The growth of snow bedforms

Kelly Kochanski

July 2020

NASA/Goddard Space Flight Center
Scientific Visualization Studio


NORTH
PACIFIC
OCEAN
ATLANTIC
SOUTH
AUSTRALIA

How does snow affect global climate?

Compared to other common materials on the surface of the Earth - like dirt, plants, sand, ice, and ocean water - snow is:

- Highly reflective, and
- Excellent thermal insulation

Thus, snow insulates the ground from hot sunlight and from warm (or cold) air.

How does wind alter snow properties?

Wind changes the structure and roughness of snow surfaces:

- It moves mass around
- It creates roughness elements, like sastrugi
- It may create bare patches on the surface

These changes increase the fluxes of solar and sensible heat through the snow

Antarctica (G. Doumani, 1967)

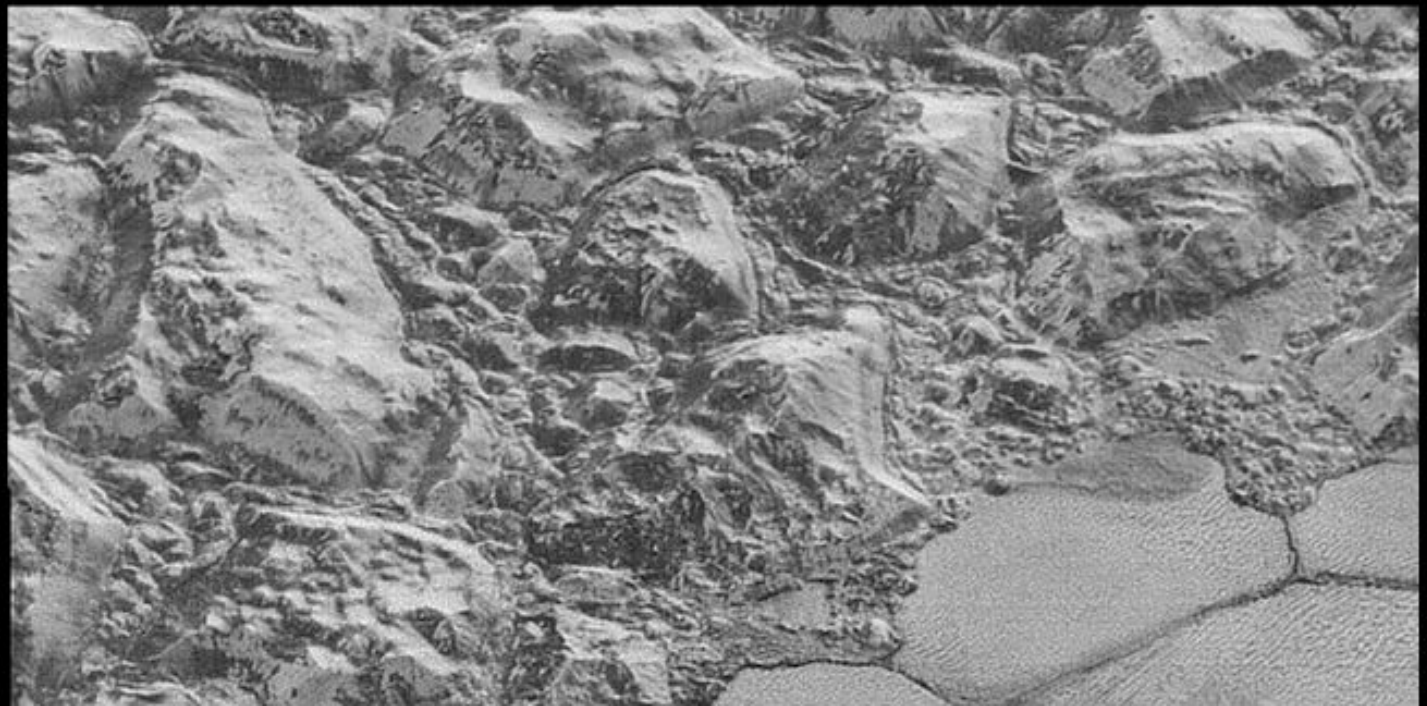

Hungary (R. Barnes, 2012)

SCI-TECH

Dunes on Pluto made of tiny frozen grains of methane

Marcia Dunn
The Associated Press

Published Thursday, May 31, 2018 2:19PM EDT
Last Updated Thursday, May 31, 2018 3:05PM EDT



The growth of snow bedforms

Kelly Kochanski

July 2020

Fieldwork

Dunes

Sastrugi (eroding)

Ripples

Dunes, again

Snow-steps (eroding)

Dunes again, both depositing and eroding

Patches

Waves

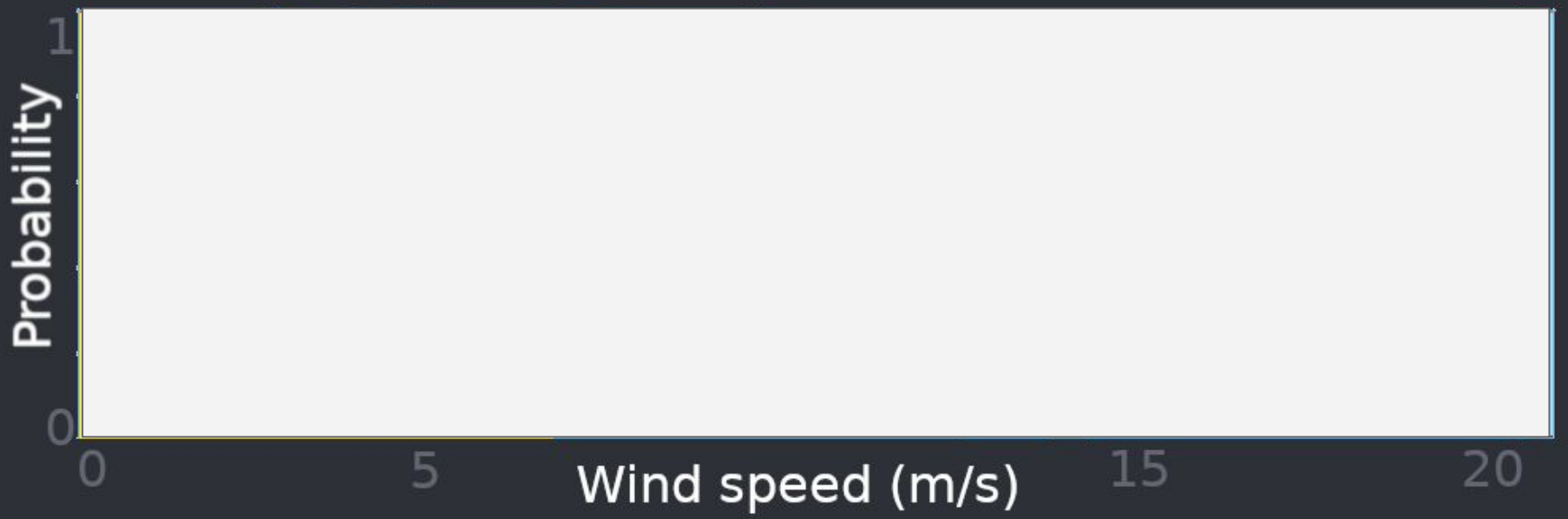
Many bedforms

Fieldwork

- 1082 hours of time-lapse footage over 3 years
- Largest snow bedform dataset by 1-2 orders of magnitude
- Led to publications in GRL and The Cryosphere

