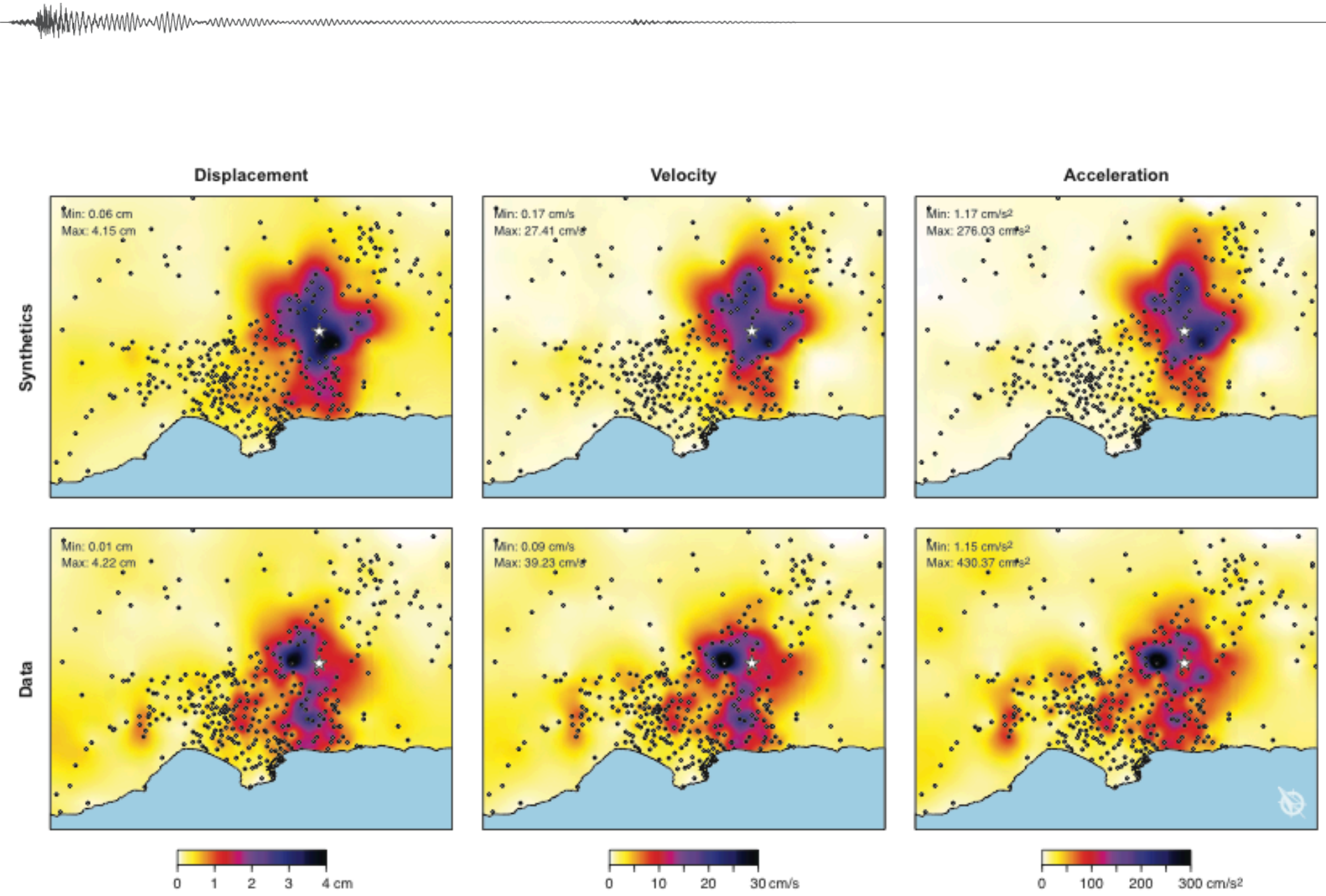
Kraken Simulation

Velocity (m/s)

