The shape, movement, and field-scale evolution of the Golden Gate sandwaves

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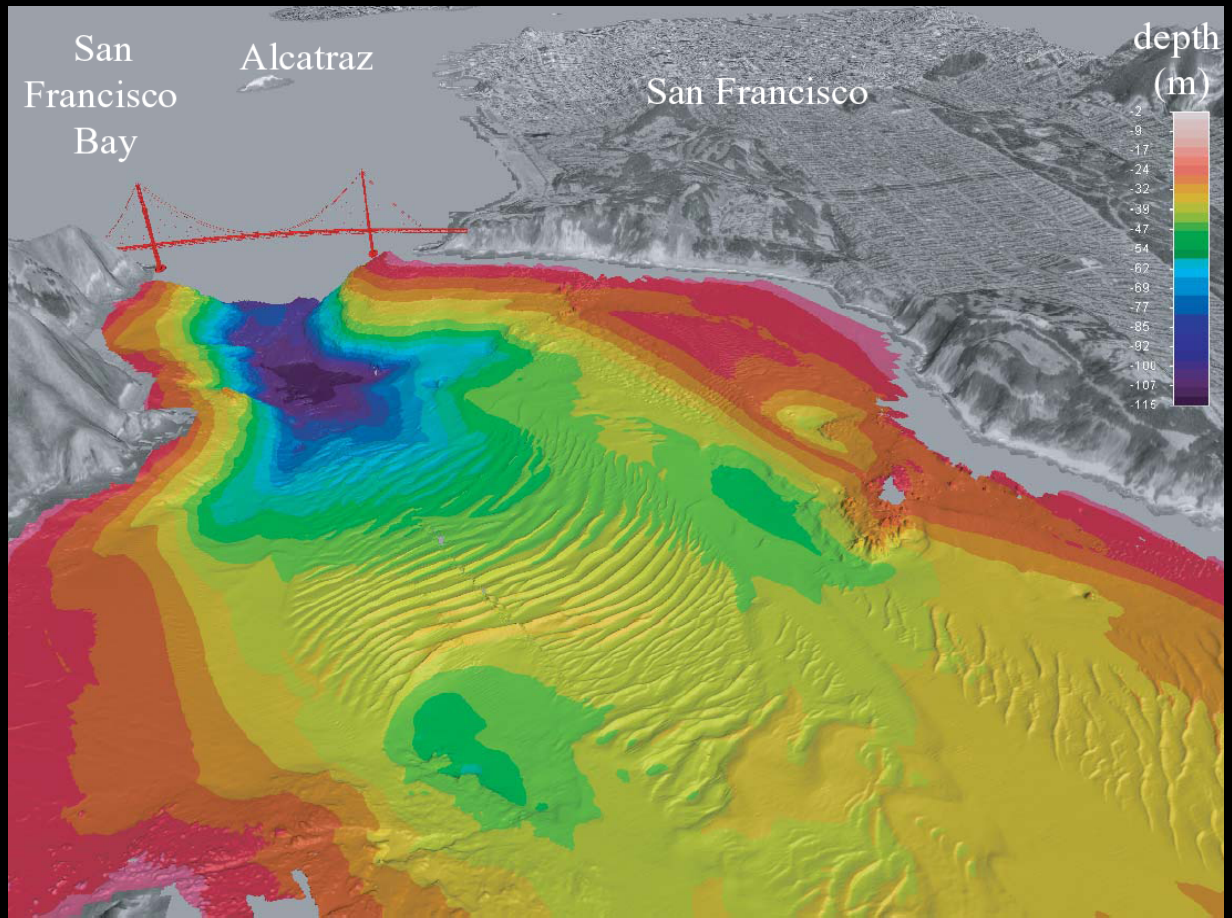
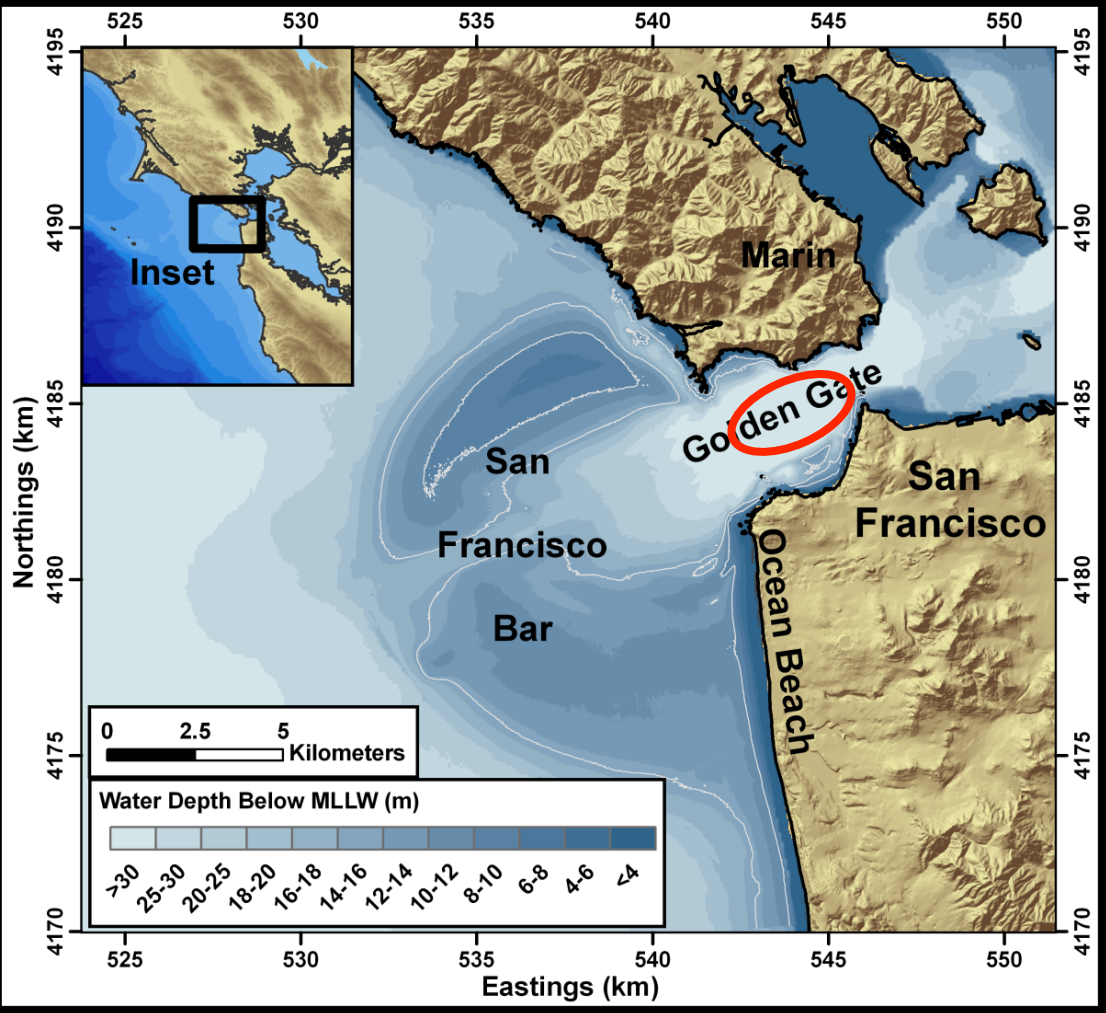