Wind speed controls surface texture

For the first day after snowfall

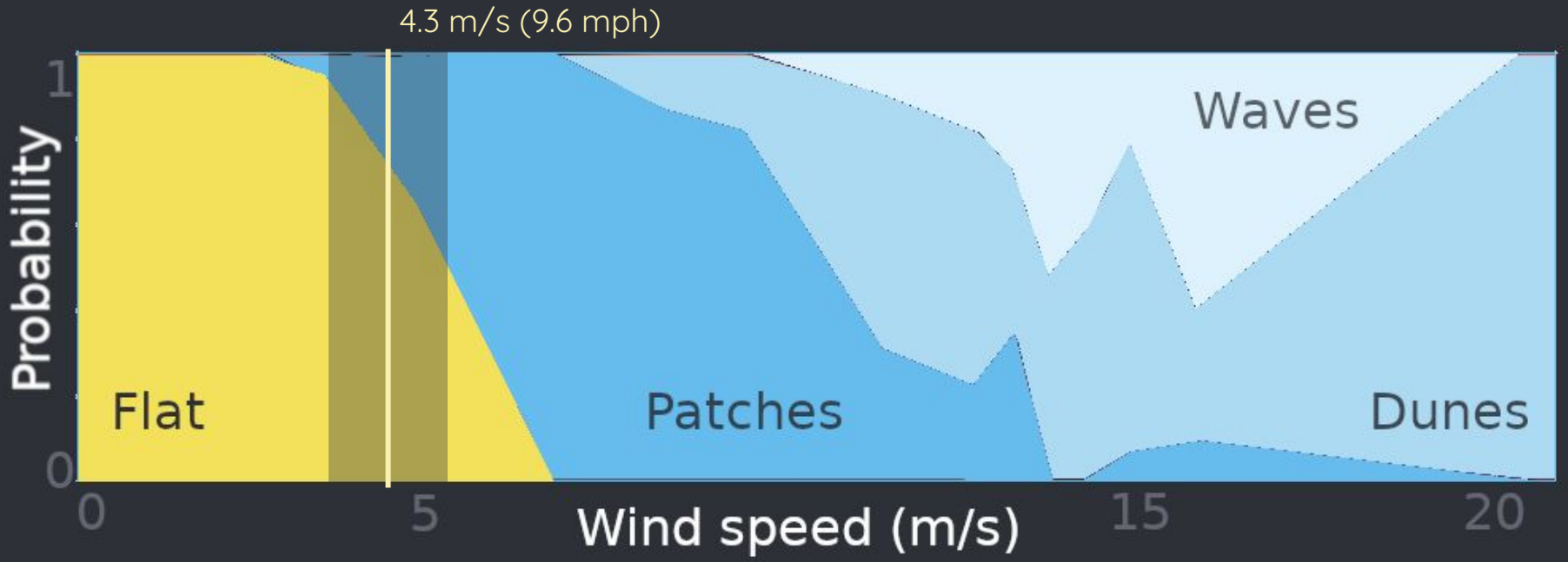


Wind speed controls surface texture

For the first day after snowfall

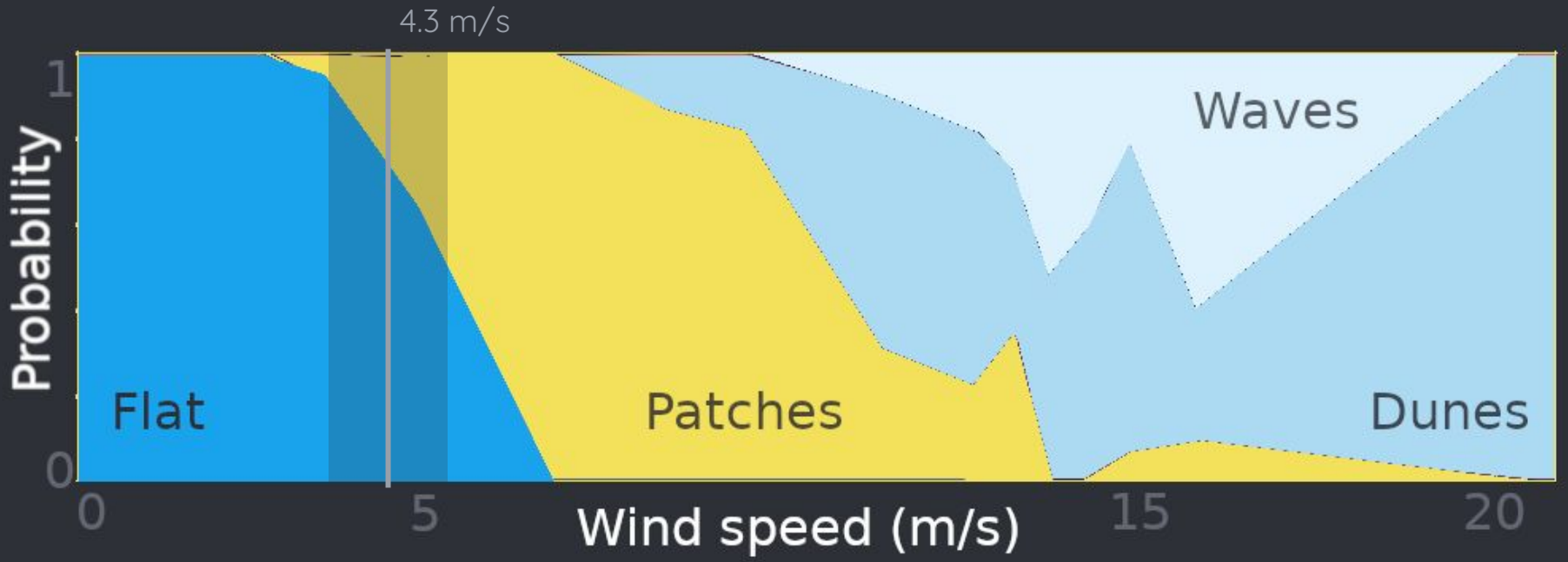
Wind speed controls surface texture

For the first day after snowfall



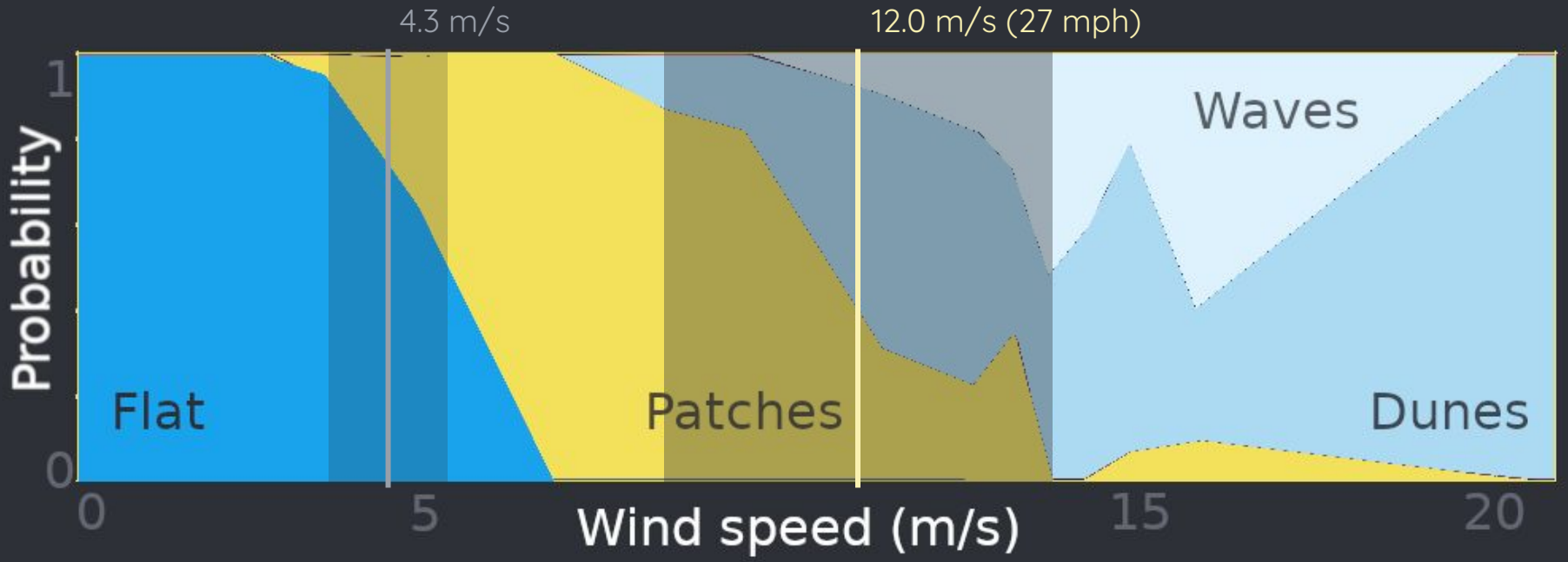
Wind speed controls surface texture

For the first day after snowfall



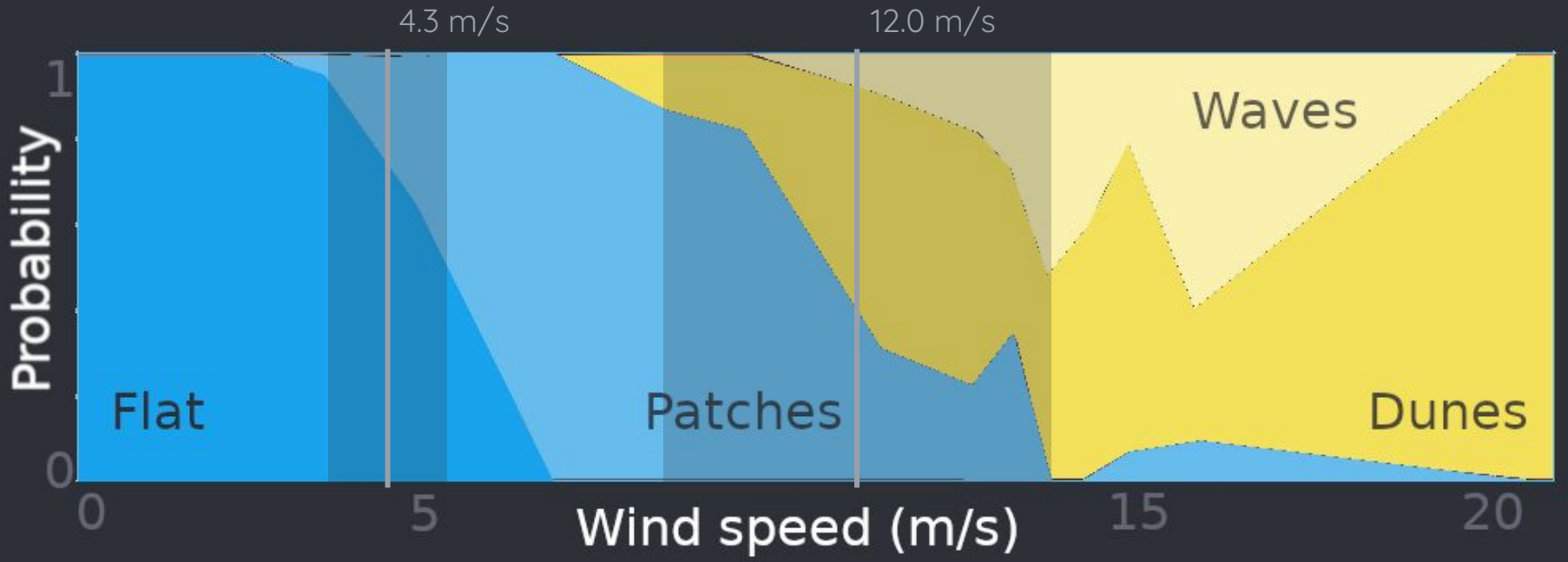
Wind speed controls surface texture

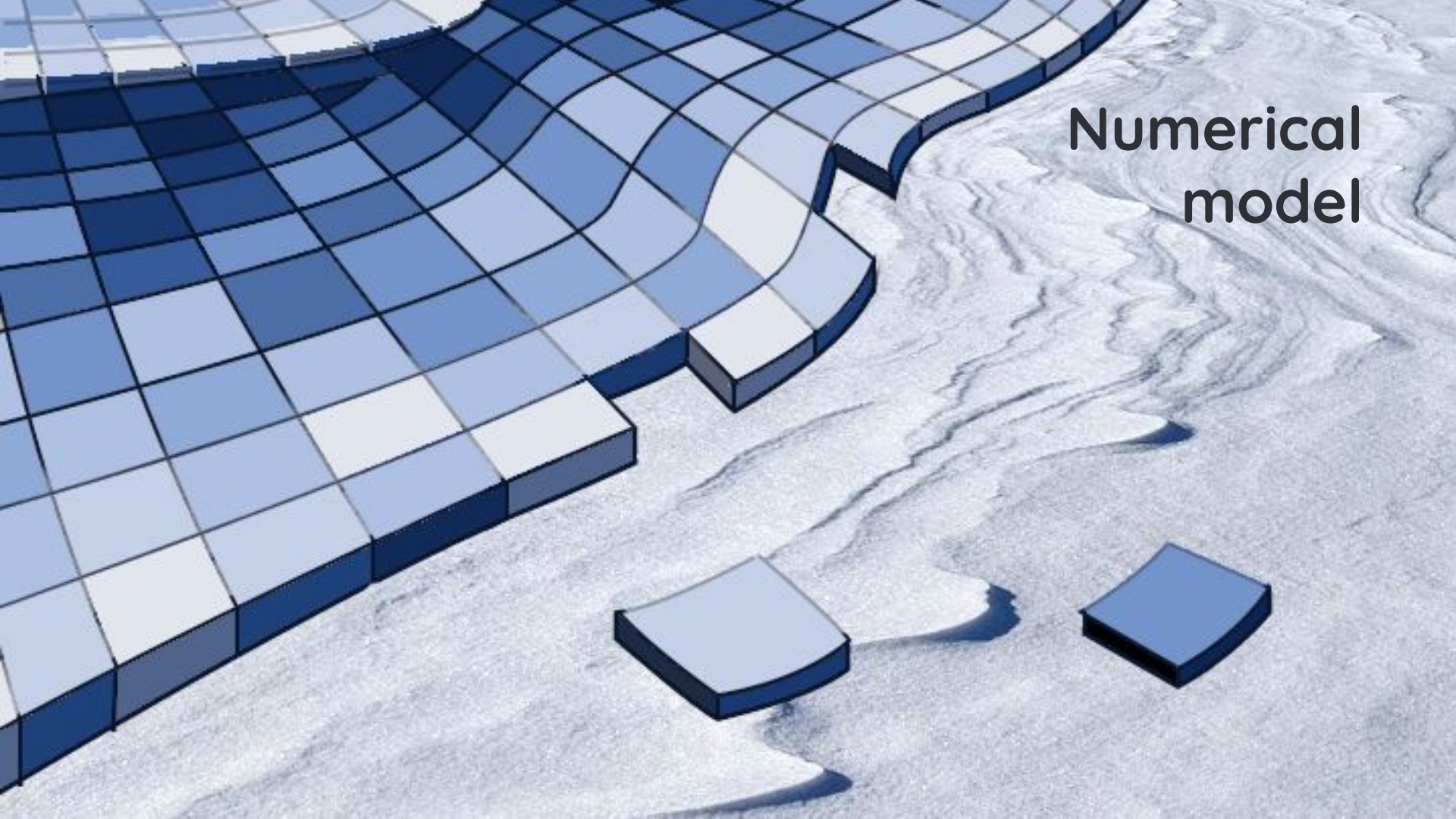
For the first day after snowfall



