Regional Erosion Rates Show Strong Climate-Driven Variability in the Arctic Since the LGM

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ABSTRACT

The last 22 kyrs, since LGM, is known for significant millennial scale changes in global climate (Barker and Knorr, 2021). Sedimentary deposits in lacustrine and marine basins bear archives of corresponding changes in sediment accumulation. Yet given the scale that the global climate exerts on geomorphological processes on Earth's surface, generalizations of the relationship between the climate and the erosion remain inconclusive. Whether the possible generalizations could even be applied to all regions has also remained unclear.

Erosion rates are a first-order response to a region's climate. The variability of erosion rates through time are needed for dating of buried surfaces, quantifying soil carbon budgets, and assessing landscape stability. Until now, a truly global analysis of comparing interregional erosion rates has not been available. Recent work in Madoff and Putkonen (2022) addresses this by generating global maps of regional erosion rates since the LGM. These results are supported by corresponding published sediment accumulation rates in sink areas corresponding to given watershed. These results show the spatial extent of higher erosion rates and larger ranges of variability through time in the Arctic and subarctic in contrast to the tropics and mid-latitudes. These results also indicate that the regional variability decreases the further from the past ice sheets a given location is. Finally, a clear take home message from these results is that the regional erosion rates vary both through time and space for the past 22 kyrs.

INTRODUCTION

Climate-driven variation in erosion was determined in one location **(Fig. 1A),** Mono Basin, CA (Madoff and Putkonen, 2016). This motivated us to look into whether erosion is variable everywhere.

The basic sediment transport law, q = K(dy/dx) was used to apply a novel approach designed to compare globally a relation between climate and erosion (Madoff and Putkonen, 2022). A systematic first-order global comparative assessment addresses two longstanding questions:

- Can erosion rates be shown to vary with climate and where?
- What is the spatial variability of time-dependent erosion?

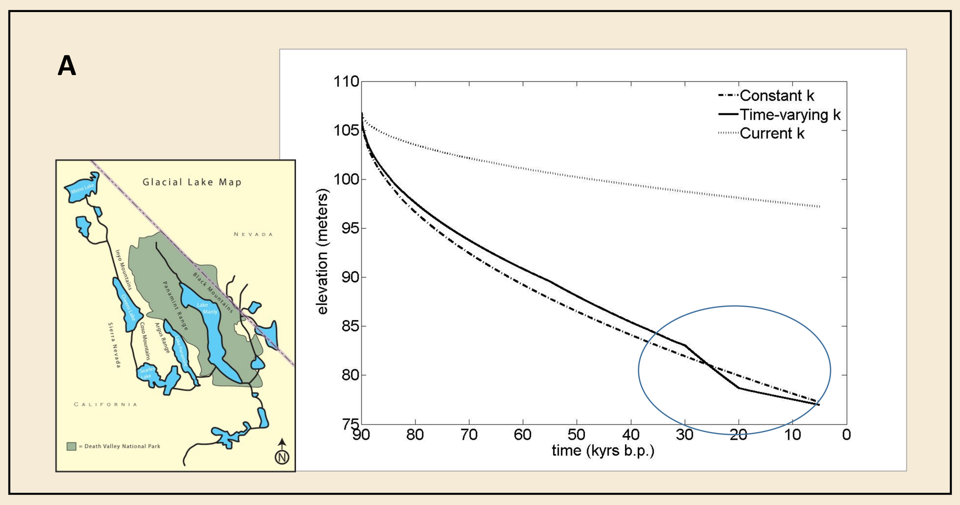


Fig. 1 (A) Curves comparing rates of elevation loss (degradation) using long-term average constant K and time varying K at a single location, Mono Basin, CA (Madoff and Putkonen, 2016) and map (Jol , 2007) showing connectivity of glacial lake basins that proxy climate record is taken from (Lowenstein, 1999).

A non-linear relationship was found between climate and erosion (**Fig.1B**) when global soil creep rates, converted to topographic diffusivities (K) in Oehm and Hallet (2005) were grouped using Köppen Climate classification in Madoff and Putkonen (2022) are found to generate a non-linear curve. Global maps of the temperatures (Fig. 2) through time in the past during which regions exhibited highest K (Fig. 3) and the mean annual air temperatures (MAAT) over 500 yr intervals were generated in MATLAB. Gridding was formatted according to transient paleo-global climate model TraCE-21 ka and ice mask from ICE-5G (Peltier, 2004). The data and substitution method with a transfer function produce a global map of average erosion since LGM (Fig.4) illustrating the results of the non-linear curve and the correlations displayed as spatial associations between erosion with air temperatures.