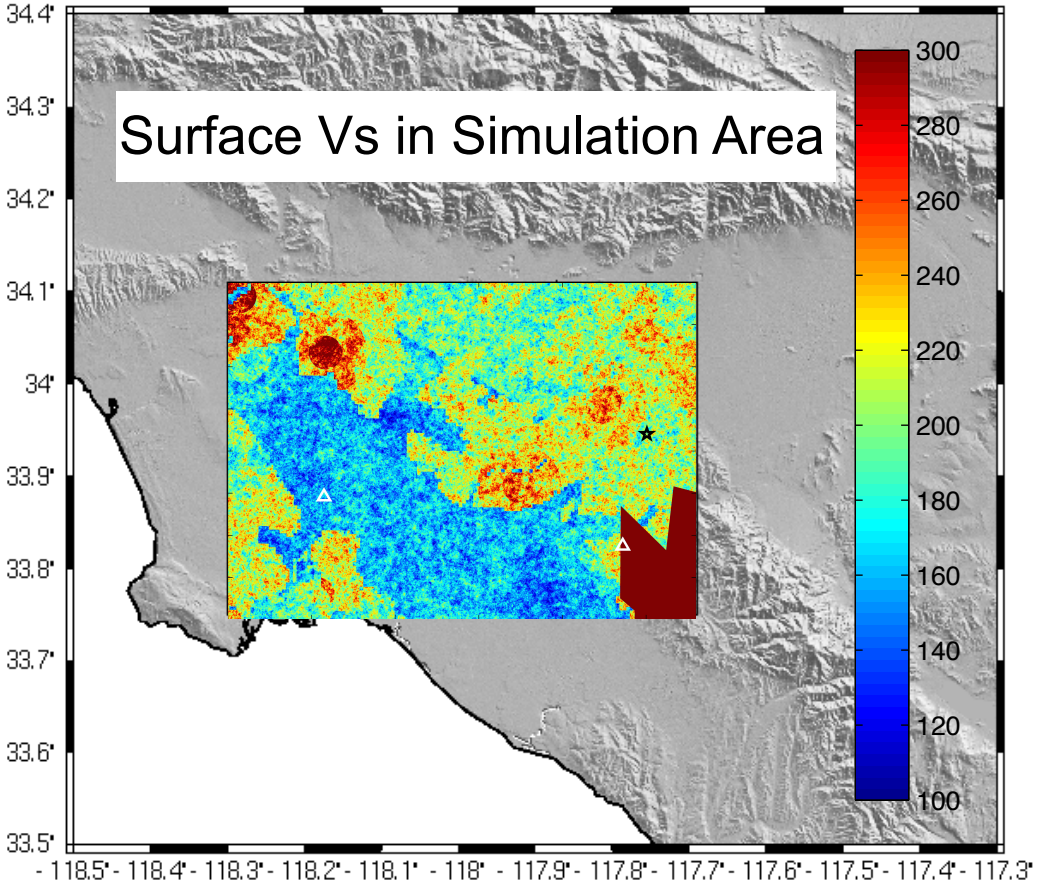
NCAR

SCEC

Chino Hills Validation at 4Hz



Incorporating Statistical Models of Small-Scale Inhomogeneities into Ground Motion Simulations



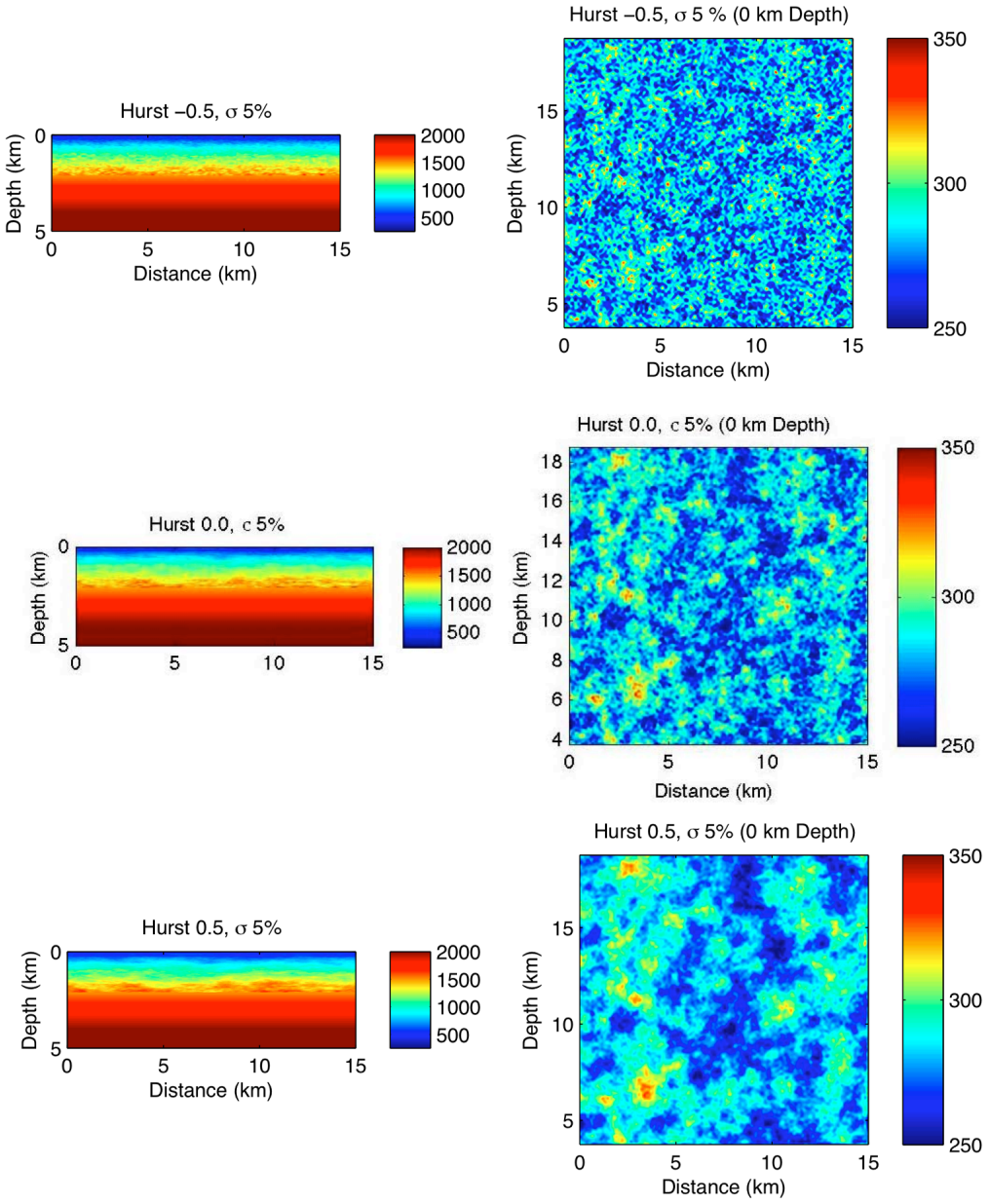
Code	AWP-ODC (FD)
Max Frequency	2.5 Hz
Minimum Vs	200 m/s
Hurst Number, σ	0.1, 10%
Δx	16 m

