2nd Broadband Ground Motion Simulation Workshop (May 26, 2006)
2006 Annual Report

Robert Graves, URS Corporation

The main objectives of this workshop are:

1) Provide and document verification of the capabilities of the simulation methods using well-controlled numerical experiments.
2) Document the methodologies that are currently available to SCEC scientists for use in simulating broadband ground motion time histories for earthquakes in Southern California.
3) Identify goals that need to be addressed in the short term (end of SCEC2) and the longer term (during SCEC3) within the broadband modeling community.

The participants in the workshop are listed below.

Name	email
Ralph Archuleta	ralph@crustal.ucsb.edu
Jacobo Bielak	jbielak@andrew.cmu.edu
Robert Graves	robert_graves@urscorp.com
Tom Jordan	tjordan@usc.edu
Daniel Lavallee	daniel@crustal.ucsb.edu
Phil Maechling	maechlin@usc.edu
Kim Olsen	kbolsen@sciences.sdsu.edu
Arben Pitarka	arben_pitarka@urscorp.com
Jan Schmedes	jasch@crustal.ucsb.edu

Verification Exercise

To accomplish the stated goals, a set of verification exercises was specified. The exercises were designed to facilitate comparison of the simulation methodologies, while retaining sufficient realism to build confidence in the abilities of the techniques to model actual earthquakes. The objectives of the verification exercises are to determine how the different simulation methodologies compare with one another when given the same input parameterization. This will provide a benchmark on the performance of the methodologies, as well as guidance on the nature and causes of differences in the response produced by different approaches.

Three modeling groups participated in the exercises:

UCSB: Ralph Archuleta, Jan Schmedes, Peng-Cheng Liu
URS: Robert Graves, Arben Pitarka
SDSU/ETH: Kim Olsen, Martin Mai

The verification exercises were designed by Robert Graves, reviewed and approved by all participants, and then distributed to all groups. Each group performed their simulations independently and then submitted the results back to URS Pasadena. All post-processing of the results and preparation of figures was performed by Robert Graves.

Analysis of Verification Exercises

Since the velocity structure used in the exercise is relatively simple and the sites are close to the fault, the wave propagation effects are fairly straightforward. Source effects, such as rupture directivity, are expected to be significant because of the fault geometry and rupture characteristics. Near fault forward rupture directivity occurs in the along strike rupture direction for strike-slip faults and results from a combination of rupture propagation and deterministic radiation pattern effects. It is manifest as a strong pulse of motion on the fault normal component of ground velocity. Observationally, sites experiencing strong rupture directivity effects have fault normal ground motions that are 2 or 3 times larger than the corresponding fault parallel motions at frequencies less than about 1 Hz. At higher frequencies (f > 2 Hz), differences in the fault normal and fault parallel motions due to the effects of rupture directivity are not generally observed.

Overall, the trends seen in the comparison of the simulation results were quite similar for the three fault cases (case 01, case 02, and case 03). This indicates that the methodologies handled the rupture prescription in a consistent manner regardless of faulting depth. This is an encouraging result because it means that the simulation methodologies themselves do not contain any implicit depth-dependent characteristics (even though the rupture prescription itself does have depth-dependent characteristics).

Low Frequency Results (< 1 Hz)

At frequencies below 1 Hz, the agreement among the three simulation groups is very good. While this result is expected, it confirms that 1) the deterministic portions of the methodologies perform as they should and 2) the SRF rupture model format provides an efficient mechanism to define and exchange complex kinematic rupture descriptions. Both of these points represent fundamental accomplishments of the verification exercise.

The most significant ground motion effect seen at the lower frequencies is rupture directivity. All of the simulation groups model this effect very well. The near fault sites show a strong polarization of motion onto the fault normal component of ground velocity (090). The ground velocity at these sites is contained in a strong pulse of motion, with the fault normal amplitude being about 3 (or greater) times larger than the fault parallel amplitude.

At very low frequencies (near DC), there are some differences among the simulation groups. These are evident in the comparisons of the displacement time histories and are typically associated with the final displacement level (static). In some cases, the difference reflects a difference in the level of residual displacement as predicted by the various models, and in other cases, there appears to be some long period drift in the computed time history. The difference in final displacement level (static) may result from differences in the subfault (or point source) sampling or the use of FK Green's functions (UCSB) compared to the use of 3D FD (URS, SDSU/ETH). The long period drift may result from filtering that is applied to the low- and high-frequency time histories when they are combined. It is expected that these differences can be reconciled in the future and do not reflect an inherent flaw in any of the methodologies.

High Frequency Results (> 1 Hz)

At high frequencies, the simulation results show some similarities, as well as some notable differences. This was expected since the methodologies at high frequencies employ different approaches in source representation, path propagation and scattering effects. The items below highlight the main differences in the high-frequency results for the three simulation models.

1) High frequency ground motion level:

URS has generally higher PGA (high frequency) amplitudes than UCSB and SDSU/ETH.

2) High frequency ground motion variability:

UCSB and SDSU/ETH show more site-to-site variability in PGA (high frequency) than URS.

