Supplementary material

S.1 stnParabel raster predictive results

S.1.1 Rockfall test sites

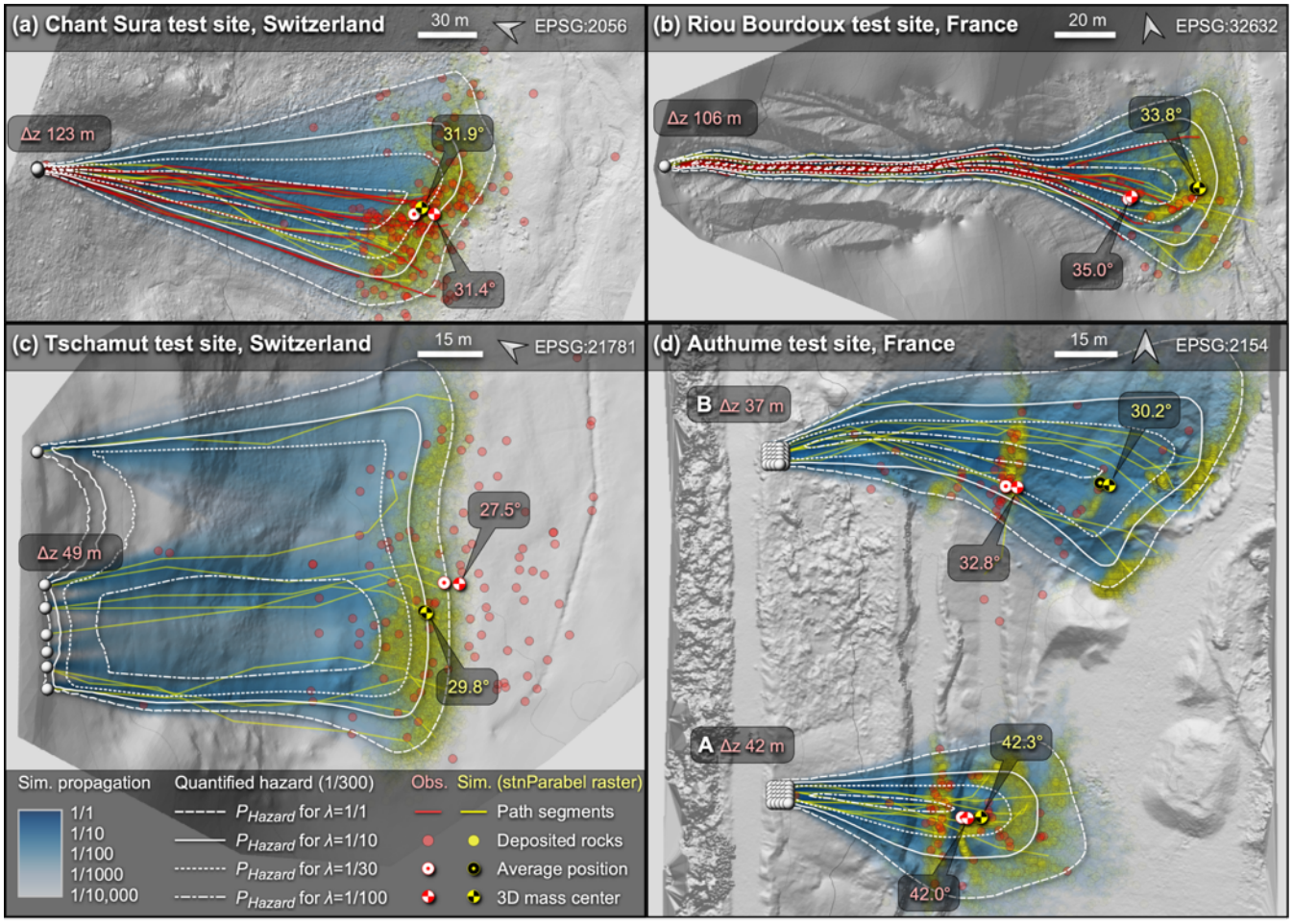

Figure S1: Comparison for the rockfall test sites of the mapped deposited rocks vs. the simulations from stnParabel raster. The observations are shown in red while the simulations are shown in yellow and blue. The deposited rocks are shown with semi-transparent colours so that areas with a high density of overlapping rocks are highlighted with stronger corresponding colours. The average deposited locations per rock fragment and per mass are overlayed with characteristic symbols. A small sample set of trajectories randomly selected for each site is shown with subtle yellow lines to help evaluate the realism of the simulated paths undertaken by the rocks. The simulated propagation ratio of the spatially distributed frequencies evaluated from rockfall paths of width corresponding to their respective rock's d_1 diameter are shown with semi-transparent blue colours to contrast with the overlaying red and yellow colours. White contours show the 1/300 quantitative guiding hazard zonation based on different expected frequency of rock fragments. Low intensities were not filtered out for drawing the guiding contours.

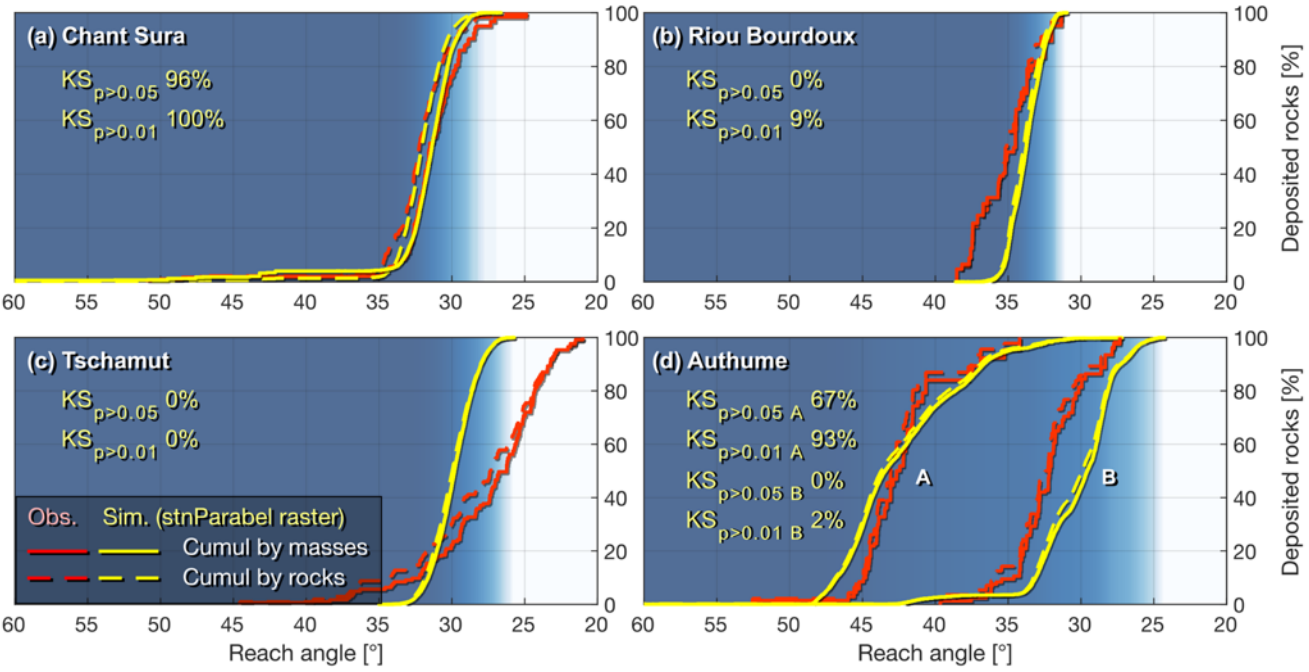

Figure S2: Comparisons of the cumulative distribution of the observed and simulated deposited rock fragments in terms of reach angles (energy line angles from the source to the deposited location). The observations are shown in red and the simulations from stnParabel raster are shown in yellow and blue. Also, for homogeneity across the paper and continuity with (Noël et al., 2022; Noël et al., 2023a; Noël et al., 2023b; Noël and Nordang, 2025), the runout propagation goes from left to right. The reach angle axes are thus inverted since the reach angles usually decrease as the runout distances increase.

