Image super-resolution for population tipping points

Heather J. Lynch, Christian Che-Castaldo, Dimitris Samaras, Matthew Schwaller, Stony Brook University
Ph.D. students: Carole Hall (Applied Math), Alex Graikos/Haoyu Wu (Computer Science), Clare Flynn (Ecology)

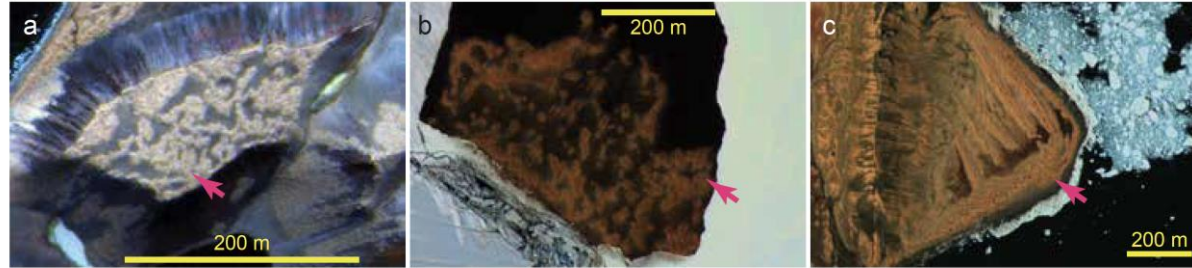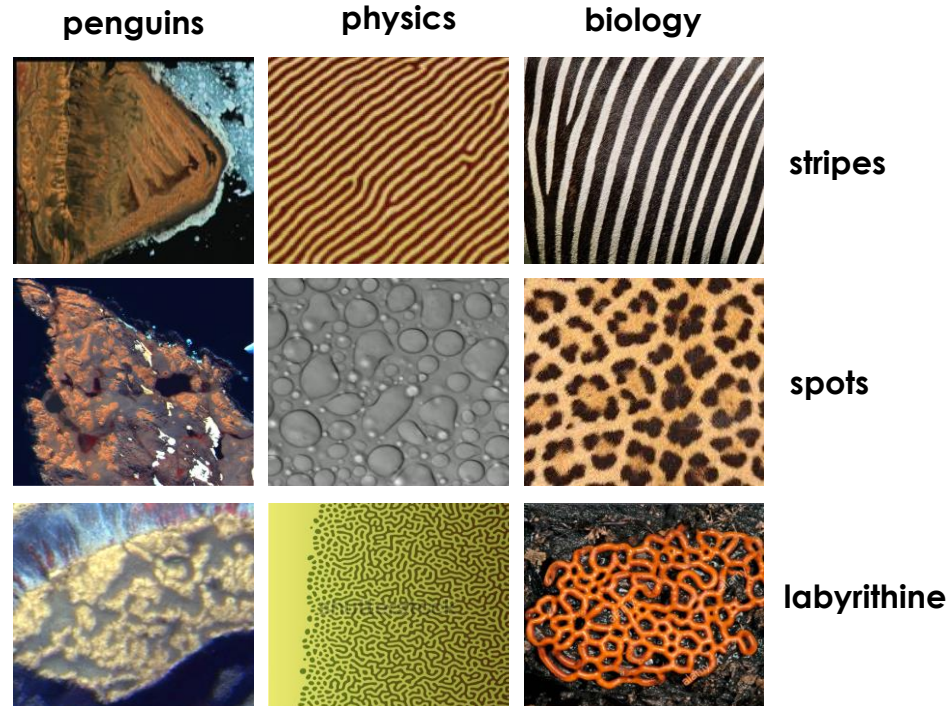Penguin colonies take a variety of forms...

Fig. 1: Satellite images illustrating small-scale spatial structuring of the Paulet Island (a), Cape Crozier (b), and Possession Island (c) Adélie penguin colonies. Colonies appear as brownish/reddish areas (see pink arrows) (© 2015 DigitalGlobe NextView License).
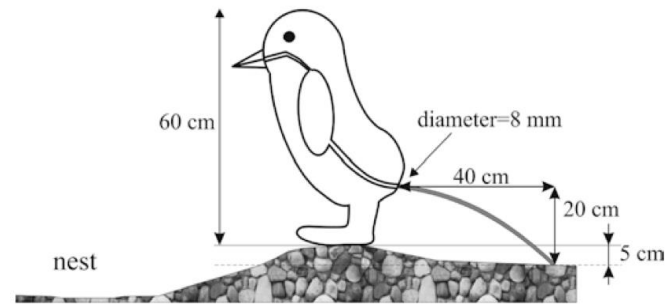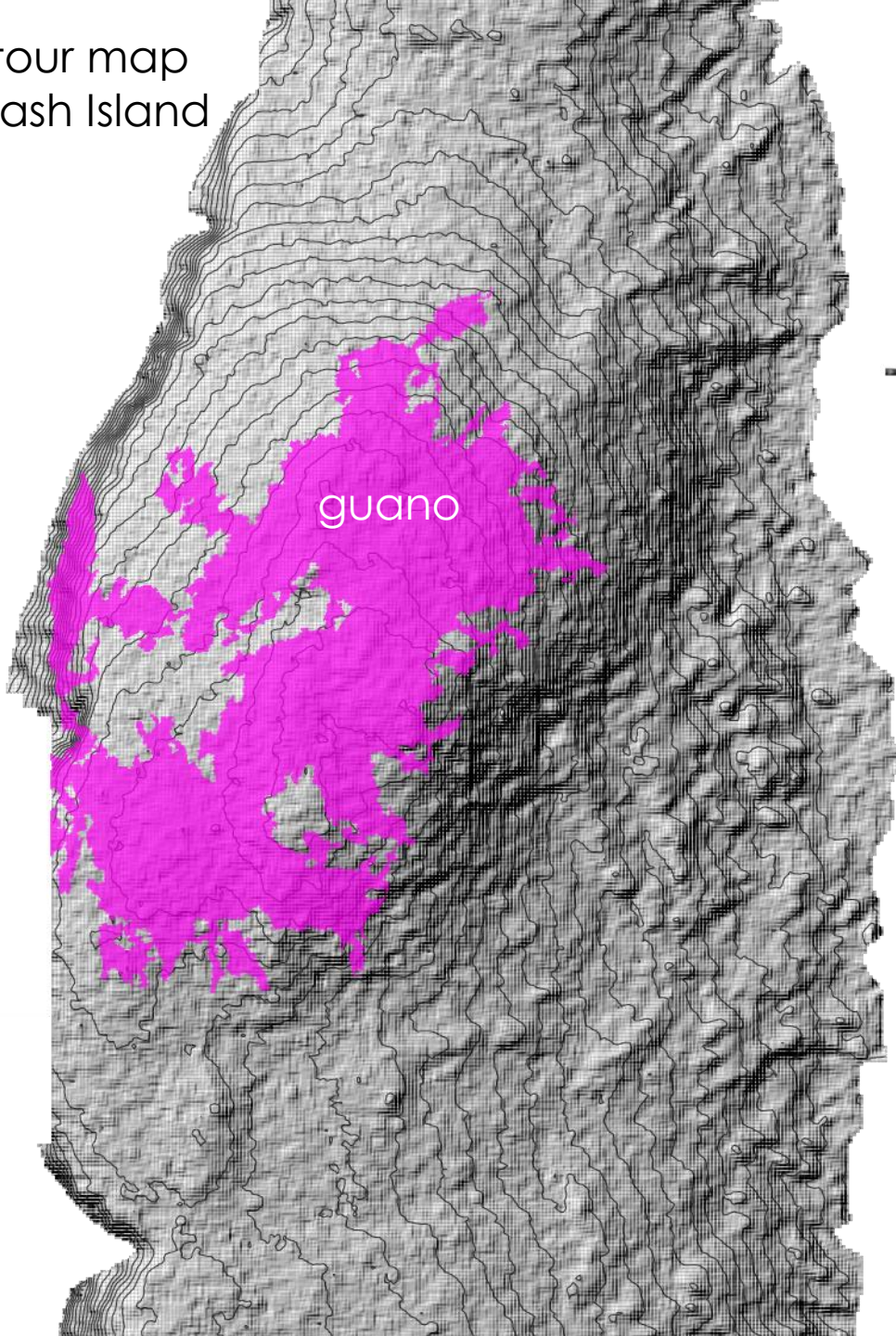
...and colony shape is tied to colony dynamics (analogies to other physical phenomena)...

penguins   physics   biology

stripes

spots

labyrithine

Imagery copyright Maxar, Inc.

