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STAIRWAY TO MESO-SCALE (~100 M) STRESS HETEROGENEITY: APPLICATIONS TO NUMERICAL COMPUTATIONS OF EARTHQUAKE RUPTURE PROCESSES

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Participation in workshops sponsored by SCEC during the period from 02/01/2009 to 01/31/2010:

- Dynamic Weakening Mechanisms (Sept. 12-13)
- Source Inversion Validation (Sept. 13)
- 2009 SCEC annual meeting (Sept. 13-15)
- Workshop on Rupture Dynamics Code Validation (Nov. 20)

1 Introduction: Meso-scale modeling of the stress heterogeneity

Computation of earthquake rupture processes requires a description of the input parameters at a length scale of the order of 100m to 500m (referred to as meso-scale lengths in this report). In this research project, we develop a procedure to generate meso-scale variability for stress profiles with an original spatial resolution of ~1 km or larger (that is at macro-scale lengths) typically obtained with kinematic inversion. This method can be used as a substitute to interpolating initial stress distribution derived in kinematic inversions (for brief discussions of the interpolation see among others Day *et al*., 1998; Spudich *et al*., 1998; and Mikumo *et al*., 2003). In this report, we summarize our findings assuming that the stress spatial variability is either distributed according to a Gauss law or a Cauchy law.

2 Theoretical background and rationales.

The procedure is based on the idea that the slip spatial distribution –or the stress spatial distribution derived from the slip spatial distribution (Andrews, 1980)- can be quantified and understood as a random process (Lavallée *et al*., 2006). As far as its statistical properties are under consideration, a slip spatial distribution is “statistically equivalent” to a synthetic random model of the slip spatial distribution (see Lavallée and Archuleta, 2003; see also Schmedes *et al*., (2009, 2010) for examples of synthetic stress spatial distribution).

Now consider two synthetic stress profiles generated with the random model discussed in Lavallée and Archuleta (2003). The two stress profiles are characterized by the same probability law and the same set of parameters. The two profiles have the same length L but differ by their spatial resolutions. The low-resolution profile τ_{LR} has a spatial resolution $\Delta L = L/n$ while the high-resolution profile τ_{HR} has a spatial resolution $\Delta l = L/m$ where $m > 0$ and $n > 0$ are even integer numbers with $m > n$ and thus $\Delta L > \Delta l$. (For simplicity, we only discuss the case where m and n are even numbers.) In the Fourier domain, the (discrete) Fourier transform of τ_{LR} is defined for a set of discrete wavenumber values in the interval $\left[0, 2\pi \times (n-1)\right]$ while the (discrete) Fourier transform of τ_{HR} is defined for a set of discrete wave number values in the larger interval $\left[0, 2\pi \times (m-1)\right]$. A high-resolution approximation of τ_{LR} can be generated by performing the following computation. In the Fourier domain, the (additional) Fourier transform of τ_{HR} (corresponding to the high resolution wavenumber values) can be grafted (at the proper location in the wavenumber interval) to the Fourier transform of τ_{LR}. After grafting the additional Fourier coefficients, the Fourier inverse is computed and properly normalized (the normalization only involves a function of the parameters m and n, and it will depend on the definition used when computing the discrete Fourier transform) to get an approximation of τ_{LR} at a resolution Δl.

The procedure can be directly applied to the computed slip (or stress) spatial distribution from a kinematic inversion at a given macro-scale length ΔL. First the parameters of the random model of the slip spatial distribution are computed (see Lavallée *et al*., 2006). Then a synthetic slip spatial distribution is computed to the desired meso-scale length Δl. The procedure outlined in the previous paragraph is computed.

In the following sections, we discuss examples of the procedure for proxies of synthetic stress profiles. (That is the proxies only differ by multiplicative and additive constants from the synthetic stress spatial distribution illustrated in Schmedes *et al*., (2009, 2010)). The spatial resolution is defined for an arbitrary spatial unit.

3 Modeling down scale heterogeneity: The Gauss probability law

The two profiles computed in this section are based on the random model discussed in Lavallée *et al*. (2006) for a Gauss probability law with the mean $\mu = 0$ and $\sigma = 1$ (see Figure 3.1). The parameter $\nu = 2$ controls the power law attenuation of the spectrum proportional to $k^{-\nu}$ where k is the wavenumber in the Fourier domain (see Andrews, 1980). The low-resolution profile has a resolution $\Delta L = 1$ while the high-resolution profile has a resolution $\Delta l = \Delta L/5$.