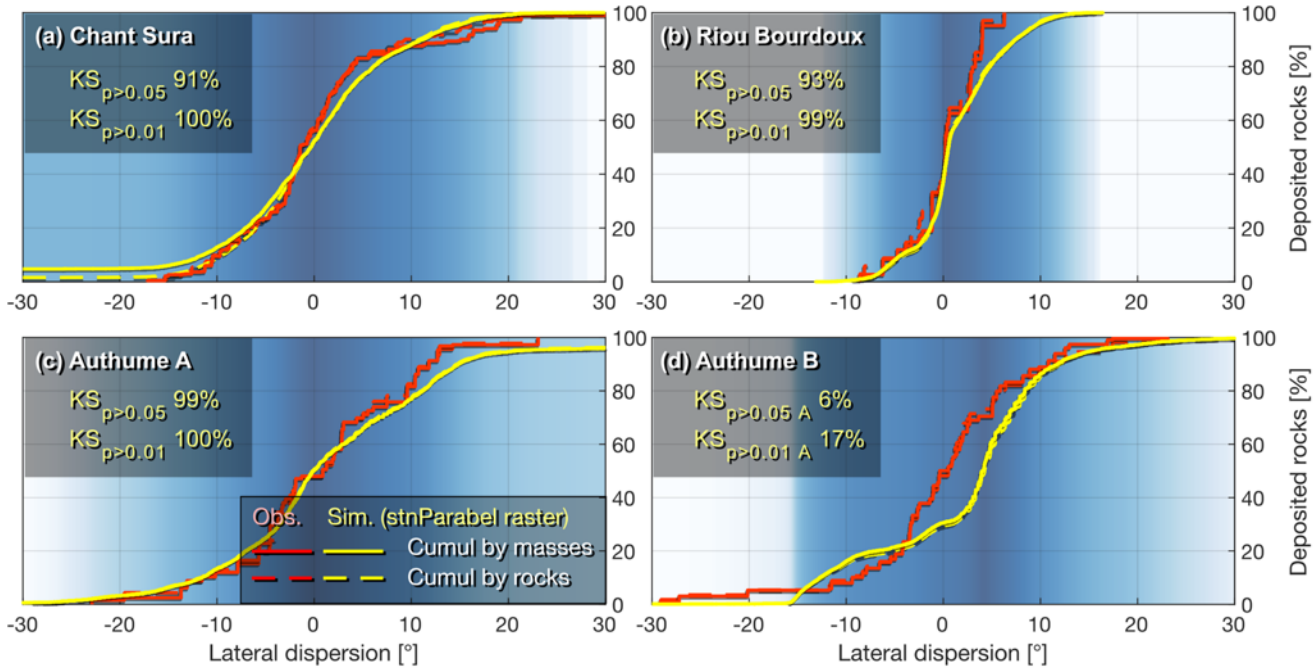

Figure S3: Comparison of the lateral dispersion of the deposited rocks for the test sites, excluding Tschamut since several release points were used. The observations are shown in red and the simulations from stnParabel raster are shown in yellow and blue. The cumulative curves are built by scanning in a counterclockwise direction around each average source point and by setting the zero-degree dispersion at the observed mass centre.

S.1.2 Real rockfall event sites

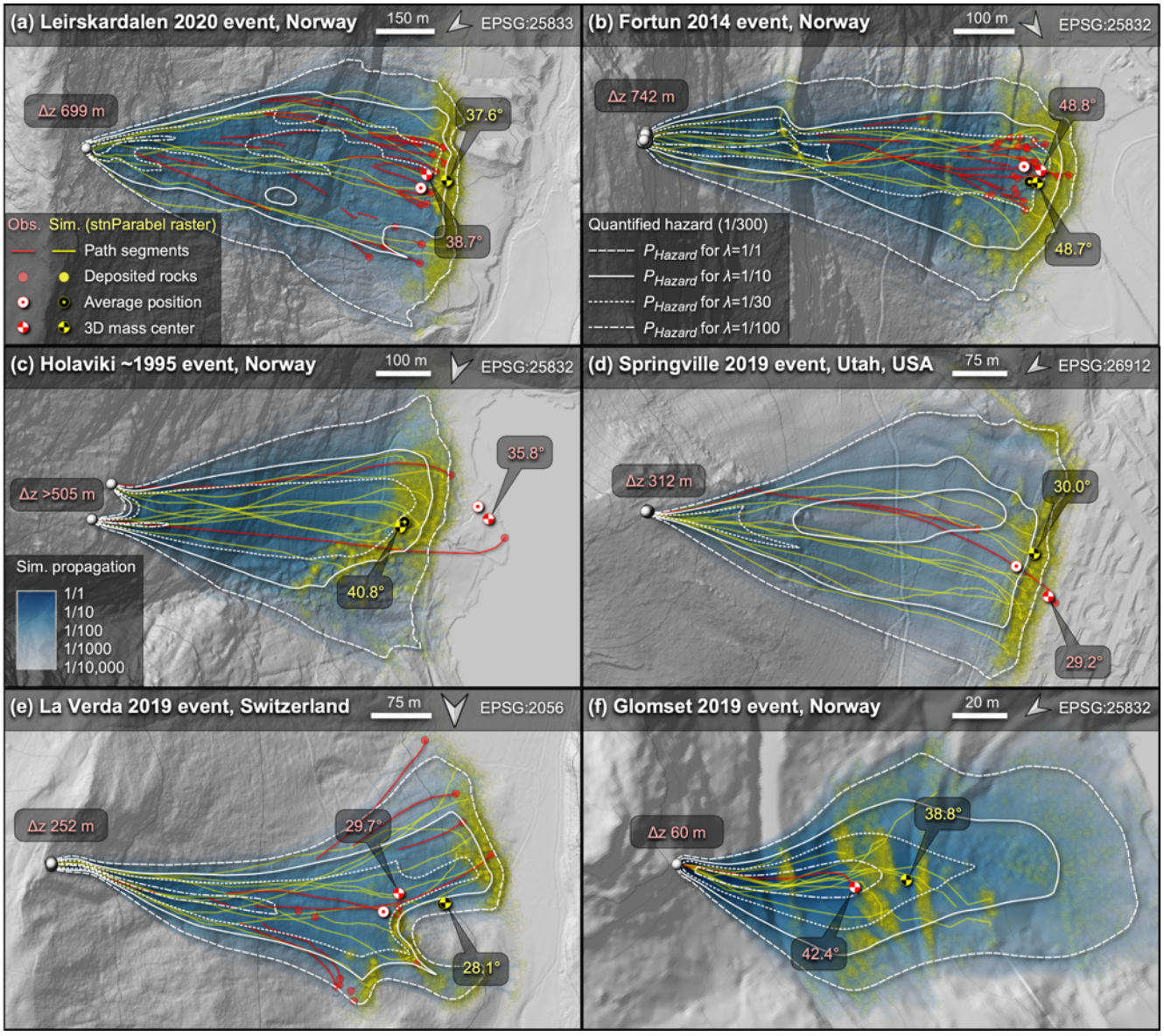

Figure S4: Comparison for the real rockfall event sites of the mapped deposited rocks vs. the simulations from stnParabel raster. The observations are shown in red while the simulations are shown in yellow and blue. The deposited rocks are shown with semi-transparent colours so that areas with a high density of overlapping rocks are highlighted with stronger corresponding colours. The average deposited locations per rock fragment and per mass are overlayed with characteristic symbols. A small sample set of trajectories randomly selected for each site is shown with subtle yellow lines to help evaluate the realism of the simulated paths undertaken by the rocks. The simulated propagation ratio of the spatially distributed frequencies evaluated from rockfall paths of width corresponding to their respective rock's d_1 diameter are shown with semi-transparent blue colours to contrast with the overlaying red and yellow colours. White contours show the 1/300 quantitative guiding hazard zonation based on different expected frequency of rock fragments. Low intensities were not filtered out for drawing the guiding

