Toward a Validated Multi-scale Seismic Velocity Model for the San Andreas Fault System in the Western US

Te-Yang Yeh and Yehuda Ben-Zion

Department of Earth Sciences and Statewide California Earthquake Center,
University of Southern California, Los Angeles

1. Introduction

- We develop a workflow for multi-scale seismic velocity models of the San Andreas fault system, aimed at supporting broadband ground motion simulations.
- Models combine large-scale crustal structures with localized high-resolution basins and features that strongly influence wave propagation.
- Each regional domain follows a two-step process: (1) assemble the best-available regional model from existing studies, and (2) merge higher-resolution models using methods such as cosine-taper windowing and dictionary learning.
- Candidate models are validated through 3D wave propagation simulations of moderate earthquakes, comparing observed and synthetic waveforms with goodness-of-fit metrics to guide iterative refinement.
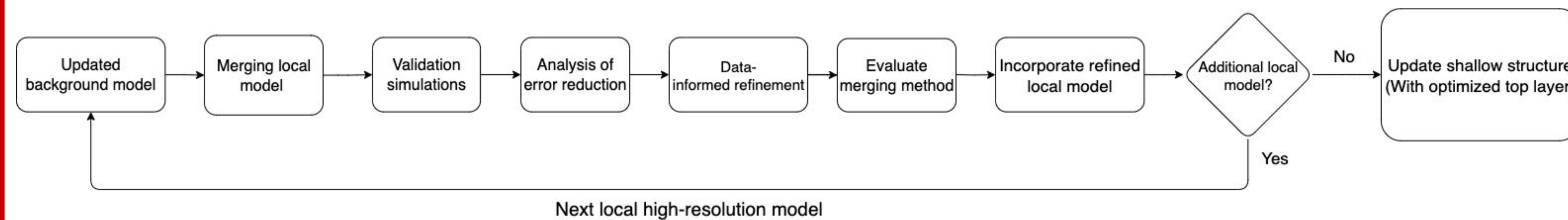
Workflow

