Supplementary Information for “The distribution of Earth’s wind-blown sand dunes”

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Supplementary Text 1

Many other secondary source maps were used to develop the map used in this study[1-29]. This text section provides further details on the manual mapping of dune presence.

Omissions

- The map is void where ERA5-Land reanalysis data is not provided, i.e., any 0.1°x0.1° grid cell where the area is majority water (except some lakes) and therefore omits many coastal dunes.
- Some dunes are too small (in height or planform) to observe at the mapping scale used.
- Some dunes are presently obscured by thick vegetation and cannot be discerned with the datasets used (e.g., COP30 is a Digital Surface Model, not a Digital Terrain Model). In some parts of Earth better datasets which would result in a more comprehensive map could be used (e.g., USGS 3DEP DTM), however, to ensure an unbiased map the same globally available datasets were used everywhere.
- Some aeolian dune fields can be identified but their surface expression is too modest, altered, or complex to identify a morphology, therefore they are omitted. This is particularly true for relict dunes. Some example regions are the Pampas, Kalahari, Low Qoz, Qoz Dango, Hausaland, Nara, East Caspian, Lapland, North Europe, North America, and Siberia.

New additions

This map includes dunes in the following regions which, to the best of the author’s knowledge, are not identified in other published maps including those used as secondary sources for this study:

- Nenetsia, Russia
- East of the Lut, Iran
- Afghanistan border with Tajikistan & Uzbekistan
- North-facing Himalaya, Tibet
- Sevrei, Mongolia
- Töv, Mongolia
- West Tabuk, Saudi Arabia
- Samara, Kazakhstan
- Jubaland coast, Somalia
- Senegal-Gambia border
- Between Bir Anzerane & Awsard, Western Sahara
- El Hank escarpment, Mauritania
- Downwind of Bel Bouna, Mauritania
- Djebel Ouarkziz, Algeria
- Between Taoundart & Amesmessa, Algeria
- Western Tazrouk Province, Algeria
- Western Tibetsi Mountains, Chad
- Around Sabkhat al Qunnayyin, Libya
- Between Ghurd as Sara & Al Jawf, Libya
- Eastern side of Jabal Nuqayy, Libya

Notes on definition of marginal dunes

Free elongating dunes are only classified if they have a sharp crest. Often there are mounds of sand in the lee of obstacles without a crest; we have not classified these as dunes. Similarly, we have not classified mounds of free sand without a clear wind-driven asymmetry in morphology as dunes. These, in some cases, may be dome dunes, however it is not possible to definitively distinguish them as aeolian.

Parabolic dunes have tremendous variety in morphology. This is partially because; they can form in unimodal winds with a variety of dispersions, have various stabilising forces (i.e., ice, vegetation, microbial mats, etc.), and, since they often are on the fringes of aeolian activity, can reactivate and degrade in unexpected ways on a variety of timescales from seasonal to Milankovitch. We have erred on a bullish identification of these dunes. We have, however, maintained a consistent approach to not classifying ‘blowouts’ without a clear downwind crest, i.e., an eroding sand patch surrounded by vegetation (or another stabilising force) containing no discernible bedforms, as dunes. These are prevalent in coastal settings and the Pampas.

Superimposed dunes with unique morphologies can prevail when either all morphologies are active, only some are active, or none. When none are active, and topography is degraded somewhat, these dunes can be difficult to identify. Therefore, there may be some locations where these are not included by mistake.

In some locations, particularly large ergs, there can be fields of consistently patterned dunes that, despite not displaying slipfaces, appear with context to be mature and free, akin to dome dunes but with high sand supply. We have classified these as dunes however they do not fit within a typical dune classification scheme. We have distinguished these from sand drifts which, despite having fine-scale micro-relief patch patterns, are not considered dunes, using historical Landsat imagery to assess their migration speed. A clear example of this distinction is seen between the Zaltan & Calanscio dune fields.

Sometimes there are clear aeolian patterns on surfaces (e.g., intermittently wet lake beds) that are not dunes. They can form for various reasons, such as through feedbacks between wind and vegetation or evaporation, but have not classified as dunes as they are not topographic forms.

There are certainly places which we have indicated dunes that would be up for expert debate, e.g., subtle relict nail dunes along the Warrego River, Australia, the crests of eroding hills south of the Nafusa Mountains, Libya, or slip faces developing upwind of the stoss of obstacles west of Mont Touside, Chad. These surmount to a negligible fraction of the dataset (<0.1%) so should not meaningfully impact the results.

