



# Analysis of the problem of sand dunes

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## Why dunes in a lesson on complexity?

The movement of sand dunes in the desert is an **emerging process**

- the overall motion of a dune is influenced by both the random interactions between individual sand particles and the action of the wind that adds and removes sand
- explaining the movement of a dune in the desert requires reasoning at different 'levels'.
  - microscopic (grains of sand)
  - macroscopic (dune-shaped)

# The processes behind the motion of a dune

- The wind deposits grains of sand on a dune
- Grains of sand are blown off a dune by the wind
- Grains of sand drift down the dune due to the effect of gravity
- These three processes occur at different **frequencies**
- Depending on how these frequencies are combined, the dunes **change in size**
- In addition, if the frequencies are not evenly distributed on the sides of the dune, the **displacement of** the dune in the desert can be deduced

# The processes behind the motion of a dune

## Desert dune processes and dynamics

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**Abstract:** This article reviews the advances made and problems encountered in the measurement, modelling and understanding of desert dune dynamics and processes in the last two decades. The main findings of three methods of investigation are reviewed: field studies, wind tunnel studies and mathematical modelling. Whilst major advances in field techniques have allowed an appreciation of the aerodynamic nature of sand dunes, particular problems with field research are evident in the measurement of aeolian processes on dune surfaces. Specifically, it is shown that attempts to ascertain shear stresses on dune windward slopes in the field and relate changes in stress to sand transport rate and erosion/deposition measurements have generally failed. These difficulties have arisen because the non-log-linear nature of wind velocity profiles on dune surfaces as a result of windflow acceleration has made the calculation of surface shear stresses unviable. Significant advances have been achieved in wind tunnel modelling where high-frequency hot-wire anemometer measurements have enabled shear stress and turbulence characteristics to be determined, although problems have been encountered in choosing appropriate scaling parameters. Empirical field and wind tunnel data have allowed the calibration of mathematical models which are now at a stage where the flow field around dunes can be calculated. It is considered, however, that the emerging technique of modelling using complex systems theory may hold the key to constructing a reliable framework for future investigations. New complex systems models have emphasized the need to return to a larger-scale perspective where dunes are not considered as individual elements, but as an integral part of a dunefield where aeolian processes at the dune scale are not thought to be significant.

## Laurel's explanation

- Let's look at the explanation by Laurel (pseudonym), a student in a master's degree programme in education, with a background in mathematics
- In the interview, Laurel formulates **several explanations** for the phenomenon of dune movement in the desert
- Explanations at **three different levels** (macro-micro-intermediate)
- The concluding explanation holds all three levels together simultaneously
- The full article (Barth-Cohen, 2018) will be available in the in-depth discussions at the course

“cause I don't think the wind would blow the whole sand dune all at once. But it could blow all the little, [pause] all the little, all the, the little sand molecules, like whatever // umm // like little by little.”

"because I don't think the wind blows the whole sand dune away all at once. But it might blow over all the little [pause] all the little, all the, the little molecules of sand, like // umm // that is, a few at a time."

## 'The dune does not move all at once'

“cause I don't think the wind would blow the whole sand dune all at once. But it could blow all the little, [pause] all the little, all the, the little sand molecules, like whatever // umm // like little by little.”

- It is not *the dune* moving from one side to the other
- Rejects an idea of centralised causality, according to which there is something external forcing the system to behave in a certain way overall
- Start considering the microscopic level, the molecules of sand

“I keep thinking about a joke or a story, you know if a bird comes and takes one grain of sand and then dumps it and one grain of sand and dumps it, then like, if you keep dumping them on top of each other it would be like, you know, when you dump whole bunch of sand and it makes like a cone shape. That would make sense. But, I don't know how the wind, cause the wind doesn't work like that linearly.”

"I keep thinking about that story, you know, if a bird comes and takes a grain of sand and then dumps it, and a grain of sand and dumps it, so if you keep dumping them on top of each other it would happen like when you dump a whole pile of sand it would make like a cone shape. That would make sense. But I don't know how the wind does it, because the wind doesn't work that linearly."



## "Like a bird forming sand cones?"

“I keep thinking about a joke or a story, you know if a bird comes and takes one grain of sand and then dumps it and one grain of sand and dumps it, then like, if you keep dumping them on top of each other it would be like, you know, when you dump whole bunch of sand and it makes like a cone shape. That would make sense. But, I don't know how the wind, cause the wind doesn't work like that linearly.”

- There is a deterministic mechanism in this explanation: the bird picking up the grains of sand one by one and accumulating them to form cones
- "That would make sense"
- However, he rejects the idea because the wind does not behave in a linear manner like a well-trained bird

“cause I don't think the wind would blow the whole sand dune all at once. But it could blow all the little, [pause] all the little, all the, the little sand molecules, like whatever // umm // like little by little.”

