Groundwater controls on episodic soil erosion and dust emissions in a desert ecosystem

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Methods: Atmospheric ^{137}Cs flux determination & Erosion Model

To calculate total ^{137}Cs atmospheric fluxes to each site we used direct measurements of atmospheric fallout collected by the Department of Energy during 1956-1972 (US ERDA, 1977) and monthly precipitation at each site calculated by the PRISM Climate Group, Oregon State University. Detailed records of weapons-derived ^{90}Sr wet deposition fluxes (Bq m^{-2}) per cm of rainfall were collected in Alabama, U.S.A. during the weapons testing era which we use to extrapolate total fluxes for each site's monthly rainfall records in Owens Valley. Total amounts of ^{137}Cs deposition to each site was calculated using conversion factor of 1.6 Bq ^{137}Cs/Bq ^{90}Sr, and accounting for radioactive decay of ^{137}Cs since deposition (to 2010, thus all measurements are corrected to this date). The magnitude of meter-scale spatial variations in fallout deposition from rainshadowing in this landscape was evaluated using measurements of ^{7}Be ($T_{1/2}$ = 53 d). Because of its short half-life, heterogeneities in soil ^{7}Be at a single site will reflect differences in atmospheric deposition patterns from small-scale rainshadowing effects and sediment redistribution from wind in the months prior to the soil collection. We use two relative standard deviations (1 σ = 17.5%) of ^{7}Be inventories[17] to generate a 95% interval that accounts for the maximum amount spatial variability that we would expect for soil ^{137}Cs and at our sites in Owens Valley that is solely from atmospheric depositional processes. We were able to directly evaluate these ^{137}Cs deposition projections and spatial heterogeneity by measuring ^{137}Cs in at reference sites with stable groundwater and vegetation cover since the late 1980s. The reference region had 654 ± 275 Bq ^{137}Cs m^{-2}, equivalent inventories to the projected ^{137}Cs deposition of 651 ± 228. Given that our calculated atmospheric ^{137}Cs flux based on Owens Valley precipitation data and ^{90}Sr measurements and our reference site inventories are equivalent, and these values are consistent with other regional depositional models (e.g., Simon et al., 2004) we feel very confident in our calculated ^{137}Cs fluxes across central Owens Valley

We apply an erosion model (Walling et al., 1997) that relates ^{137}Cs inventories to soil loss by comparing ^{137}Cs at different points on the landscape to levels supported by atmospheric deposition. The

model accounts for the vertical migration of ^{137}Cs into the soil since the 1960s and for the preferential removal of fine-grained material, which tends to have higher ^{137}Cs concentrations than coarser materials (Walling et al., 1997). Mobilized sediment collected in the BNSE stems was used to for the grain-size correction, and the advection-diffusion parameters of the model were calibrated using vertical profiles from the reference sites similar to the one in Figure 3A. While this model gives a first-order measure of the magnitude of soil erosion at our sites in Owens Valley (Table DR1), these values should be considered minimum erosion rates because of three model assumptions: i) erosion rates have been steady since ^{137}Cs deposition, ii) a zero value of ^{137}Cs can return a magnitude of erosion that is limited by the total depth penetration for ^{137}Cs , and iii) the model cannot account for the possibility that a location on the landscape was eroded but subsequently had deposition of soil with ^{137}Cs. Excess ^{210}Pb is calculated by subtracting the ^{210}Pb which is supported by soil ^{222}Rn from the total ^{210}Pb activity. This method uses the deficiency of ^{210}Pb to ^{226}Ra measured at depth to estimate the fraction of ^{222}Rn which escapes the soil (Kaste et al., 2011). Soluble salts (Figure 3) were determined by equilibrating 10 g dry soil with 50 mL of distilled de-ionized water for 30 minutes, and using a conductivity meter calibrated with KCl to measure and calculate mg salt/liter in the solution (Poage et al., 2008). We filtered and gamma-counted a subset of these solutions and found no detectable ^{210}Pb or ^{137}Cs activity, indicating that the radionuclides were not significantly soluble in water.