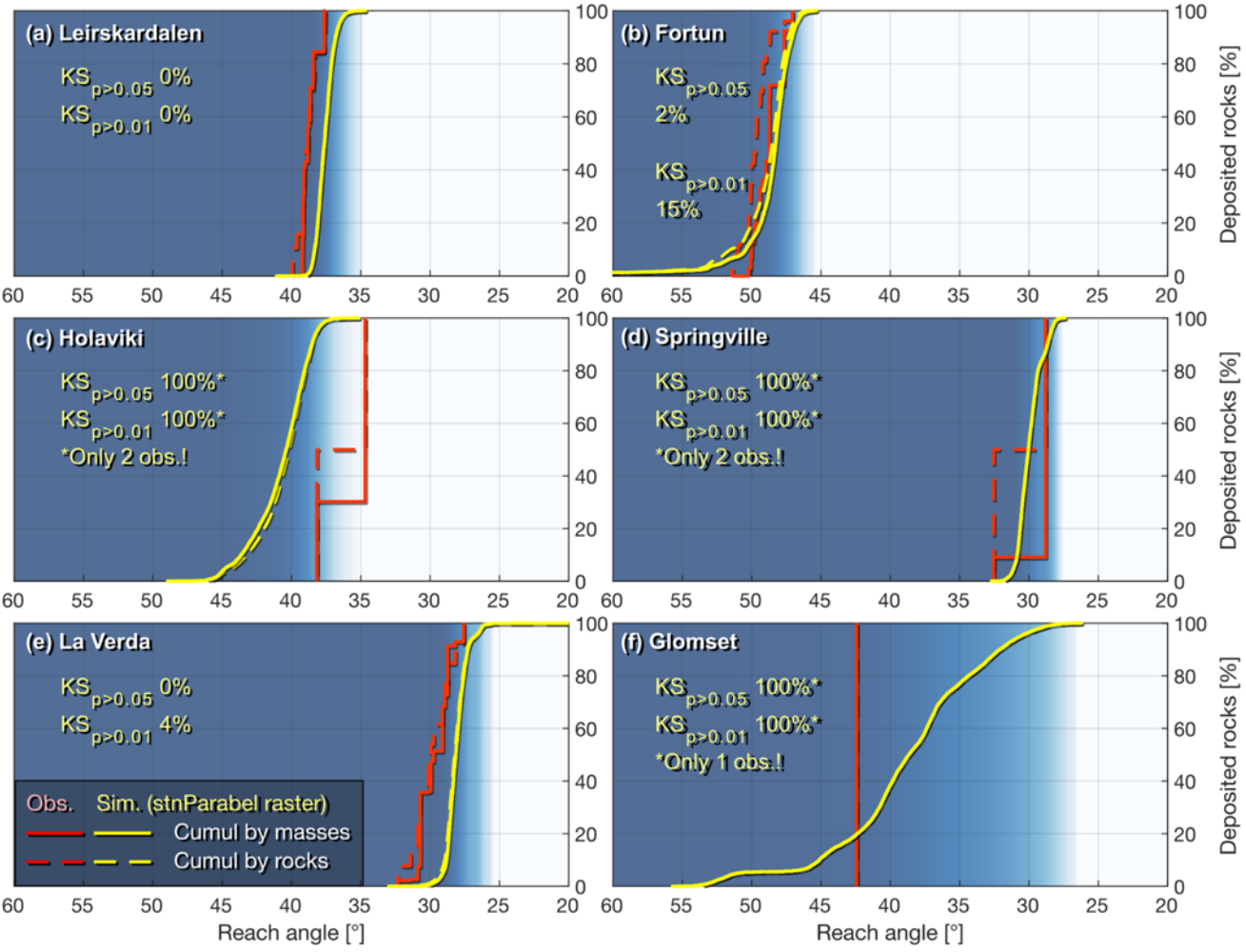

Figure S5: Comparisons of the cumulative distribution of the observed and simulated deposited rock fragments in terms of reach angles (energy line angles from the source to the deposited location). The observations are shown in red, and the simulations from stnParabel raster are shown in yellow and blue. Also, for homogeneity across the paper, the runout propagation goes from left to right. The reach angle axes are thus inverted since the reach angles usually decrease as the runout distances increase.

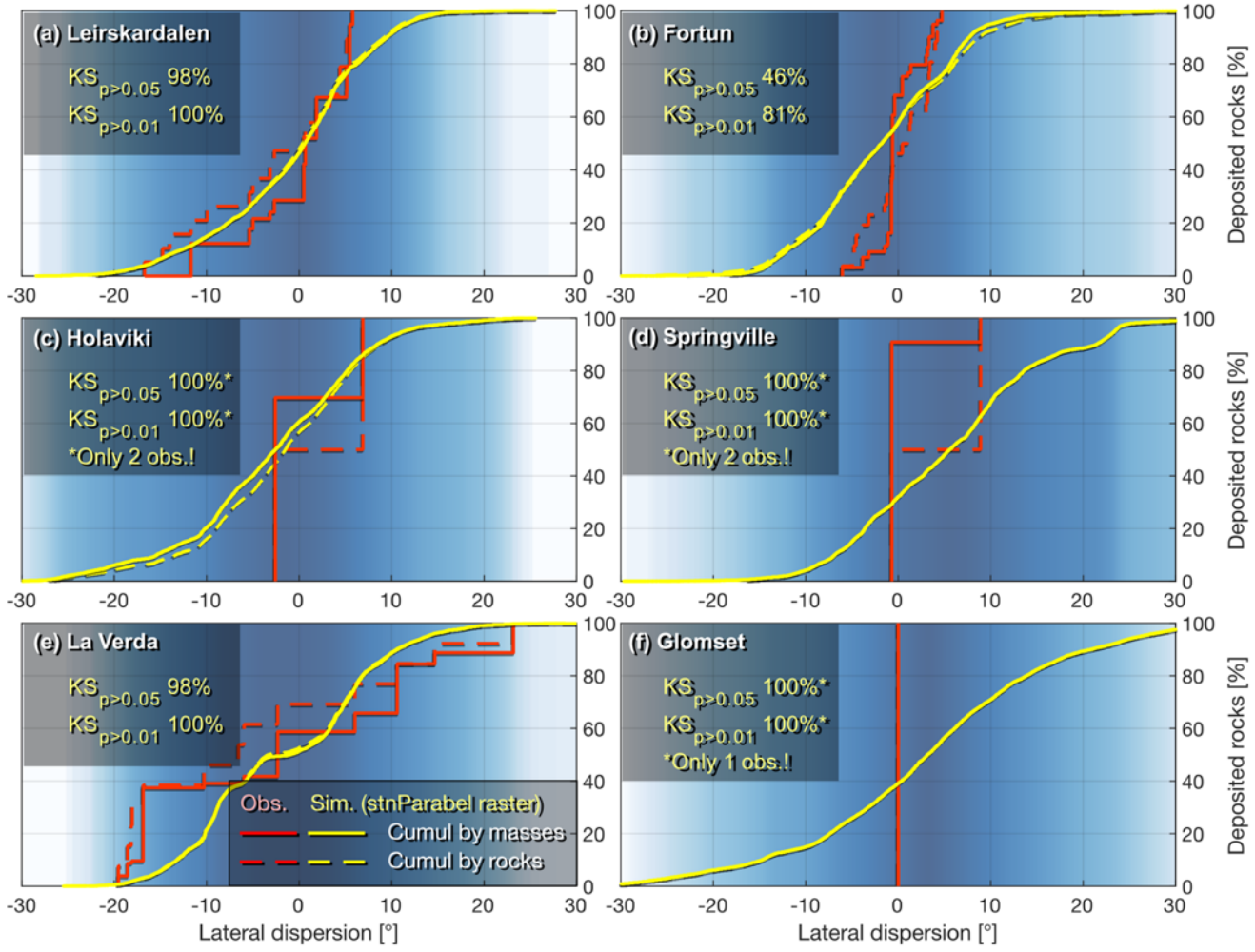

Figure S6: Comparison of the lateral dispersion of the deposited rock fragments of the real rockfall event sites. The observations are shown in red, and the simulations from stnParabel raster are shown in yellow and blue. The cumulative curves are built by scanning in a counterclockwise direction around each average source point and by setting the zero-degree dispersion at the observed mass centre.