Step 1: Creating Best Background Model for the Region
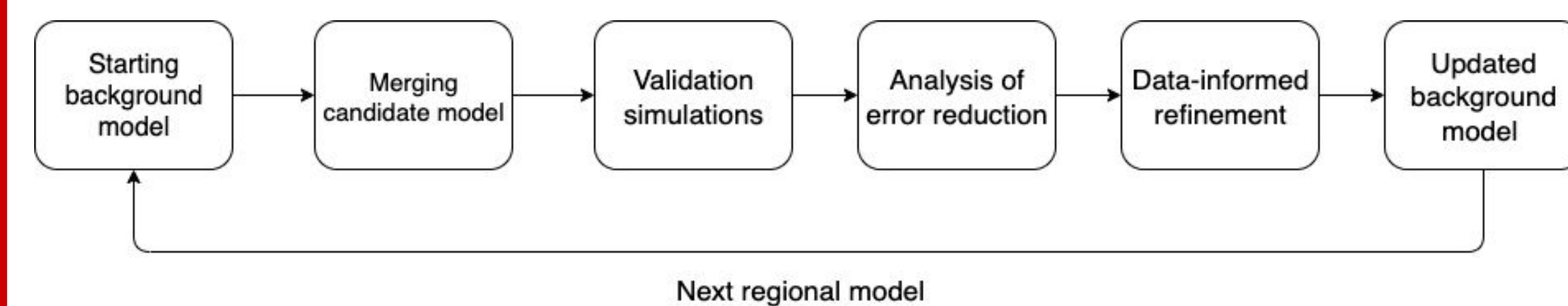
Step 2: Including Local High-Resolution Models
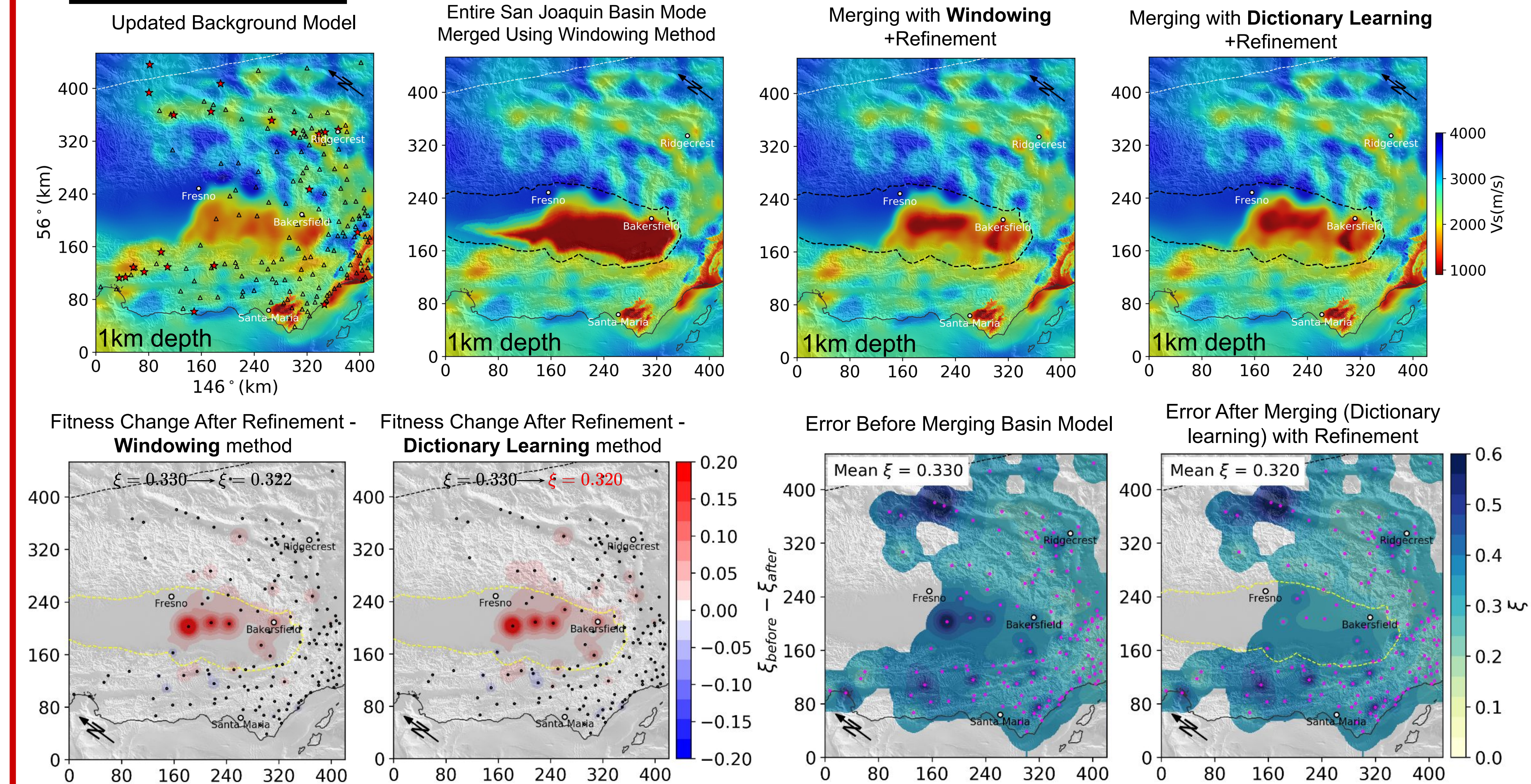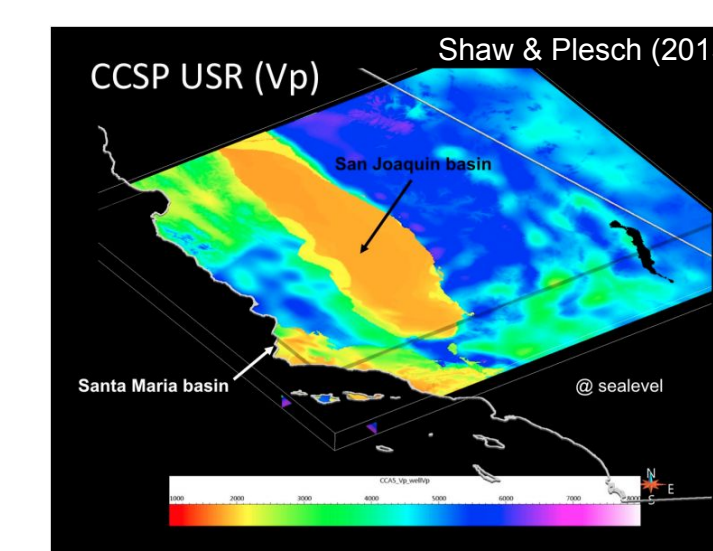Merging: windowing or dictionary learning followed by validation and updates

Error metrics

Error (e_i)	Weight (w_i)
FAS_E	1
FAS_N	1
FAS_Z	1
VER_E	1/2
VER_N	1/2
VER_Z	1/2
AER_E	1/2
AER_N	1/2
AER_Z	1/2

Errors are measured in the form of absolute log10 ratios in both frequency and time domains between 0.1-0.5 Hz.