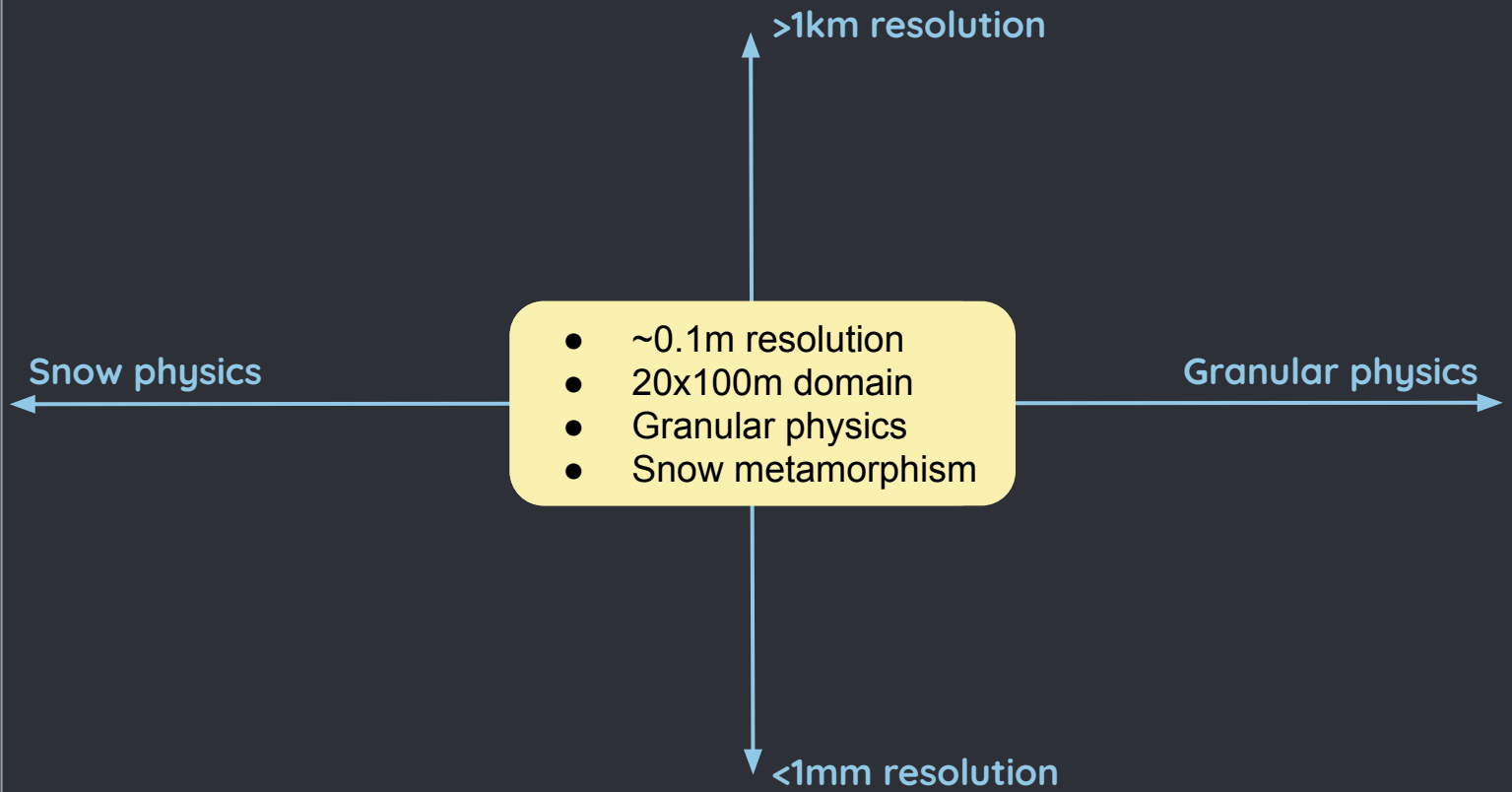
Wind speed controls surface texture

For the first day after snowfall

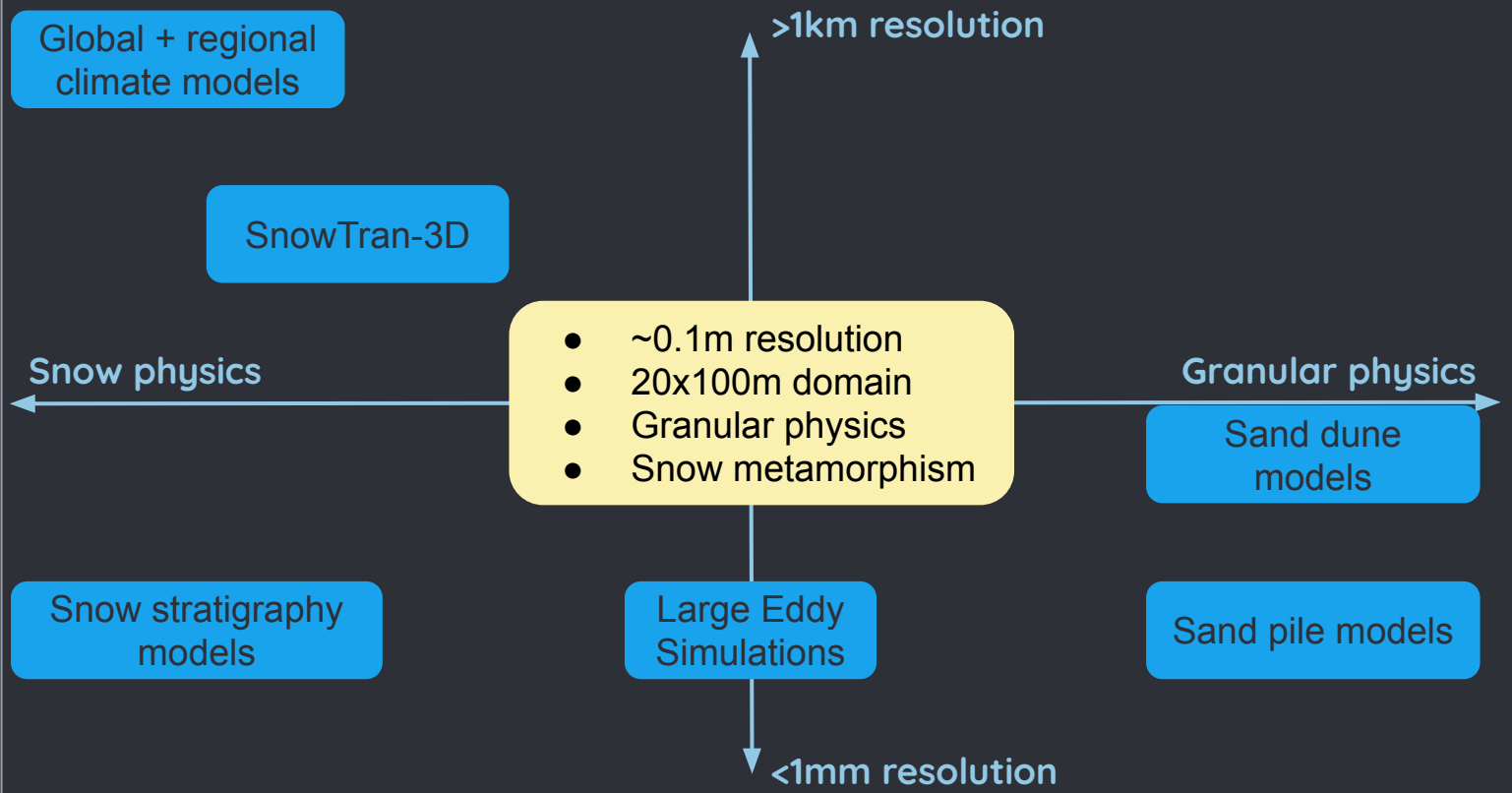



Numerical
model

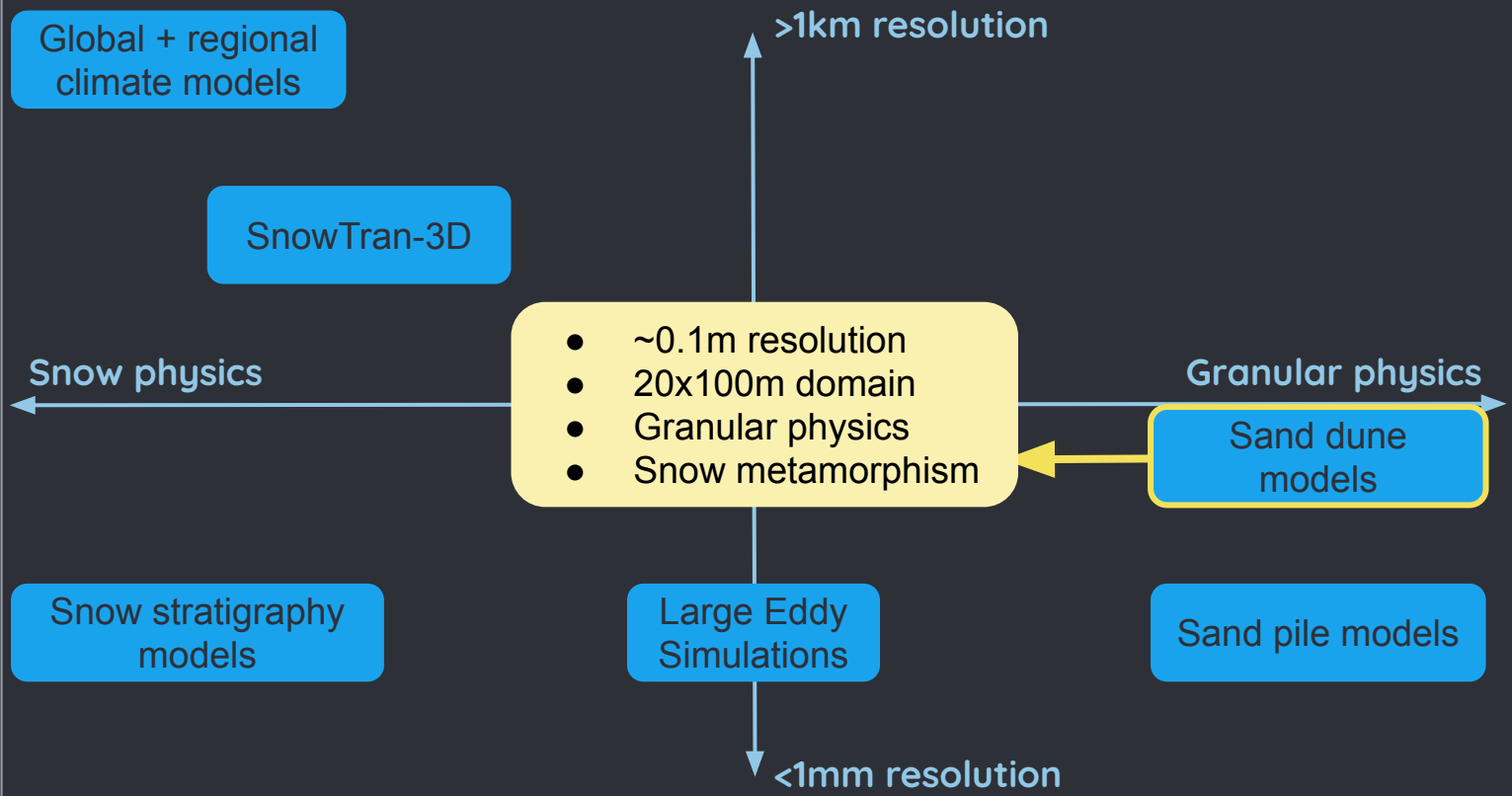
Model specification



Existing models



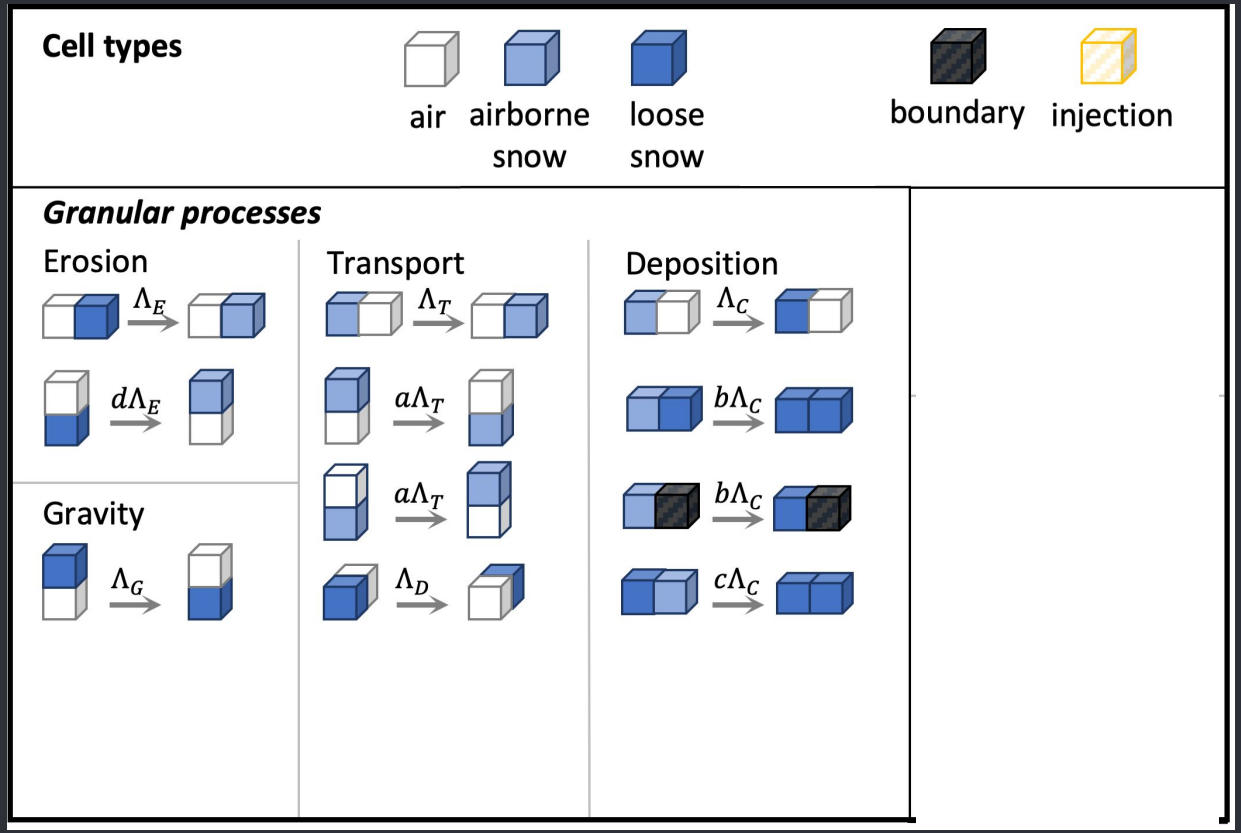
Existing models



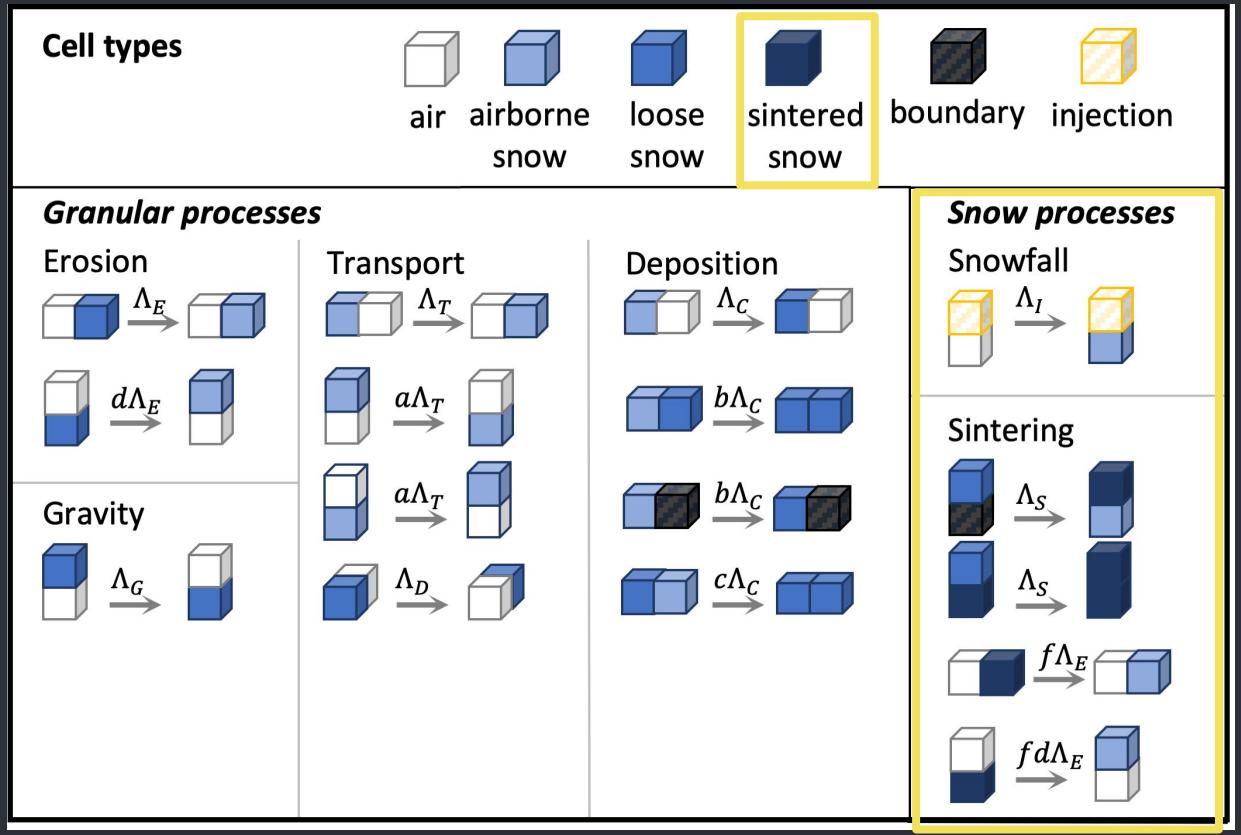
Model selection

ReSCAL: A Real-Space Cellular Automaton Laboratory
Rozier & Narteau, 2014, *Earth Surface Processes and Landforms*

Model architecture: cellular automaton



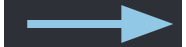