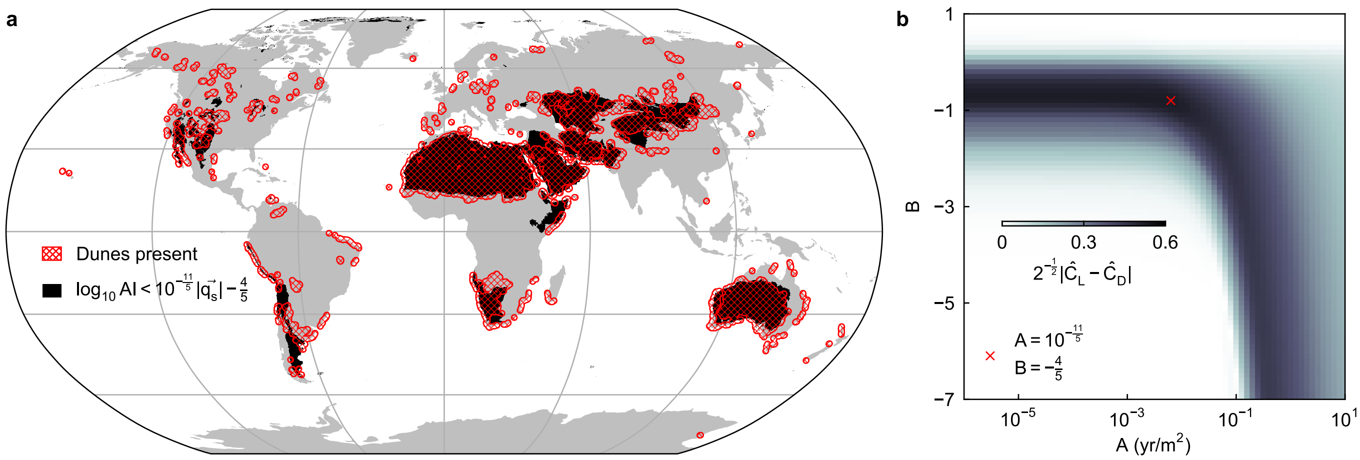
Supplementary Text 2

Past studies have introduced Mobility Indices for dune activity which have proved extremely useful for distilling the competing effects of wind and vegetation on dune activity[30-37]. These include myriad parameterisations for important hydroclimate and wind climate properties, such as the percentage of time wind exceed a threshold for sand transport[30,32,34], the mean wind speed raised to some power[31,32], the "RDP/DP"[35] (Methods M4), different flavours of the Aridity Index[30,36], and the ratio of actual to potential evapotranspiration[32]. Some also include reasonable memory effects which parameterise the influence of drought[32] or existing non-equilibrium vegetation[37]. Threshold values for these Mobility Indices are proposed which delineate when dunes become active or should be present[30-34]. Here we compare the precision and recall of the relation $\log_{10} AI < 10^{-11/5}|\overrightarrow{q_s}| - 4/5$ to commonly employed past criteria (Supplementary Table 1).

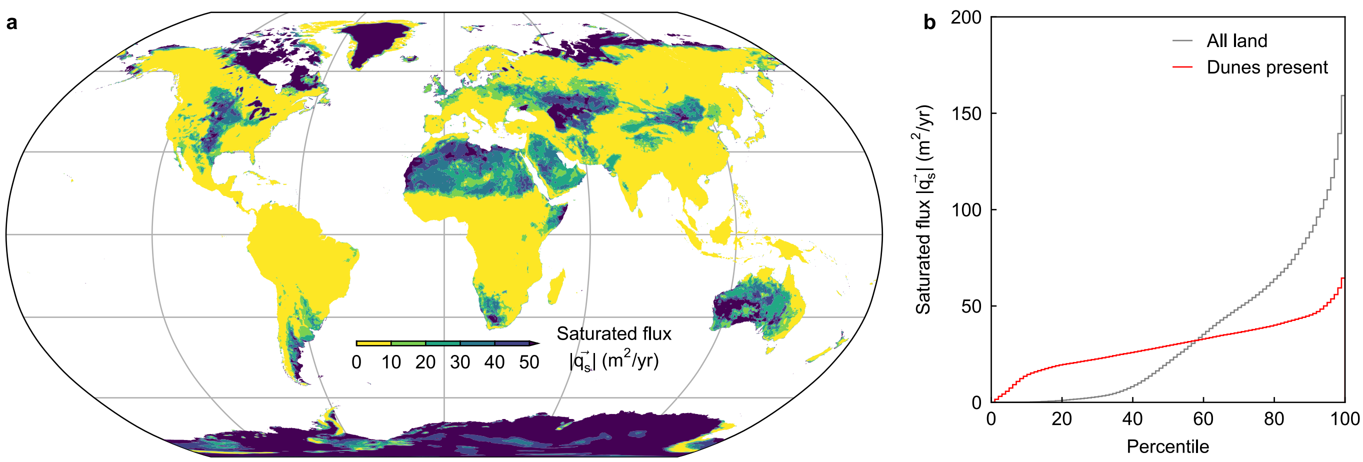
In order to make this comparison, we have made some minor assumptions. Lancaster[30] proposed that dune activity occurs when $W/AI > 50$, where W (%) is the percentage of time $|\overrightarrow{u_{10}}| > 4.5$ (m/s) and AI is the Aridity Index, where calculated in the Thornthwaite method—we assume the AI is consistent with the values used in this study. Ash & Wasson[32] proposed that dune activity occurs when $|\overrightarrow{u_{10}}|^4/(AET/PET) > 10^4/3.8$ or $W^2/(AET/PET) > 10^4/5$, where AET is the actual evapotranspiration and PET is the potential evapotranspiration—we approximate AET/PET as AI. Thomas et al.[31] proposed that dune activity occurs when $|\overrightarrow{u_{10}}|^3/AI > 70$, with a month-long memory effect due to drought—we neglect the memory effect.