We consider:
FAS: Fourier amplitude spectrum
VER: Velocity waveform envelope RMS
AER: Acceleration waveform envelope RMS.

Each error (e_i) is averaged across all available events at each station.

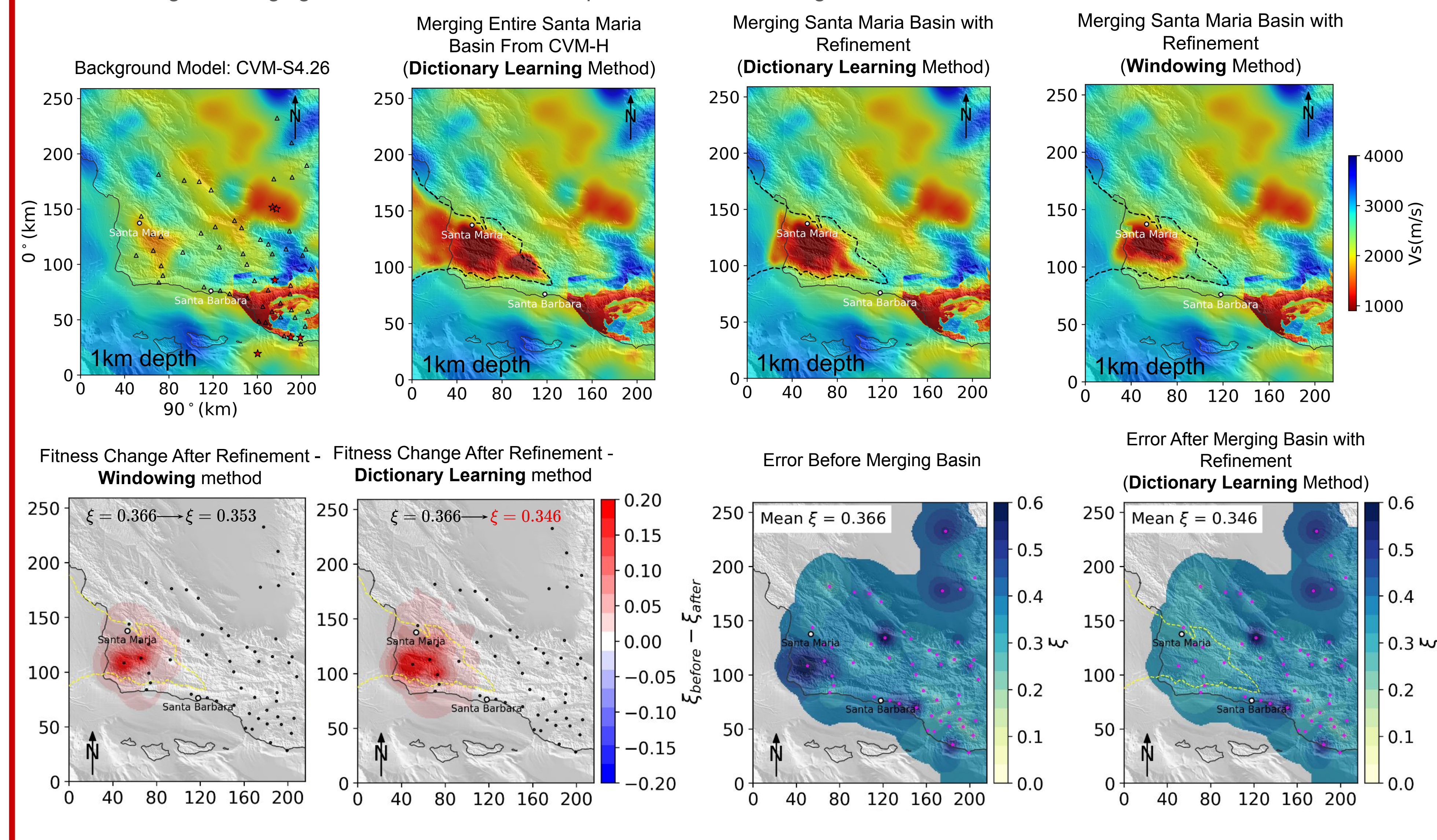Event-averaged errors are weighted to form a combined error :

