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Observation of far-field Mach waves generated by the 2001 Kokoxili supershear earthquake

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Regional surface wave observations offer a powerful tool for determining source properties of large earthquakes, especially rupture velocity. Supershear ruptures, being faster than surface wave phase velocities, create far-field surface wave Mach cones along which waves from all sections of the fault arrive simultaneously and, over a sufficiently narrow frequency band, in phase. These waves are essentially the Mach waves that have been the focus of ground motion studies in the near-source region. We present the first observation of far-field Mach waves from the major Kokoxili earthquake (Tibet, 2001/11/14, M_w 7.9) and confirm that ground motion amplitudes are indeed enhanced on the Mach cone. Theory predicts that on the Mach cone, bandpassed surface wave seismograms from a large supershear rupture will be identical to those from much smaller events with similar focal mechanisms, with an amplitude ratio equal to the ratio of the seismic moments of the two events. Cross-correlation of 15–25 s Love waves from the Kokoxili event with those from a much smaller (M_w 5) foreshock indicates a high degree of similarity (correlation coefficients ranging from 0.8 to 0.95) in waveforms recorded at stations near the far-field Mach cone. This similarity vanishes away from the Mach cone. These observations provide further evidence for supershear propagation of the Kokoxili rupture, and demonstrate how this simple waveform correlation procedure can be used to identify supershear ruptures. The existence of these Mach waves has also direct implications in terms of seismic hazard assessment. The most important one concerns the spatial location, relative to the fault, of the large amplitude ground motions. For subshear earthquakes, the region directly ahead of the fault in line with the rupture propagation direction will experience the strongest shaking. The directivity pattern for supershear ruptures, at least at regional distances (typically distances of tens to hundreds of kilometres from the fault), is radically different. Instead, the extreme ground motions occur at stations near the Mach cone, which lies at some angle off to the side of the fault.