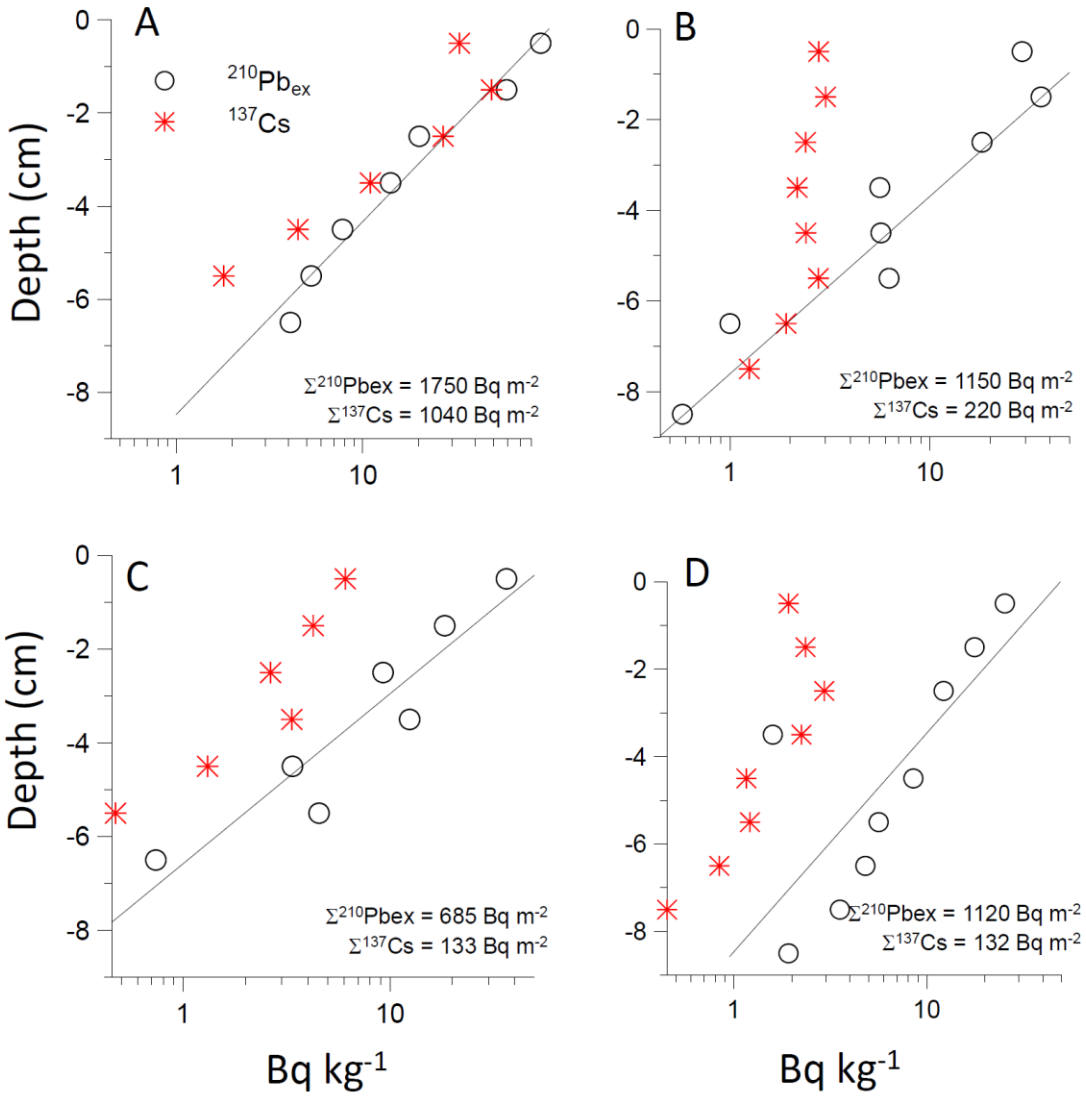

Figure DR1. Vertical profiles of excess ^{210}Pb ($^{210}Pb_{ex}$, ^{210}Pb in excess of that supported by in-situ decay of ^{222}Rn) and ^{137}Cs in soils at a reference (A) and sites with vegetation decline (B-D). $^{210}Pb_{ex}$ has significant logarithmic decline (line) with depth at each site, but ^{137}Cs is more mixed in the upper soil at impacted sites with shallow groundwater (B-D). Integrated inventories given for each profile in Bq m^{-2}.