$$\xi = \frac{\sum_{i=1}^{9} e_i w_i}{\sum_{i=1}^{9} w_i}$$

2. Example From Central California - Step 1

(i) Merging CCA

(ii) Data-informed Refinement for CCA

- Background model: CANVAS (Doody et al. 2023)
- Merging order: (1) CCA (2) CVM-H (3) CVM-S
- 17 Mw 4.2-4.7 events, 150 stations.
- Average error value reduced from 0.481 (CANVAS) to 0.330 (updated model).

(iii) Merging CVM-H with Refinement
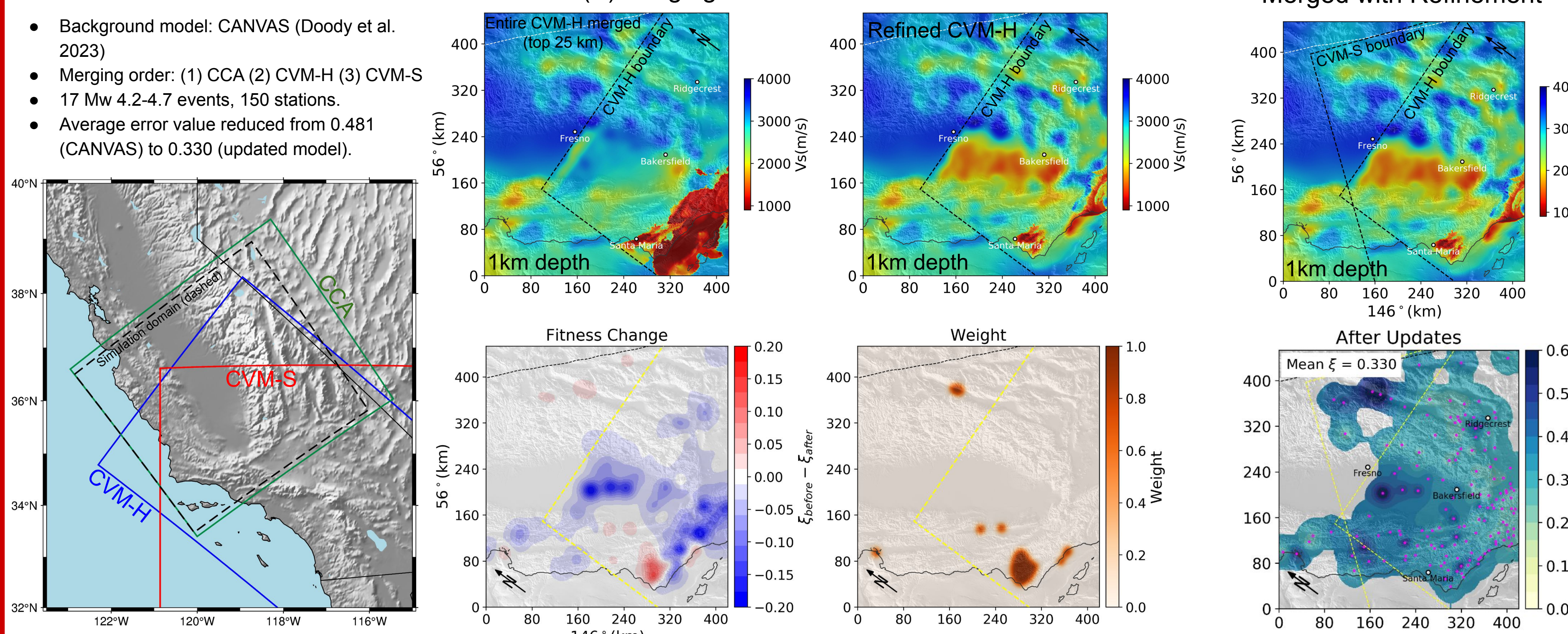
(iv) CCA+CVM-H+CVM-S
Merged with Refinement