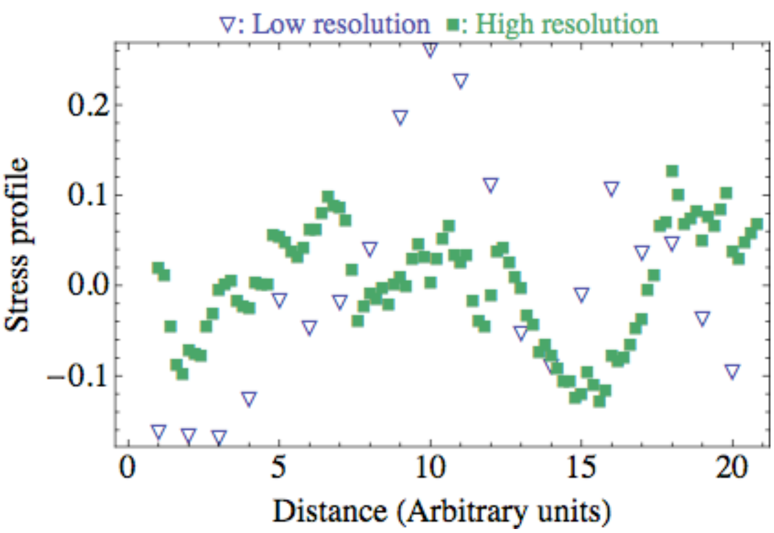

Figure 3.1: Stress profiles with different resolutions.

The low-resolution stress profile is illustrated in Figure 3.2 with the low-resolution stress profile modified according to the procedure discussed in Section 2 to include high-resolution heterogeneity (grafted from the high resolution proxy illustrated in Figure 3.1). In Figure 3.3, the spectra of the low-resolution stress profile, the high-resolution stress profile and low-resolution stress profile modified to include high-resolution heterogeneity are illustrated.

The low-resolution profile is also computed to a resolution $\Delta l = \Delta L/5$ using a linear interpolation scheme (Figure 3.4). In Figure 3.5, the spectrum of the interpolated profile is compared to the spectrum of low-resolution stress profile modified to include high-resolution heterogeneity.

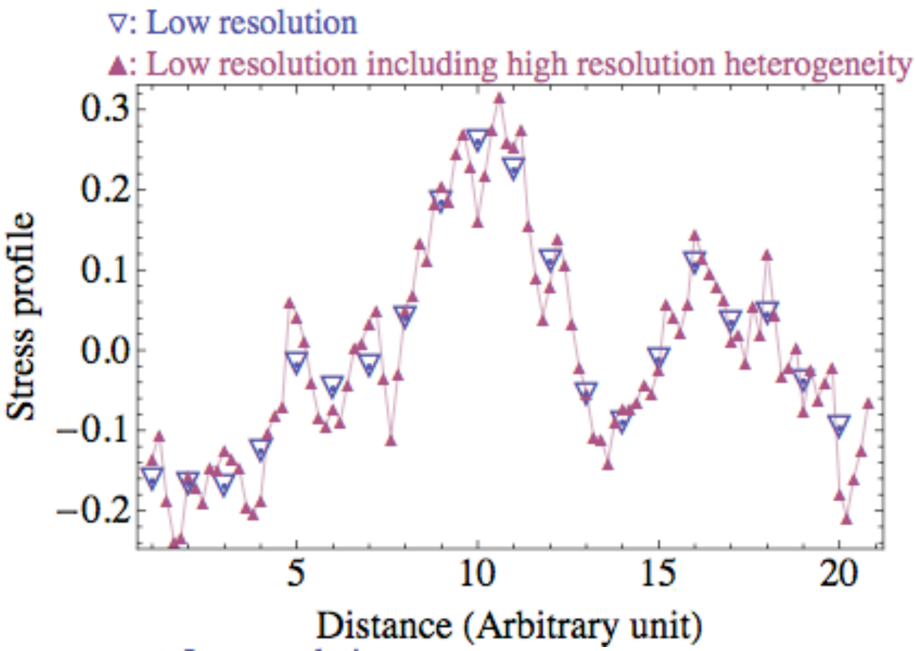

Figure 3.2: Illustration of the low-resolution stress profile modified to include high-resolution. Note that the high-resolution variability (▲) is controlled by the same random process that defines the low-resolution stress profile (▽).