Fractal Distribution

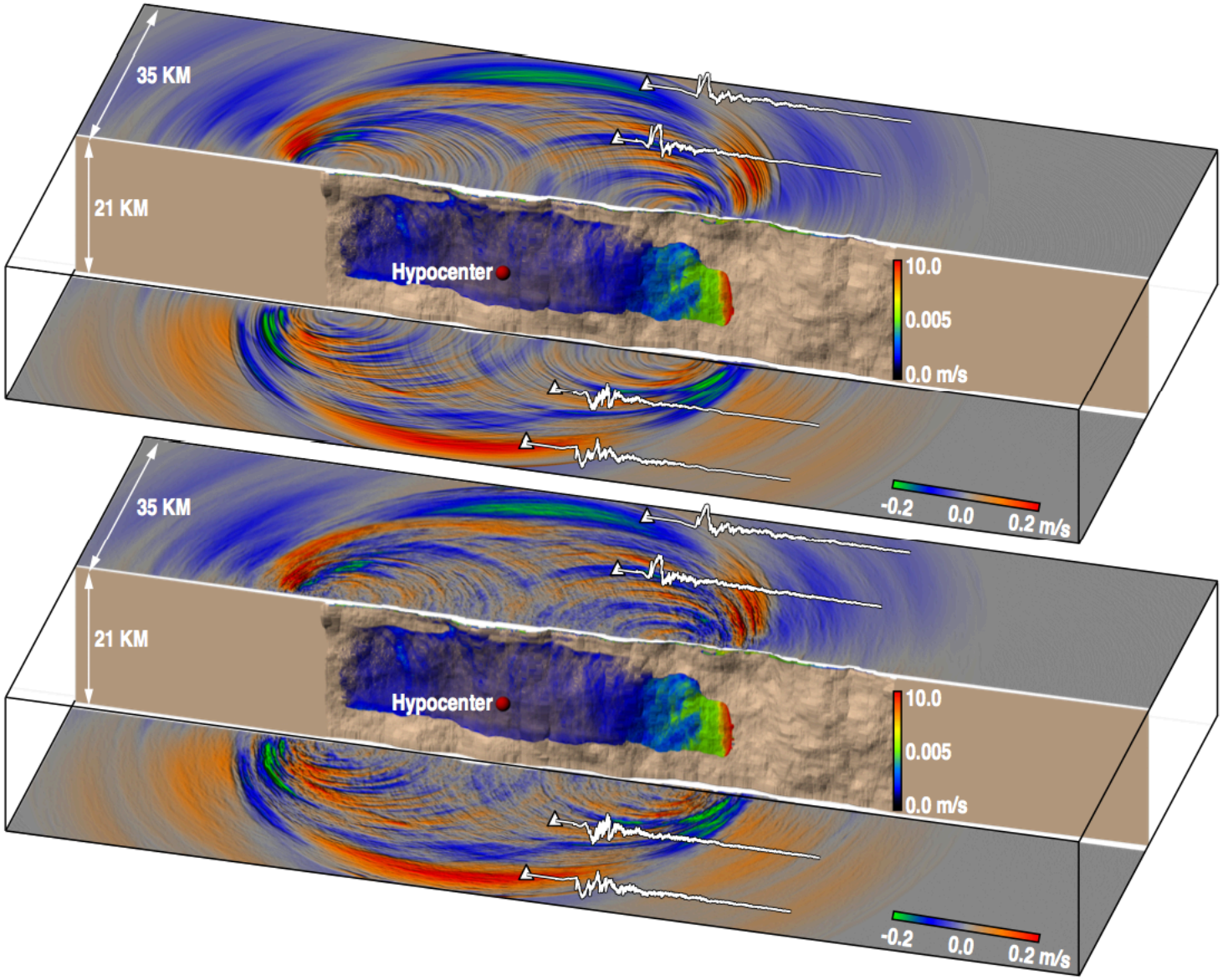
In 3D, a fractal distribution has a high wave-number decay of the power spectrum P(k) as:

$$P(k) = P_0\left(1+\left(k/k_{corner}\right)^2\right)^{-(1.5+H)}$$

where *H* is the Hurst number, k_{corner} is a wave number below which the spectrum is approximately constant

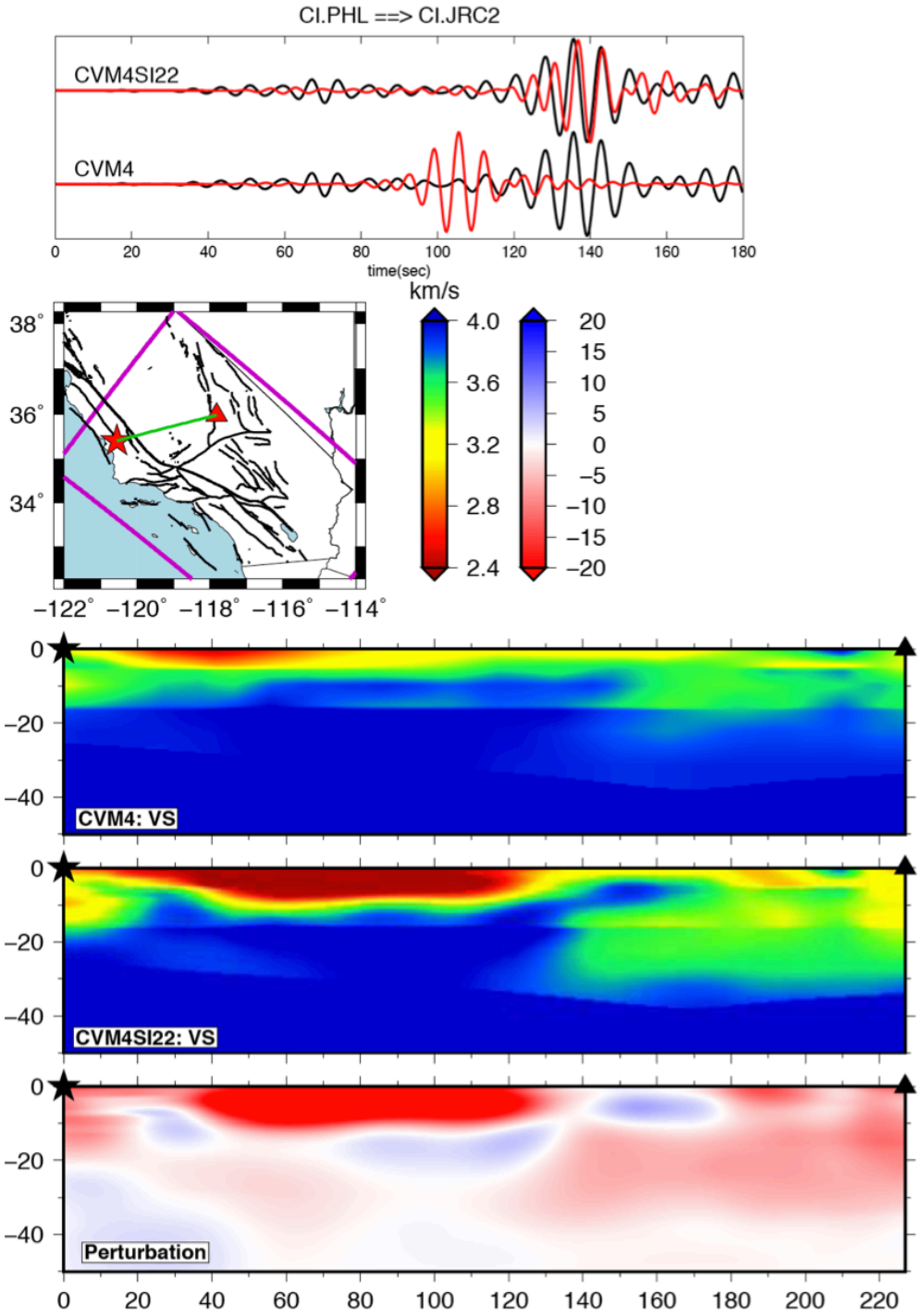


10Hz SORD Dynamic Rupture and Wave Propagation with and without small scale Heterogeneities