3. Example From Central California - Step 2

- Merging San Joaquin Basin (Shaw & Plesch, 2015) into the **updated** background model for central California
- Evaluating cosine taper windowing (Ajala & Persaud, 2021) and dictionary learning (DL) (Zhang & Ben-Zion, 2024) methods
- Two merging methods deliver similar performance for the San Joaquin basin, with DL providing higher spatial resolution and slightly lower averaged error
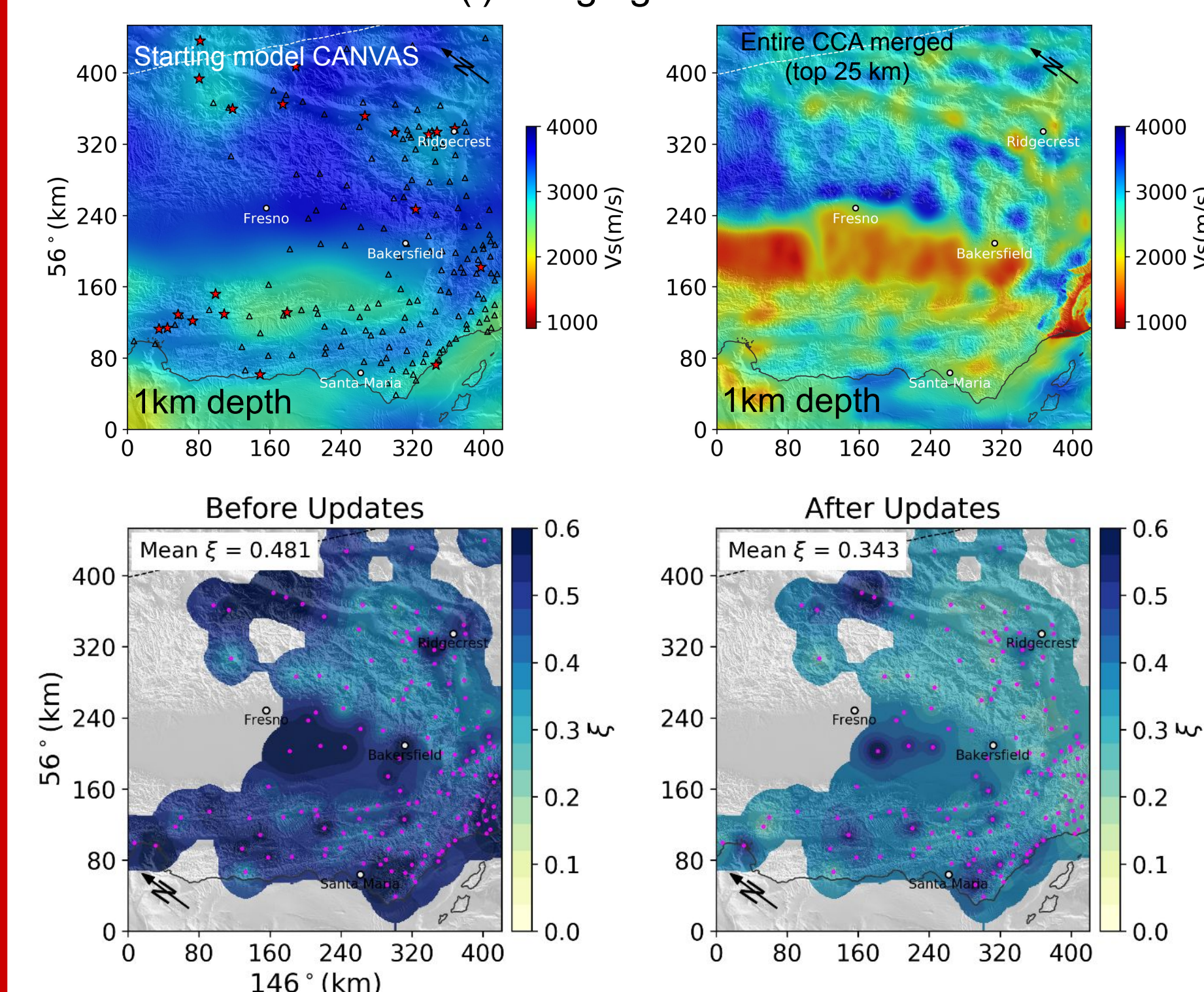

