Dynamic intermittency in discrete erodible-bed avalanches

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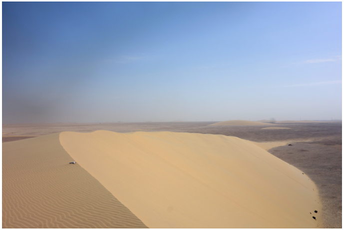
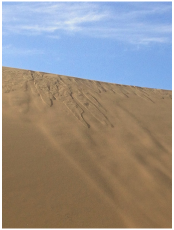
Geoflo16, 14th March 2016

Outline

Dune structure

- Consistent sub-cm layering observed
- Significant effect on water permeation
- Arises from slip-face avalanches



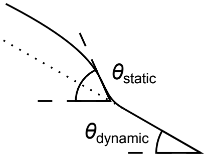


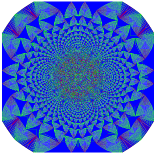
Granular unjamming transition

- Flowing and static regions can be regarded as two phases
- Unjamming/Jamming as flow starts/stops a phase transition
- Behaviour determined by order of transition

A first or second-order transition?

- First-order transition:
  - Associated with a 'latent heat'
  - Described by 'static' and 'dynamic' angles of repose
  - Gives rise a simple hysteresis and periodicity
  - Observed by e.g. Jaeger et al (1989), Evesque (1991)
- Second-order transition:
  - Predicted by BTW theory of Self-Organised Criticality
  - Local dynamics result in macroscopic power-law behaviour
  - Mixed evidence: only for rice/precursors? Not at all?

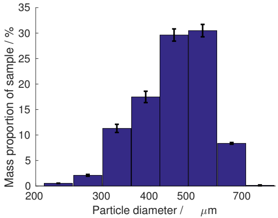


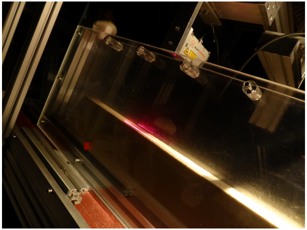


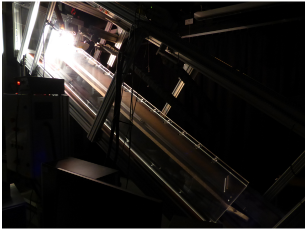
Credit:
Claudio Rocchini

Apparatus

- Channel 2m long, 5cm wide
- Inclination 32^o
- Grains construction sand $d_{4,3} = 470\mu$m.
- 11cm deep erodible bed developed
- Influx 0.9, 3.3 cm^{3}s^{-1}



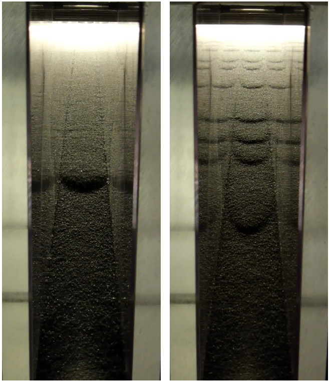




Observed behaviour

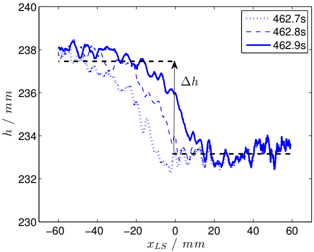
Dynamic intermittency observed between two regimes:

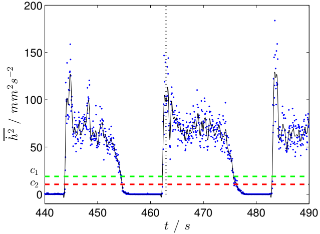
1. Quasi-periodicity:
   - Avalanches at approximately constant intervals
   - Propagation consistently to end of chute
2. Irregularity:
   - Intervals between avalanches highly variable
   - Most avalanches stop part-way down



Continuous time measurements

- Laser scanner fixed at each of 19 distances downslope
- Flow rate and profile rate constant
- Times detected at which avalanches in field of view
- Avalanche front heights and positions extracted





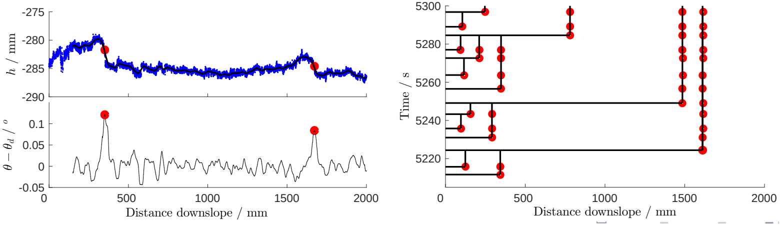
Continuous position measurements

For each avalanche:

- Inflow stopped at start of avalanche
- Entire bed profile measured after cessation
- Flow restarted and time until next avalanche measured

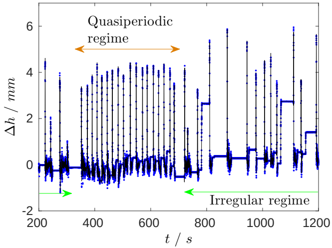
From measured profiles:

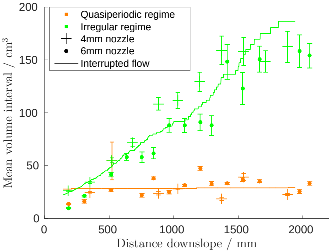
- Stopped front positions detected
- Avalanches reconstructed



Avalanche intervals

- Regimes easily distinguished from data
- Results collapse under scaling by flux rate
- Mean interval between avalanches constant/linear with distance downslope in quasiperiodic/irregular regime
- Implies avalanche length distributions $f_A(L) = 0$ / $f_A(L) \sim L^{-2}$





Experimental Summary

Observations indicate two regimes:

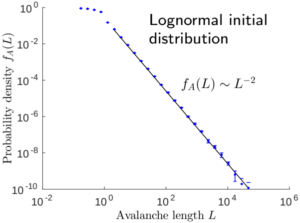
- Quasiperiodic regime, non-stopping
  - typical of first-order phase transition
- Irregular regime, power-law probability distribution
  - typical of second-order phase transition
- Dynamical intermittency between them

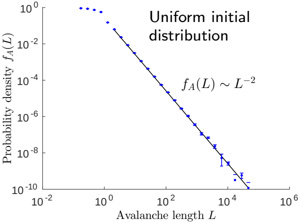
Questions:

1. How does power-law behaviour emerge?
2. Why does the system switch between regimes?
3. Why does the system tend to stay in each regime?