S.2 Rockyfor3D predictive results

S.2.1 Rockfall test sites

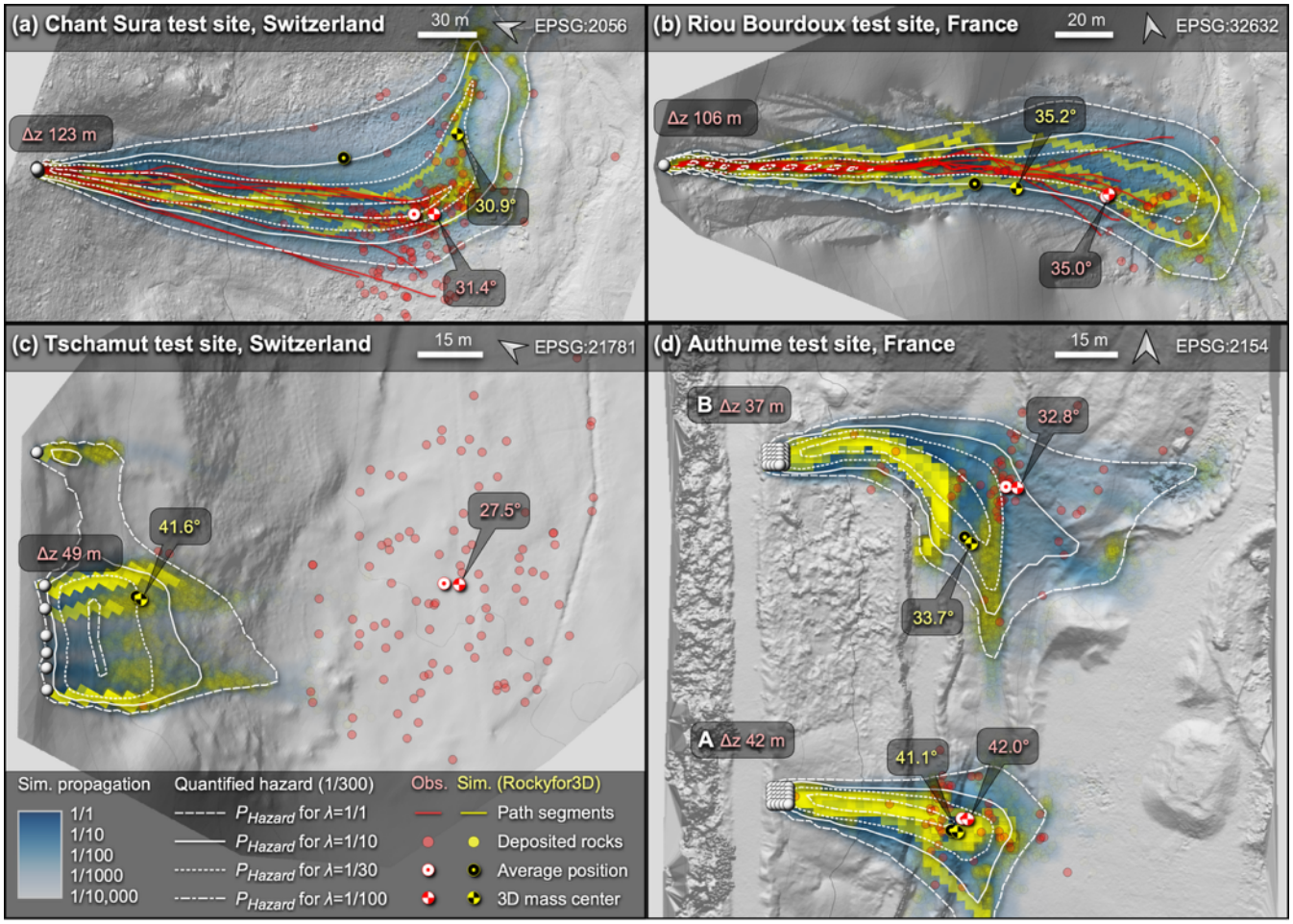

Figure S7: Comparison for the rockfall test sites of the mapped deposited rocks vs. the simulations from Rockyfor3D. The observations are shown in red, while the simulations are shown in yellow and blue. The deposited rocks are shown with semi-transparent colours so that areas with a high density of overlapping rocks are highlighted with stronger corresponding colours. The average deposited locations per rock fragment and per mass are overlayed with characteristic symbols. A small sample set of trajectories randomly selected for each site is shown with subtle yellow lines to help evaluate the realism of the simulated paths undertaken by the rocks. The simulated propagation ratio of the spatially distributed frequencies evaluated from rockfall paths of width corresponding to their respective rock's d_1 diameter are shown with semi-transparent blue colours to contrast with the overlaying red and yellow colours. White contours show the 1/300 quantitative guiding hazard zonation based on different expected frequency of rock fragments. Low intensities were not filtered out for drawing the guiding contours.

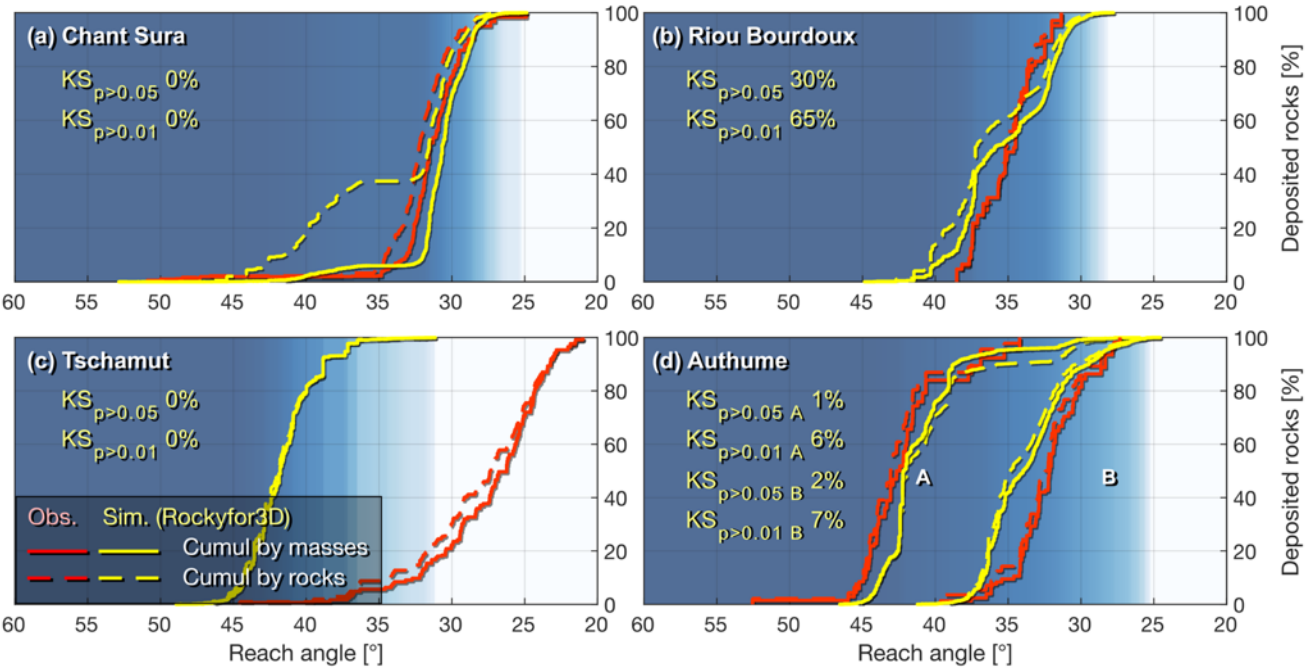

Figure S8: Comparisons of the cumulative distribution of the observed and simulated deposited rock fragments in terms of reach angles (energy line angles from the source to the deposited location). The observations are shown in red, and the simulations from Rockyfor3D are shown in yellow and blue. Also, for homogeneity across the paper and continuity with (Noël et al., 2022; Noël et al., 2023a; Noël et al., 2023b; Noël and Nordang, 2025), the runout propagation goes from left to right. The reach angle axes are thus inverted since the reach angles usually decrease as the runout distances increase.