Model improvements: new snow physics



Technical improvements

- Complex calibration procedure
  - Quantified calibration uncertainty
- Irritatingly slow
  - Optimized random number generator (bottleneck)
  - Figured out why it can't be parallelized
- Enigmatic comments in broken French
  - New documentation and tutorial

```
743  void propagate_mvtcel(int32_t i, int32_t ii) {
744    int32_t ii0;
745
746    CelMvt[ii] = 0;
747
748    //SOLID+OUT
749    CelMvt[ii] |= (CelMvt2[ii] & (MVT_SOLID | MVT_OUT));
750
751    //EST
752    ii0 = ii - 1;
753  #ifdef CYCLAGE_MVT
754    if (i == NB_MVT_EO) {
755      ii0 += CLEO - 2 * NB_MVT_EO;
756    }
```



1. Tutorial aims and features
2. Getting started
   i. Prerequisites
   ii. Example 1: a snow cone
3. Controlling the simulations
   i. Example 2: sintering snow
   ii. Example 3: dune growth by snowfall
4. Visualizing the output
5. Setting up parallel runs
   i. Example 4: parameter space exploration

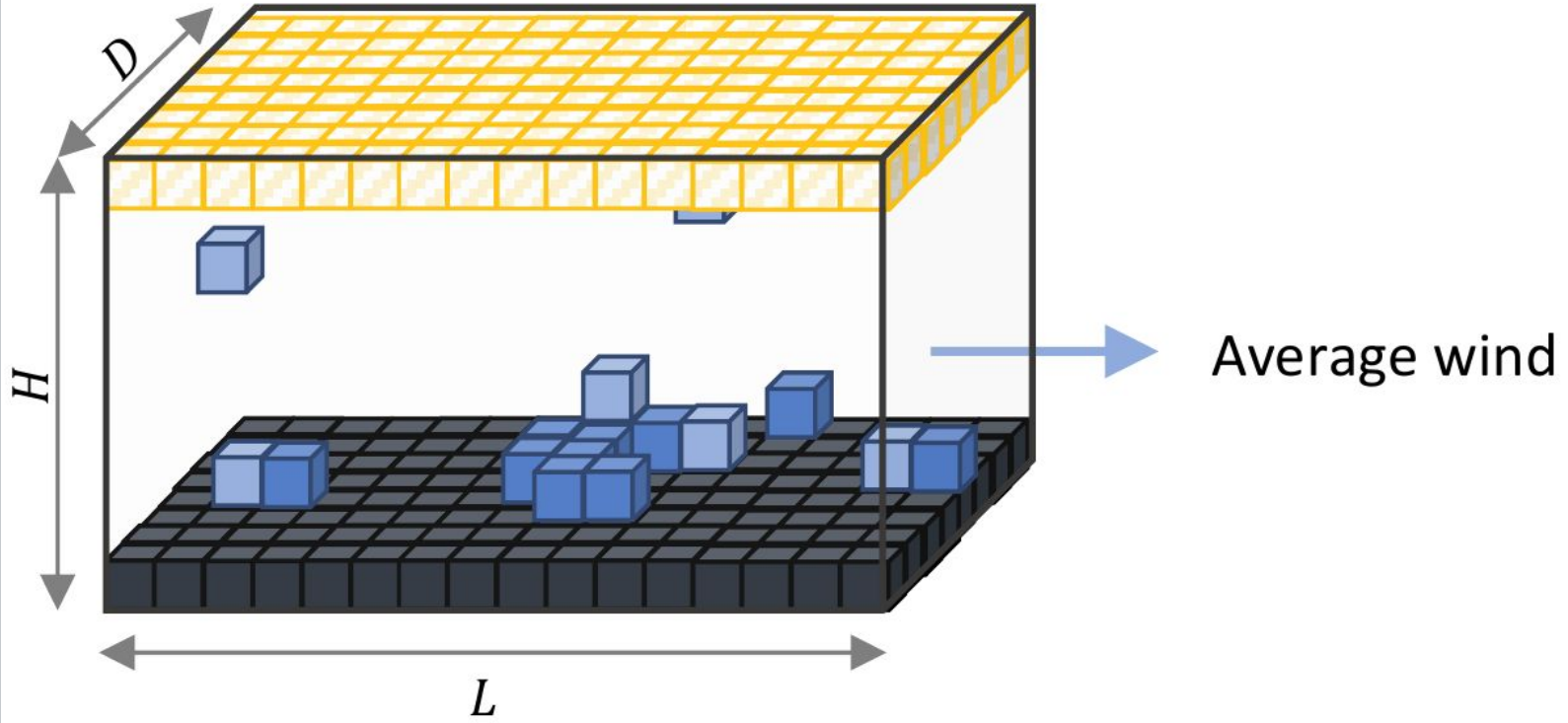
1. Tutorial aim and features

This tutorial walks through a series of examples that demonstrate how to use Rescal-sn