GLOBAL DATA

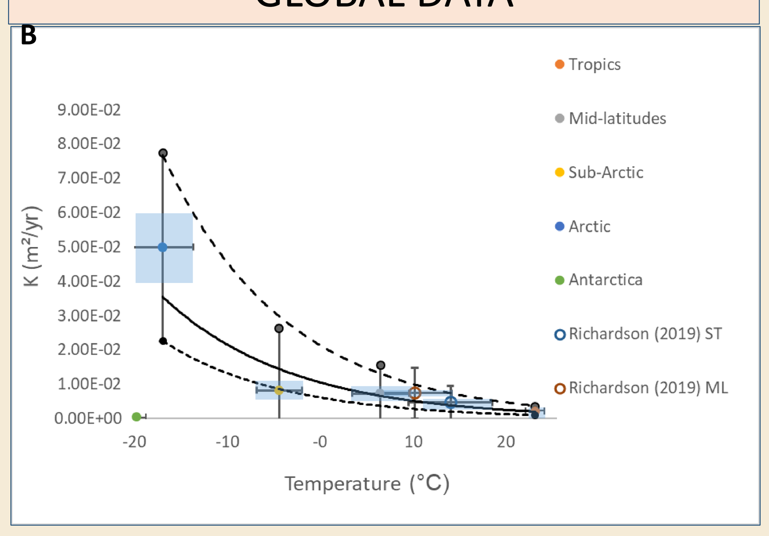


Fig. 1 (B) Global MAATs with diffusivities (K) are related through a non-linear curve. Stippled curves are SDs and transparent boxes are the standard uncertainties, well within SDs.

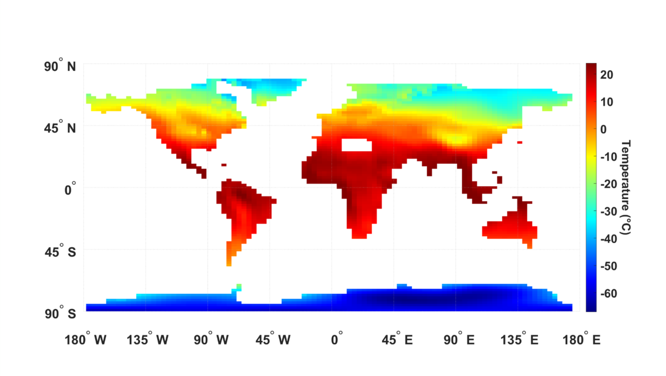


Fig. 2 Global map showing the temperatures through time since LGM associated with all the regions of highest diffusivities.

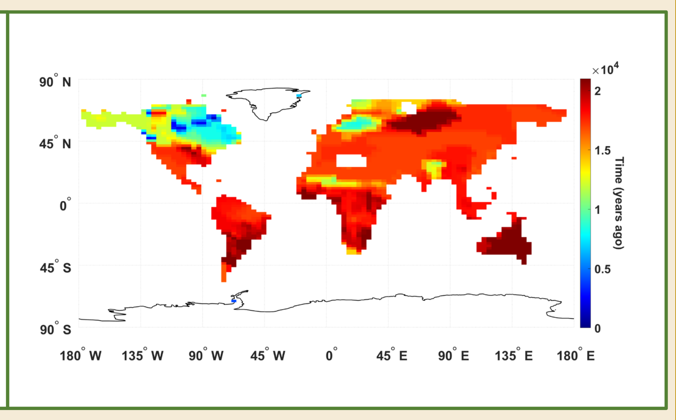


Fig. 3 Map showing the times when regions in Fig. 2 had their highest diffusivities. Times represent 500 yr intervals of averaged highest Ks.

EROSION THROUGH TIME

Variable ⟹ Arctic
Constant ⟹Tropics

Time varying diffusivities reveal largest min-max range of erosion rates in the Arctic

The Arctic region as whole exhibits the largest ranges in erosion rate variability, as a difference between minimum and max erosion rates (**Fig. 5**). These high ranges correlated temporally most directly with proximity to the last ice-sheet for those neighboring regions, and length of time temperatures were driven by glaciation, in those Arctic regions that were never covered by the ice sheet. Regional difference is also revealed in **Fig. 6** which shows the long term average erosion in relation to the present. The present erosion is higher, i.e. there are enough present temperatures colder than on average because the ice covered western Arctic longer, therefore erosion in the model started later there than in the eastern Arctic.

