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Mapping the interactions between rivers and sand dunes: Implications for fluvial and aeolian geomorphology

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ABSTRACT

The interaction between fluvial and aeolian processes can significantly change Earth surface morphology. When rivers and sand dunes meet, the interaction of sediment transport between the two systems can lead to change in either or both systems. However, these two systems are usually studied independently, which leaves many questions unresolved in terms of how they interact. This paper carries out a global inventory, using satellite imagery, to identify 230 sites where there are significant fluvial–aeolian interactions. At each location key attributes such as wind/river direction, net sand transport direction, fluvial–aeolian meeting angle, dune type and river channel pattern were identified and relationships between each factor were analysed. From these data, six different types of interaction were classified that reflect a shift in dominance between the fluvial and aeolian systems. Results from this classification confirm that only certain types of interaction were significant: the meeting angle and dune type, the meeting angle and interaction type and finally the channel pattern and interaction type. However, the findings also indicate the difficulties of classifying dynamic geomorphic systems from snapshot satellite images.

1. Introduction

Fluvial and aeolian actions are important agents in modifying landscapes and shaping the surface of the Earth, over a range local to regional scales. In humid/sub-humid areas moving water is often the dominant process shaping the land surface (Charlton, 2008), whilst in areas where water resources are more limited wind can become the dominant process. Bullard and Livingstone (2002) and Field et al. (2009) summarise how changes in moisture can affect the balance between aeolian and fluvial processes suggesting the highest levels of fluvial–aeolian interaction occur where neither fluvial nor aeolian processes dominate.

Significant interactions between fluvial and aeolian processes have previously been noted in many places across the world (Goudie, 2013; Warren, 2013), for example, the great dunes of Pyla on the French coast (Tastet and Pontee, 1998), the Athabasca sand dunes along the William River in Canada (Smith and Smith, 1984), sand dunes in Yarlung Zangbo River valley in China (Li et al., 1999) and the sand dunes in Victoria valley in Antarctica (Bourke et al., 2009). Sedimentological research has also identified fluvial and aeolian interaction in the interbedded fluvio-aeolian sediments found in stratigraphic records (Mazzullo and Ehrlich, 1983; Langford and Chan, 1989; Veiga et al., 2002; Song et al., 2006; Williams, 2009). Reviewing the literature, fluvial and aeolian systems are largely studied separately, yet, Earth surface processes rarely operate independently of each other and, as described above, there are many locations where fluvial and aeolian processes operate together—and thus interact with each other. Furthermore, previous studies that have looked at the interactions between fluvial and aeolian processes tend to examine these from the perspective of either fluvial or aeolian research, with only a few examples where there is a balance or mixture of approaches.

From a fluvial perspective, researchers have observed how flow can affect the development of aeolian features. By the action of fluvial erosion, sand dunes bordering channels can be changed in both size and location. Alternatively, dune sand can slump into rivers as a result of over-steepening of dune flanks from river erosion and the sand is then transported and re-deposited by river which, in turn, determines the location of new dunes sourced by this sediment (Langford, 1989; Han et al., 2007; Maroulis et al., 2007). These type of dunes are named source-bordering dunes as they closely border the downwind side of their sediment supply from sand bed streams. In addition, some river systems can intercept the sediment transport from dune fields to the extent that they block dune movement. For example, the Colorado River was found to be not only the boundary of Algodones dunefield but also at the end of the transport path of sand from the Mojave Desert (Sweet et al., 1988; Muhs et al., 2003). In Africa, the dunefields in Northern Sudan are terminated by the Nile River (Bullard and McTainsh,

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2003), the Namib Sand Sea is terminated by the ephemeral Kuiseb River (Thomas et al., 1997), the Skeleton Erg ends at the Hoarusib River (Krapf et al., 2003) and the perennial Orange River marks the downwind margin of the southwest Kalahari dunefield (Ward, 1987; Thomas et al., 1997; Bullard and McTainsh, 2003; Krapf et al., 2003).

Contrastingly, aeolian process can heavily influence fluvial process. Sand dunes can deflect and confine overbank flows, dam and divert river courses and thus determine the position of many contemporary waterholes and channels (Langford, 1989; Loope et al., 1995; Maroulis et al., 2007). Jones and Blakey (1997) described how an ephemeral stream flowing along the edge of an erg in South Central Utah, USA was diverted several times by aeolian sands obstructing the river until it was forced to take a different route to the sea, leaving relic dry channels. In central Australia, previous floodplains of the Todd River are now new fields of dunes—though it is difficult to determine whether the climate change, large floods or possibly aeolian damming are responsible (Hollands et al., 2006). Additionally, some river systems can dramatically change pattern and behaviour when they encounter aeolian processes. For example, the lower William River in Canada undergoes a rapid adjustment from a relatively narrow and deep single-channel stream to a braided pattern when it encounters a large dune field (Smith and Smith, 1984). By studying the change of lithological and sedimentological characteristics in the Vecht valley from the Middle Pleniglacial to the Holocene, Huisink (2000) found a correspondence between historical changes in channel pattern and aeolian activity where low energy meandering rivers were associated with periods of low aeolian activity and high energy braided systems were associated with periods of high aeolian activity. It is unclear, however, whether these changes in channel style were caused by an influx of sediment resulting from aeolian activity or whether the climate change led to change in vegetation and thus bank stability. Furthermore, fluvial systems can supply sediment to, and be the primary sediment sources for, many sand seas and dunefields. For example in Israel, Roskin et al. (2011) found the sand supply and storage in Sinai was initiated by the Late Pleistocene exposure of the Nile Delta sands. Studies carried out in the Mojave Desert appear to prove that the sand in the Mojave Desert have been transported from the Mojave River Wash source (Ramsey et al., 1999). The Colorado River is shown to be the source of sand for at least three of the major dune fields of the Sonoran desert of western Arizona and northern Mexico (Muhs et al., 2003; Draut, 2012). In China, sedimentological and mineralogical analyses were carried out in two major sand areas on the Ordos Plateau and it was found that the dune sands were derived from local fluvial and lacustrine sediments (Peterov, 1959; Zhu et al., 1980; Wu, 1987; Liu et al., 2005).