Supplementary Table 1 shows that all other methods tested here have reduced precision relative to the relation in this study, apart from $|\overrightarrow{u_{10}}|^4/(AET/PET) > 10^4/3.8$ which has significantly worse recall. Note that the reduced recall relative to some other studies should be weighed against the increase in precision: since dune grid cells only account for 7.8% of the land surface, precision scores are far harder to increase relative to recall. Also note that, as discussed elsewhere in the study, all precisions are relatively low due to the role that other boundary conditions (i.e., flux divergence and sediment source location) play in the distribution of dunes, and recall is lower since relict dunes make up a small fraction of the dataset.

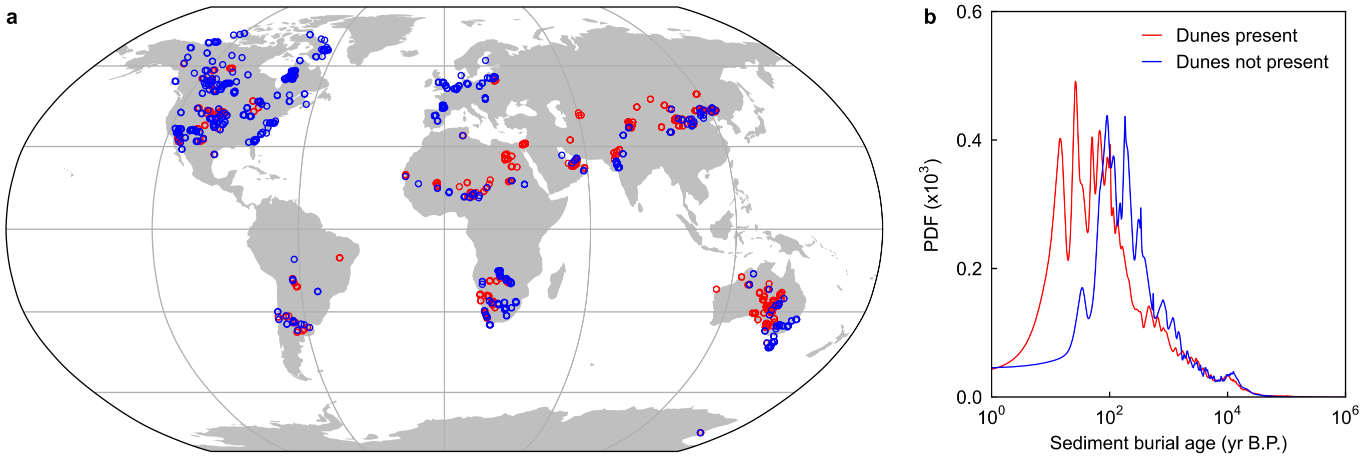
Supplementary Figures & Tables



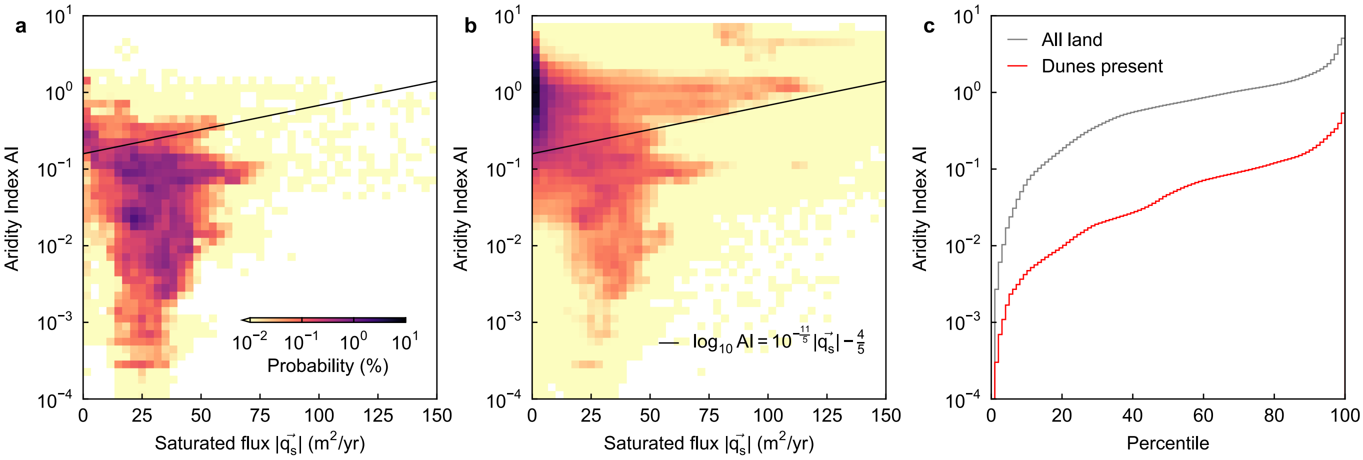
Supplementary Fig. 1: Aridity and saturated flux inequality for dune presence. a, Dune presence hatched in red on a world map (ESRI:54030) where $\log_{10} AI < 10^{-11/5}|\overrightarrow{q_s}| - 4/5$ (black). **b**, The $\hat{C}_L = \hat{C}_D$-normal distance between $\hat{C}_L = \hat{C}_D$ and $\hat{C}_L(A,B), \hat{C}_D(A,B)$, $|\hat{C}_L - \hat{C}_D|/\sqrt{2}$, where $\hat{C}_D$ and $\hat{C}_L$ are the fraction of land that satisfies $\log_{10} AI < A|\overrightarrow{q_s}| + B$ where dunes are, and are not, present, respectively (Methods M5), and its maximum (red cross).



Supplementary Fig. 2: Saturated sand flux magnitude. a, World map (ESRI:54030) of the average saturated sand flux magnitude $|\overrightarrow{q_s}|$ (m²/yr). **b**, The area-weighted percentiles for land (grey) and regions where dunes are present (red).