UCVM Development Plans

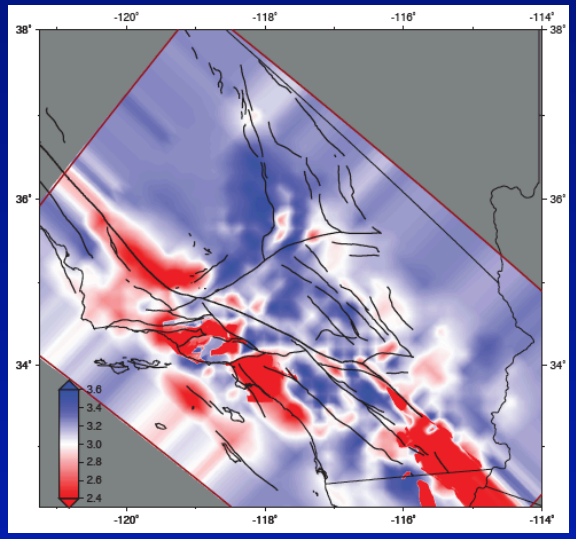
- Conversion from “Personal Code” to “Public Code”
- Support for High Frequency Simulations
- Delivery of Inversion Results



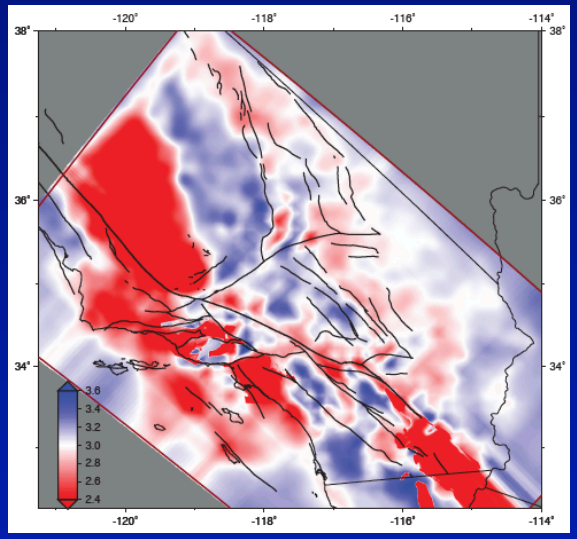
Cross-section view of the S-wave velocity in the starting model and the updated model along a source-station path across the Great Valley. Observed (black) and synthetic (red) ambient-noise Green's functions for the starting model (lower) and the updated model (upper) are shown in the top box.