The lowest variability is displayed in the tropic regions where the past transition from glacial to interglacial correlates with the smallest erosion rate variability, as rates changed relatively little through time.

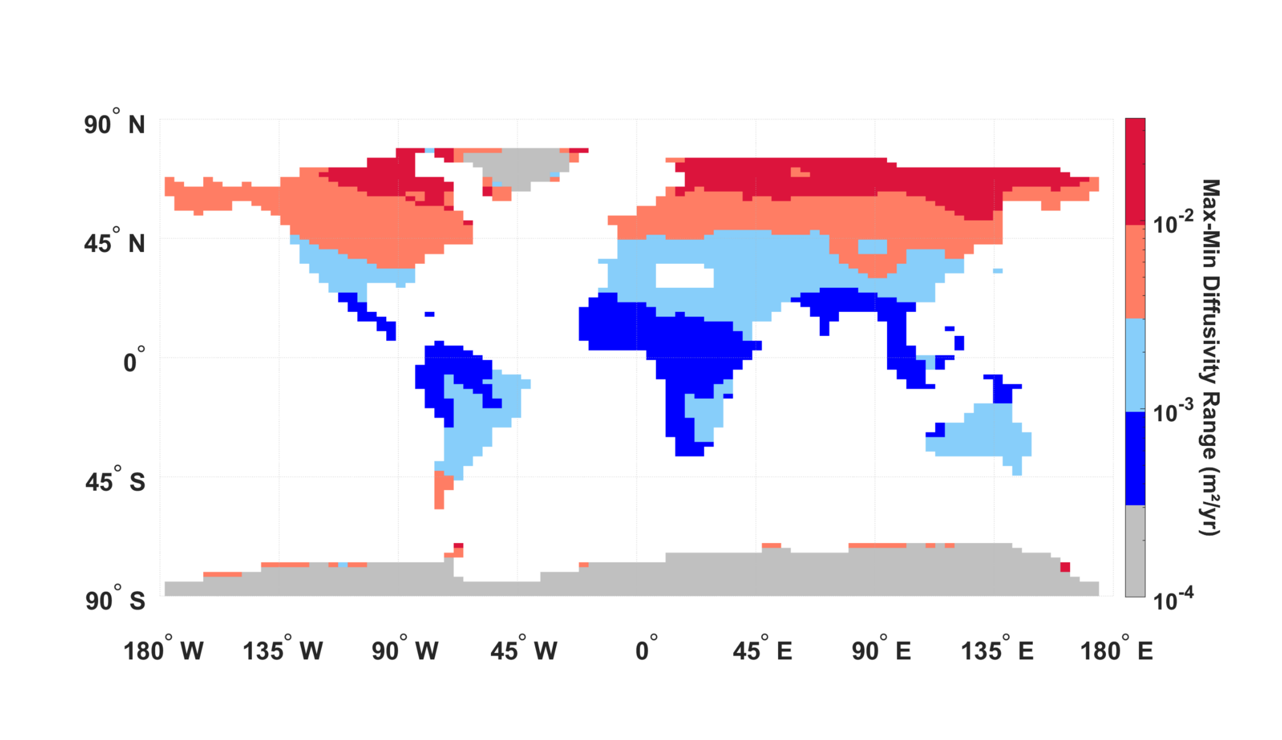


Fig. 5 Map of global minimum to maximum ranges in diffusivity

TAKE-HOME MESSAGE

Global time-slice mapping reveal climate-forcing on Arctic erosion rates.

- Climate forcing on regional degradation revealed on millennial time scale in the Arctic
- Arctic erosion accelerated by last deglaciation 20-8 ka