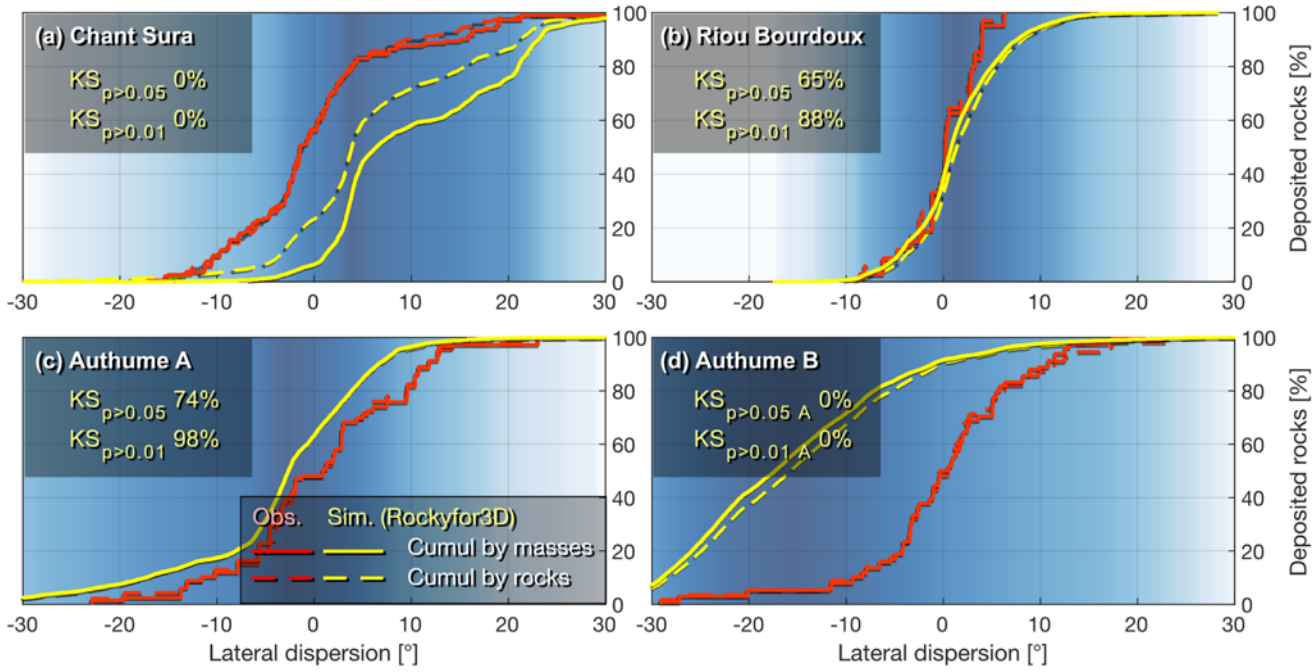

Figure S9: Comparison of the lateral dispersion of the deposited rocks for the test sites, excluding Tschamut since several release points were used. The observations are shown in red, and the simulations from Rockyfor3D are shown in yellow and blue. The cumulative curves are built by scanning in a counterclockwise direction around each average source point and by setting the zero-degree dispersion at the observed mass centre.

S.2.2 Real rockfall event sites

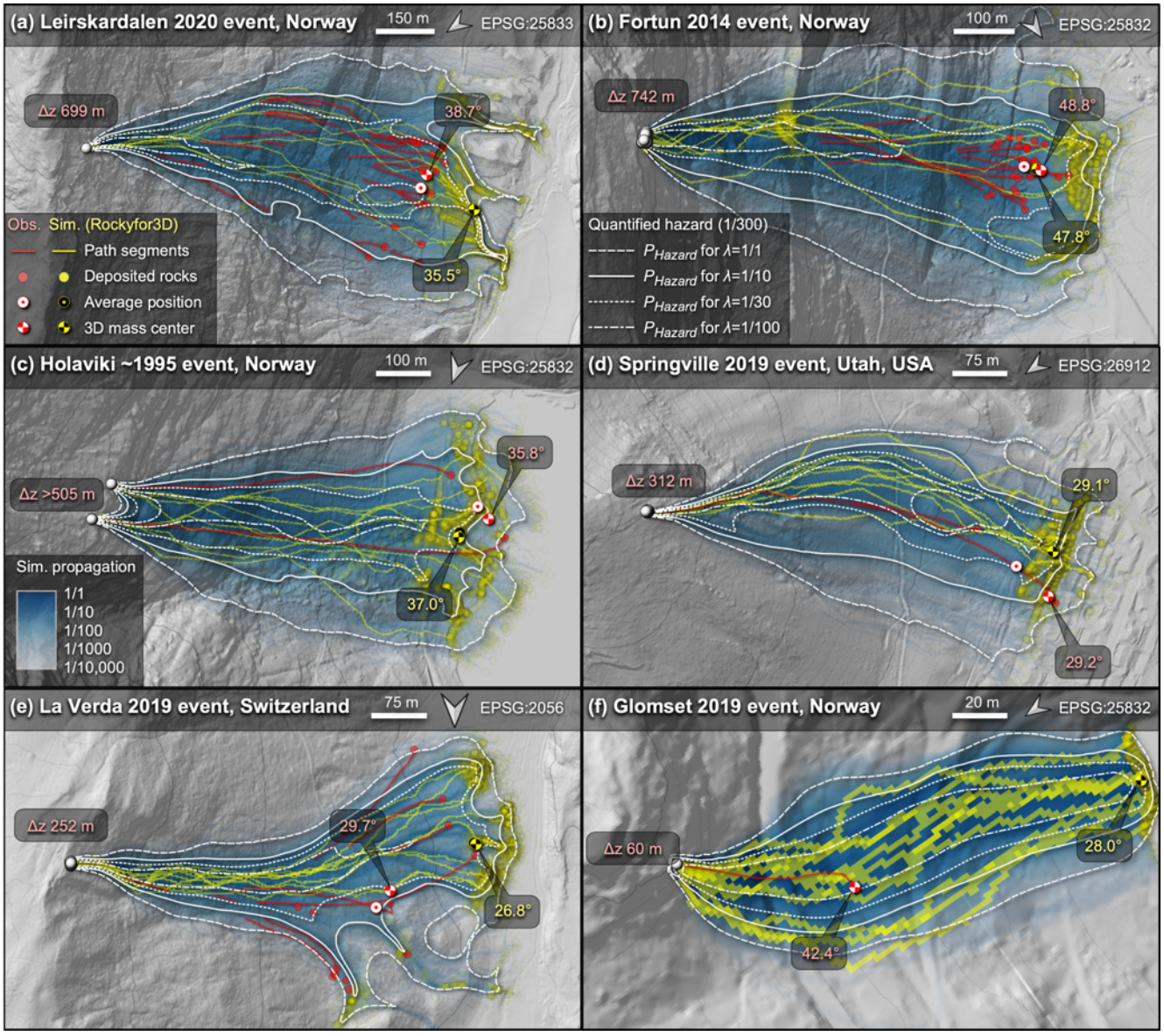

Figure S10: Comparison for the real rockfall event sites of the mapped deposited rocks vs. the simulations from Rockyfor3D. The observations are shown in red, while the simulations are shown in yellow and blue. The deposited rocks are shown with semi-transparent colours so that areas with a high density of overlapping rocks are highlighted with stronger corresponding colours. The average deposited locations per rock fragment and per mass are overlayed with characteristic symbols. A small sample set of trajectories randomly selected for each site is shown with subtle yellow lines to help evaluate the realism of the simulated paths undertaken by the rocks. The simulated propagation ratio of the spatially distributed frequencies evaluated from rockfall paths of width corresponding to their respective rock's d_1 diameter are shown with semi-transparent blue colours to contrast with the overlaying red and yellow colours. White contours show the 1/300 quantitative guiding hazard zonation based on different expected frequency of rock fragments. Low intensities were not filtered out for drawing the guiding contours.