SCEC

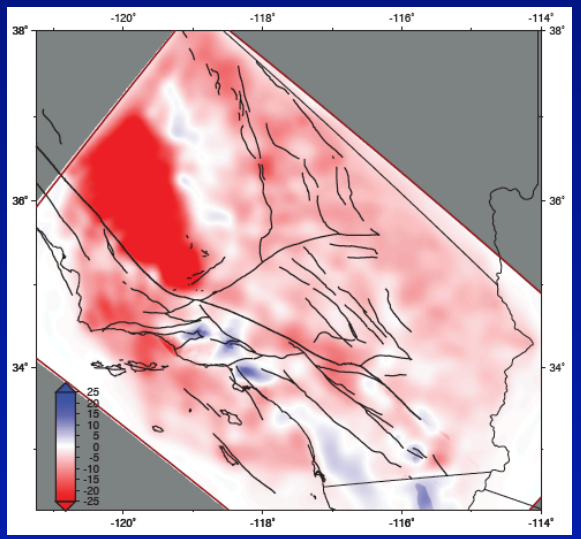
CVM4 VS 2km
3.0 ± 0.6 km/s



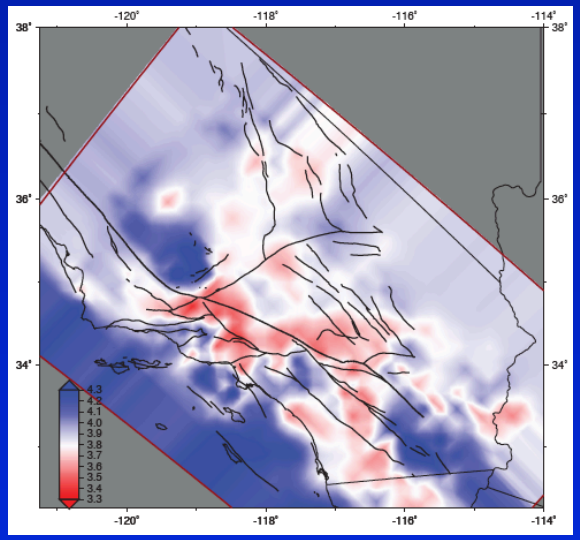
CVM4SI21 VS 2km
3.0 ± 0.6 km/s



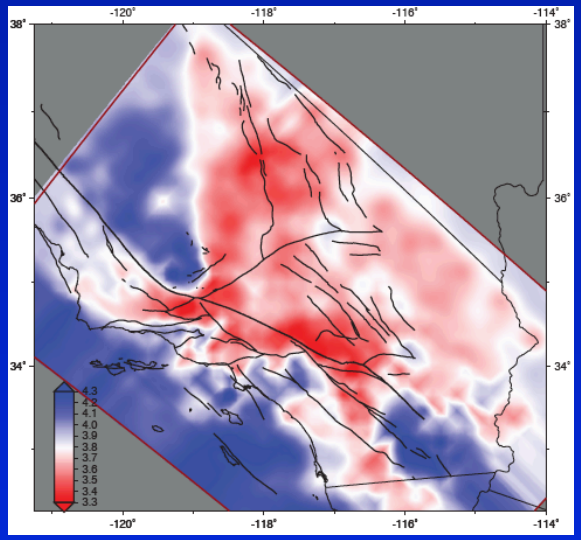
Perturbation 2km
VS of CVM4 ± 25%



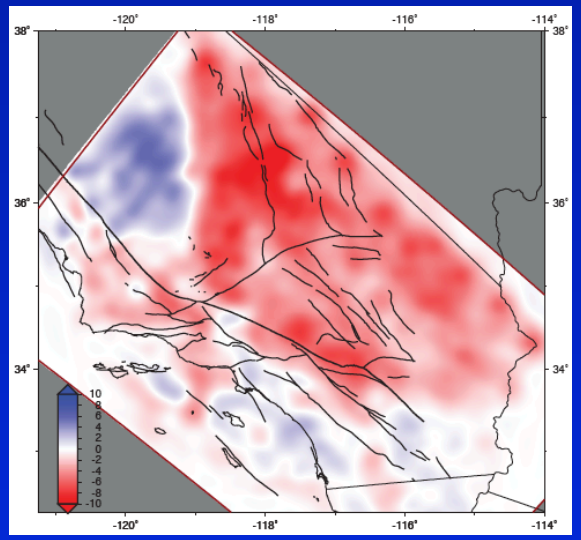
CVM4 VS 20km
3.8 ± 0.5 km/s



CVM4SI21 VS 20km
3.8 ± 0.5 km/s

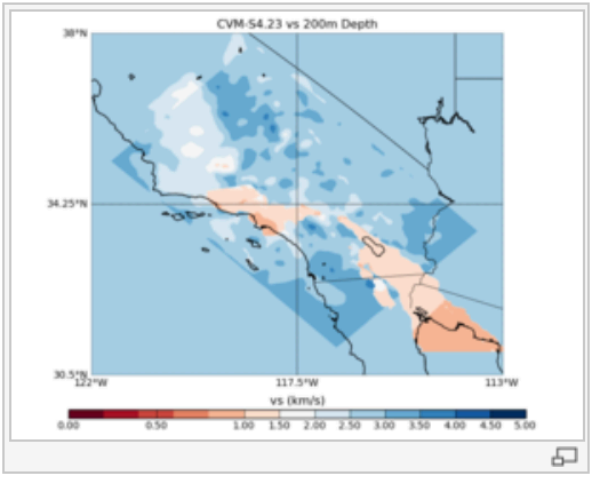


Perturbation 20km
VS of CVM4 ± 10%

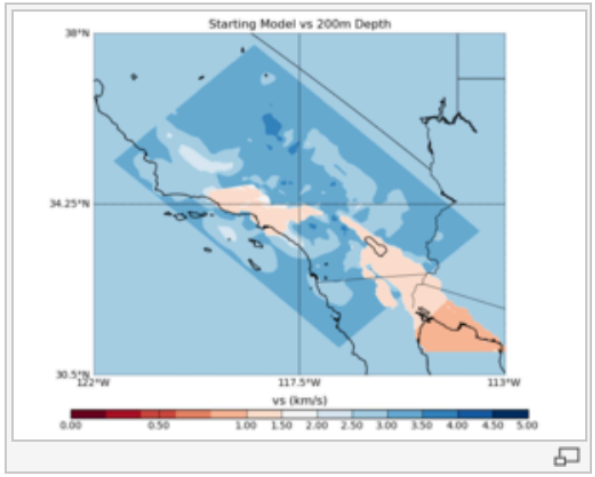


Delivery Perturbations using UCVM

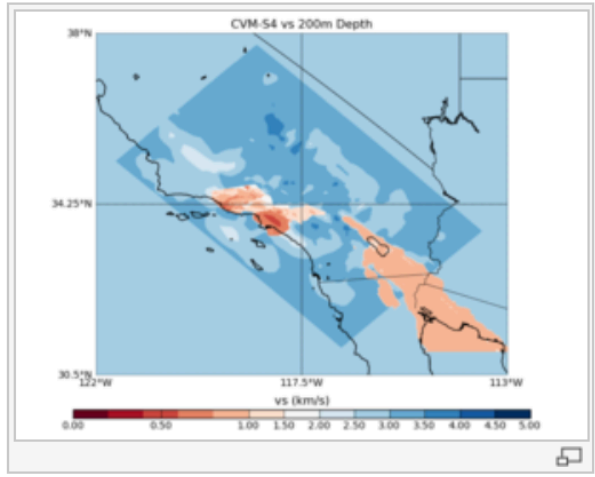
CVM-S4.23



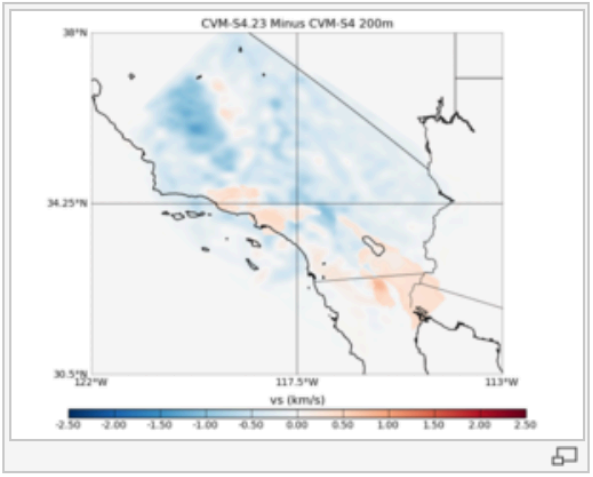
Starting Model