Marine Sand Waves

Large bedforms (10's to 100's meter wavelength) found worldwide in medium to coarse sand coastal environments with strong tidal forcing. Typically: Wavelength is on the order of, or larger than, the water depth; Orientation is nearly perpendicular to the primary tidal constituent; Height is limited to approximately 10% of the water depth.

Overview: Hulscher and Dohmen-Janssen, Eds., JGR 2005 special issue on Marine Sand Wave and River Dune Dynamics (DOI: 10.1029/2005JF000404)

Sand Waves in the San Francisco region: Rubin and McCulloch (1980); Chin et al (1997), Barnard et al (2006), Sterlini et al (2009), Hanes (2012).



SF Bay Tidal Prism = 2,000,000,000 m3 !!!

Typical Max Tidal Currents (m/s)

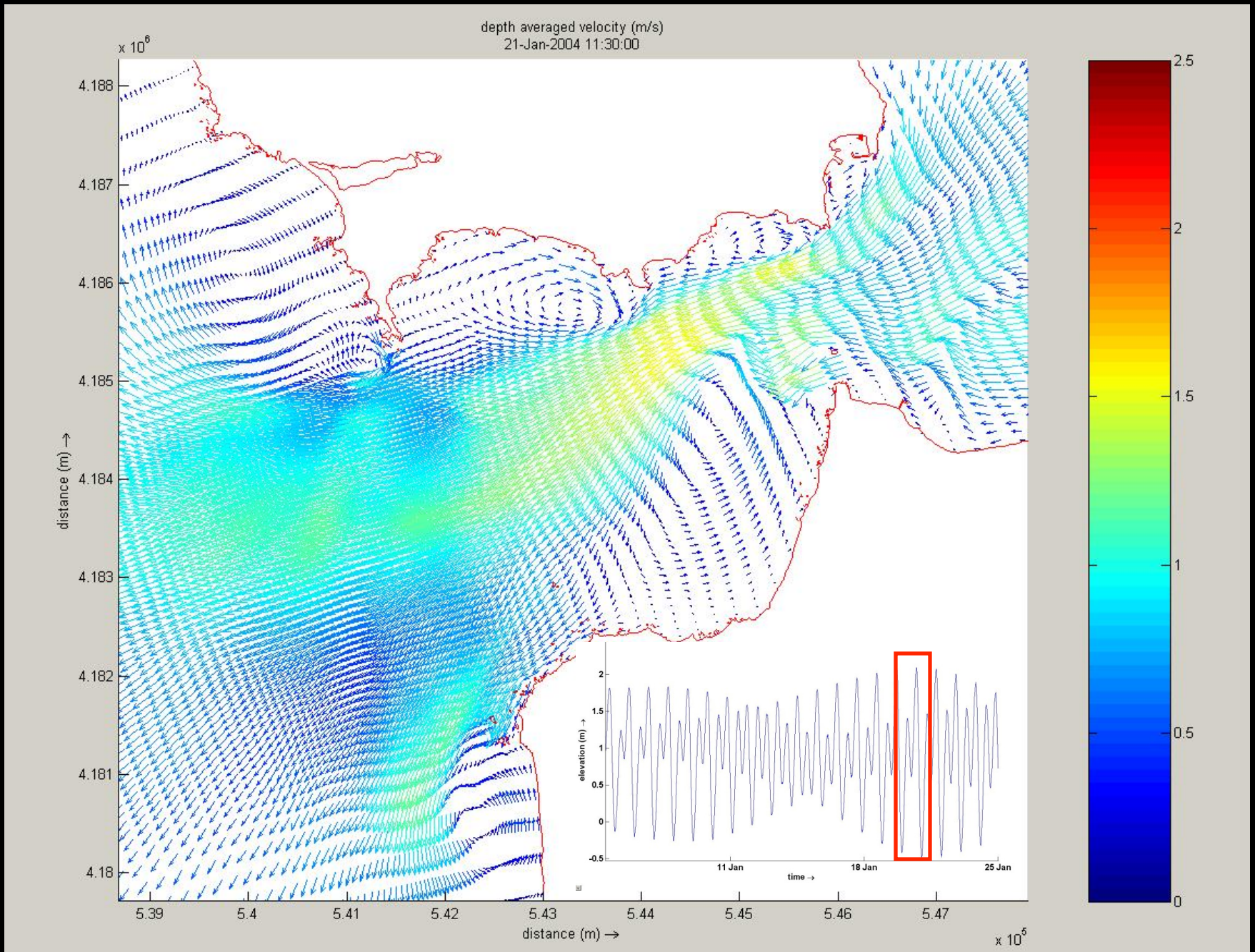
Golden Gate	2.5
Point Lobos	1.5
Central Ocean Beach	1.0

Offshore Wave Climate Annual Statistics:

Max Hs (m)	8.4
Avg Hs (m)	2.5
Avg dir (deg)	297
Avg Tp (s)	11

Surficial Sediment

Mouth of SF Bay Tidal Currents



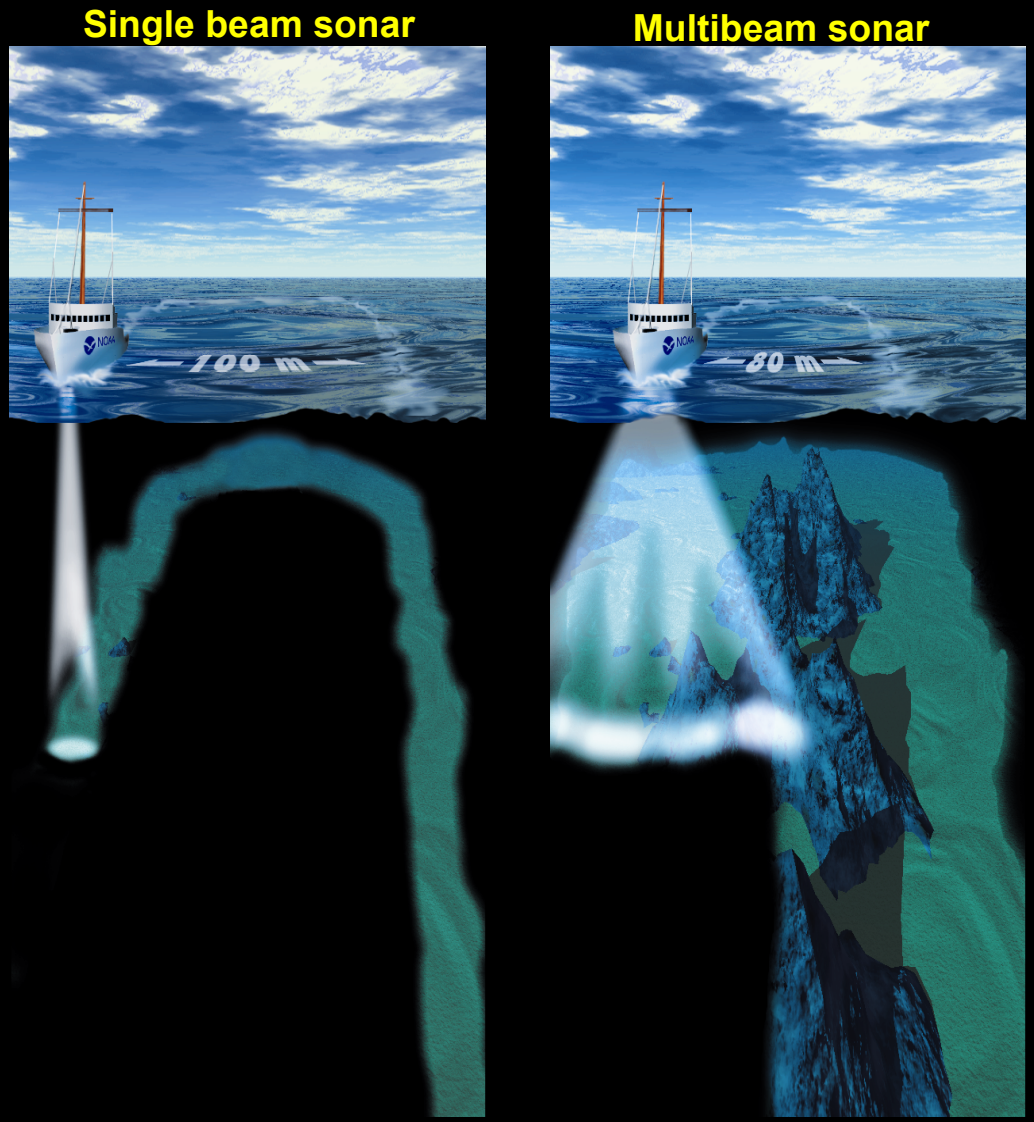
High resolution multi-beam bathymetric survey