4. Example from Southern California (Including the Santa Maria Basin)

- Incorporate Santa Maria Basin (from CVM-H) into CVM-S4.26 (assumed background model)
- Small testing simulation domain for validation with
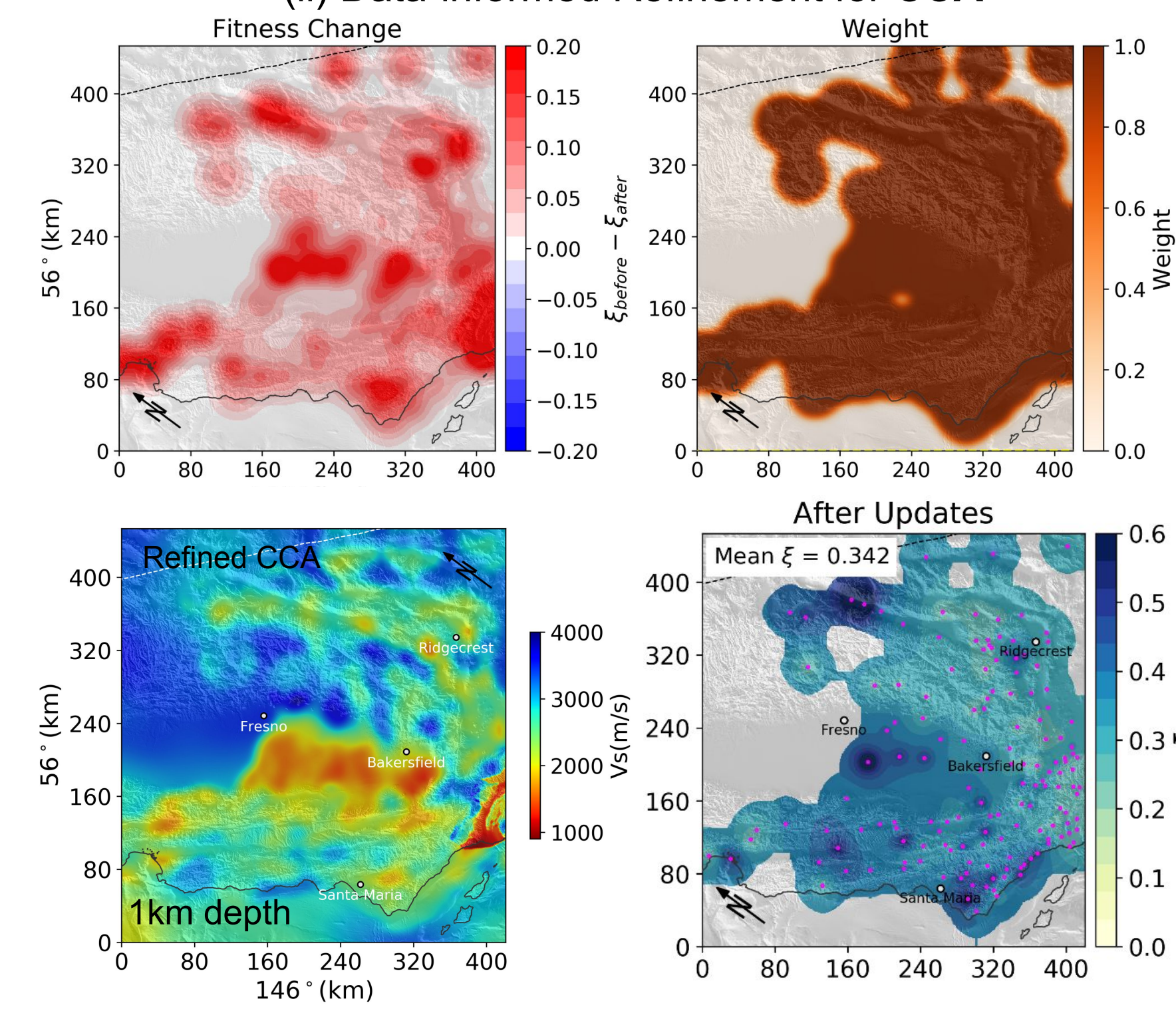- Testing two merging methods -> DL method outperforms the windowing method