...as well as to the underlying terrain.
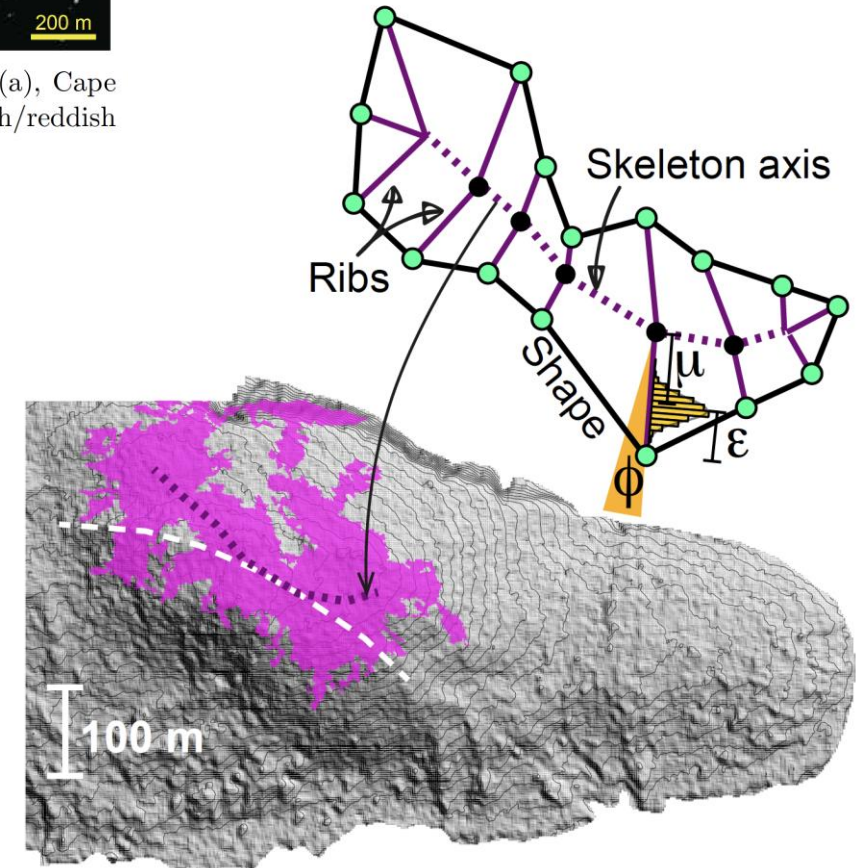
contour map
of Brash Island

guano

diameter=8 mm

60 cm

40 cm

20 cm

5 cm

nest

Meyer-Rochow and Gal (2003)

+
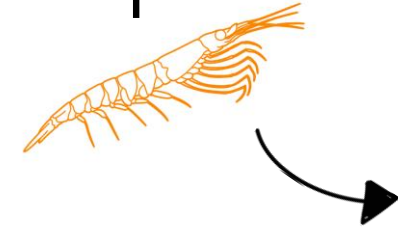
|				
Anemone SW 6567	Rosily SW 6574	Verbena SW 6581	Diminutive Pink SW 6588	Amour Pink SW 6595
Lighthearted Pink SW 6568	Priscilla SW 6575	Impatiens Petal SW 6582	Alyssum SW 6589	Bella Pink SW 6596
Childlike SW 6569	Azalea Flower SW 6576	In The Pink SW 6583	Loveable SW 6590	Hopeful SW 6597
Haute Pink SW 6570	Jaipur Pink SW 6577	Cheery SW 6584	Amaryllis SW 6591	Dishy Coral SW 6598
Cyclamen SW 6571	Tuberose SW 6578	Coming Up Roses SW 6585	Grenadine SW 6592	Begonia SW 6599
Ruby Shade SW 6572	Gala Pink SW 6579	Heartfelt SW 6586	Coral Bells SW 6593	Enticing Red SW 6600
Juneberry SW 6573	Cerise SW 6580	Valentine SW 6587	Poinsettia SW 6594	Tanager SW 6601

Are colonies on more complex terrain inherently more vulnerable to stochastic fluctuations in abundance?
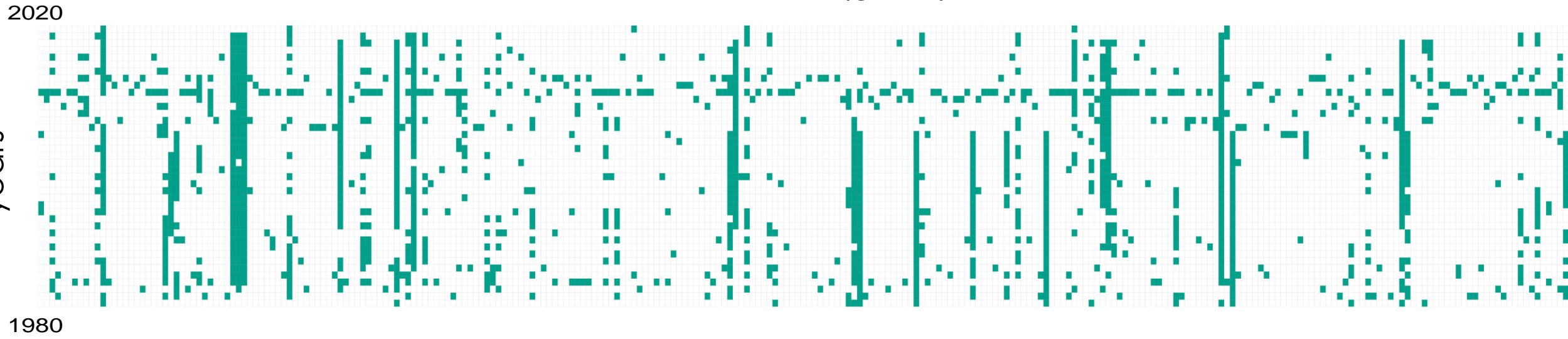
and

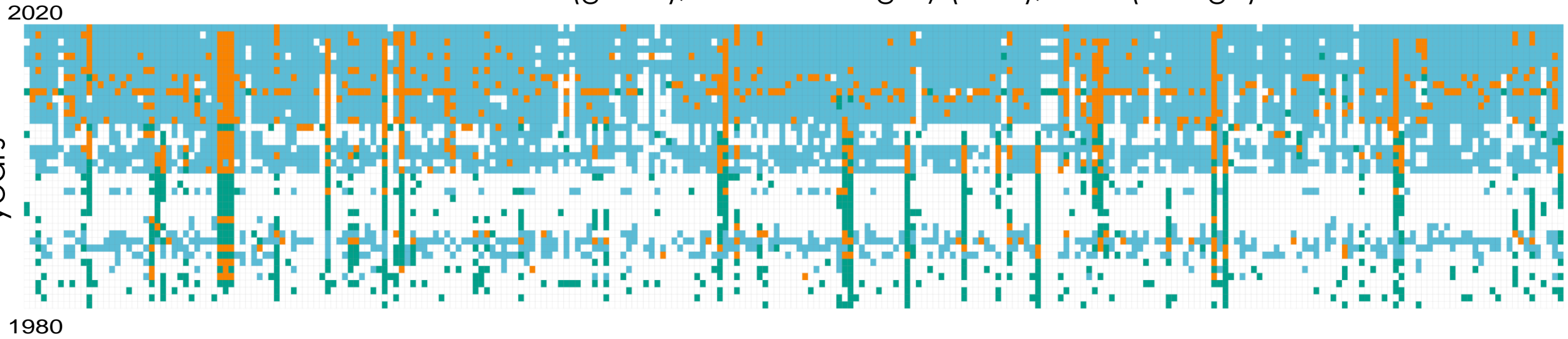Do shifts in diet precede shifts in the spatial structure of the colony?