Emergent L^{-2} behaviour

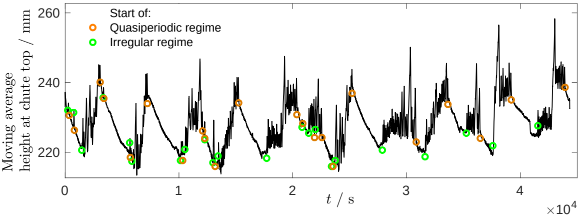
- Minimal model of stopping avalanches
- For ith avalanche:
  - Say ordered stopped fronts at $(s_j^{(i)})_j$
  - Assign 'initial length' $l^{(i)}$
  - While $l^{(i)} > s_1^{(i)}$:
    - Stopped front overrun
    - $(s_j^{(i)}) := (s_2^{(i)}, s_3^{(i)}, \ldots)$,
      $l^{(i)} := l^{(i)} + s_1^{(i)}$
  - Avalanche stops, length $^{(i)}$
  - $(s_j^{(i+1)}) := (l^{(i)}, s_1^{(i)}, s_2^{(i)}, \ldots)$
- Reproduces $f_A(L) \sim L^{-2}$
- Insensitive to initial length distribution





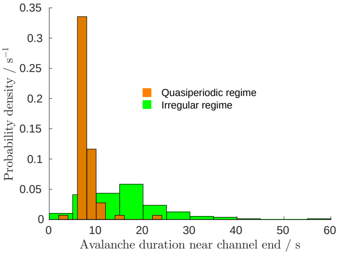
Regime switching

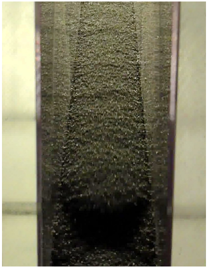
- Laser scanner fixed at channel's top
- Profiles taken over more than 100l of sand drainage
- Note net erosion/deposition in quasiperiodic/irregular regime
- Lower/higher bed angle increases/decreases likelihood of avalanche stopping

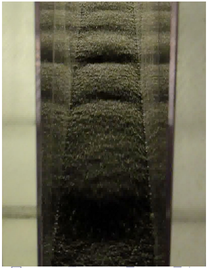


Regime continuation

- Governed by state of erodible bed
  - Avalanches stop when local bed angle sufficiently low
- Role of secondary instabilities?
  - In irregular regime, full-length avalanches less frequent
  - Therefore larger volume, longer duration
  - Therefore roll waves larger amplitude
  - Therefore local bed angle more variable?







Conclusions

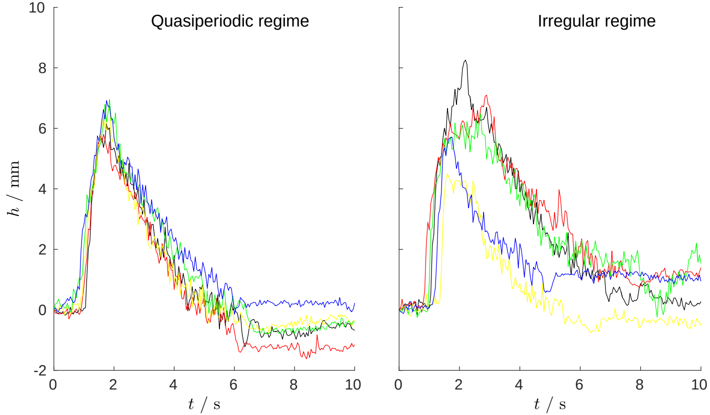
Current progress:

- Two regimes of behaviour observed, quasiperiodic and irregular
- Behaviour in each reproduced by simple models
- Intermittency between them explicable via bed state

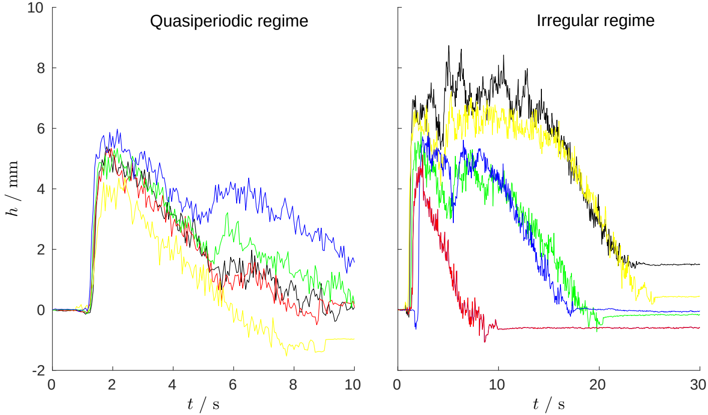
Future work:

- Apply depth-averaged continuum model
- Examine effect on and of bed angle mean, variation
- Consider effect on structure via segregation

Avalanche profiles: top



Avalanche profiles: bottom



Front heights & speeds