Numerical model

- First snow bedform model
- Documented, open source
- Published in JOSS

Numerical experiments simulate wind and snowfall

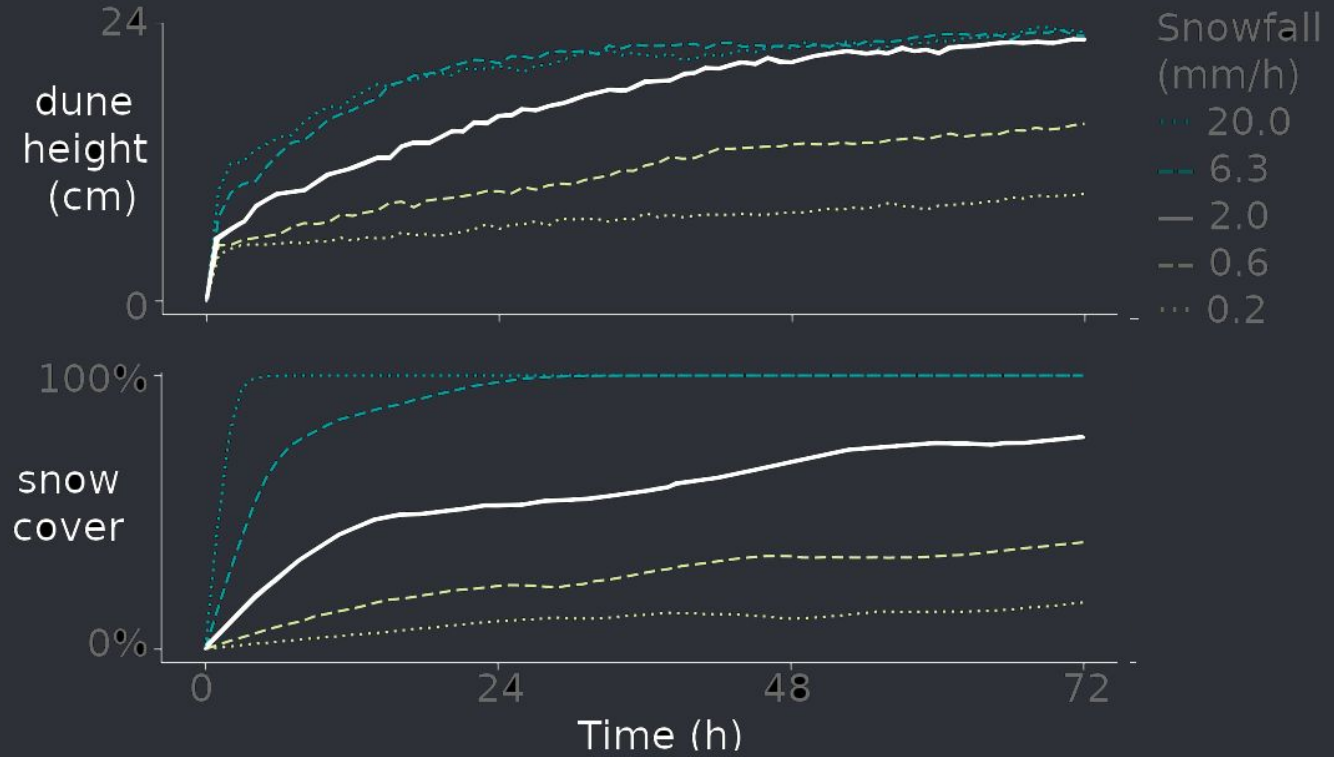



10m

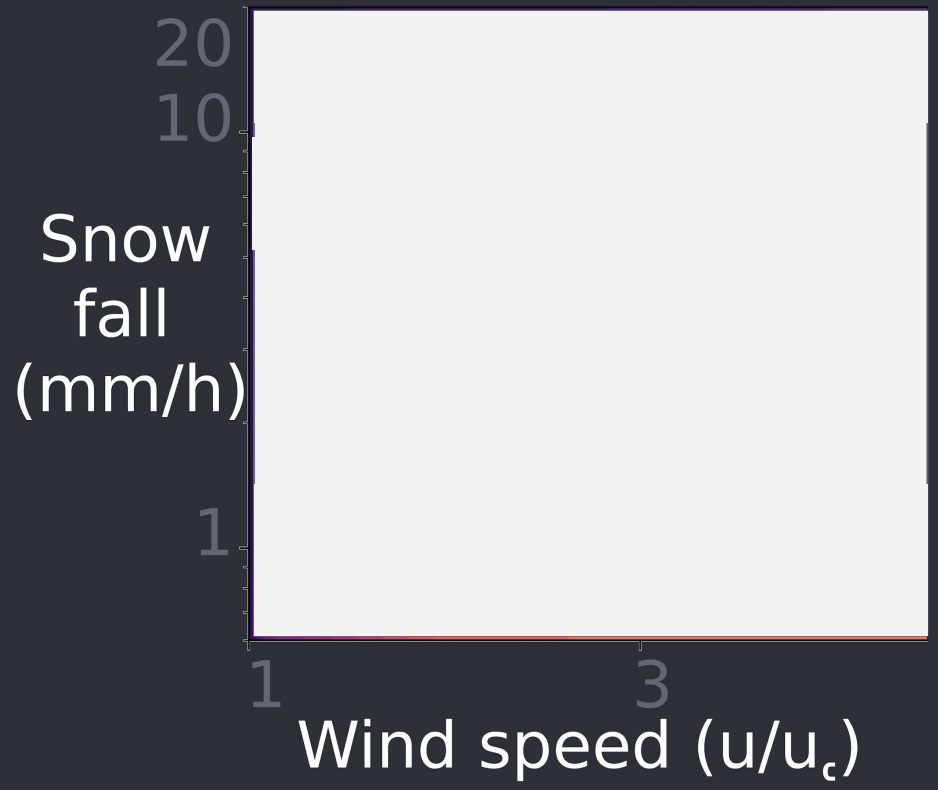
Slow snowfall builds widely-separated bedforms

These examples are at a fairly high wind speed, u/uc = 2 (or about 23mph)

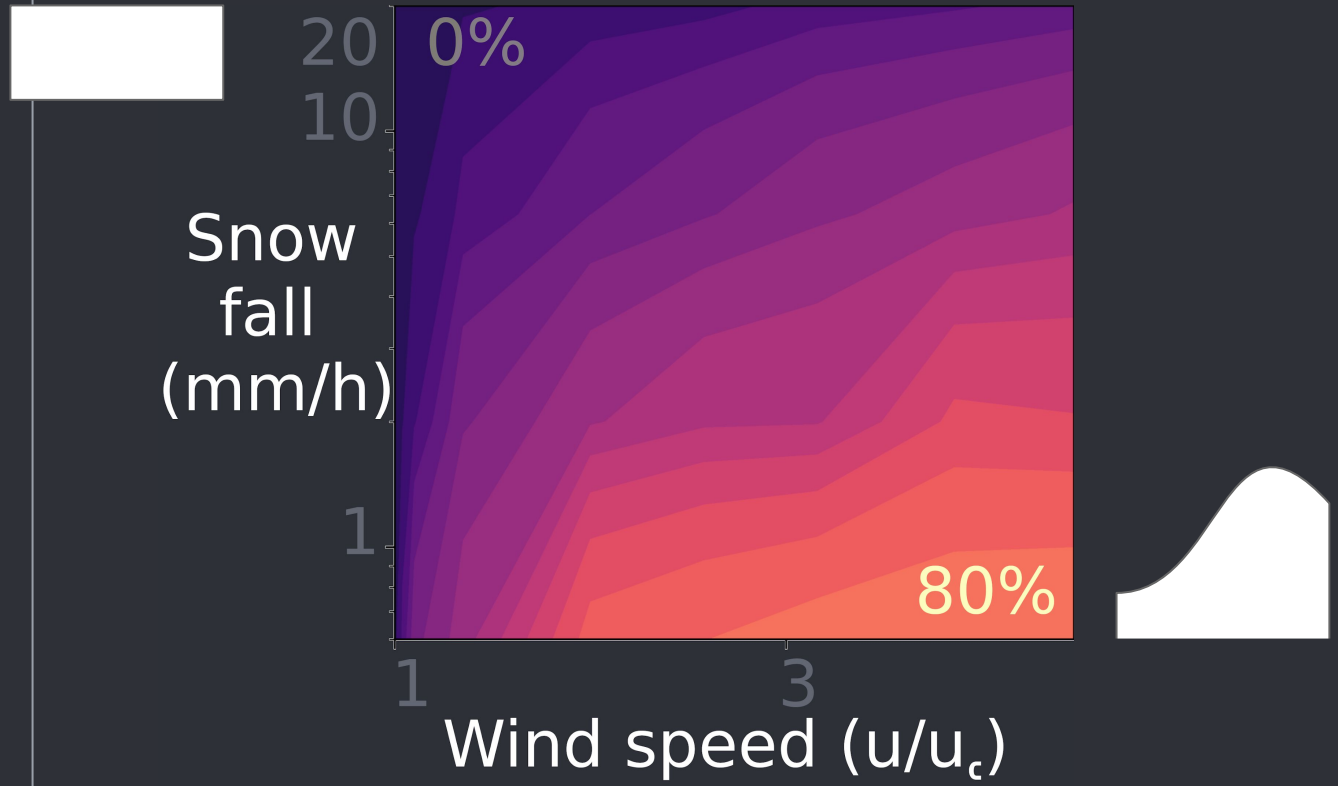
- Slow snowfall builds widely-separated bedforms



