

**SIMULATED GROUND MOTION IN SANTA CLARA VALLEY, CALIFORNIA, AND VICINITY FROM  
M6.7 AND GREATER SCENARIO EARTHQUAKES**

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## **Abstract**

Models of the Santa Clara Valley (SCV) 3D velocity structure and 3D finite-difference software are used to predict ground motions from scenario earthquakes on the San Andreas (SAF), Monte Vista/Shannon, South Hayward, and Calaveras faults. Twenty different scenario ruptures are considered that explore different source models with alternative hypocenters, fault dimensions, and rupture velocities, and three different velocity models. Ground motion from the full wave field up to 1-Hz is exhibited as maps of peak horizontal velocity and pseudo-spectral acceleration at periods of 1, 3, and 5 s. Basin edge effects and amplification in sedimentary basins of the SCV are observed that exhibit effects from shallow sediments with relatively low shear-wave velocity (330 m/s). Scenario earthquakes have been simulated for events with the following magnitudes: (1) **M**6.8 to **M**7.4 Calaveras sources, (2) **M**6.7 to **M**6.9 South Hayward sources, (3) **M**6.7 Monte Vista/Shannon sources, and (4) **M** 7.1 to 7.2 Peninsula segment of SAF sources. Ground motions are strongly influenced by source parameters such as rupture velocity, rise time, maximum depth of rupture, hypocenter and source directivity. Cenozoic basins also exert a strong influence on ground motion. For example, the Evergreen Basin on the northeastern side of the SCV is especially responsive to 3- to 5-s energy from most scenario earthquakes. The Cupertino Basin on the southwestern edge of the SCV tends to be highly excited by many Peninsula and Monte Vista fault scenarios. Sites over the interior of the Evergreen Basin can have long-duration coda that reflects the trapping of seismic energy within this basin. Plausible scenarios produce predominantly 5-s wavetrains with greater than 30 cm/s sustained ground motion amplitude with greater than 30 s duration within the Evergreen Basin.

This electronic supplement presents pseudo-acceleration response spectral acceleration (SA) associated with several of the scenario Santa Clara Valley earthquakes of the BSSA article. The response values are presented as contour maps for two horizontal components and oscillator periods 1 s, 3 s, and 5 s, with 5% damping. The maps are indexed to six of the scenarios discussed in the article, with summary information in table 2, reproduced below. The purpose of this presentation is to demonstrate that PSA values exhibit strong correlation with the relatively shallow geologic structure, such as basin margins, basin depth and shallow shear-wave velocity. Although none of this correlation should be deemed as surprising, it is frequently overlooked in the standard models of median spectral response that are used in probabilistic seismic hazard mapping studies. Added value is associated with mapping spectral response in specified directions (here northwest and northeast) using a virtual array that covers the entire study area (San Francisco Bay region). This additional information tells what geologic structures are likely to amplify and deamplify strong earthquake ground motion at specified spectral periods in specified compass directions at specific locations.

Features to note include a variable level of excitation of the two components of horizontal motion over various basins at a range of periods. For example, in figure 1 below, corresponding to a Calaveras fault earthquake scenario, the northeast-oriented component of 3-s SA (*top center* panel) is at its strongest in the Livermore Basin near the fault, whereas the northwest component (*bottom center* panel) exhibits equally strong vibration over parts of the Evergreen Basin, over 10 km away from the fault. Both horizontal components of the 5-s SA are stronger over the more distant Evergreen Basin than over the Livermore Basin. Similarly, in figure 6 below, some of the strongest 3- and 5-s SA is observed in the Cupertino basin, more than 10 km from the San Andreas fault, on which the scenario earthquake takes place. The degree of response at any given location is often strongly dependent on spectral period. For example, figure 6 below shows that 3-s response is elevated over the Plio-Pleistocene Merced Basin, where the San Andreas fault comes onshore, whereas the 5-s response is not much affected, probably because the Merced basin low-velocity sediment layer is thick enough (about 1000 m, avg.  $V_s \sim 1200$  m/s) to generate significant 3-s shear-wave resonance but not 5-s. (The Merced Basin is about 2 km thick

but the deeper sediments are modeled with  $V_s$  equal to that of the surrounding Franciscan rock.) None of these features of the theoretical response can be said to be strongly exhibited in available empirical models of spectral response on rock and soil sites. Some current empirically derived models actually deny any basin amplification at the spectral periods shown for basins in the one to three kilometer depth range. Thus, if the underlying geologic and seismic models are reasonably correct, these and other scenario maps may give seismic-resistant design engineers a new and far more detailed view of the seismic hazard associated with future  $M > 6.5$  earthquakes in the San Francisco Bay area, a view which can contrast sharply with predictions from the current generation of attenuation models.