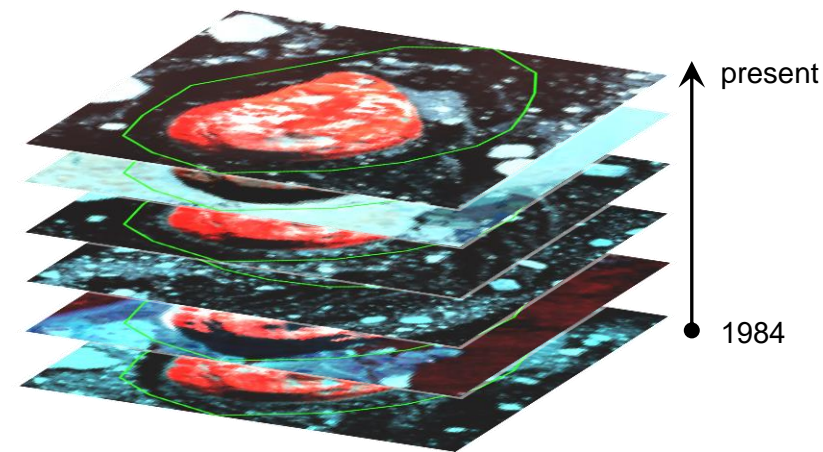Almost everything we know about colony shape comes from sub-meter commercial satellite imagery.
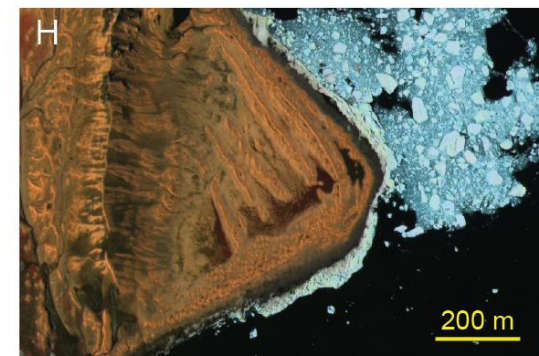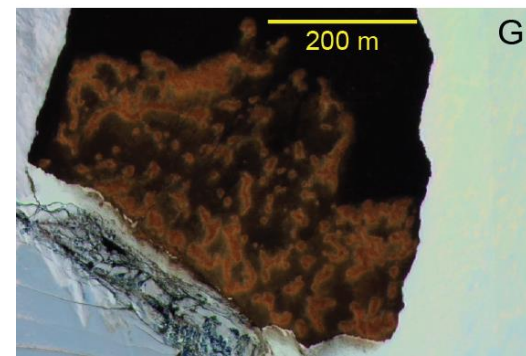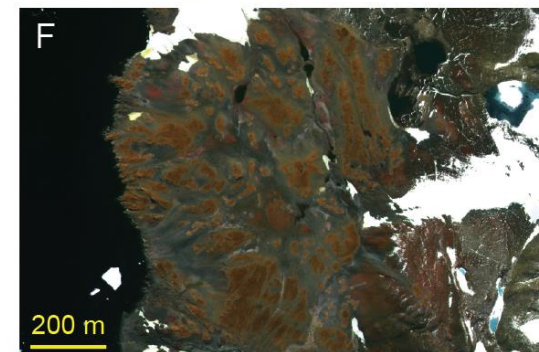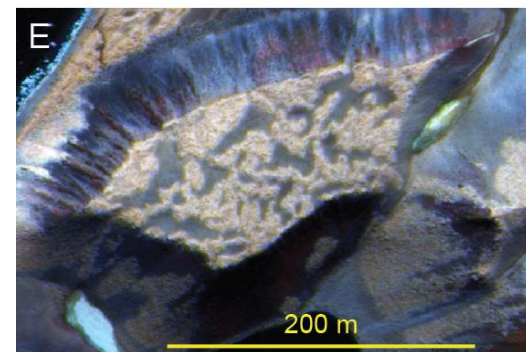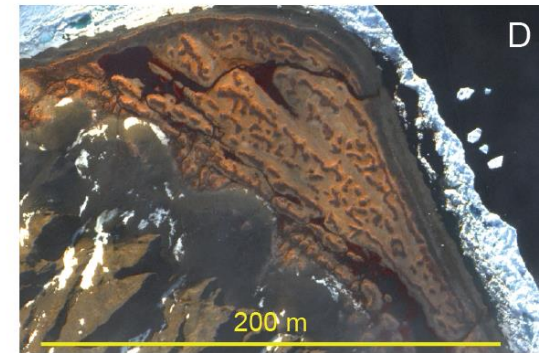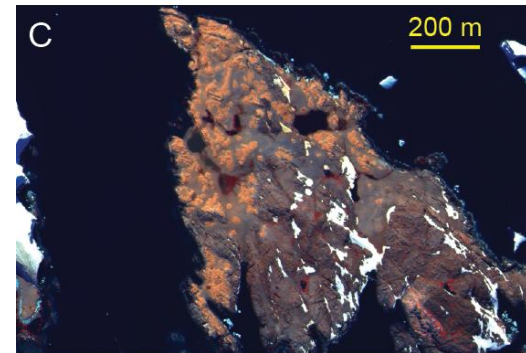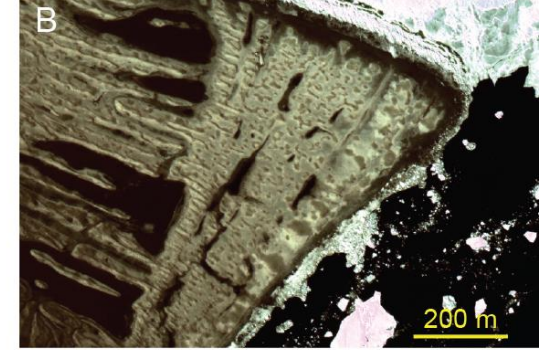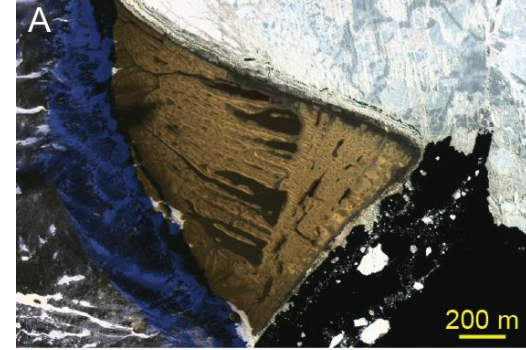
Ground counts (green)

Ground counts (green), Landsat imagery (blue), both (orange)

→ extracting colony shape from Landsat is key

The key technical challenge is extracting information about colony shape from low-resolution Landsat imagery

imagery "super-resolution"

We can estimate the percentage of each Landsat pixel covered in guano

			3%	42%
30%	95%	93%	11%	
31%	91%	99%		
13%	25%	27%	98%	95%
		5%		

reconstructed guano polygon

This process requires a pixel-level stacking of Landsat imagery over the entire Landsat era

Christian Che-Castaldo
(co-PI and Black-belt Landsat wrangler)

present

1984

Custom interactive applications design to allow teams of students to manually sift through **~90,000 Landsat images** to eliminate cloud contamination and manually align Landsat to high resolution imagery