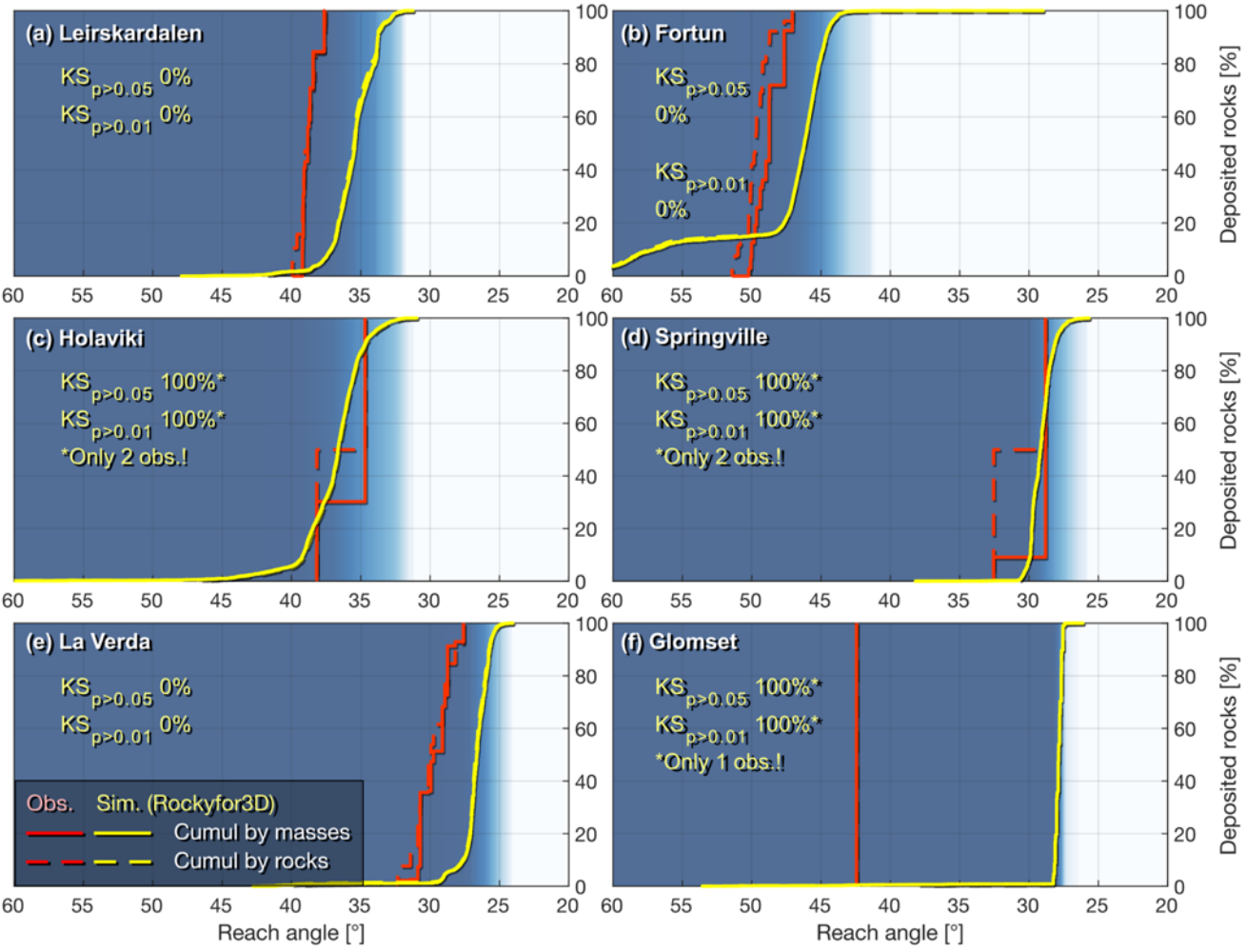

Figure S11: Comparisons of the cumulative distribution of the observed and simulated deposited rock fragments in terms of reach angles (energy line angles from the source to the deposited location). The observations are shown in red, and the simulations from Rockyfor3D are shown in yellow and blue. Also, for homogeneity across the paper, the runout propagation goes from left to right. The reach angle axes are thus inverted since the reach angles usually decrease as the runout distances

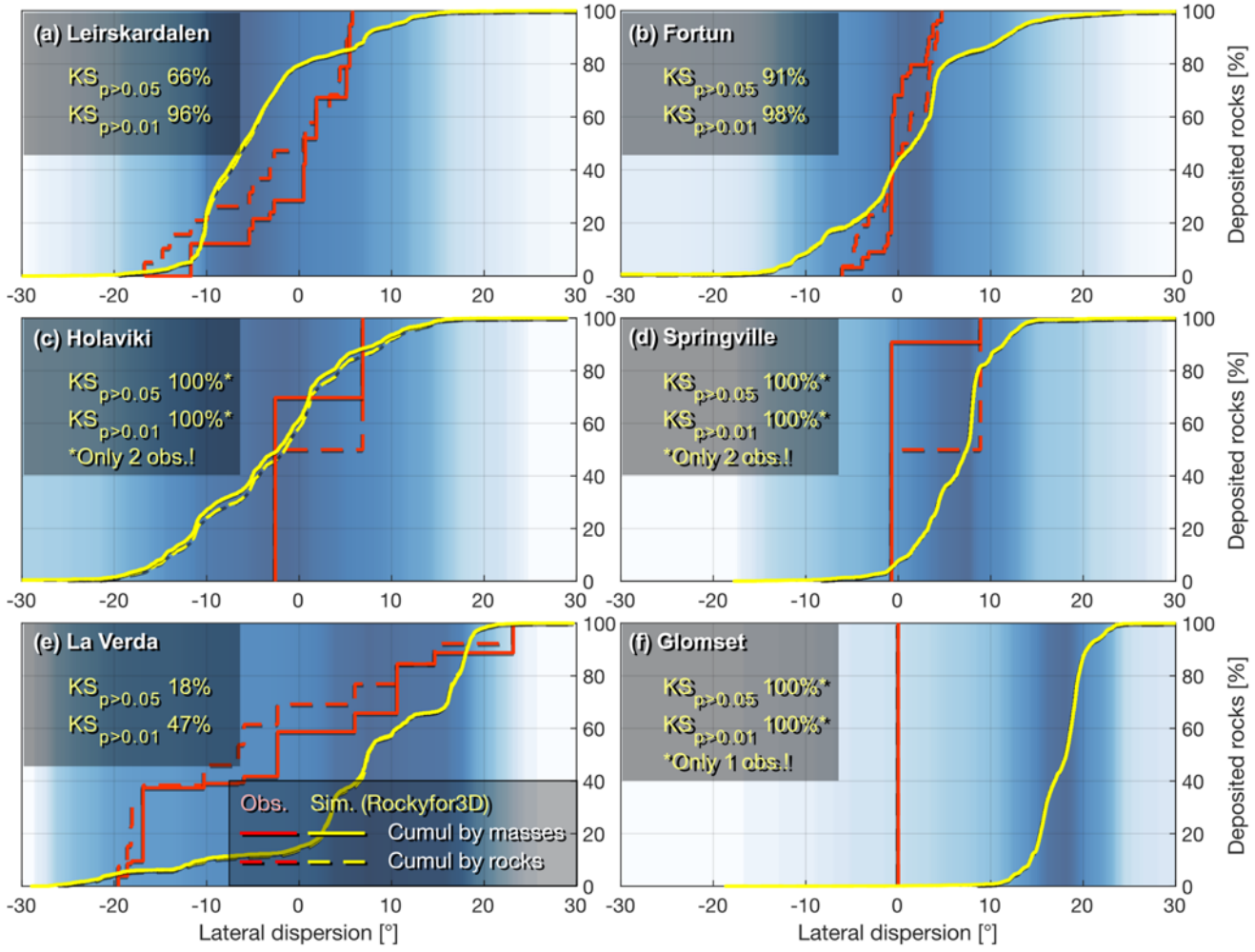

Figure S12: Comparison of the lateral dispersion of the deposited rock fragments of the real rockfall event sites. The observations are shown in red, and the simulations from Rockyfor3D are shown in yellow and blue. The cumulative curves are built by scanning in a counterclockwise direction around each average source point and by setting the zero-degree dispersion at the observed mass centre.