**Table 2: Summary of Rupture Scenarios**

Fault & Scenario # keyed to text	Segment & Length (km)	Epicenter	Hypo. Depth (km)	M <sub>0</sub> Averaged Depth (km)	V <sub>rup</sub> / Vs	Average T <sub>r</sub> (s)	M	M <sub>0</sub> (n-m)	Z <sub>max</sub> (km)	Velocity Model	Magnitude, & Location of PHV(m/s) <sup>1</sup>
Calaveras 1	CN, 46	N, Danville	14	10.1	0.75	1.65	6.8	1.78 · 10 <sup>19</sup>	16	V12m	0.96, NEB
2	CN, 46	S, Calav. Reservoir	14	10.1	0.8	1.65	6.8	1.78 · 10 <sup>19</sup>	16	V12m	0.85, NEB
3	CN+CC, 103	N, Danville	14	9.5	0.75	1.65	6.9	2.61 · 10 <sup>19</sup>	16CN 11CC	V12m	1.02, NEB
4	CN+CC, 103	N, Danville	14	10.1	0.75	3.18	7.4	14.1 · 10 <sup>19</sup>	16	V12m	2.4, SEB
5	CN+CC, 103	SE, Coyote L	13	10.1	1.5	3.18	7.4	14.1 · 10 <sup>19</sup>	16	V12m	3.0, SLV
6	CN+CC, 103	SE, Coyote L	13	13.0	*	3.18	7.4	14.1 · 10 <sup>19</sup>	16	V12m	2.69, NEB
Hayward 7	South, 57	SE, south Milpitas	10.7	9.6	0.82	1.29	6.7	1.26 · 10 <sup>19</sup>	16	V12m	0.48, SLV
8	South, 57	SE, north Milpitas	9.5	9.5	0.85	1.29	6.7	1.26 · 10 <sup>19</sup>	16	V12m	0.85, NLV
9	South, 57	NW, Oakland	9.6	9.6	0.85	1.29	6.7	1.26 · 10 <sup>19</sup>	16	V12m	0.85, NEB
10	South, 57	Bilateral, Fremont	8.5	9.6	0.75	1.29	6.7	1.26 · 10 <sup>19</sup>	15	V12m	0.65, Piedmont
11	South, 57	NW, Oakland	9.6	9.7	0.75	1.60	6.9	2.2 · 10 <sup>19</sup>	16	V9	0.93, NEB
12	South, 57	NW, Oakland	9.6	9.7	0.75	1.60	6.9	2.2 · 10 <sup>19</sup>	16	V12	0.84, NEB
Monte Vista/Shannon 13	All, 45	NW	9.5	7.7	0.75	1.62	6.7	1.13 · 10 <sup>19</sup>	12	V9	0.99, mCB
14	All, 45	SE	11.3	7.7	0.75	1.62	6.7	1.13 · 10 <sup>19</sup>	12	V12m	0.70, LaH
SAF 15	Peninsula, 88	NW, offshore	20	12.6	0.75	2.58	7.2	7.07 · 10 <sup>19</sup>	20	V12m	0.66, LaH
16	Peninsula, 88	NW	20	12.6	0.75	2.58	7.2	7.07 · 10 <sup>19</sup>	20	V9	1.04, mCB
17	Peninsula, 88	NW	14	10.1	0.75	2.58	7.2	7.07 · 10 <sup>19</sup>	16	V9	1.97, mCB
18	Peninsula, 88	NW	12	8.3	0.75	2.61	7.1	5.01 · 10 <sup>19</sup>	12	V9	2.00, mCB
19	Peninsula, 88	NW	12	8.3	0.75	2.61	7.1	5.01 · 10 <sup>19</sup>	12	V12m	0.84, LaH
20	Peninsula, 88	SE	18.8	11.6	0.75	2.68	7.2	7.07 · 10 <sup>19</sup>	20	V9	1.16, mCB

<sup>1</sup>Abbreviations: MV/S, Monte Vista-Shannon fault system; NEB, northern Evergreen basin; SEB, southern Evergreen basin; SLV, southern Livermore Valley, NLV, northern Livermore Valley, LaH, La Honda Basin, mCB, southwest margin of Cupertino basin

\* Variable from 0.6 to 1.1 with supershear over central 1/3 of fault.