In some locations the balance between fluvial and aeolian action has changed over relatively short time-scales, which may correspond to seasonal changes (for example ephemeral rivers). This presents the scenario where during dry seasons, the sand may travel over a dried-up river channel that crosses its transport pathway. The river may then form an obstacle to aeolian transport when river levels rise (Muhs et al., 2000). For example, Xu et al. (2006) studied 56 basins of the Yellow River in China and observed that in the areas with seasonally alternating wind–water action, during winter and spring, the aeolian sands driven by strong winds move slowly across river channels covering dry river beds and filling small gullies. In the following summer, the aeolian sand stored on the river bed was removed by flood events. At the Sachs River in Canada, the fluvial deposits of the ephemeral streams and the channel are subject to aeolian modification during the arid summer months to the extent that interbedded fluvial–aeolian sediments accumulate (Good and Bryant, 1985).

As shown above, the interactions between fluvial and aeolian processes are clearly important for the development of many landscapes, yet there is relatively little research investigating these interplays. Langford (1989) documented six types of modern fluvial–aeolian interaction after observing the Medano Creek intermixed with the aeolian landforms in the Great Sand Dunes in America, including: (1) aeolian landforms dammed streams; (2) interdune areas were flooded, particularly alongside channels and behind aeolian dams; (3) dunes bordering flooded channels and interdunes were eroded; (4) fluvial sediment was deposited in interdune areas; (5) interdunes were flooded by groundwater derived from the fluvial system; and (6) fluvial sediment was eroded by the wind and blown into the aeolian system. However, these six types were only described in temperate climates and at a local scale. Therefore, there is a clear need to examine, describe and classify the interaction between fluvial and aeolian processes at a large (global) scale.

This paper aims to provide a global classification, establish what interaction types exist and how common they are. This is carried out using a global inventory of fluvial–aeolian interactions based on different data sources (Landsat images, published literature, station records, etc.). In the following sections, the different types of interaction are categorised, and at each site additional information is collected to determine what may control the interactions and how this may change the geomorphology.

2. Methods

This study used a global visual search of fluvial–aeolian interactions using remotely sensed imagery hosted on Google Earth (GE). Using such remotely sensed images, however, presents difficulties as these images can only identify surface features and landforms—in effect the symptoms of aeolian and fluvial action. For this reason the study focussed on the interaction between sand dunes and rivers as both features are readily identifiable. Sand sheets were not recorded as it is difficult to accurately differentiate them from bare or scrub ground at the resolution of the imagery used here (e.g. Fig. 1A, B). The survey also excluded vegetated dunes as vegetation adds a level of uncertainty to the behaviour of the dunes that is difficult to interpret from satellite imagery (Fig. 1C, D). To augment the visual search examples from published studies were also used where available.

The search methodology started at the margins of dryland areas visually identified within Google Earth. The margins of these areas are where the aeolian and fluvial processes were most likely to meet each other (Bullard and Livingstone, 2002). Identifiable river courses were then traced up and down stream to find places where aeolian dunes interact with river courses. Interactions were identified at a regional scale, where the interaction within one single river catchment will be recorded as one case (Fig. 2A, B). On some very long-course rivers, that may cross more diverse landscapes or even different climatic zones, examples were selected where they were not located in the same region or where there were clear examples of different interaction types at different location (Fig. 2C). However, in some locations many small streams flow down from mountains and dissipate into dune fields. To prevent double counting such cases were recorded as a single example as these small streams are all located in the same region and all exhibit similar behaviour in interacting with the local aeolian process (Fig. 2D). To additionally reduce uncertainty wherever examples are located, the location must be in areas outside of the influence of obvious human activity. As a result many places with fluvial and aeolian interactions were excluded from the final dataset because of the high population densities found along many rivers, for example, the Tarim River on the north border of Taklamakan Desert in China (Fig. 1E).

At each site, several other basic variables were recorded: the channel type, the dune type, the channel flow direction and the aeolian transport direction. These allowed further analysis of possible causes of different types of fluvial/aeolian interaction. The following sections describe the classification method, as well as how channel pattern, dune type, channel flow direction and wind direction were determined.