Sea Floor Mapping Lab, CSU Monterey Bay, Rikk Kvitek, director

Co-funded by USGS and USACE, SF District

Linked to R.T.K. GPS

Recent advances in seafloor coverage with multibeam and swath sonars



Courtesy NOAA Hydrographic Program

Bedform Examples from Multibeam Survey

Extremely variable bedform morphology and scale, with some very sharp boundaries;

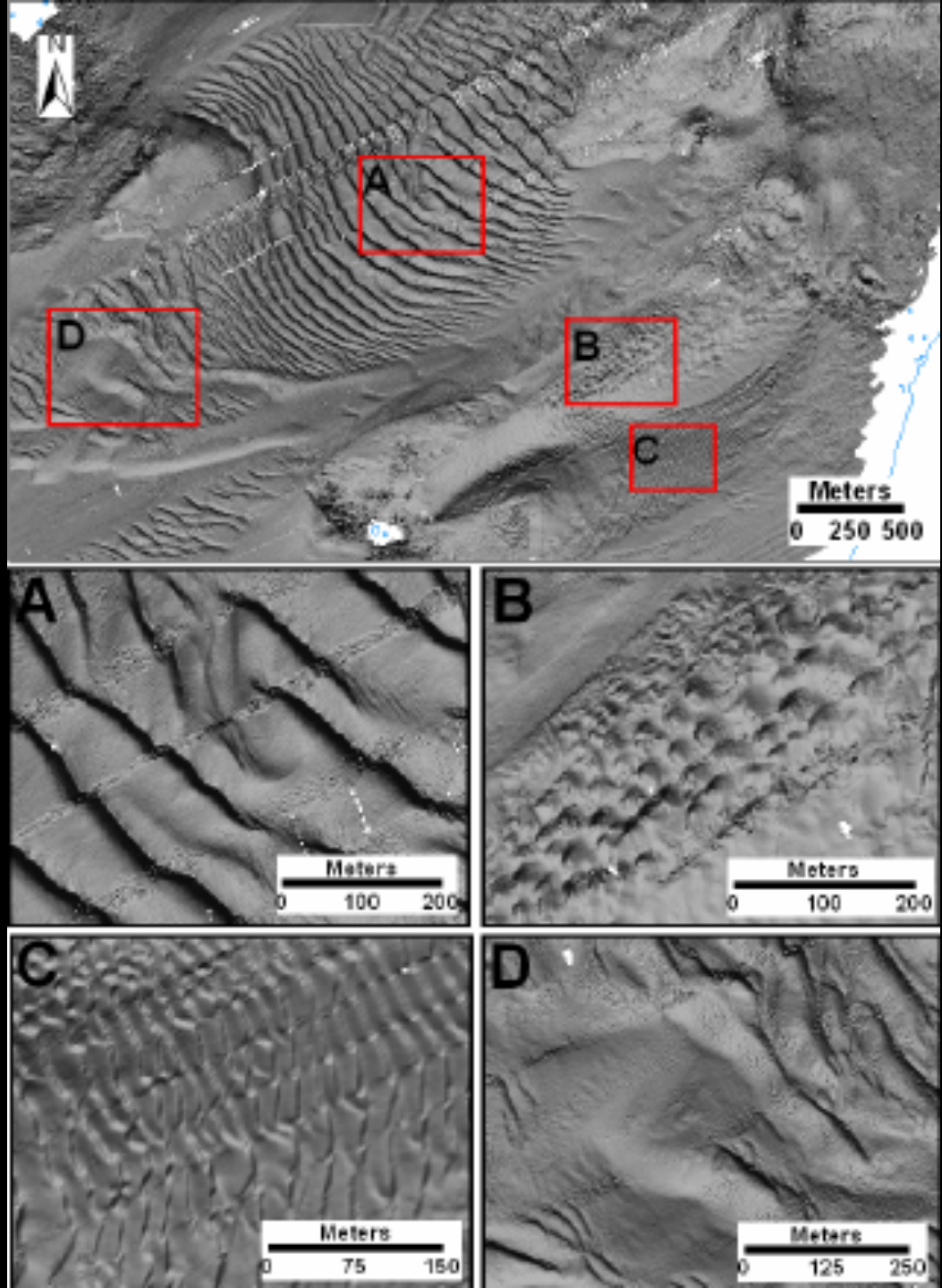
Panels:

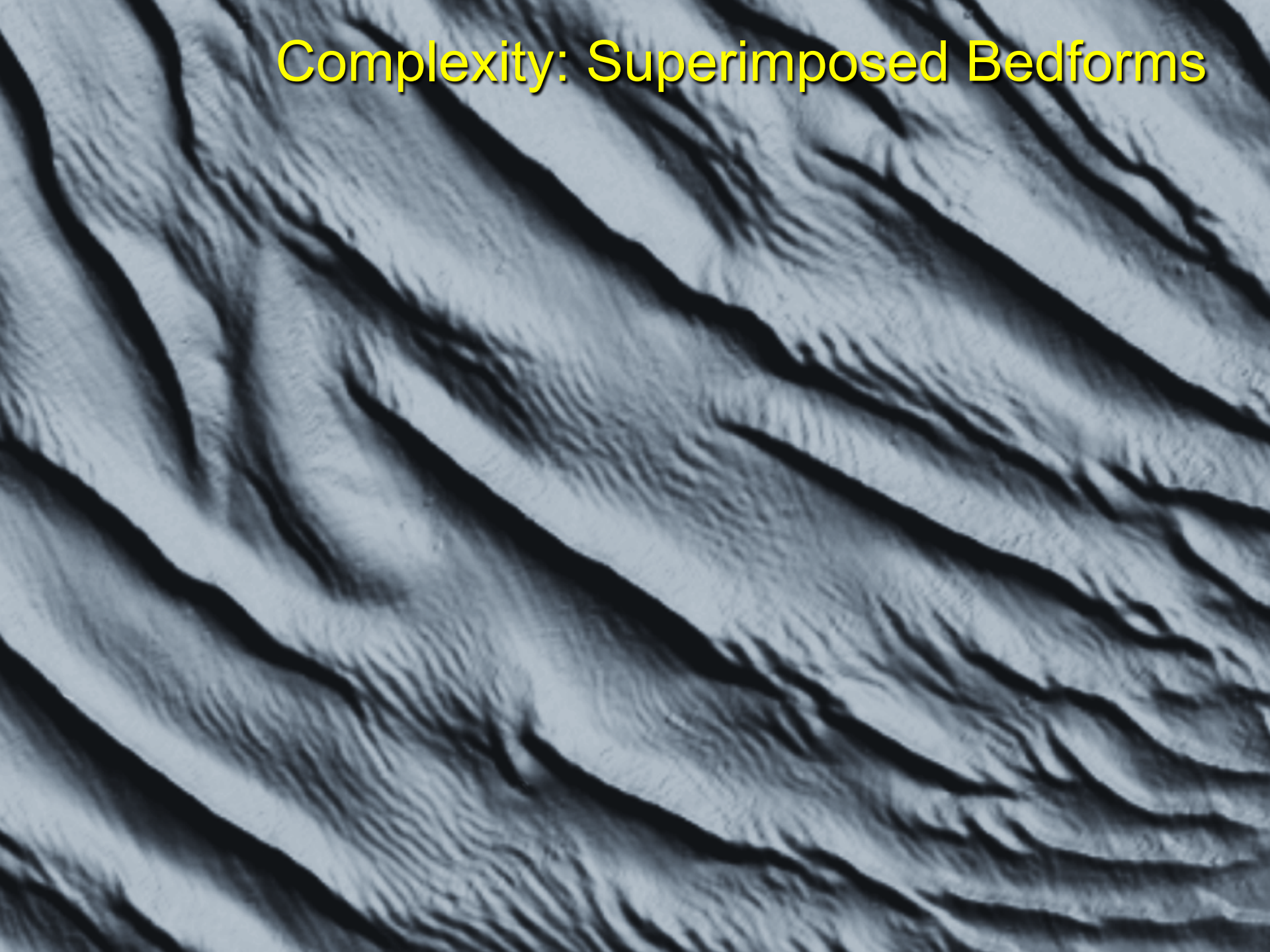
A) Giant sand wave field, up to 150 m wavelengths, nearly two dimensional, ebb dominated with superimposed 5 to 10 meter scale dunes.