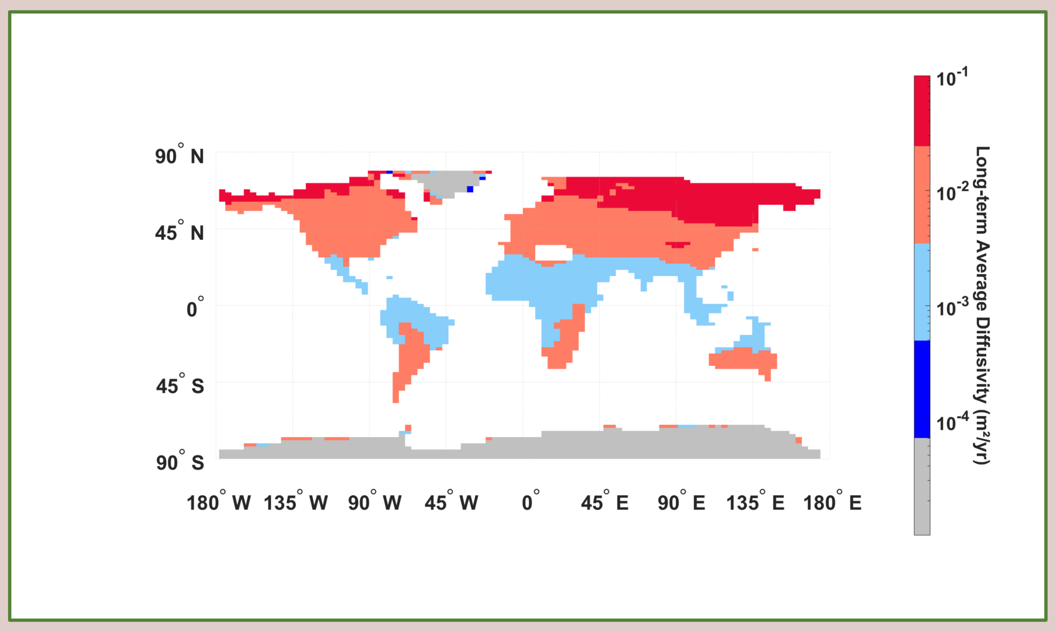


Fig. 4 Map of regional diffusivities averaged over 500 yr intervals since LGM. Values derived through substituting present values given in Fig. 1 with associated past Ts output from TraCE-21 ka that generated past Ks.

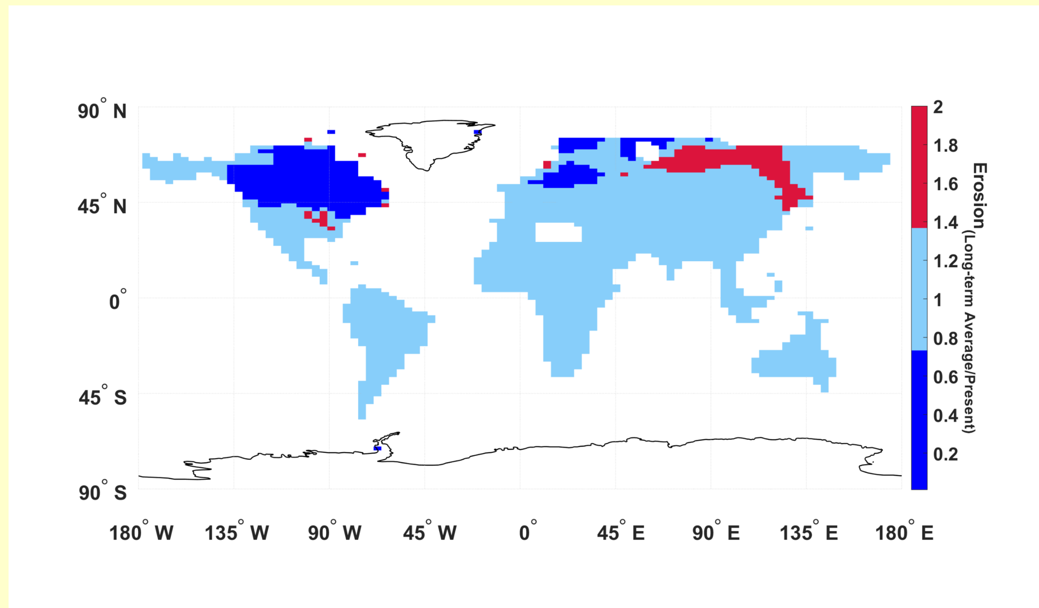
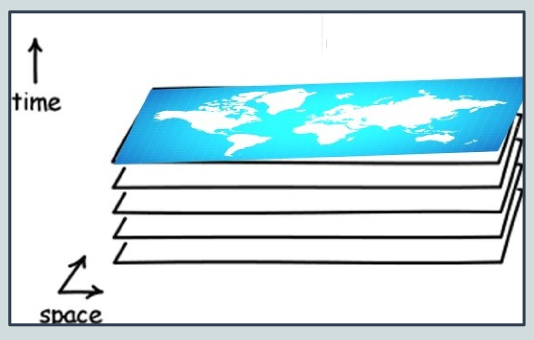


Fig. 6 Map of global ratios between long term average diffusivity/present diffusivity