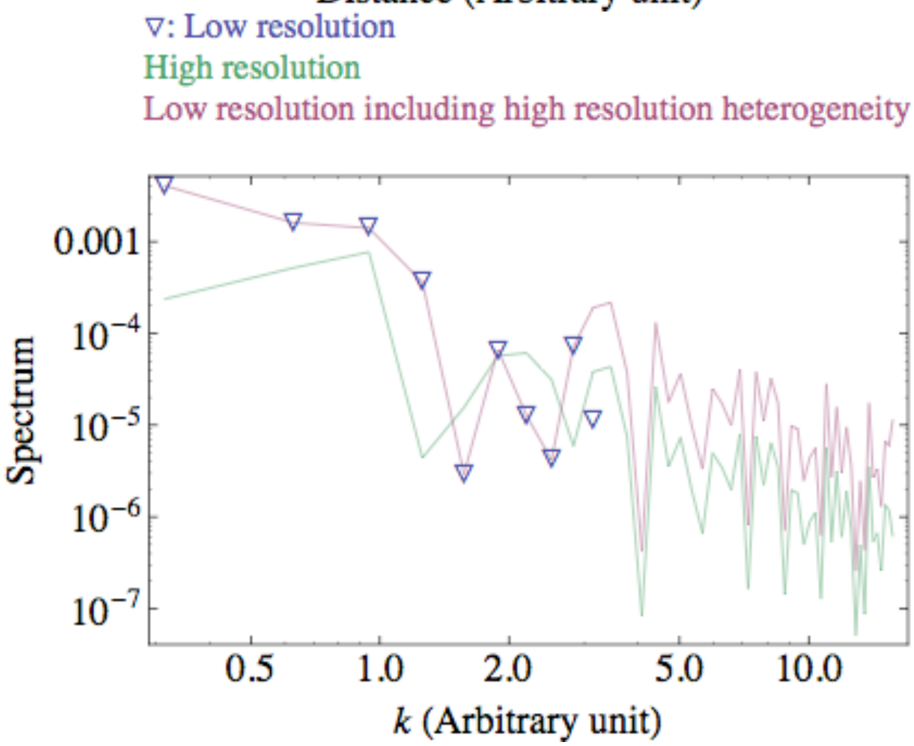

Figure 3.3: Spectrum curves of the low-resolution stress profile, the high-resolution stress profile and the low-resolution stress profile modified to include high-resolution heterogeneity.

4 Modeling down scale heterogeneity: The Cauchy probability law

The two profiles computed in this section are based on the random model discussed in Lavallée *et al*. (2006) for a Cauchy probability law with the location parameter $\mu = 0$ and the scale parameter $\gamma = 1$. The parameter $\nu = 2$ controls the power law attenuation of the spectrum proportional to $k^{-\nu}$. The low-resolution profile has a resolution $\Delta L = 1$ while the high-resolution profile has a resolution $\Delta l = \Delta L/5$.

The low-resolution stress profile is illustrated in Figure 4.1 with the low-resolution stress profile modified according to the procedure discussed in Section 2 to include high-resolution heterogeneity. The low-resolution profile is also computed to a resolution $\Delta l = \Delta L/5$ using a linear interpolation scheme. In Figure 4.2, the spectrum of the interpolated profile is compared to the spectrum of the low-resolution stress profile modified to include high-resolution heterogeneity.