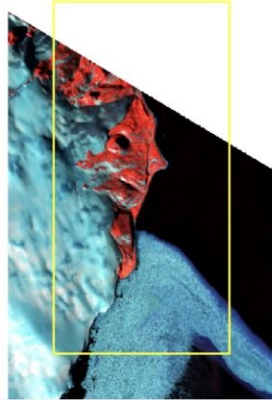## Select dataset:
L8C2L1

Select chip:
BRDM_BRDN_BRDS

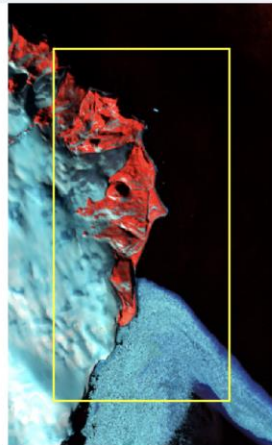## Select season:
2013

Subset scenes:
kept

☑ Show multiple seasons

SEASON = 2013, CHIP_ID = BRDM_BRDN_BRDS
LC08_L1GT_053115_20131125_20201016_02_T2
month = 11
day = 25
year = 2013
Sun Elevation = 26.5
Sun Azimuth = 66.9

☑ keep

☐ dump

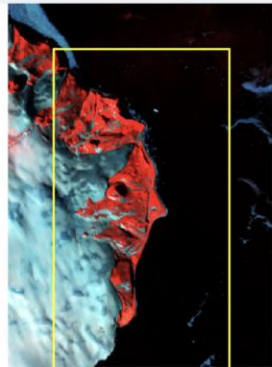☐ scanline error

☐ radiometric striping

☐ check_it

☐ register

[Log Picks]

SEASON = 2013, CHIP_ID = BRDM_BRDN_BRDS
LC08_L1GT_053116_20131125_20201016_02_T2
month = 11
day = 25
year = 2013
Sun Elevation = 25.2
Sun Azimuth = 70.9

☑ keep

☐ dump

☐ scanline error

☐ radiometric striping

☐ check_it

☐ register

[Log Picks]

SEASON = 2013, CHIP_ID = BRDM_BRDN_BRDS
LC08_L1GT_056115_20131130_20201016_02_T2
month = 11
day = 30
year = 2013
Sun Elevation = 27.3
Sun Azimuth = 67.6

☑ keep

☐ dump

☐ scanline error

☐ radiometric striping

☐ check_it
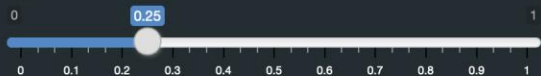
Landsat aligned with high-resolution imagery
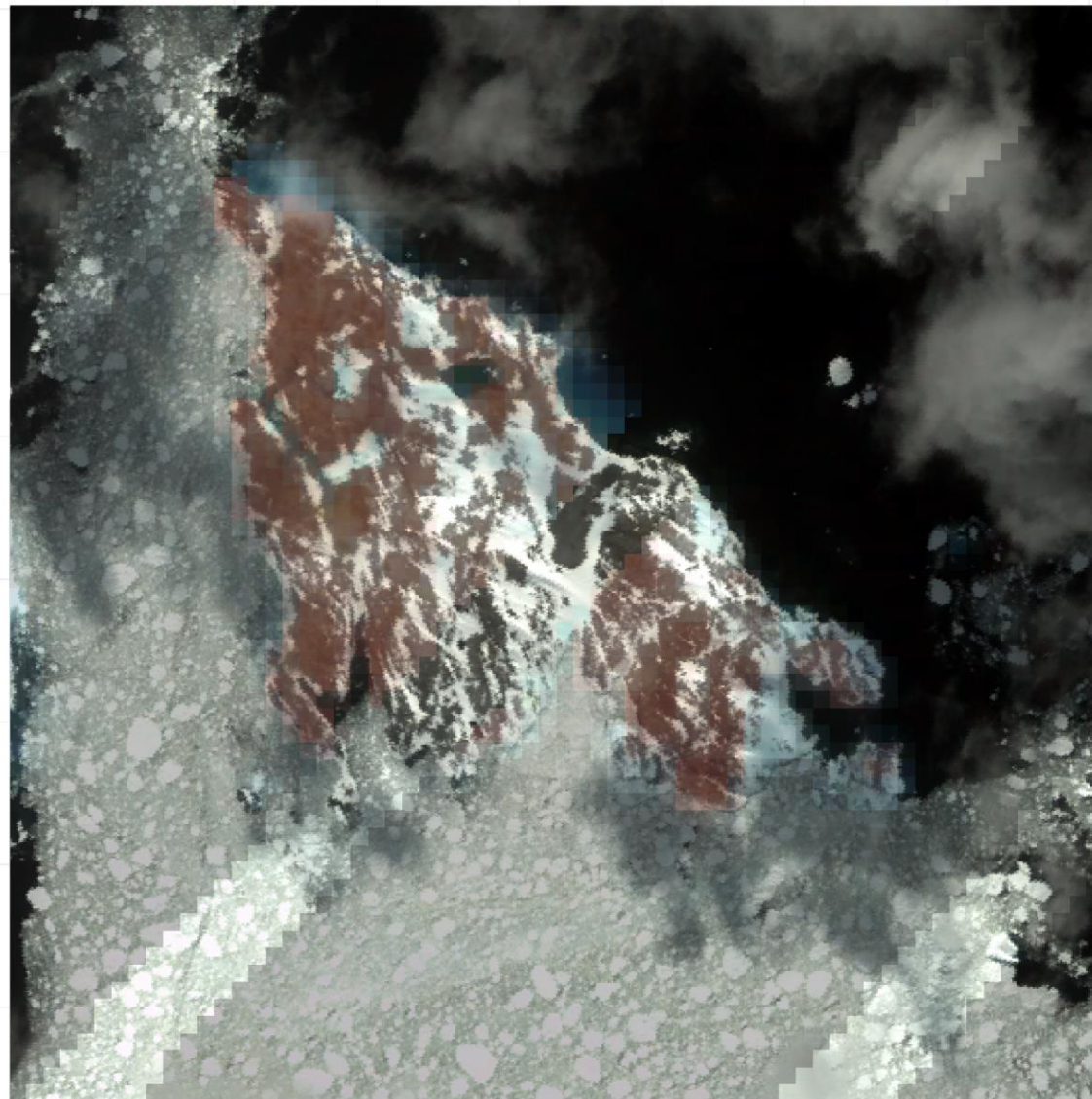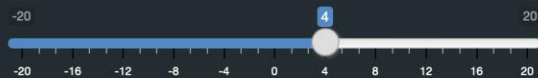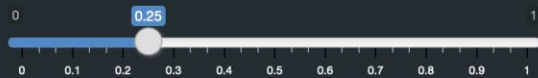
Landsat not aligned with high-resolution imagery
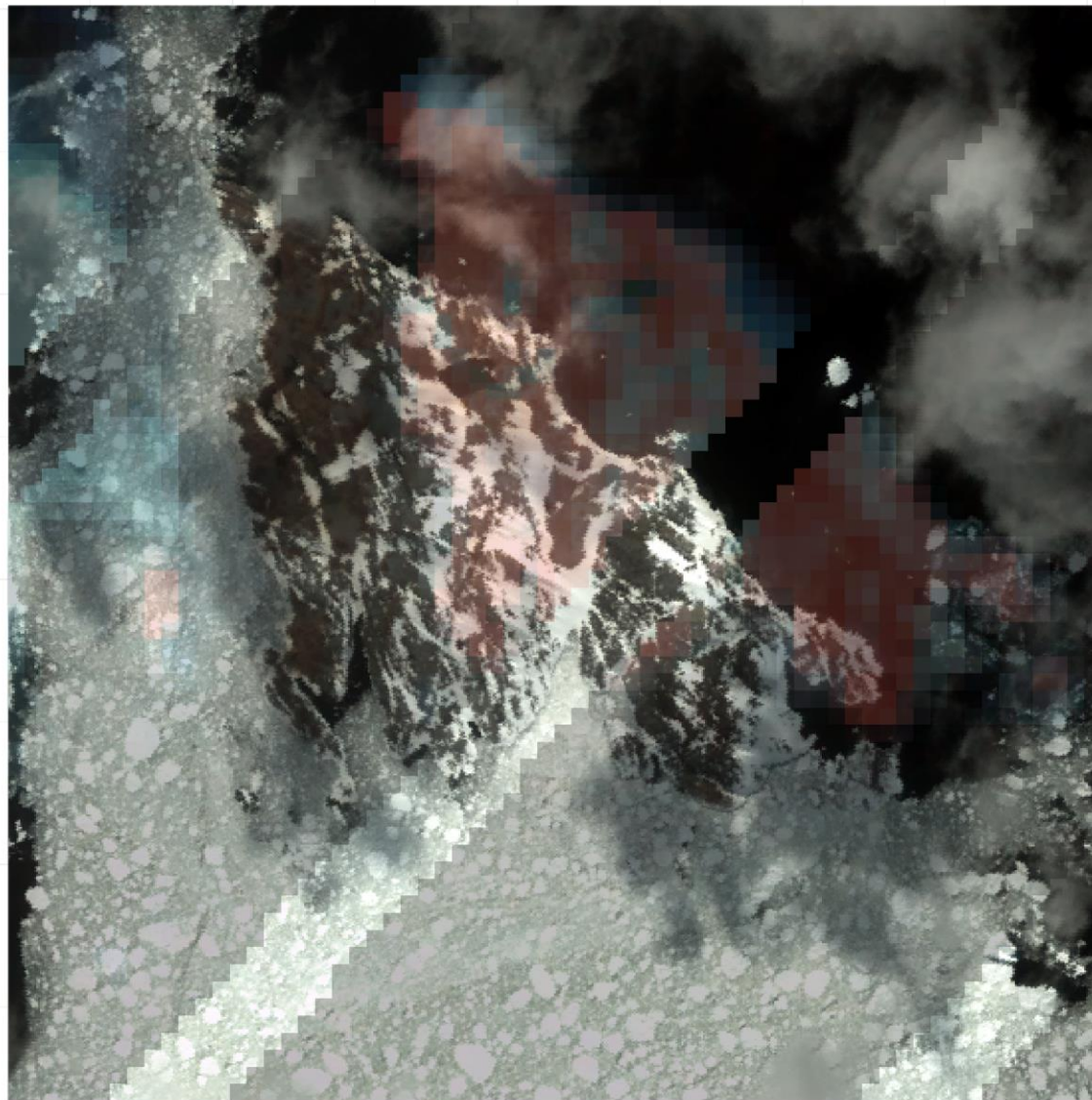
Spatial point process models