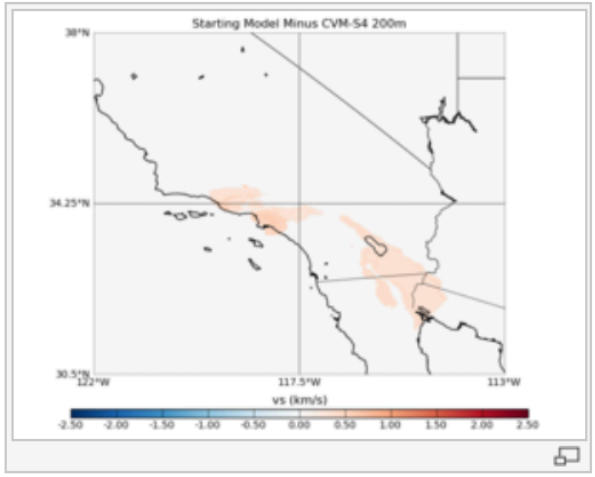
CVM-S4



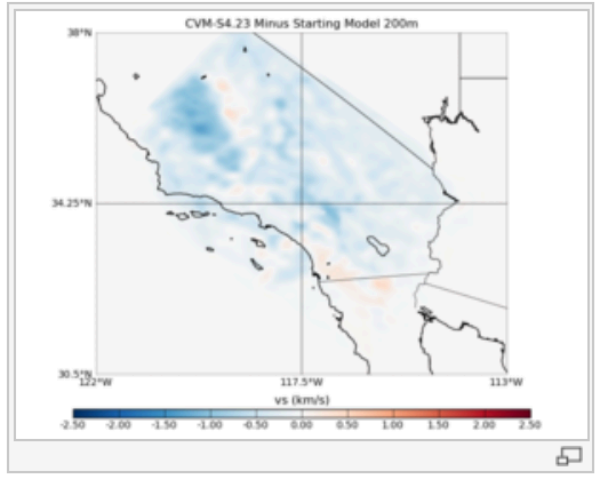
CVM-S4.23 - CVM-S4

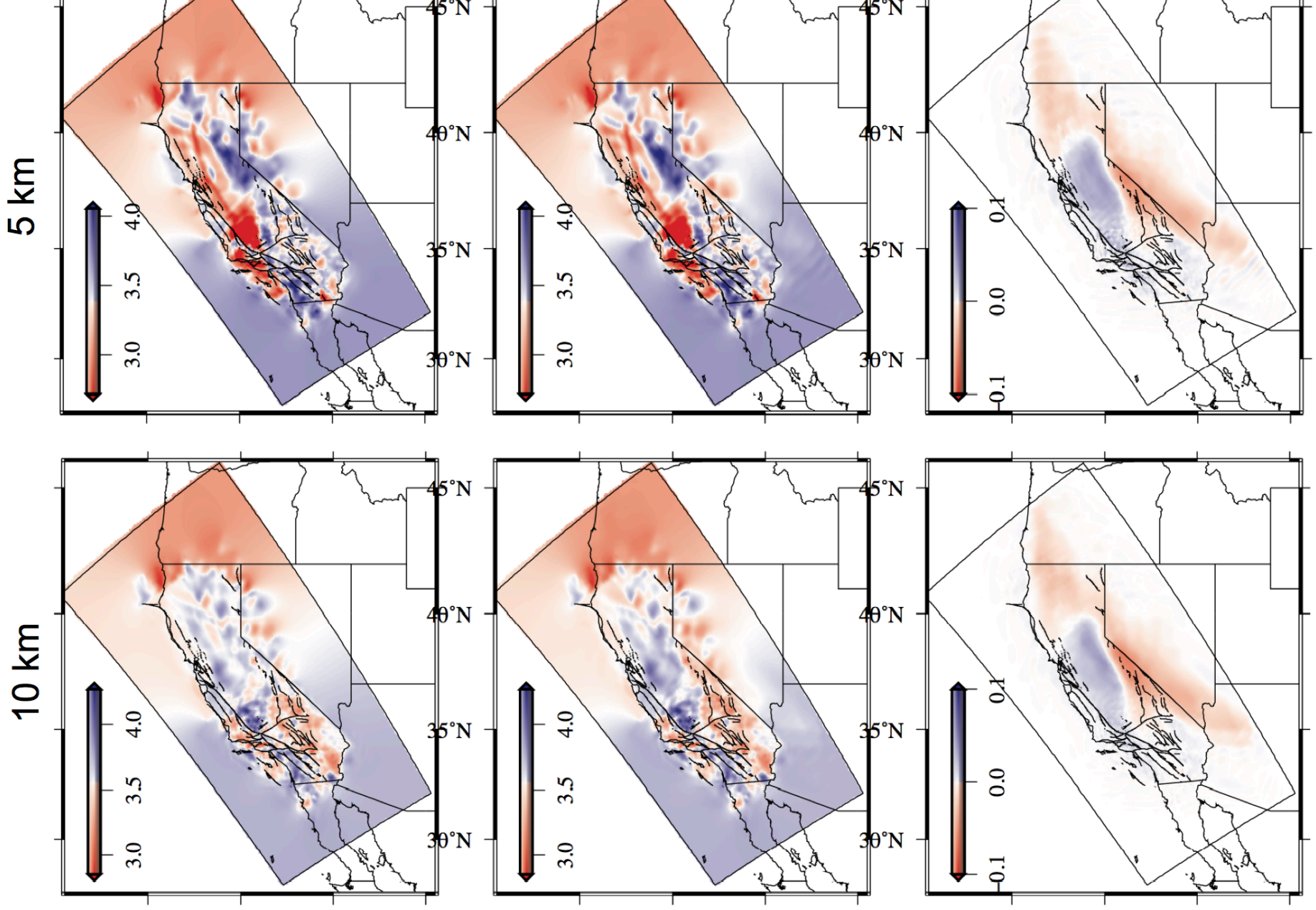


Starting Model - CVM-S4



CVM-S4.23 - Starting Model





igure 3. Map-view of the S-wave velocity in the statewide starting model (left), the updated model (center) and the perturbation between them (right) at 5 km (upper) and 10 km (lower) depths.

Outline

- Motivation for Building UCVM
- UCVM Development Status
- Future UCVM Plans
- Conclusions

Conclusions

Reasons you might want to try the UCVM Software:

1. To work with alternative California 3D CVMs
2. To query an existing 3D CVM at large scale
3. To deliver a 3D CVM to users
4. To add a Vs30-based GTL to a 3D CVM
5. To deliver a 3D CVM based on tomography results
6. To export a 3D CVM in broadly used format (such as netCDF) for viz or other purpose
7. To create simulation mesh from 3D CVM for high frequency deterministic simulations.

Thank You

For More Details and Examples, Please see our Poster at this Workshop:

SCEC Unified Community Velocity Model Framework Mesh Generation and Visualization (David Gill et al)

UCVM and Southern California CVMs are available for download from SCEC Wiki. http://scec.usc.edu/scecpedia/UCVM