Dynamic intermittency in discrete erodible-bed avalanches

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Outline

Motivation

Observations

Analysis

Modelling
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

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?
Apparatus

- Channel 2m long, 5cm wide
- Inclination 32°
- 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 $f_A(L) = 0 / f_A(L) \sim L^{-2}$
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 $i$th avalanche:
  - Say ordered stopped fronts at $(s_j^{(i)})_j$
  - Assign ‘initial length’ $l^{(i)}$
  - While $l^{(i)} > s_1^{(i)}$:
    - Stopped front overrun
    - $(s_j^{(i)}) := (s_2^{(i)}, s_3^{(i)}, ...)$,
    - $l^{(i)} := l^{(i)} + s_1^{(i)}$
  - Avalanche stops, length $(i)$
  - $(s_j^{(i+1)}) := (l^{(i)}, s_1^{(i)}, s_2^{(i)}, ...)$
- 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?

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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

Quasiperiodic regime

Irregular regime

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Avalanche profiles: bottom

Quasiperiodic regime

Irregular regime

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Front heights & speeds

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