➤ spatial point process models for describing nesting patterns

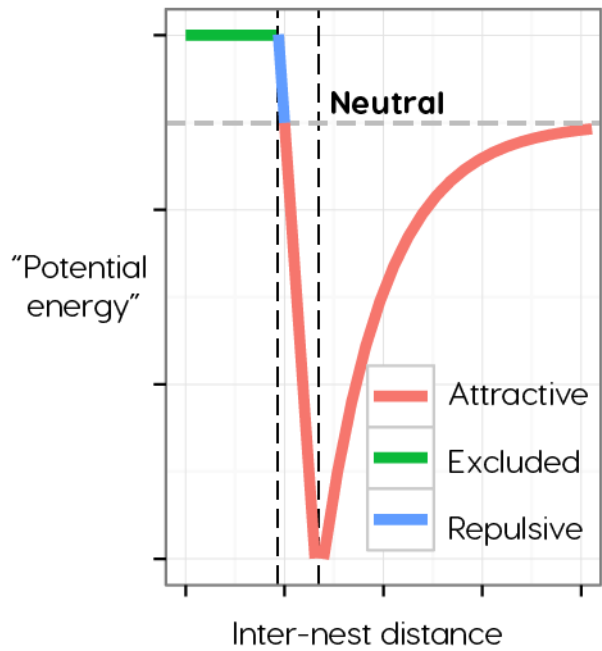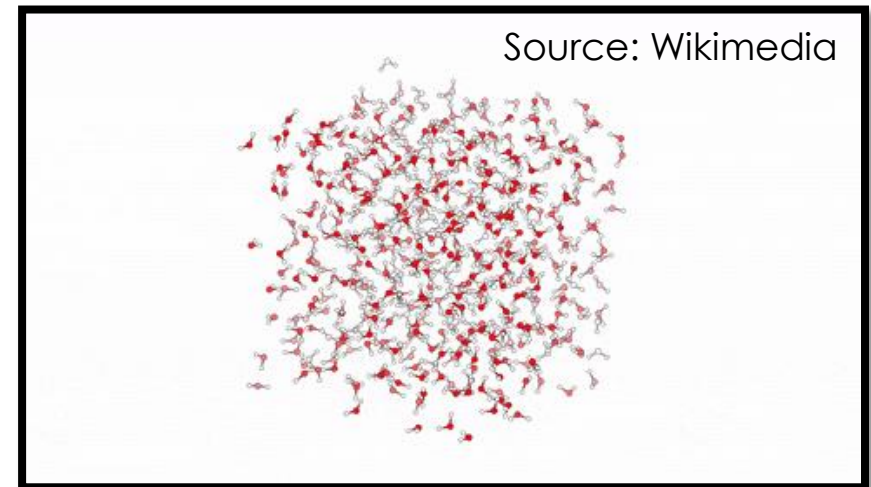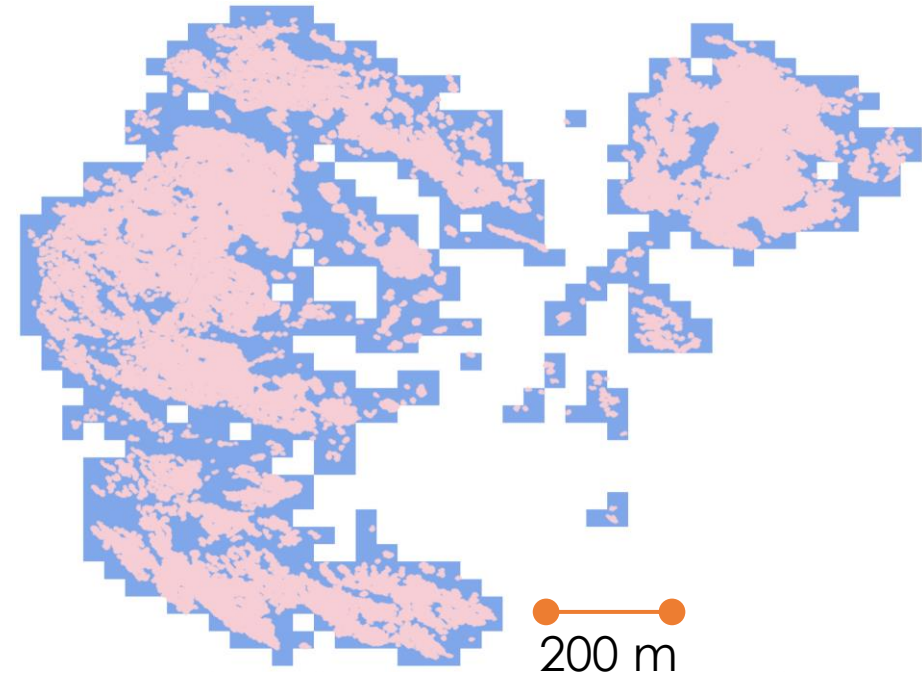Physical barrier presented by two fully formed nests

Optimal spacing for predator defense

Neutral

"Potential energy"