### Figure Captions for Electronic Supplement

Figure 1 . Pseudo-spectral acceleration (PSA) (in units of g, 5% damped) for a **M6.8** scenario earthquake on the Calaveras CN fault segment with epicenter near Danville (H) (scenario 1). *Left* column 1-sec period, *center* column 3-sec period, *right* column 5-sec period. *Top* row northeast component, *bottom* row northwest component.

Figure 2 . PSA (in units of g, 5% damped) for a **M6.8** scenario on the Calaveras CN fault segment with southeast-to-northwest propagating rupture (scenario 2). *Left* column 1-sec period, *center* column 3-sec period, *right* column 5-sec period. *Top* row northeast component, *bottom* row northwest component.

Figure 3. PSA (in units of g, 5% damped) for a **M6.7** scenario with northwestpropagating rupture on the South Hayward fault (scenario 8). *Left* column 1-sec period, *center* column 3-sec period, *right* column 5-sec period. *Top* row northeast component, *bottom* row northwest component.

Figure 4. PSA (in units of g, 5% damped) for a **M6.7** scenario on the South Hayward fault with epicenter near Oakland (H) (scenario 9). *Left* column 1-sec period, *center* column 3-sec period, *right* column 5-sec period. *Top* row northeast component, *bottom* row northwest component.

Figure 5. PSA (in units of g, 5% damped) for a **M6.7** scenario on the Monte Vista/Shannon with epicenter on the southeast end of the fault (H) (scenario 14). *Left* column 1-sec period, *center* column 3-sec period, *right* column 5-sec period. *Top* row northeast component, *bottom* row northwest component.

Figure 6. PSA (in units of g, 5% damped) for a **M7.2** scenario on the Peninsula segment of the San Andreas fault with a northwest-to-southeast rupture (scenario 15). *Left* column 1-sec period, *center* column 3-sec period, *right* column 5-sec period. *Top* row northeast component, *bottom* row northwest component.