3) High frequency ground motion duration:

In general, all three methods produce similar shaking durations at high frequencies. No systematic trends are apparent in the results.

4) High frequency radiation pattern effects:

4.1) UCSB shows strong systematic trends in component polarization at high frequencies:
- fault normal significantly larger than fault parallel for sites within 15 km of the fault
- fault parallel larger than fault normal at more distant sites, which are generally broadside to the fault

4.2) SDSU/ETH shows strong systematic trends in component polarization with fault normal significantly larger than fault parallel for sites within 15 km of the fault.

4.3) URS shows similar amplitude and duration for both fault normal and fault parallel components at all distances.

Summary and Recommendations

Overall, the agreement among the methods is very good at frequencies lower than 1 Hz. At frequencies above 1 Hz, the methods show some similarity in overall amplitude and duration levels, but also exhibit systematic differences that appear to be related to the manner in which radiation pattern is incorporated at the higher frequencies.

The preliminary analysis of the results suggests the following:

- The UCSB methodology includes deterministic radiation pattern effects for both low and high frequencies. This gives rise to the large fault normal to fault parallel ratio across all frequencies for sites within 15 km, as seen in. Additionally, for the more distant sites that are broadside to the fault (s18, s19, s20), this radiation pattern effect also gives rise to the large fault parallel to fault normal ratio that is seen at both low- and high frequencies.
- The URS methodology transitions from a deterministic radiation pattern at low frequencies (< 1 Hz) to a stochastically averaged radiation pattern at high frequencies (> 1 Hz). This gives rise to the transition from a large fault normal to fault parallel ratio at lower frequencies to a value near unity at high frequencies.
- The SDSU/ETH methodology appears to include deterministic radiation pattern effects for both low and high frequencies. This gives rise to the large fault normal to fault parallel ratio across all frequencies for sites within 15 km. At the more distant sites, the fault normal and fault parallel amplitudes become more similar, which may be due to the washing-out of the radiation pattern by the effects of the stochastic scattering operators employed in this methodology.