Attractive
Excluded
Repulsive

Inter-nest distance

A molecular dynamics inspired approach to extracting colony shape

blue = low-resolution starting point
pink = truth

blue = high-resolution reconstruction
pink = truth

200 m

Source: Wikimedia
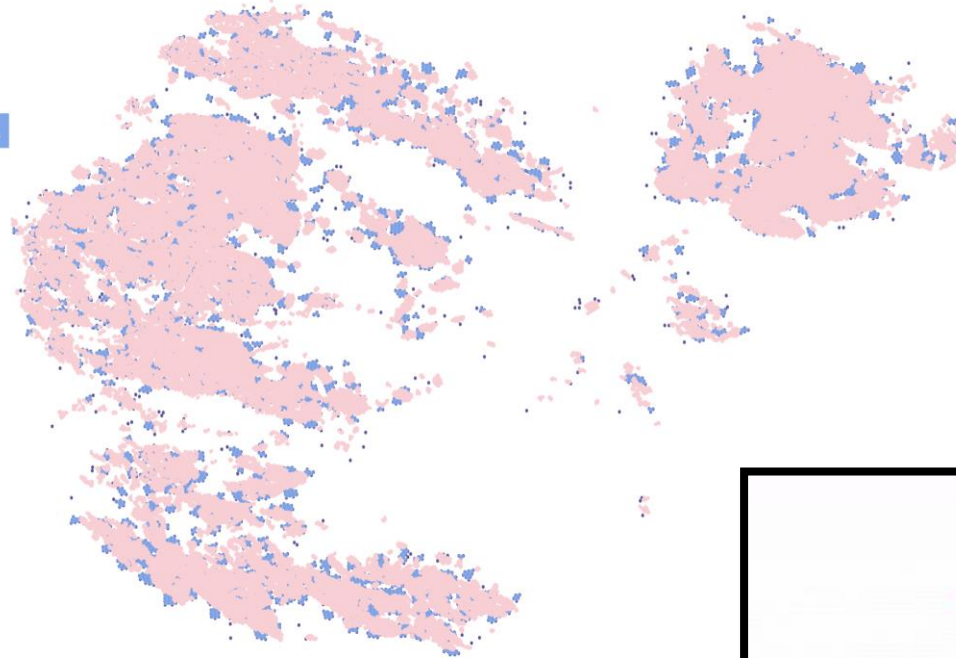
Pushing the envelop of phototourism

Digital elevation model

+

Photo

=

Precisely geopositioned photo for colony location extraction

A molecular dynamics inspired approach to extracting colony shape

blue = low-resolution starting point
pink = truth

blue = high-resolution reconstruction
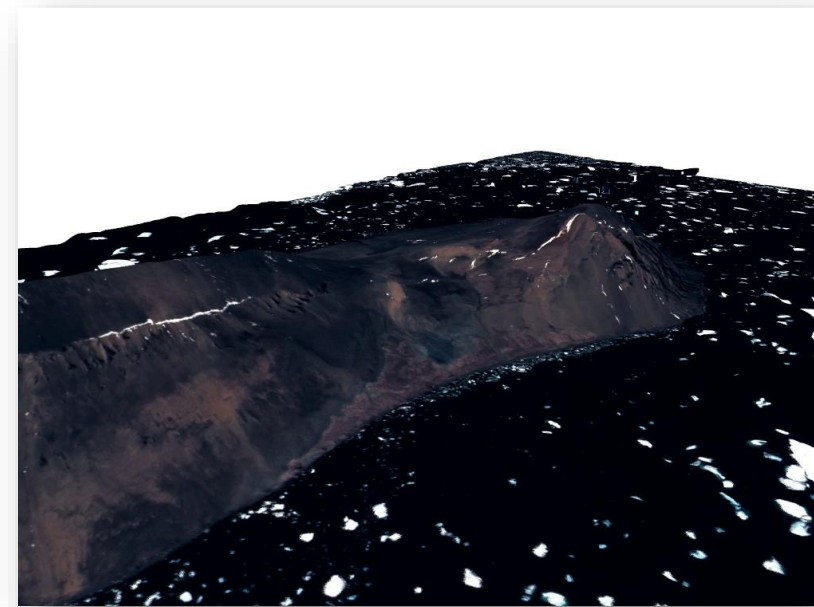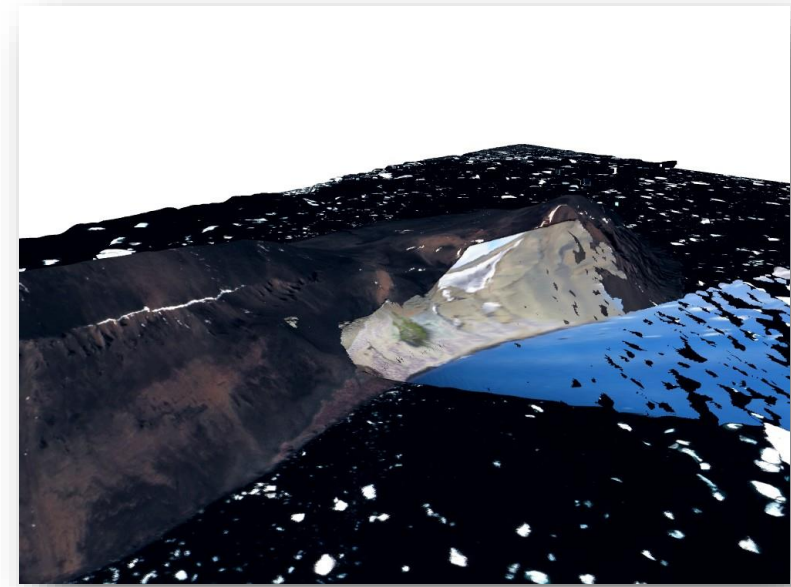pink = truth

200 m
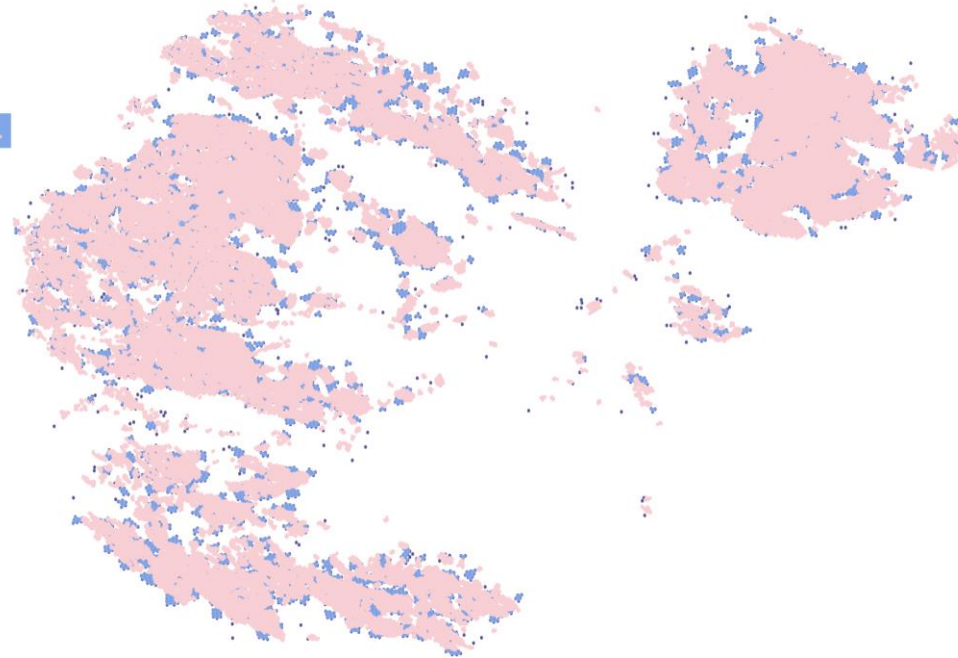
Can phototourism data constrain shape reconstruction?

We sure hope so!

Arthur Harbor colony 2005

overlay

Arthur Harbor colony 2006

How do we quantify shape change?