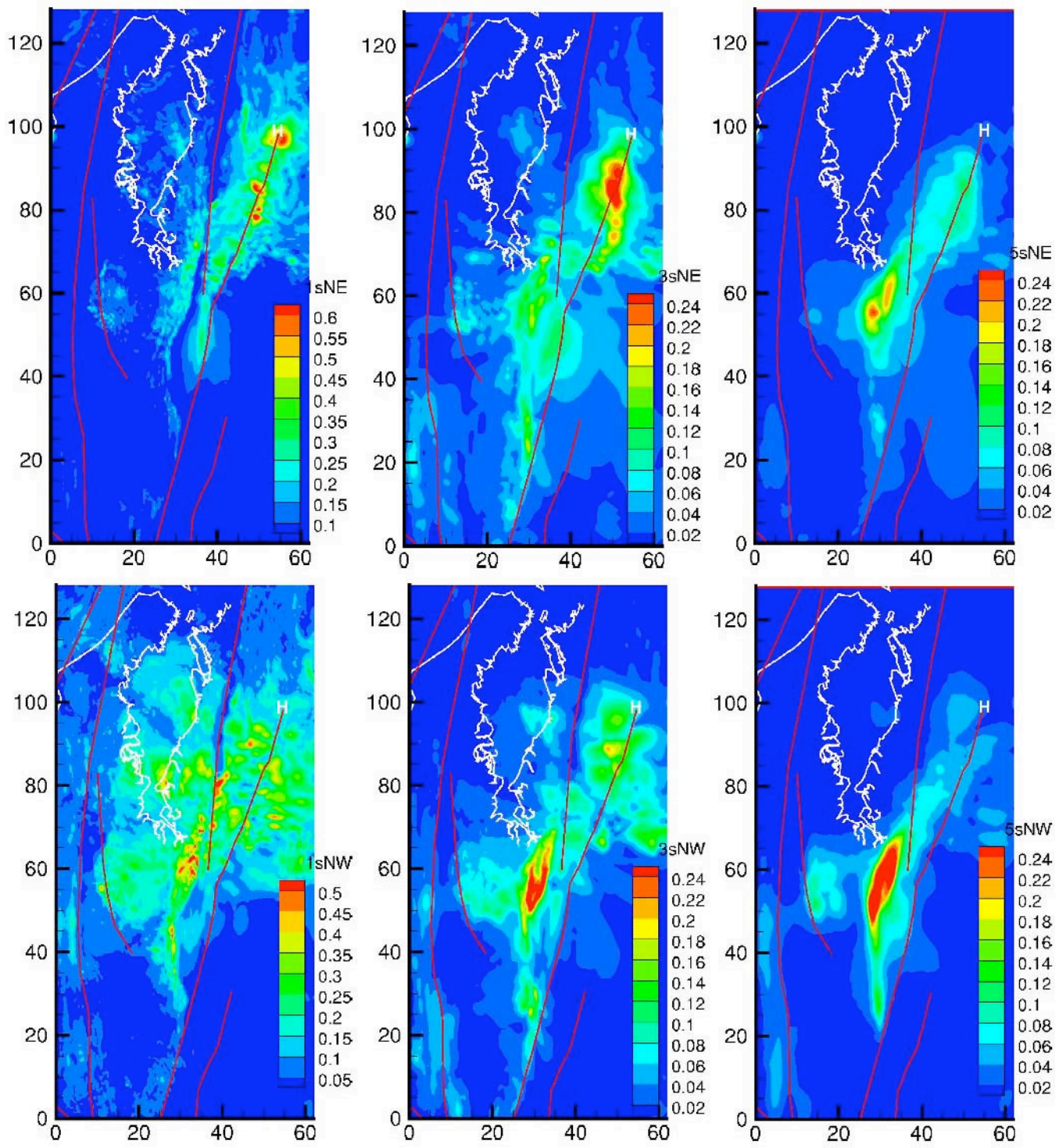


Figure 1