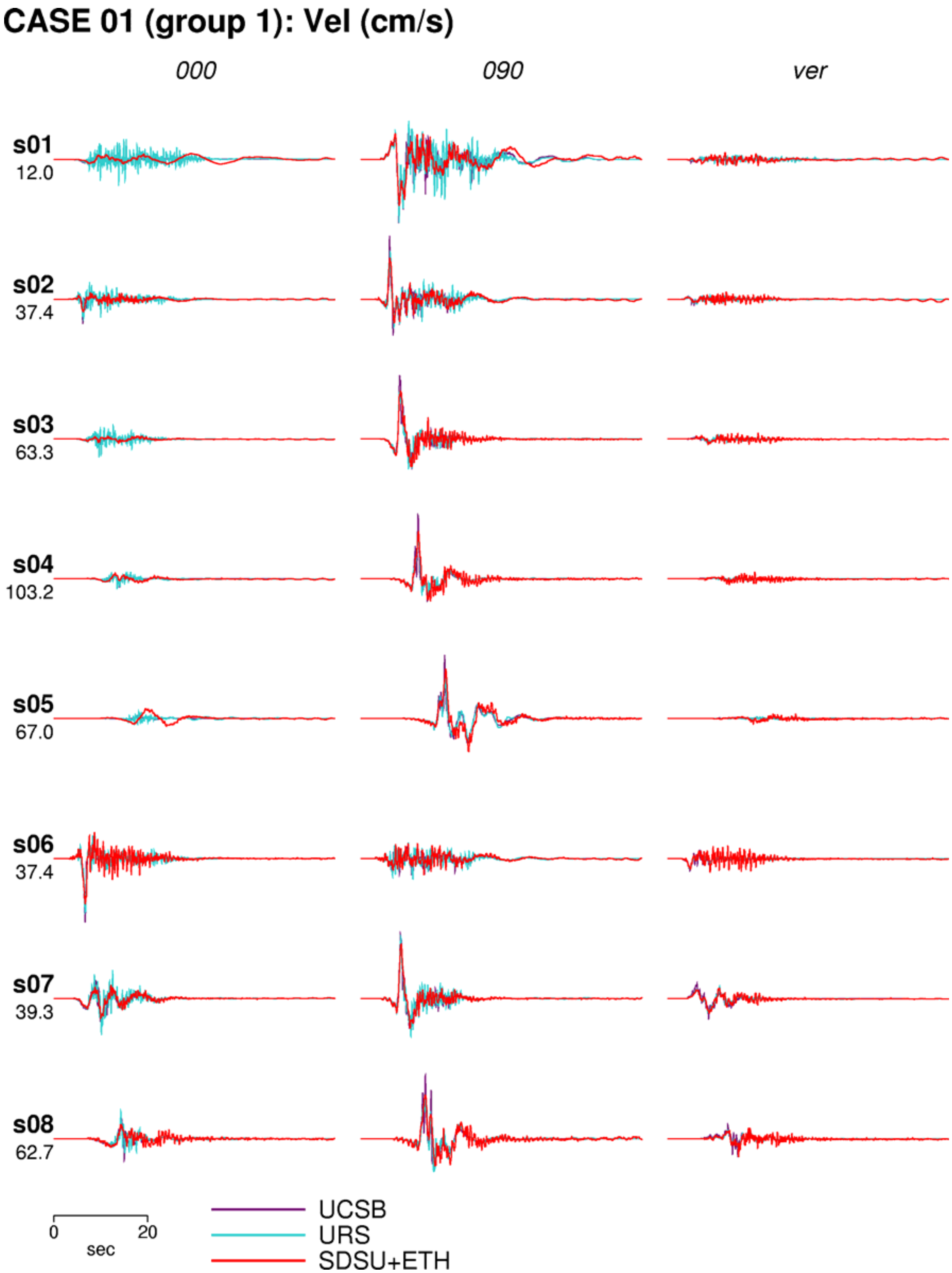

Figure 1: Three component velocity time histories for stations s01 – s08.

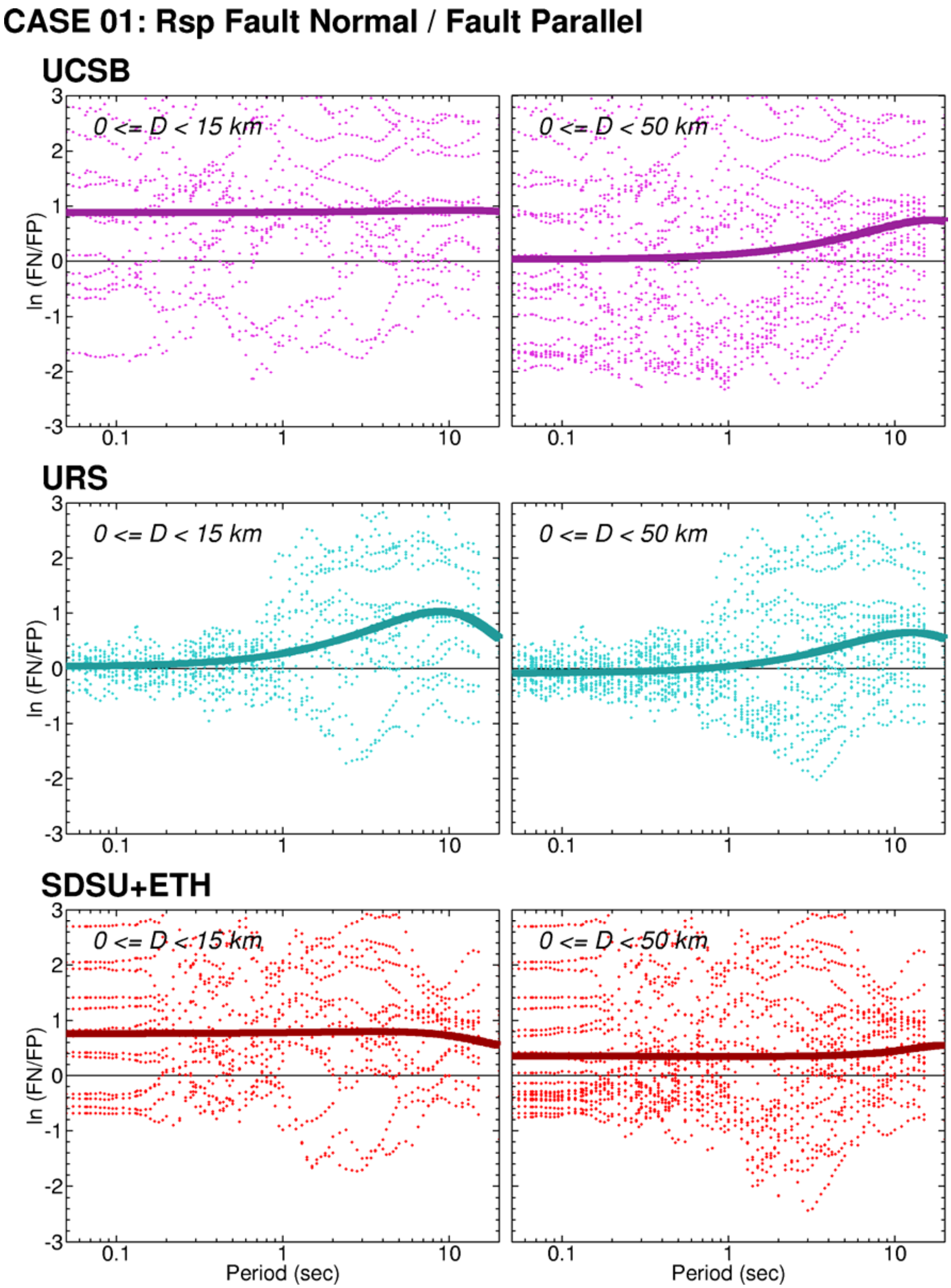

Figure 2: Ratio of fault normal to fault parallel response spectra as a function of period. Stations within 15 km are shown on left, right panels show all stations. Individual symbols (dots) indicate FN/FP value at a given station for a given period. The heavy line on each panel is a curve fit to the individual data.