5. Toward the Statewide Model

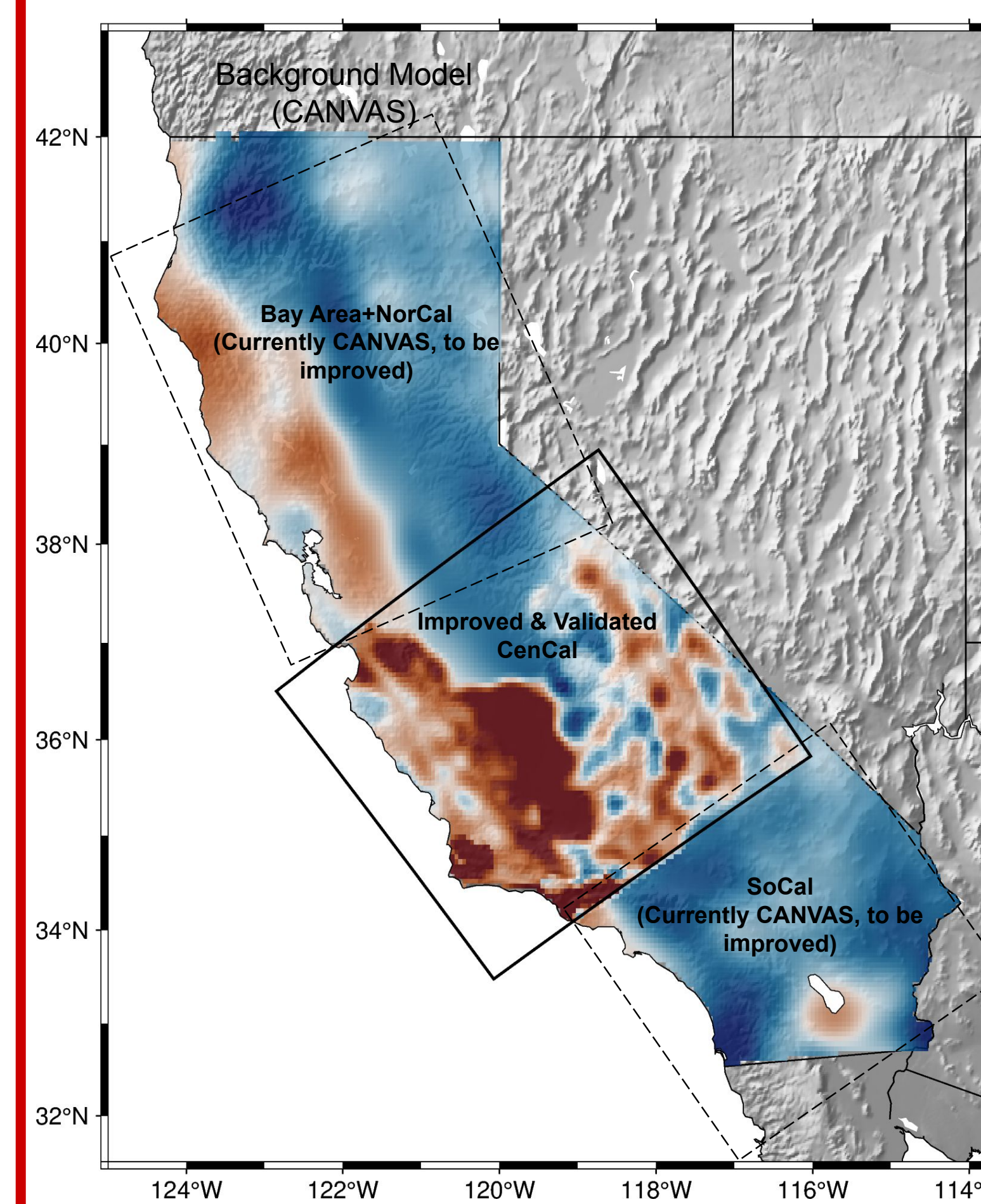- Follow through the developed workflow in two other subregions and develop the statewide updated background model:

  Northern California and Bay Area
  - San Francisco Bay Velocity Model
  - Furlong et al (2024)
  ... etc

  Southern California
  - CVM-S4.26
  - CVM-H
  - Berg et al (2021)
  - Fang et al (2022)
  ... etc

- Validation against an independent dataset not used for model merging

- With the validated statewide background model, incorporate local high-resolution models
  - Merged and validated at a higher frequency (1+Hz)
  - Optimize shallow structures using low-velocity taper