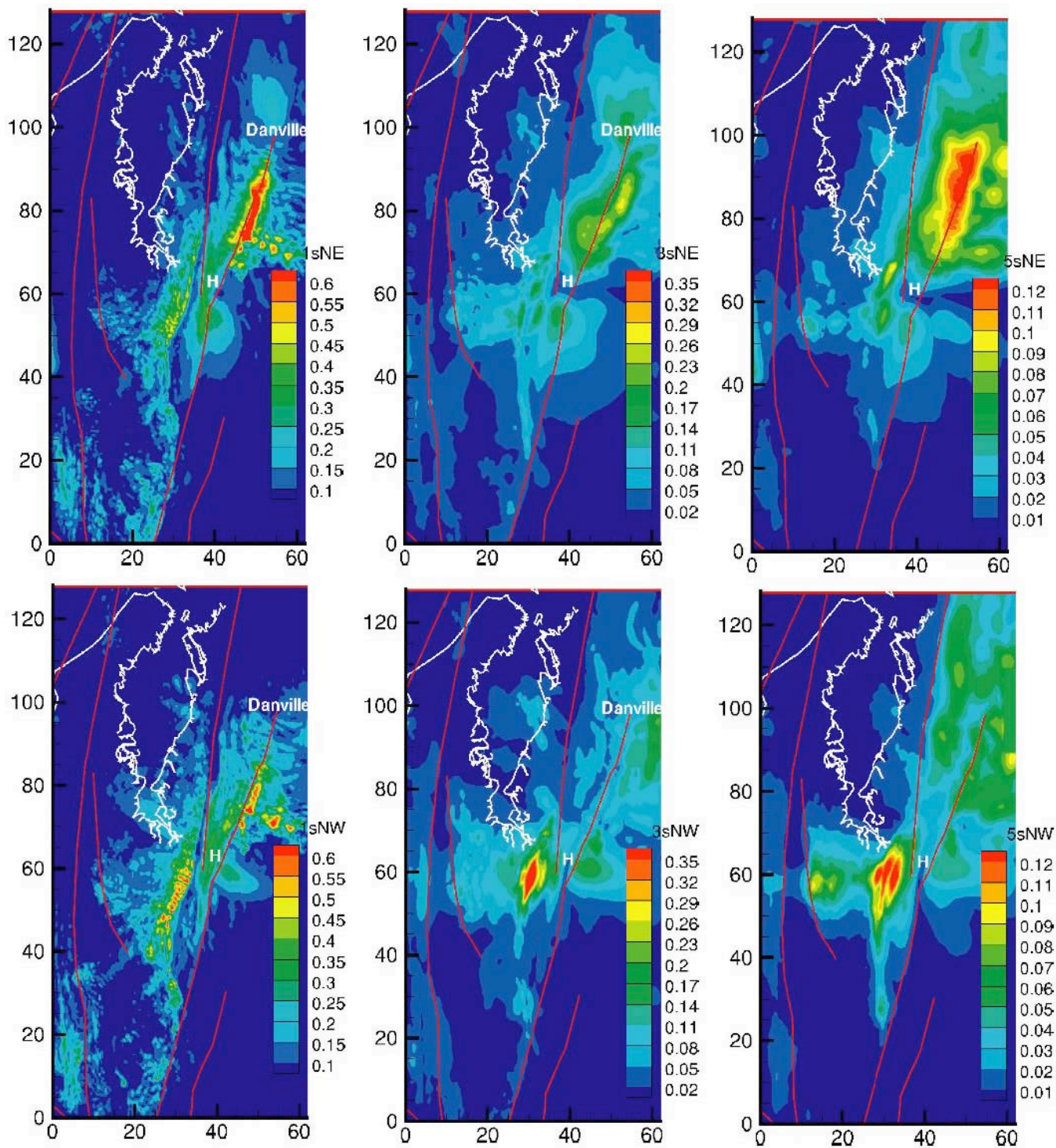


Figure 2