S.3 Geometrical model predictive results

S.3.1 Rockfall test sites

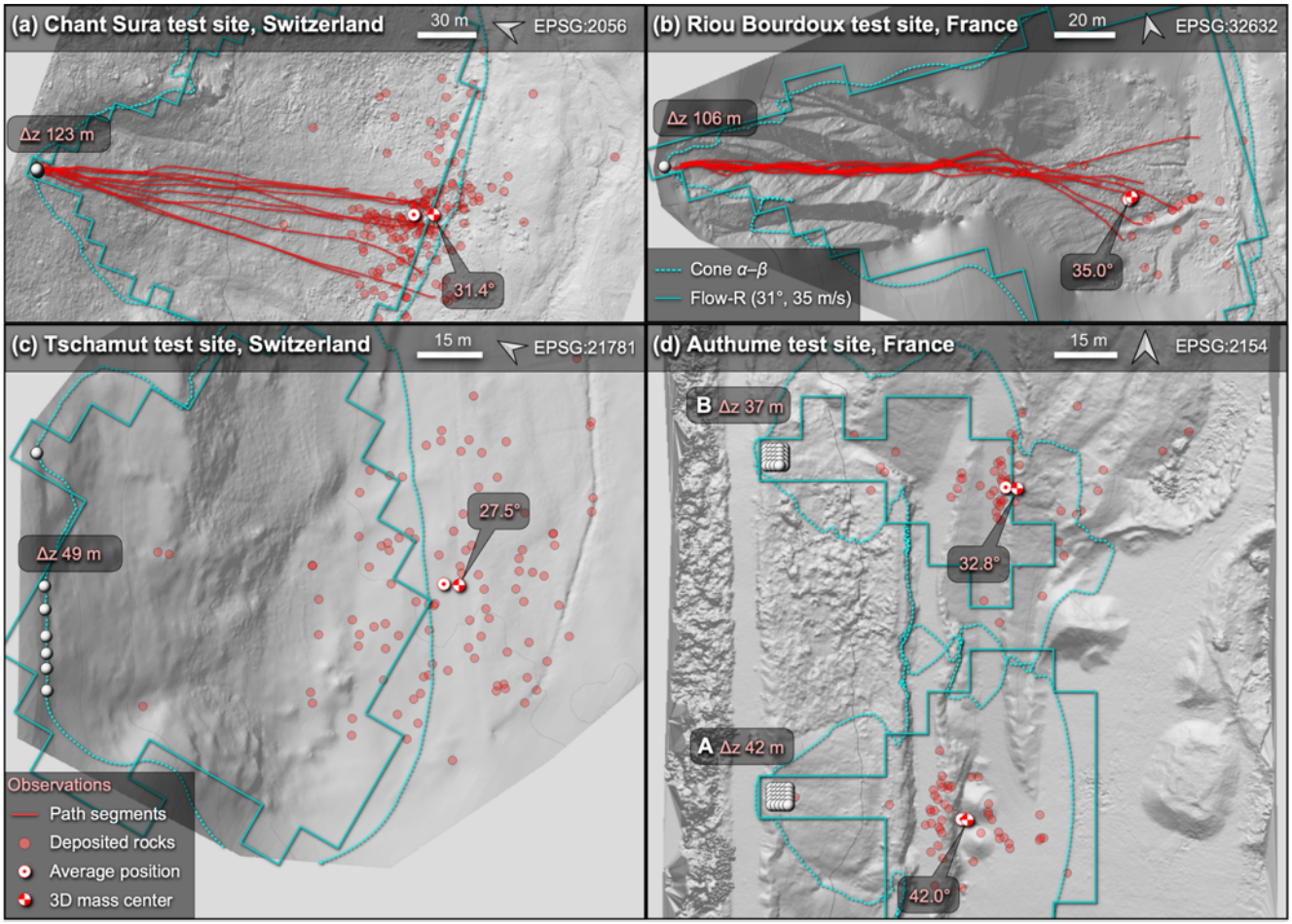

Figure S13: Comparison of the rockfall test sites of the mapped deposited rocks vs. the geometric methods. The observations are shown in red. The geometrically produced runout extents are shown in cyan.

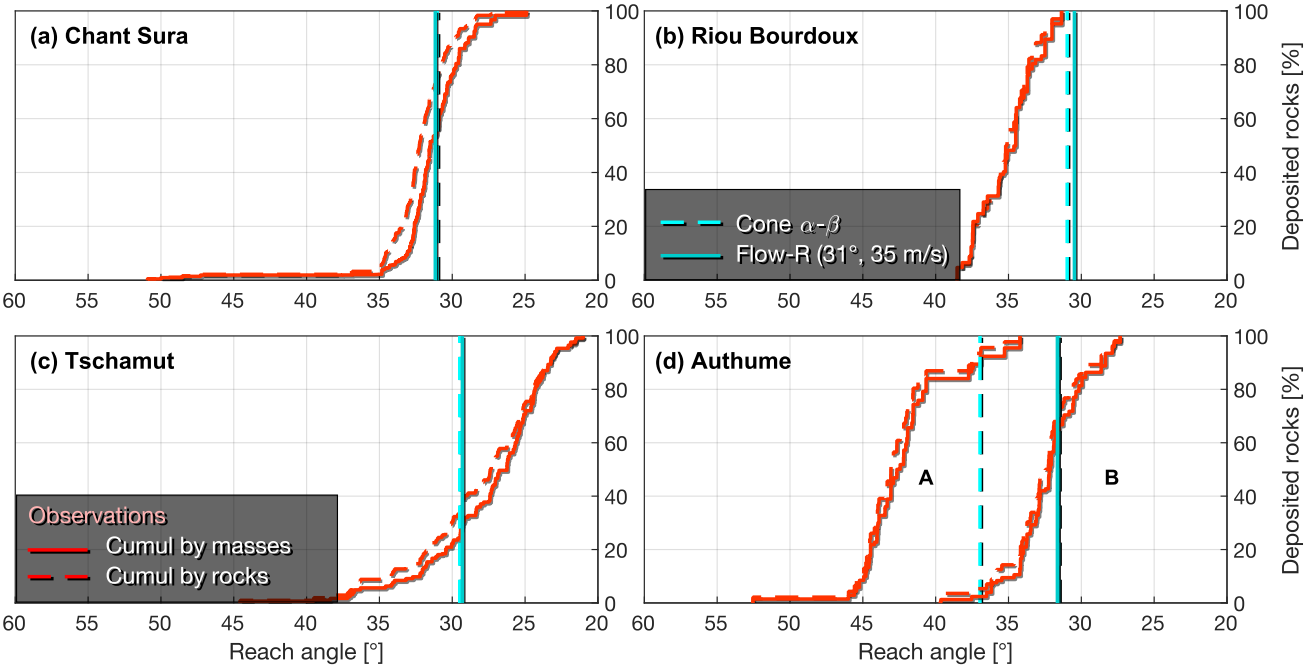

Figure S14: Comparisons of the cumulative distribution of the observed deposited rock fragments in terms of reach angles (energy line angles from the source to the deposited location) with the longest runout extents of the geometric methods. The observations are shown in red and the longest geometrically produced runout extents are shown in cyan. Also, for homogeneity across the paper, the runout propagation goes from left to right. The reach angle axes are thus inverted since the reach angles usually decrease as the runout distances increase.