METHODS



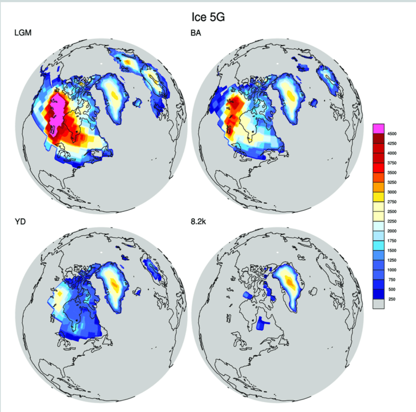
Time and space dimensionality of computational grids generated using MATLAB

SPACE-FOR-TIME SUBSTITUTION

COMPUTATIONAL GRIDS --- TRANSFER FUNCTION

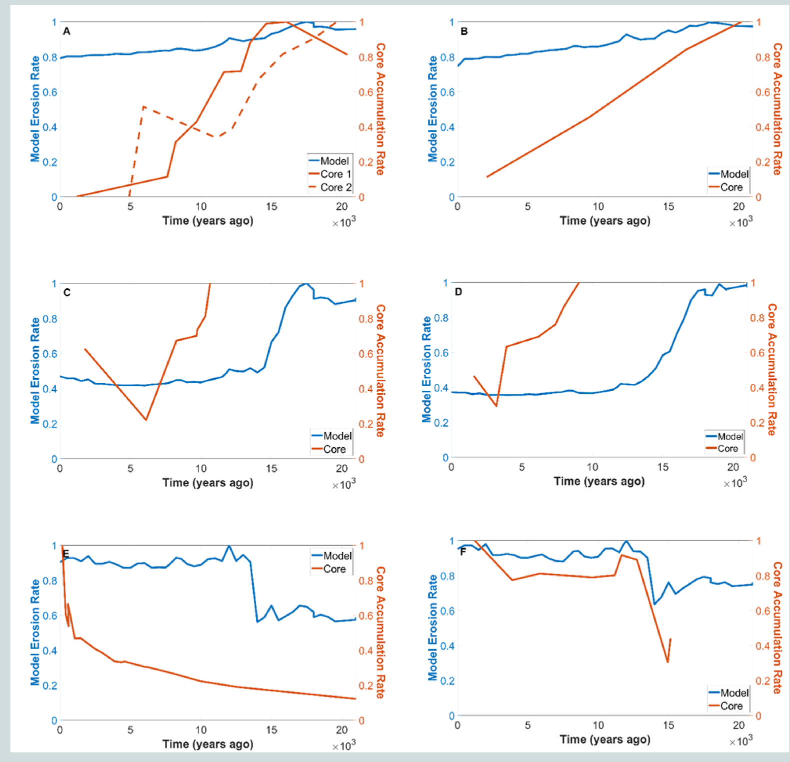
- ✓ Soil creep ⟹ diffusivity (K)
- ✓ Soil creep coupled with climate reanalysis air temperature data (T)
- ✓ Ts grouped according to Köppen Climate Classification
- ✓ Ks plotted against the grouped average Ts
- ✓ Curve and transfer function generated from K/T relationship
- ✓ Using gridded T data output from TraCE-21 ka, transfer function transfers Ks through time to generate past diffusivities at same locations at 500 yr intervals since LGM
- ✓ Ice mask applied from ICE-5G (Peltier, 2004) to exclude ice-covered regions from substitution
- ✓ Erosion rates mapped
- ✓ Model erosion sources areas compared with published offshore and lake sediment accumulation rates from sink areas and correlation coefficients calculated

Global Paleoclimate Models



Examples from global ice-sheet extent model (Peltier, 2004)

MODEL VALIDATION



Published sediment accumulation rates from offshore and lake sediment cores strongly support a physical process connecting source area erosion rates as modeled and adjacent sink areas (Fig. 7). The similar directions and their temporal correlations provide a preliminary validation of the model approach and at the given time scale.

Fig. 7 Panels A-F showing comparability of trends between source region model erosion rates (blue) and corresponding sink area published sediment accumulation rates (orange) from offshore and lake sediment cores representing major watersheds – A (Amazon), B (Ganges), C (Lena River watershed, D (Yenisei River watershed), E (southwest Alaska), F(Northeast Alaska). Correlation coefficients ranged from moderate to high (0.65 – 0.91), which provides supporting evidence of the erosion model's validity in approach and spatial scale.

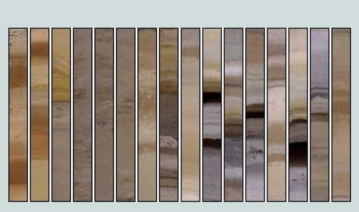


Image courtesy of IODP via https://earthobservatory.nasa.gov [accessed April 15, 2022].

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