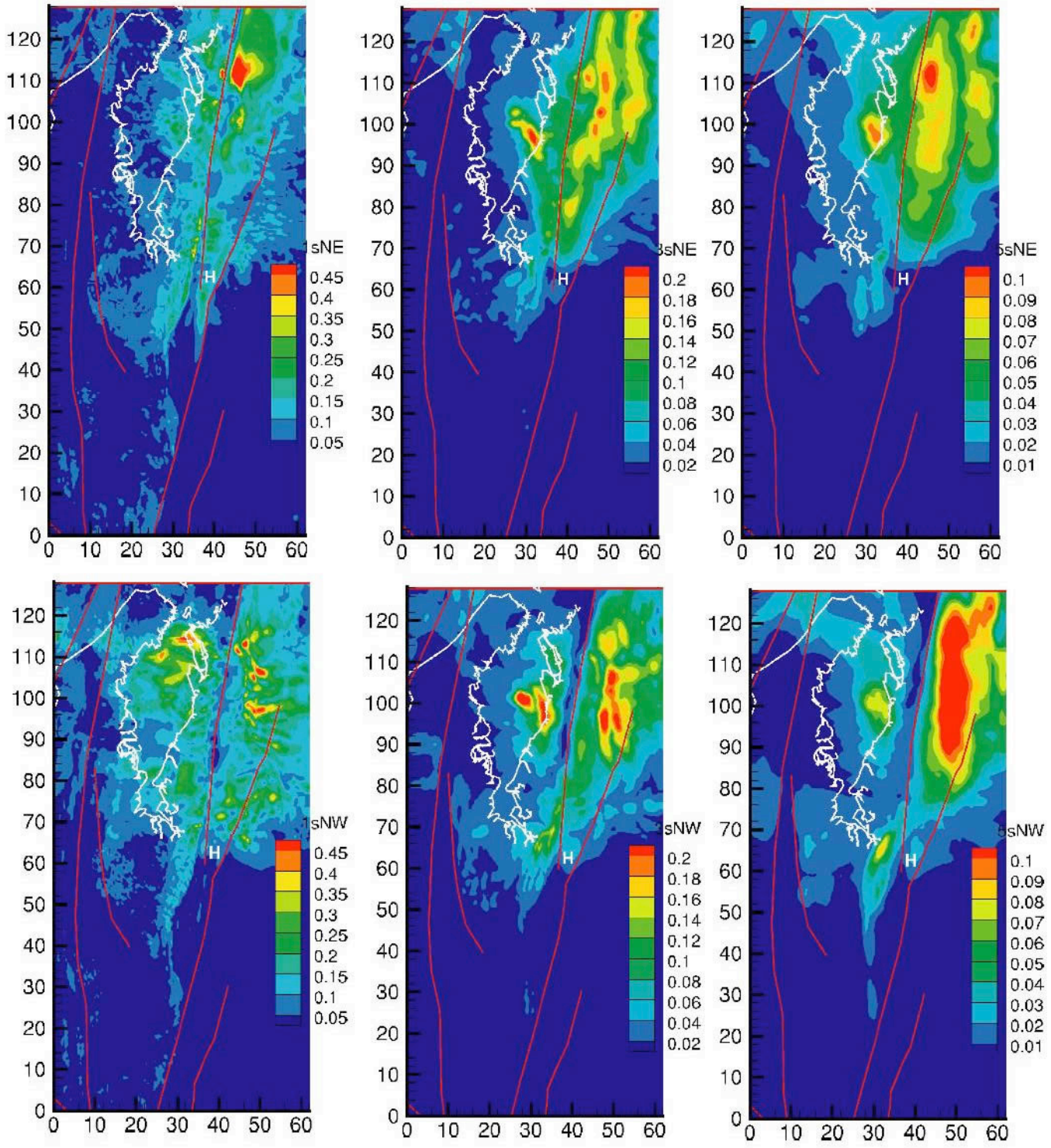


Figure 3

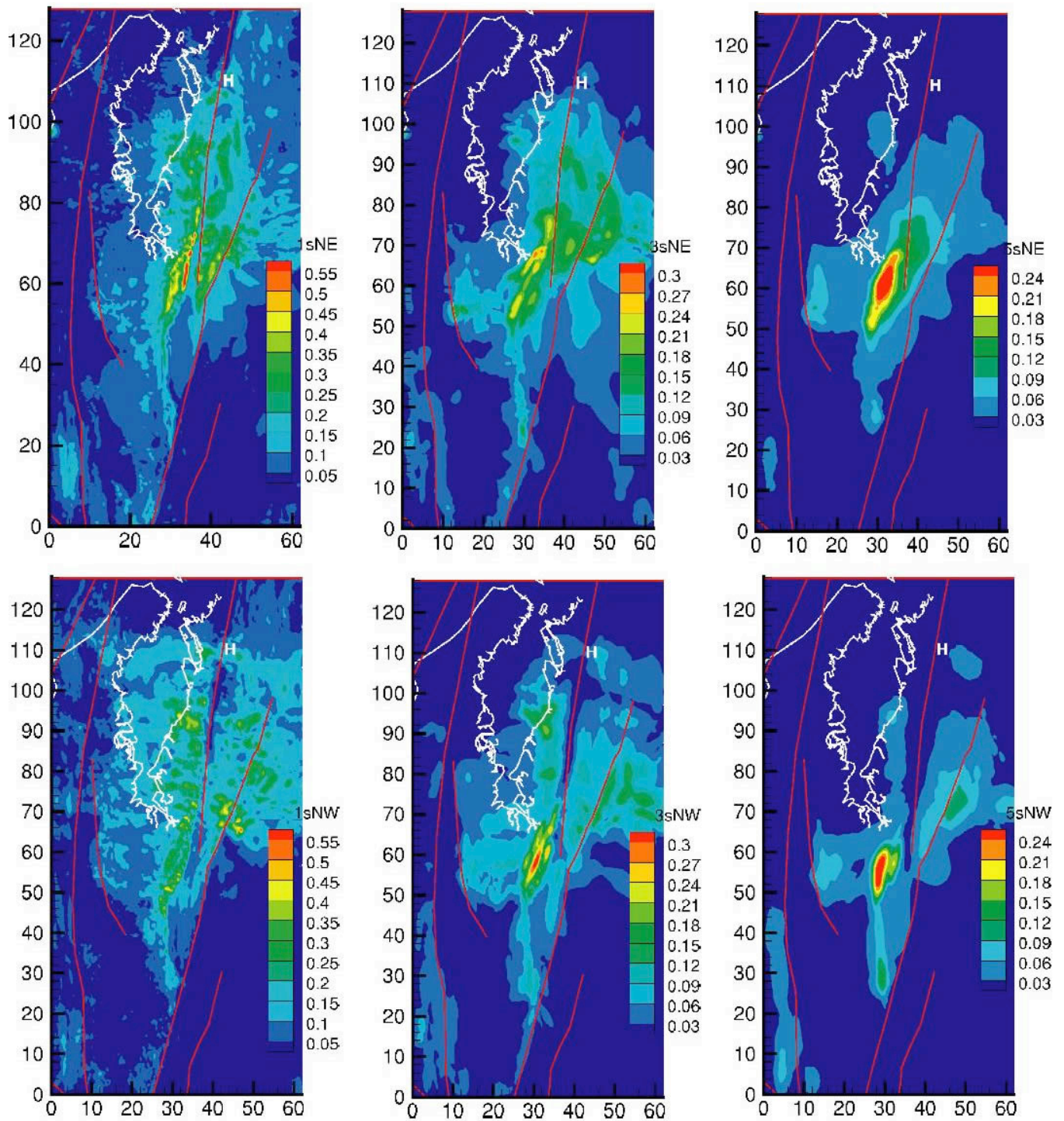