Complexity

"Overall change"

(scale/shift/rotate doesn't change complexity)

Quantifying shape change: three options (of many)

①

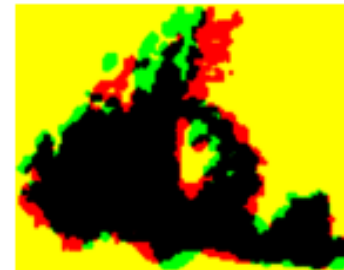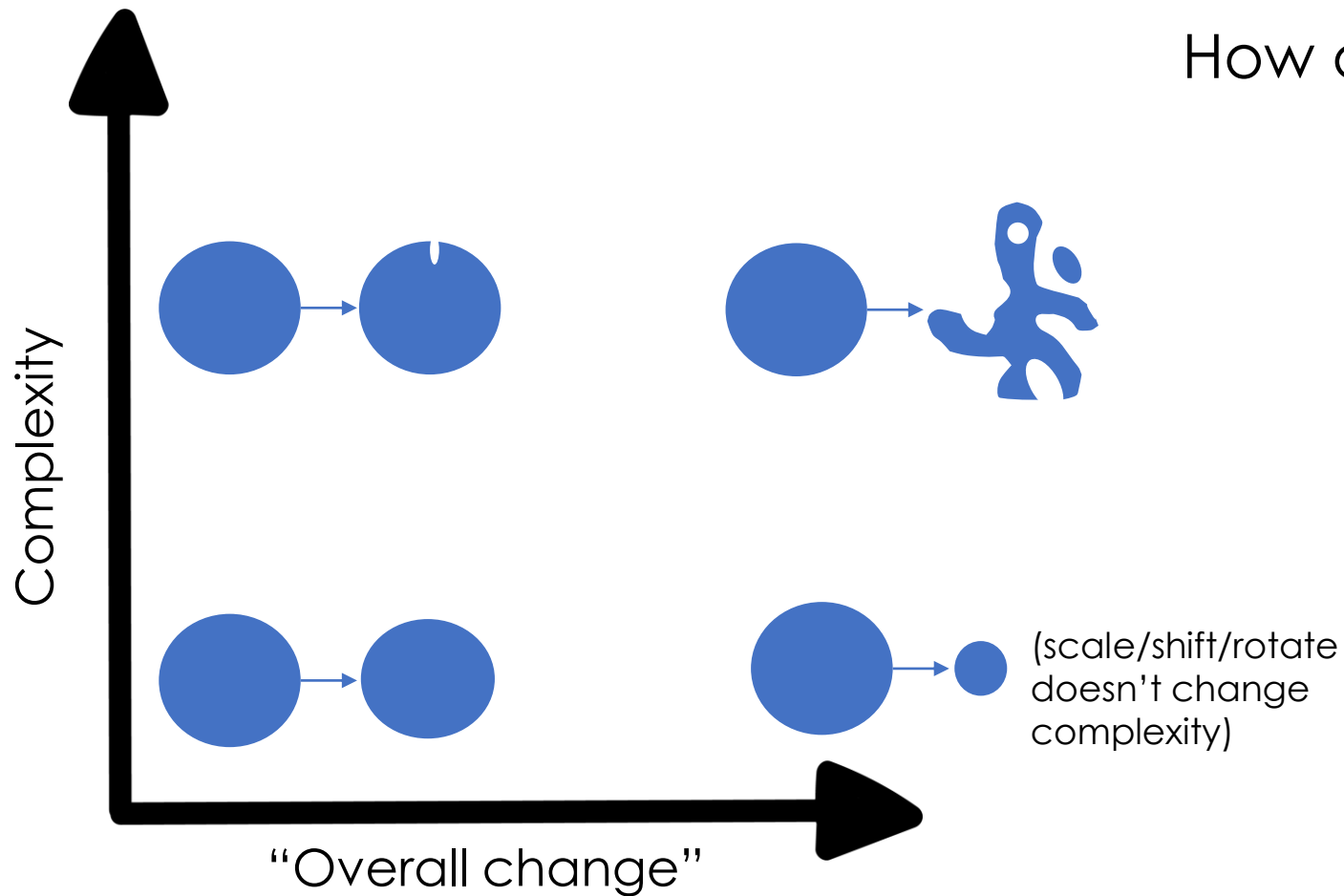$$\frac{perimeter^2}{area}$$ nice option because it handles multi-part shapes well and has a basis in penguin biology
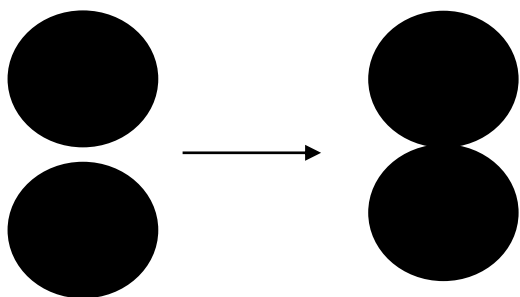
② Diffeomorphism provide differentiable metrics of shape difference

2005 ➤ 2006 transform   2006 ➤ 2005 transform

③

Skeleton axis

Ribs

Shape

μ

ϵ

ϕ
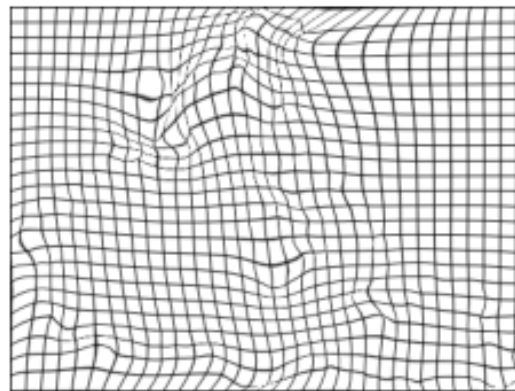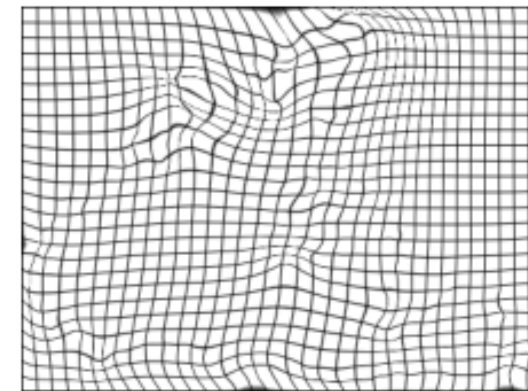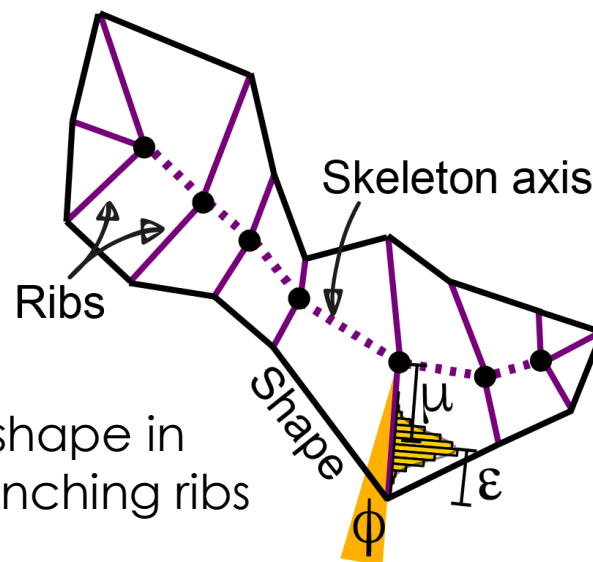
Statistical description of shape in terms of a skeleton and branching ribs

Günay Dogan (NIST)

Reaching back even further in time with Landsat MSS

CHAL

CHAL

ADAR

ADAR

Want more details?