	BSNE Sediment Traps	^{137}Cs 1965-2010	p value
Reference Vegetation Cover >50%	3-28 (4)[a]	0-60 (0)†, [A]	0.85
Vegetation decline DTW >6m	28-193 (30)[b]	0-60 (0)†,[A]	0.064
Vegetation decline DTW <6m	10-49 (22)[a]	80-133 (115)[B]	0.001

Table DR1. Annual vertical fluxes (g m^{-2} y^{-1}) calculated using BNSE sediment collectors and annual soil losses (g m^{-2} y^{-1}) measured from 1960 using ^{137}Cs distributions in soil under different groundwater decline conditions. Vertical fluxes were determined using the relationship between soil texture, horizontal fluxes captured by the BSNE stems, and dust emissions (Marticorena and Bergametti, 1995).Interquartile ranges given with median values in parentheses. †Net soil losses not detectable because ^{137}Cs inventories were not significantly different than atmospheric depositional fluxes at the site scale. P values are given for a Mann-Whitney U test of differences between samples within a row, and different letters (a, b, etc.) show significant differences detected ($p<0.05$) within a column.

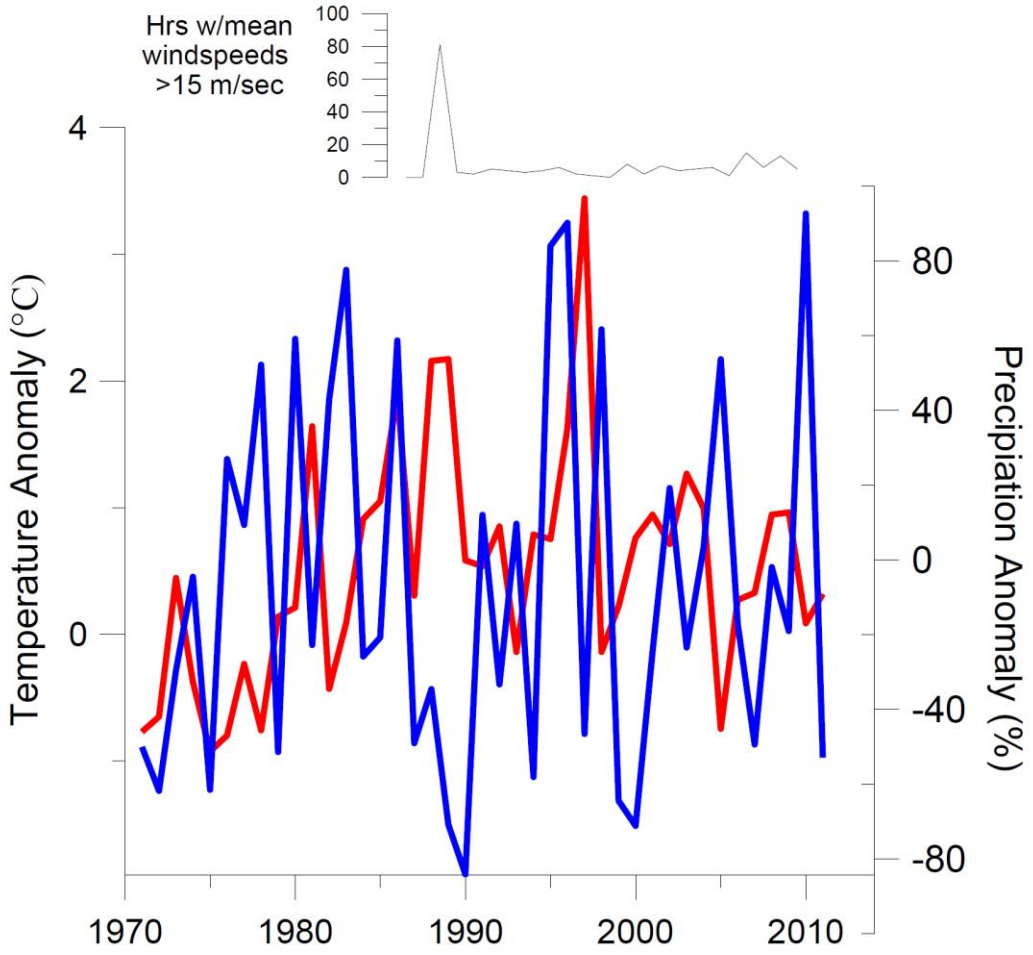

Figure DR2. Temperature (red), precipitation (blue), and wind data for the study area. Temperature and precipitation data are from Independence, CA (Western Regional Climate Center), and are plotted relative to the National Climate Data Center's annual normal for that station. The upper inset shows the number of hours that the Great Basin Air Pollution Control District Lone Pine monitoring station recorded average hourly windspeeds >15 m/s (record began in 1986)

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