Figure 4

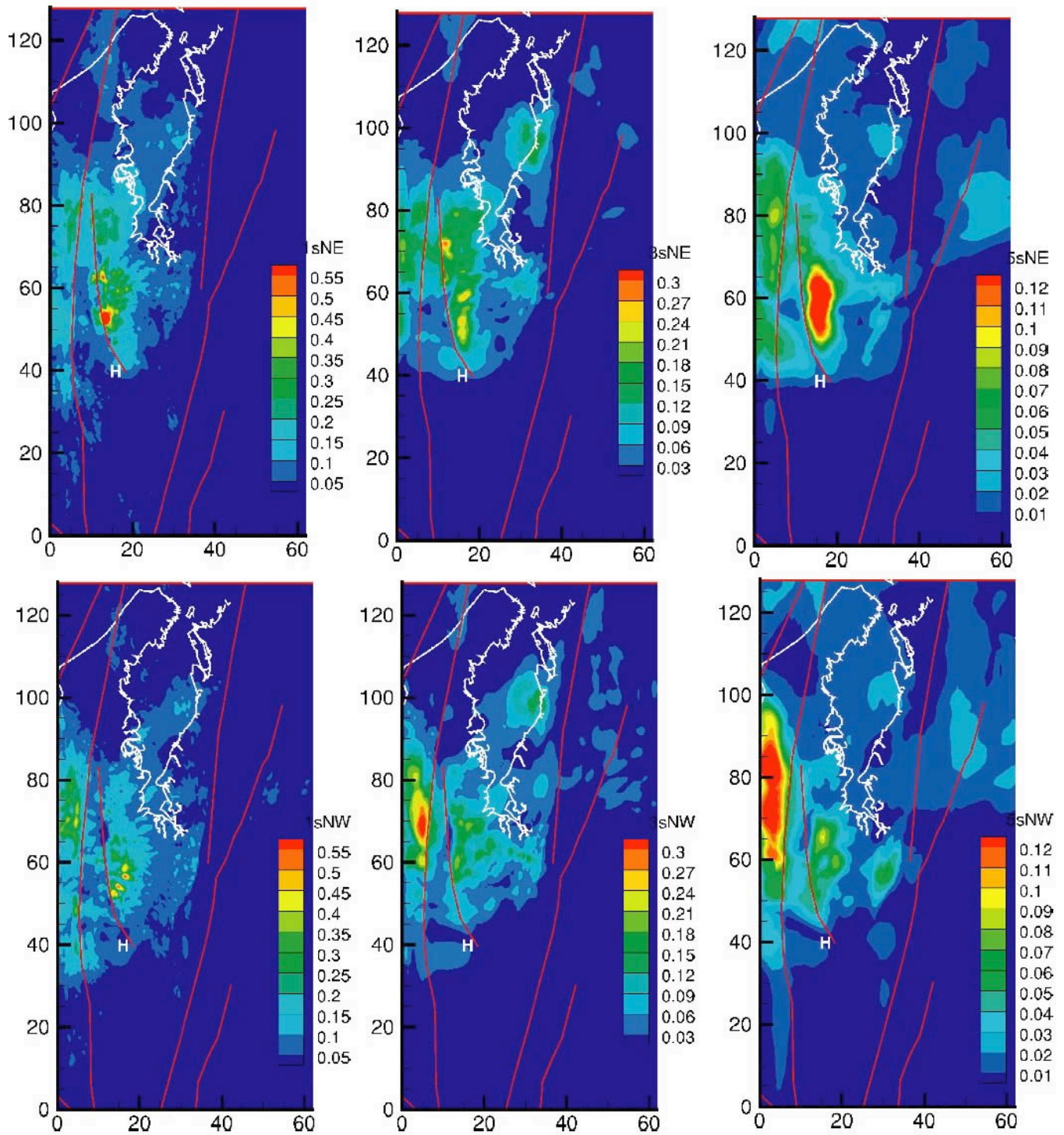