- Wind and snowfall change snow geometry

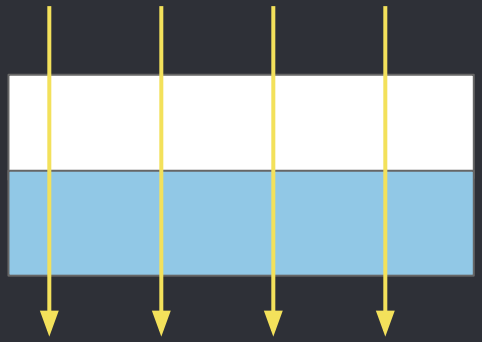


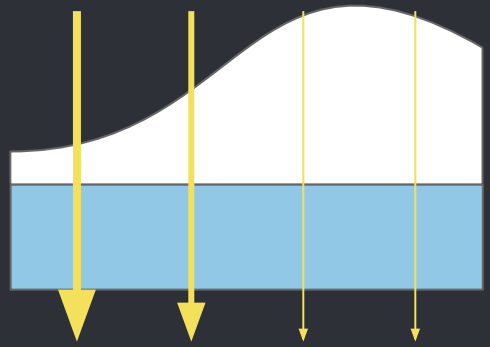
Bedforms increase the **standard deviation** of snow depth



Variable depth increases heat transfer

Example:
10cm of snow on top of 10 cm of sea ice in the Bering Strait

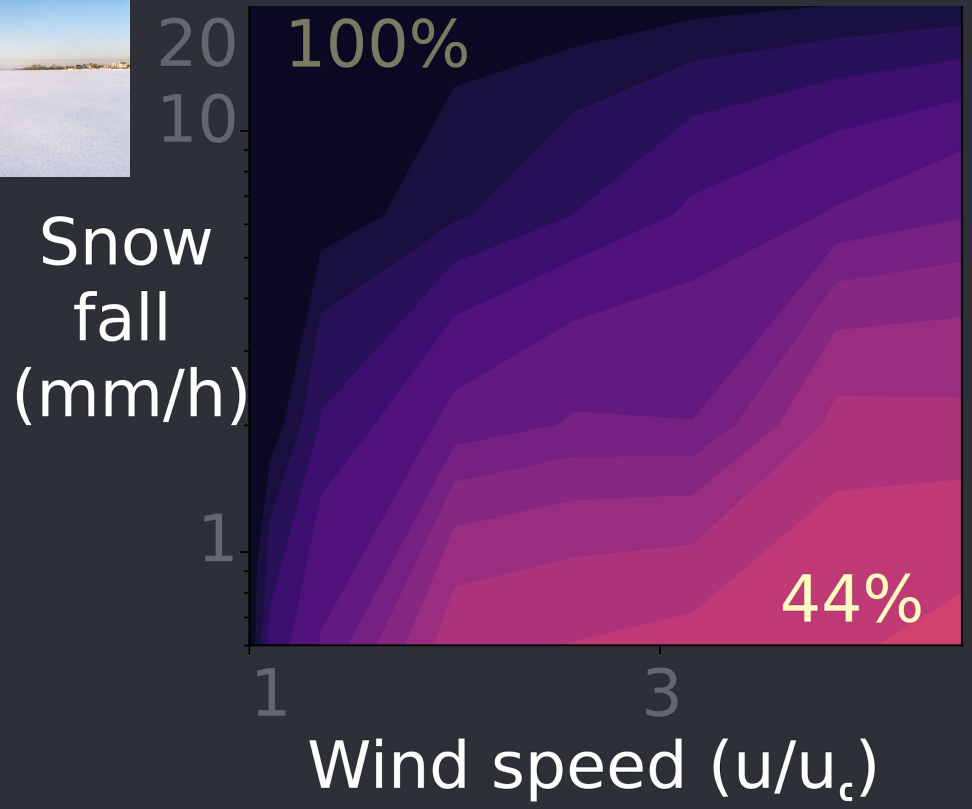




Heat flux +45%

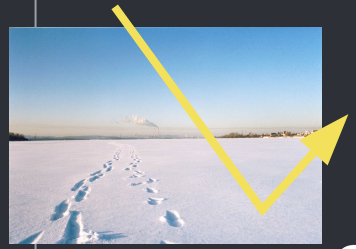
Bedforms decrease

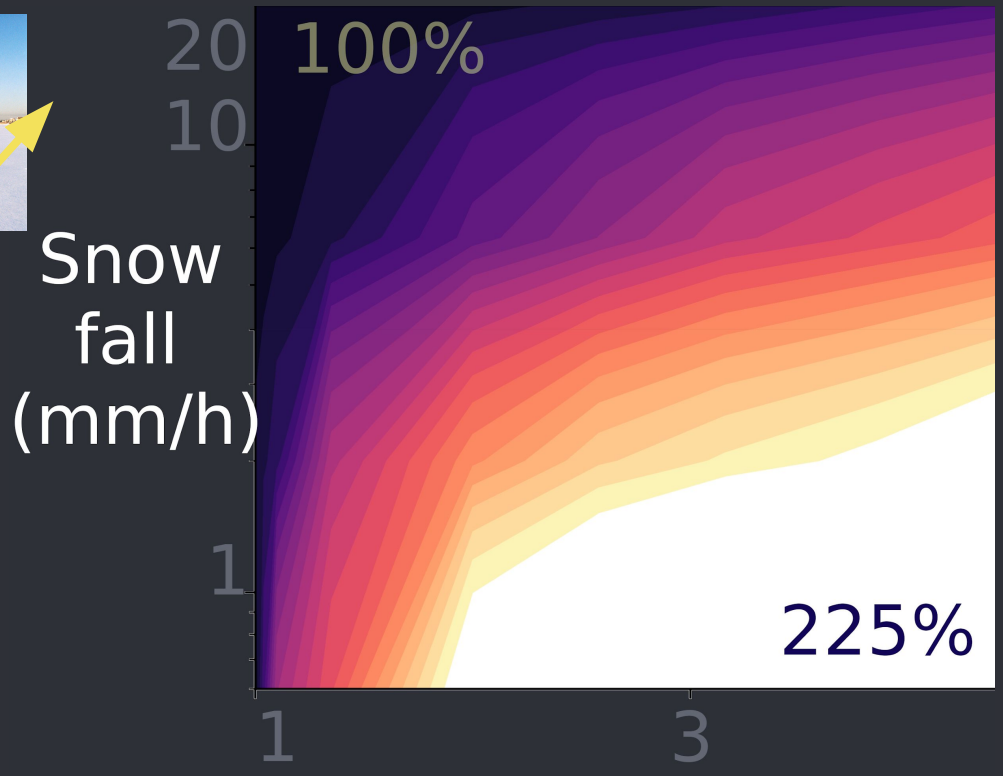
- **snow cover fraction**



Bedforms increase the

- **absorbed solar energy**





Conclusions (new science!)