S.3.2 Real rockfall event sites

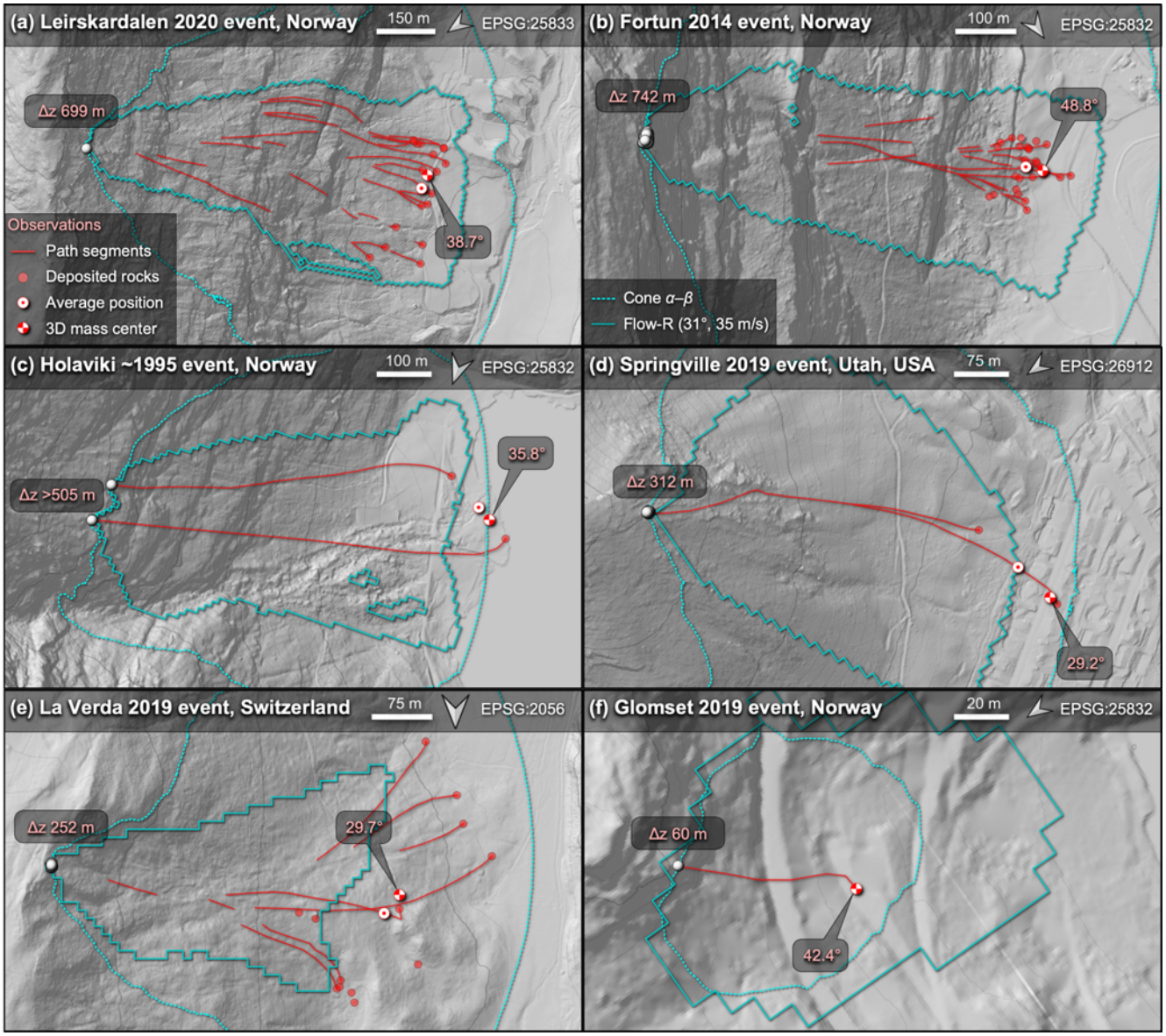

Figure S15: Comparison of the real rockfall event sites of the mapped deposited rocks vs. the geometric methods. The observations are shown in red. The geometrically produced runout extents are shown in cyan.

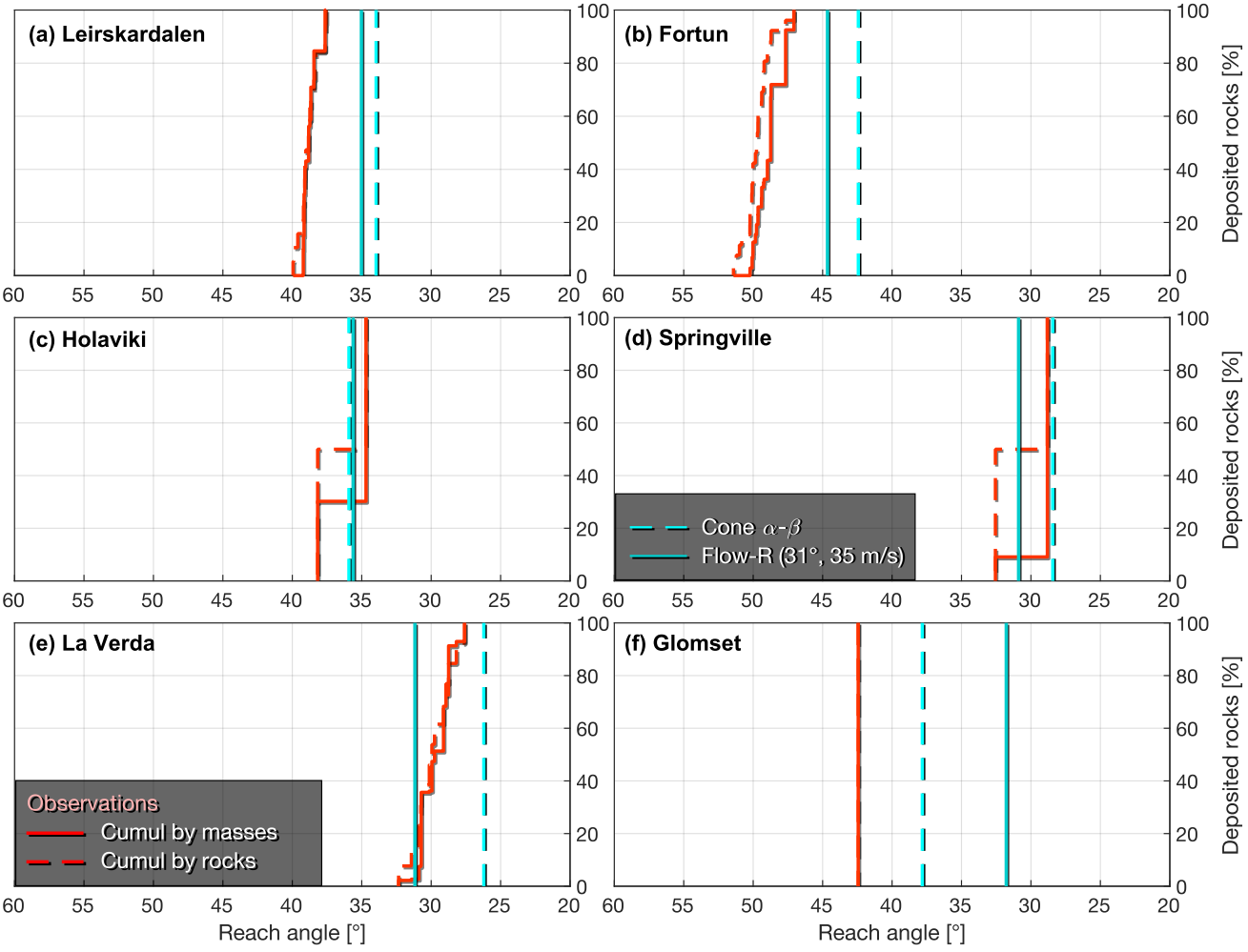

Figure S16: Comparisons of the cumulative distribution of the observed deposited rock fragments in terms of reach angles (energy line angles from the source to the deposited location) with the longest runout extents of the geometric methods. The observations are shown in red and the longest geometrically produced runout extents are shown in cyan. Also, for homogeneity across the paper, the runout propagation goes from left to right. The reach angle axes are thus inverted since the reach angles usually decrease as the runout distances increase.