Figure 5

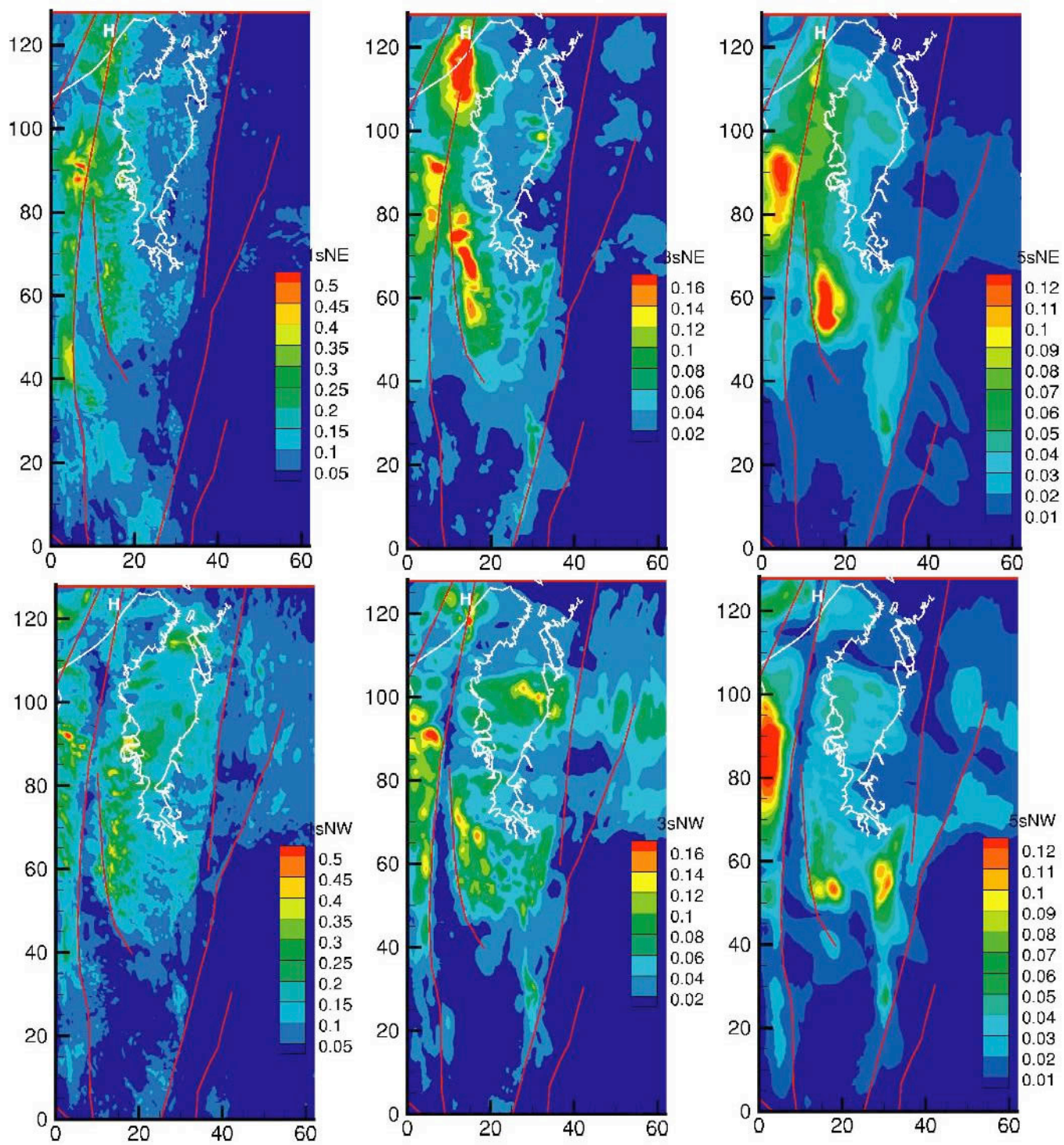


Figure 6