



Wave propagation and subsurface velocity structure at the Virgo gravitational wave detector (Italy)

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The performances and sensitivity of gravitational wave (GW) detectors are significantly affected by the seismic environment. In particular, the seismic displacements and density fluctuations of the ground due to seismic-wave propagation introduce noise in the detector output signal; this noise is referred to as gravity-gradient noise, or Newtonian Noise (NN). The development of effective strategies for mitigating the effects of NN requires, therefore, a thorough assessment of seismic wavefields and medium properties at and around the GW detector. In this work, we investigate wave propagation and the subsurface velocity structure at the Virgo GW detector (Italy), using data from a temporary, 50-element array of vertical seismometers. In particular, we analyze the recordings from the catastrophic Mw=6.2 earthquake which struck Central Italy on August 24, 2016, and six of the following aftershocks. The general kinematic properties of the earthquake wavefields are retrieved from the application of a broad-band, frequency-domain beam-forming technique. This method allows measuring the propagation direction and horizontal slowness of the incoming signal; it is applied to short time windows sliding along the array seismograms, using different subarrays whose aperture was selected in order to match different frequency bands. For the Rayleigh-wave arrivals, velocities range between 0.5 km/s and 5 km/s, suggesting the interference of different wave types and/or multiple propagation modes. For those same time intervals, the propagation directions are scattered throughout a wide angular range, indicating marked propagation effects associated with geological and topographical complexities. These results suggest that deterministic methods are not appropriate for estimating Rayleigh waves phase velocities. By assuming that the gradient of the displacement is constant throughout the array, we then attempt the estimation of ground rotations around an axis parallel to the surface (tilt), which is in turn linearly related to the phase velocity of Rayleigh waves. We calculate the ground tilt over subsequent, narrow frequency bands. Individual frequency intervals are investigated using sub-arrays with aperture specifically tailored to the frequency (wavelength) under examination. From the scaled average of the velocity-to-rotation ratios, we obtain estimates of the Rayleigh-wave phase velocities, which finally allow computing a dispersion relationship. Due to their diffusive nature, earthquake coda waves are ideally suited for the application of Aki's autocorrelation method (SPAC). We use SPAC and a non-linear fitting of correlation functions to

derive the dispersion properties of Rayleigh wave for all the 1225 independent inter-station paths. The array-averaged SPAC dispersion is consistent with that inferred from ground rotations, and with previous estimates from seismic noise analysis. Using both a semi-analytical and perturbational approaches, this averaged dispersion is inverted to obtain a shear wave velocity profile down to ~1000m depth. Finally, we also perform an inversion of the frequency-dependent travel times associated with individual station pairs to obtain 2-D, Rayleigh wave phase velocity maps spanning the 0.5-3Hz frequency interval.