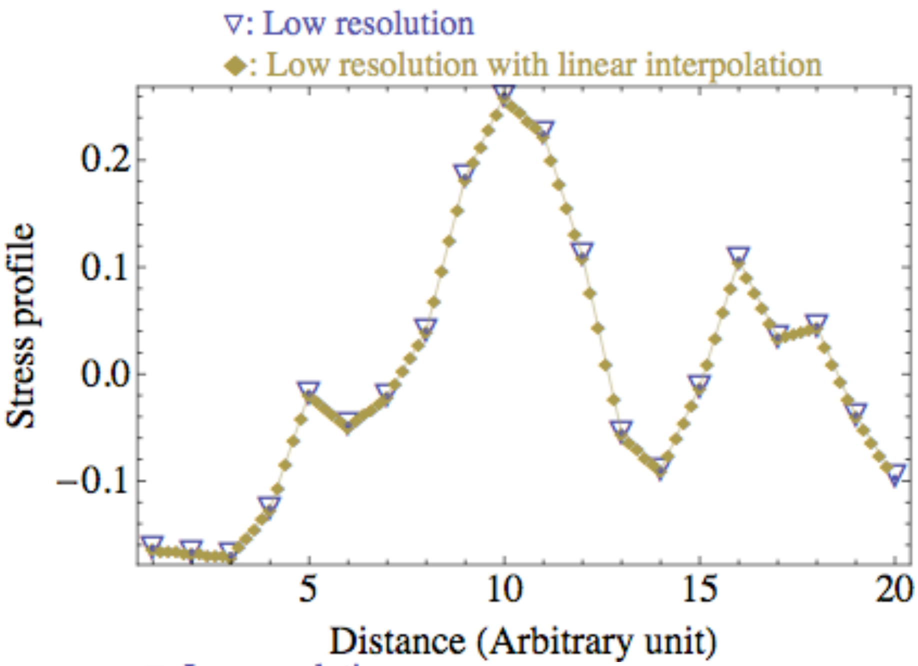

Figure 3.4: Curve of the low-resolution stress profile modified to include high-resolution using a linear interpolation scheme. Note that there is no irregular variability –as in Figure 3.1- for resolution smaller than $\Delta L = 1$.

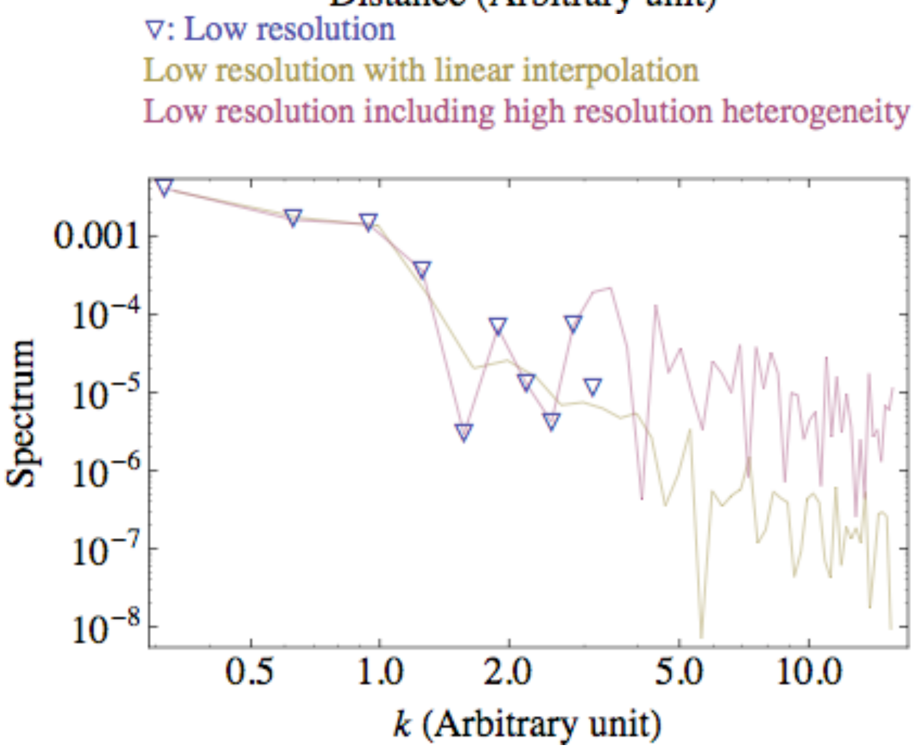

Figure 3.5: Spectrum curves of the low-resolution stress profile, the low-resolution stress profile modified to include high-resolution heterogeneity and the low-resolution interpolated to higher resolution. Attenuation of the spectrum curve for the interpolated low-resolution profile is significantly different from the two other spectrum curves (on this question see also Lavallée and Archuleta, 2003).