Supplementary Fig. 3: Reported aeolian sediment burial ages. **a**, World map (ESRI:54030) of the locations of luminescence and radiocarbon dating burial ages in aeolian sediments from the INQUA Dune Atlas[18] where errors are reported, where dunes with surface morphologies are present (red) or not (blue). **b**, The probability distribution functions, i.e., the simple-mean gaussian mixture, of all burial ages where dunes are present (red; N=2,295) or not (blue; N=2,097). Note that, in lieu of a detailed analysis of each specific age, this simplistic approach neglects contextual information about samples such as their depth or stratigraphic unit.



Supplementary Fig. 4: Likelihood of aridity and saturated flux. **a**, The joint area-weighted probability (log-scale) of Aridity Index AI and average saturated sand flux magnitude $|\vec{q_s}|$ (m^2/yr) where dunes are present, and **b**, for all land, with the relation $\log_{10} AI = 10^{-11/5}|\vec{q_s}| - 4/5$ (Methods M5) shown in black. **c**, The area-weighted percentiles for land (grey) and regions where dunes are present (red).

Study	Criterion	Precision	Recall
Lancaster (1988)[30]	$W/AI > 50$	26	96
Thomas et al. (2005)[31]	$\lvert\vec{u_{10}}\rvert^3/AI > 70$	23	98
Ash & Wasson (1983)[32]	$\lvert\vec{u_{10}}\rvert^4/(AET/PET) > 10^4/3.8$	41	72
	$W^2/(AET/PET) > 10^4/5$	28	93
Muhs & Holliday (1995)[33]	$AI < 0.35$	25	98
Wasson (1984)[34]	$0.13W + \ln AI^{-1} > 1/0.21$	27	90
This study	$\log_{10} AI < 10^{-11/5}\lvert\vec{q_s}\rvert - 4/5$	32	93

Supplementary Table 1: Precision and recall of mobility indices. Reported threshold criterion for dune mobility in other studies (Supplementary Text 2), and this study (Methods M5), and their area-weighted precision and recall scores (%).

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