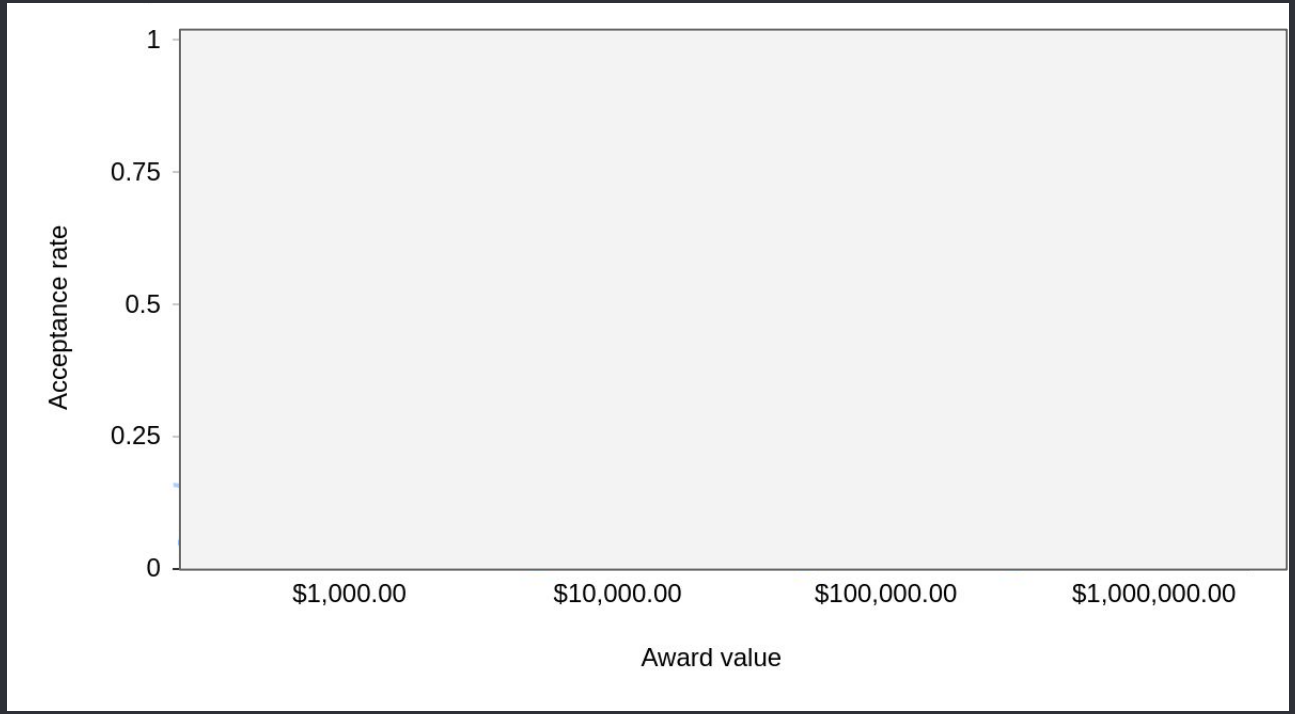
- Snow has remarkable thermodynamic properties
- Strong winds sweep snow into bedforms
- The growth of these bedforms can increase thermal heat fluxes by +45%, and solar heat fluxes by +125%
- High winds + slow snowfall → faster warming

Grad school

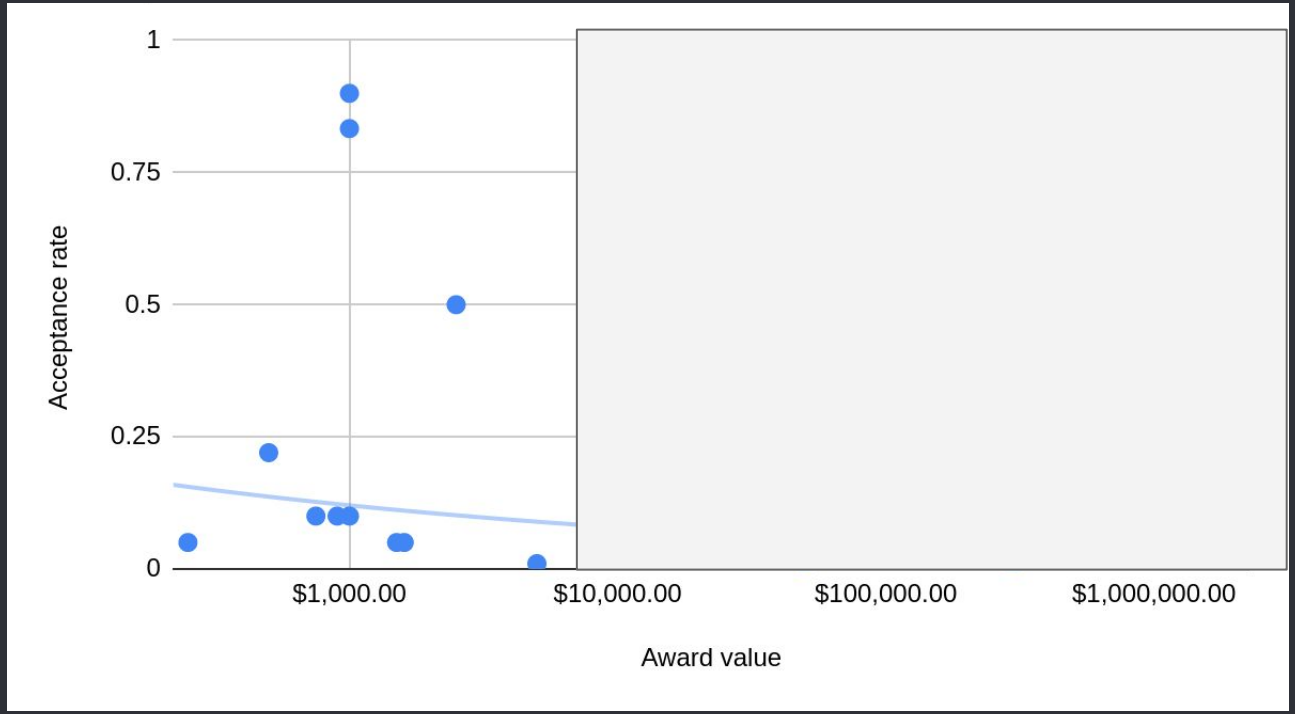
&

things that didn't work how I expected

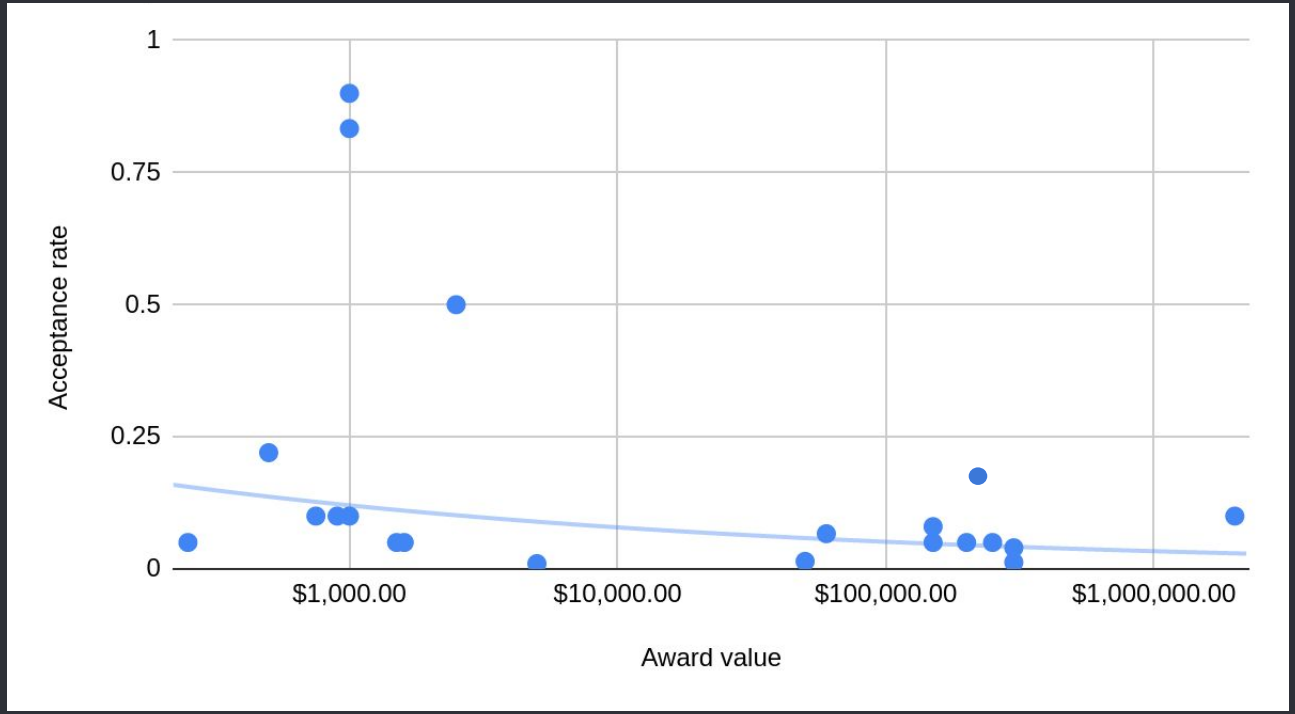
Go **big**


1
0.75
0.5
0.25
0
Acceptance rate
$1,000.00
$10,000.00
$100,000.00
$1,000,000.00
Award value

Go **big**


1
0.75
0.5
0.25
0
Acceptance rate
$1,000.00
$10,000.00
$100,000.00
$1,000,000.00
Award value

Go **big**



Award competitiveness is barely related to value

Thanks to:

Robert Anderson (CU)
Gregory Tucker (CU)
Elizabeth Hunke (LANL)
Barry Rountree (LLNL)
Ghaleb Abdulla (LLNL)
Don Lucas (LLNL)

and thank you for listening.

QUESTIONS?