Ask Matt Schwaller

And in the midst of Omicron, a nearly miraculous expedition to the Weddell Sea

Where the Ice Is Still Abundant, These Penguins Are, Too

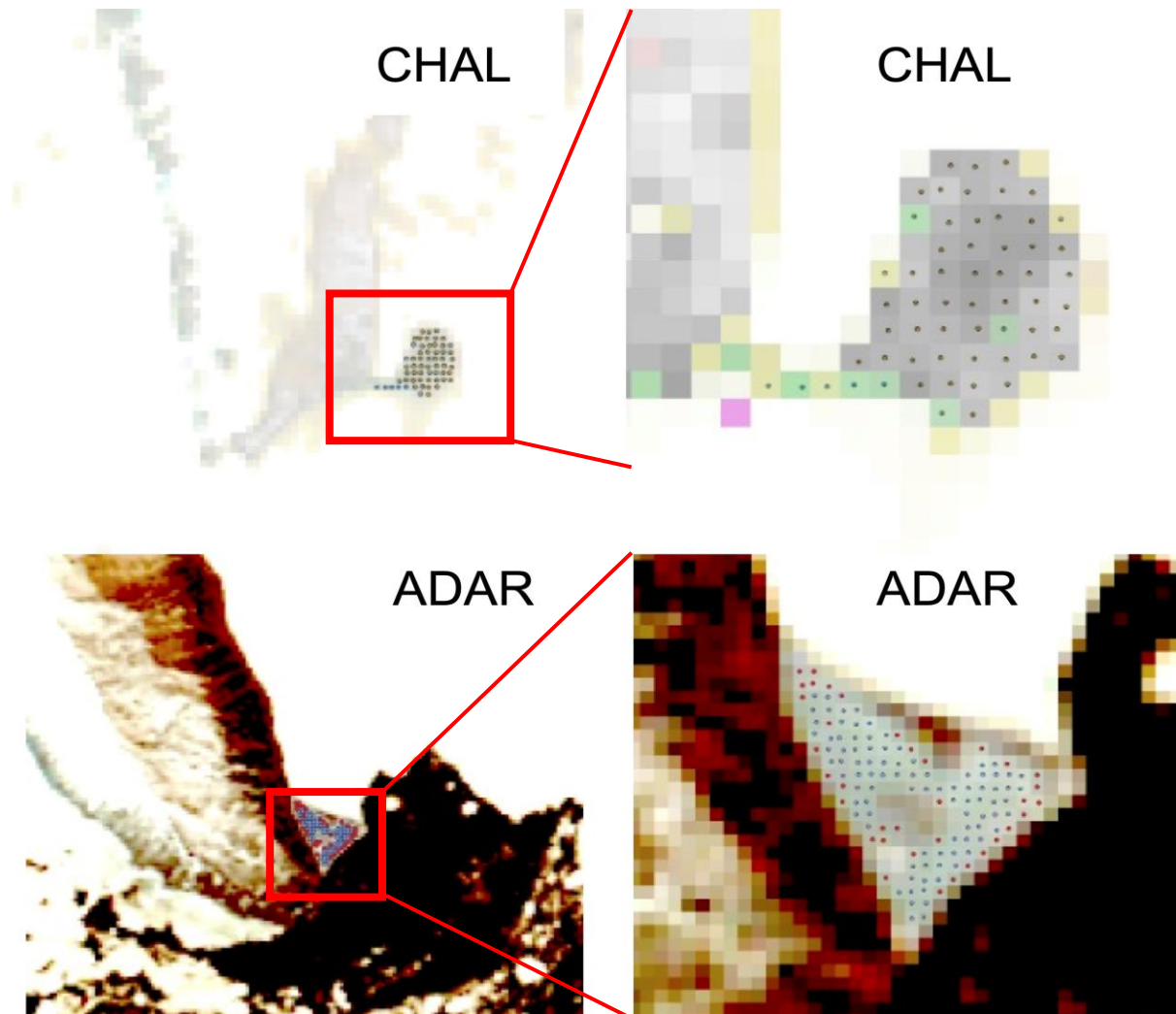Give this article

By Henry Fountain   Photographs by Tomás Munita
April 12, 2022, 2:00 a.m. ET

Adélie penguins have had a rough time of it on the western side of the Antarctic Peninsula, where warming linked to climate change has occurred faster than almost anywhere else on the planet. That and other factors have led to sharp declines in Adélie populations in recent decades.

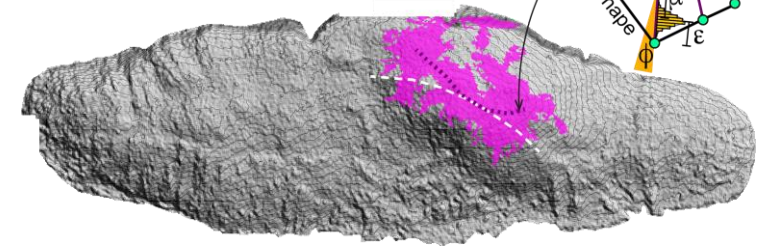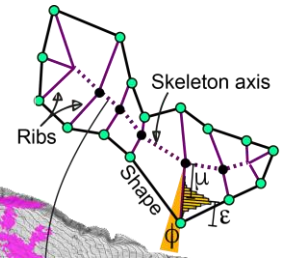But on the eastern side, it's a different story.

"It's just a complete train wreck on the western side of the peninsula," said Heather J. Lynch, a statistical ecologist at Stony Brook University who studies penguin populations and how they are changing. "But on the eastern side, the populations are stable and quite healthy."

Dr. Lynch uses satellite imagery in much of her work, but also organizes penguin-surveying expeditions to the peninsula, the northernmost part of the Antarctic continent. On the latest one, in January, three of her current and former doctoral students did the counting, at islands on the eastern side of the peninsula in the Weddell Sea.
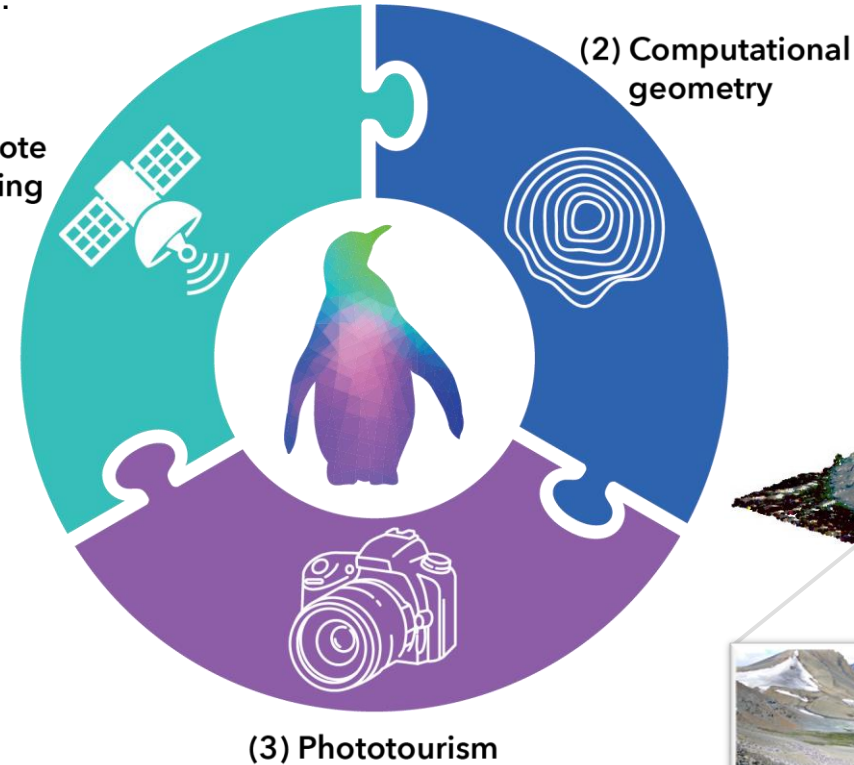
Step 1: Landsat images over penguin colonies are georegistered and stacked for a super-resolution methodology based on 'detection modelling' in wildlife ecology.

Step 2: Computational geometry is used to reconstruct the most likely shape given the Landsat estimates.

Skeleton axis

Ribs

Shape

(1) Remote sensing

(2) Computational geometry

(3) Phototourism

present

1984

➢ processed 20,502 Landsat 5-7 images from 1984 to present

Step 3: Photographs of the Antarctic landscape taken by tourists can be aligned to digital elevation models and the colony boundaries extracted as a constraint on shape reconstruction.