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- Focus on the dune as a whole (macroscopic level)
- Step forward: the dune moves little by little

- Focus on sand particles (microscopic level)
- Step forward: particles accumulate

Both explanations - which Laurel rejects - are deterministic

“This top layer of sand would kind of get blown first... But some of the outside of the sand dune [motions for the outside of a dune] would kind of get blown over here and then it would kind of end up somewhere and then now that layer gone so then if the wind kept blowing, then it would kind of blow, whatever, some of the outside again, and those ones would get blown over here somehow and then it would start, I don't know. Then it would keep doing that until it all kind of moved over here, to a new sand dune. But then, I know that when its windy, its not like the wind is constant, it's always blowing in exactly this direction at exactly the same, exactly the same strength, because if it were that would make sense right.”

"This top layer of sand would be blown first.... But some of the outside of the sand dune [movements for the outside of a dune] would be blown from here and then it would end up somewhere and then now that layer is gone, so if the wind kept blowing, then it would blow some of the outside again, and those would be brought here somehow and then it would start, I don't know. Then it would keep doing that until it all moved here, to a new sand dune. But then, I know that when there's wind, it's not constant, it doesn't always blow in this direction at exactly the same force, because if it did it would make sense."

## 'A dune made of layers'

“This top layer of sand would kind of get blown first... But some of the outside of the sand dune [motions for the outside of a dune] would kind of get blown over here and then it would kind of end up somewhere and then now that layer gone so then if the wind kept blowing, then it would kind of blow, whatever, some of the outside again, and those ones would get blown over here somehow and then it would start, I don't know. Then it would keep doing that until it all kind of moved over here, to a new sand dune. But then, I know that when its windy, its not like the wind is constant, it's always blowing in exactly this direction at exactly the same, exactly the same strength, because if it were that would make sense right.”

- An intermediate level intervenes: that of the sand layers of which the dune is composed.
- First he says that the layers move in sequence, first the wind blows the higher and outer ones and then gradually the others
- However, it also rejects this explanation because the wind is not constant

“Sand that was being blown would get stuck there, or not stuck, but like it would kind of, maybe hit the, it could hit the, hills somehow and stop there, right? It would kind of join in, in a way, with that little pile and then it would start get bigger and bigger.”

"The sand blown away would get stuck there, like it would hit the slopes somehow and stop there, right? It would sort of join that little pile and then it would start to get bigger and bigger."

## 'Growing piles of sand'

“Sand that was being blown would get stuck there, or not stuck, but like it would kind of, maybe hit the, it could hit the, hills somehow and stop there, right? It would kind of join in, in a way, with that little pile and then it would start get bigger and bigger.”

- When sand is moved by the wind, it accumulates along the dune slopes and adds to what is already there
- The explanation concerns individual sand particles but is used to justify the increase in size of the entire dune (macroscopic level)

“I was saying how the wind was like taking the outside layer or something, maybe it's like this big and then it starts doing that and the dune gets smaller. But it wouldn't get flat probably, there would still be a little cone there and then maybe that would start collecting more and growing and then the wind could take it away get smaller and like this. Maybe it's more like a wave getting bigger and then getting smaller and then getting bigger. Just rotating like that....Maybe it depends on like, cause if things are being, like joining in and some things are being blown away, I'm thinking that if that's happening equally then its never going to change.”

I was saying that the wind would pick up the outer layer or something, maybe the dune is this big and then the wind starts to blow and the dune gets smaller. But it probably wouldn't become flat, there would still be a cone there and then maybe it would start to pick up more and grow, and then the wind might take it away and get smaller and like that. Maybe it's more like a wave that gets bigger and then smaller and then bigger. A cycle like that... Maybe it depends... because if some things bunch up and then other things get blown away, it occurs to me that if this happens the same way, then it will never change!

## "Maybe it's more like a wave."

“I was saying how the wind was like taking the outside layer or something, maybe it's like this big and then it starts doing that and the dune gets smaller. But it wouldn't get flat probably, there would still be a little cone there and then maybe that would start collecting more and growing and then the wind could take it away get smaller and like this. Maybe it's more like a wave getting bigger and then getting smaller and then getting bigger. Just rotating like that....Maybe it depends on like, cause if things are being, like joining in and some things are being blown away, I'm thinking that if that's happening equally then its never going to change.”

- This explanation contains the idea of an emergent phenomenon: the wind blows sand away and the dune accumulates more (circular pattern)
- The wave similarity to explain the emergent property
- Here Laurel moves on the three levels introduced earlier:
  - the movement of individual sand particles
  - the overall change in the dune
  - the intermediate layer of layers



# Inventing a “Mid Level” to Make Ends Meet: Reasoning between the Levels of Complexity

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