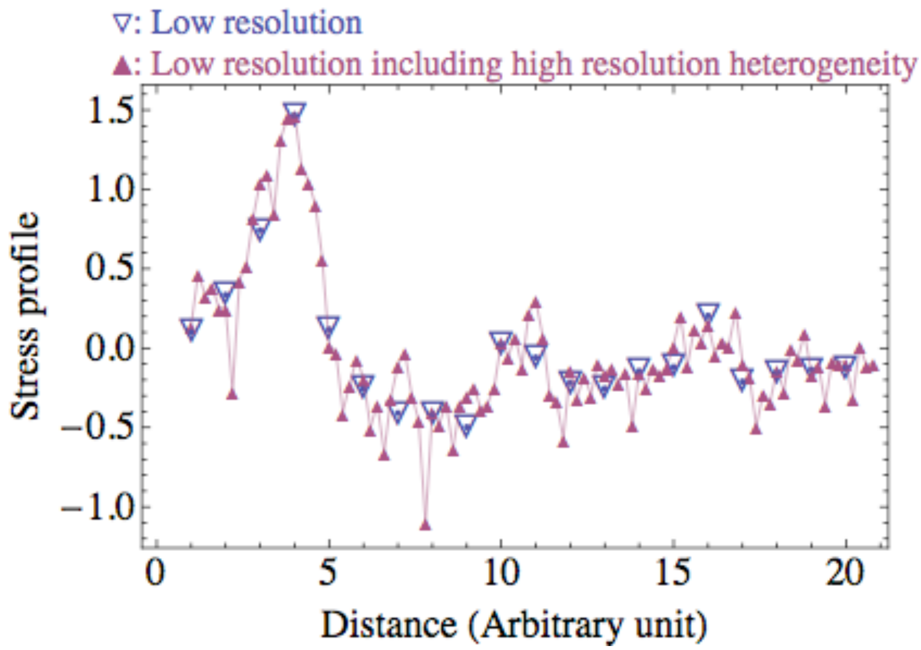

Figure 4.1: Same as Figure 3.2 but for a stress profile generated with amplitude values distributed according to a Cauchy law.

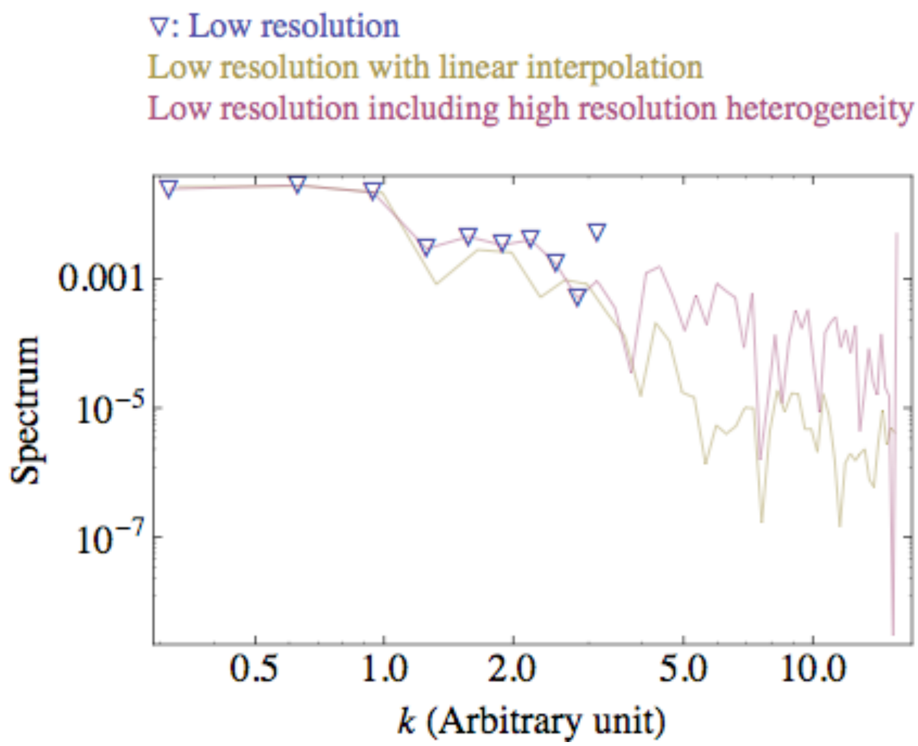

Figure 4.2: Same as Figure 3.5 but for a stress profile generated with amplitude values distributed according to a Cauchy law.

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