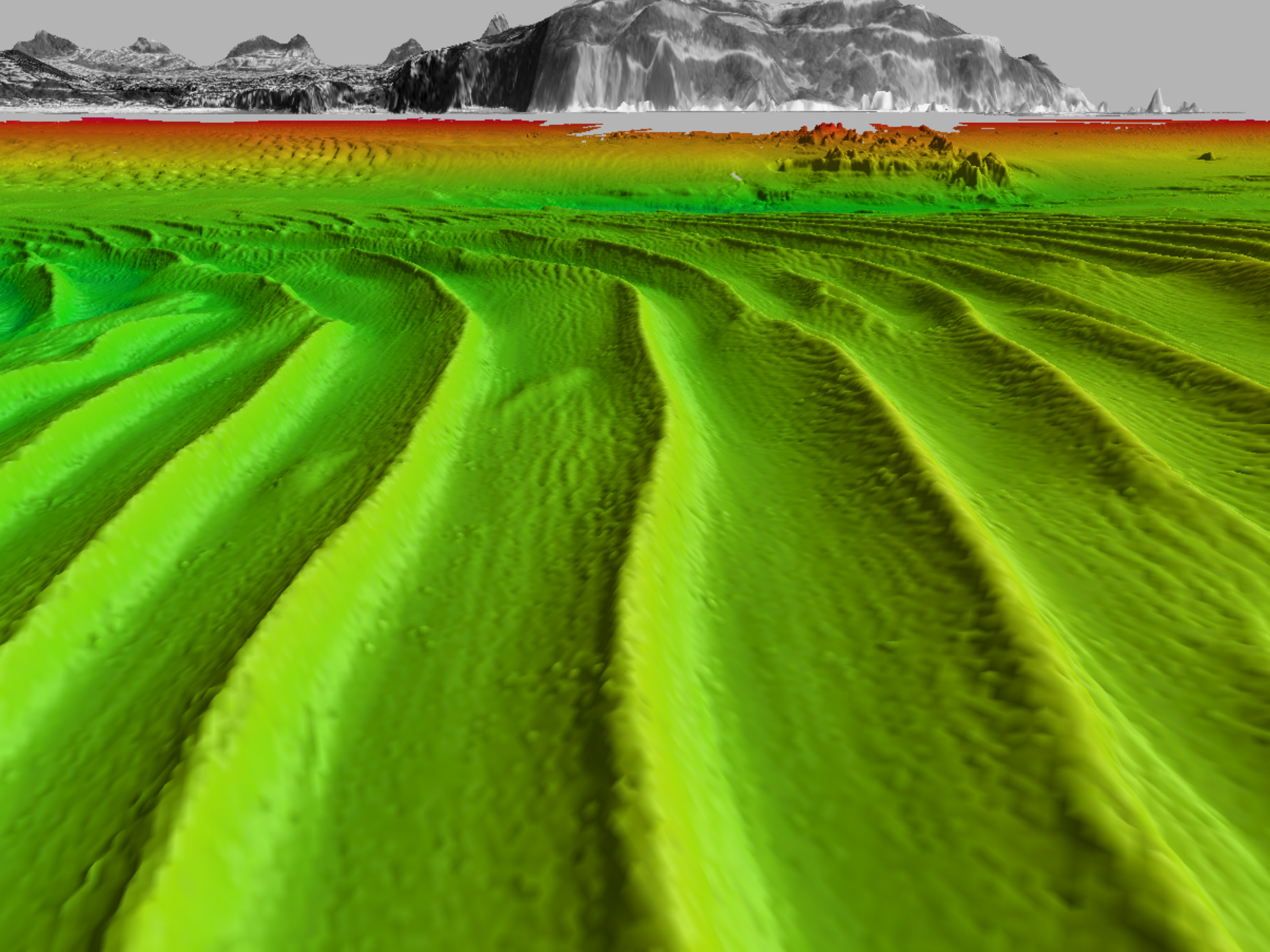
B) Linguoid sand waves or very large megaripples, regular but three dimensional pattern, 20-30 m scale.

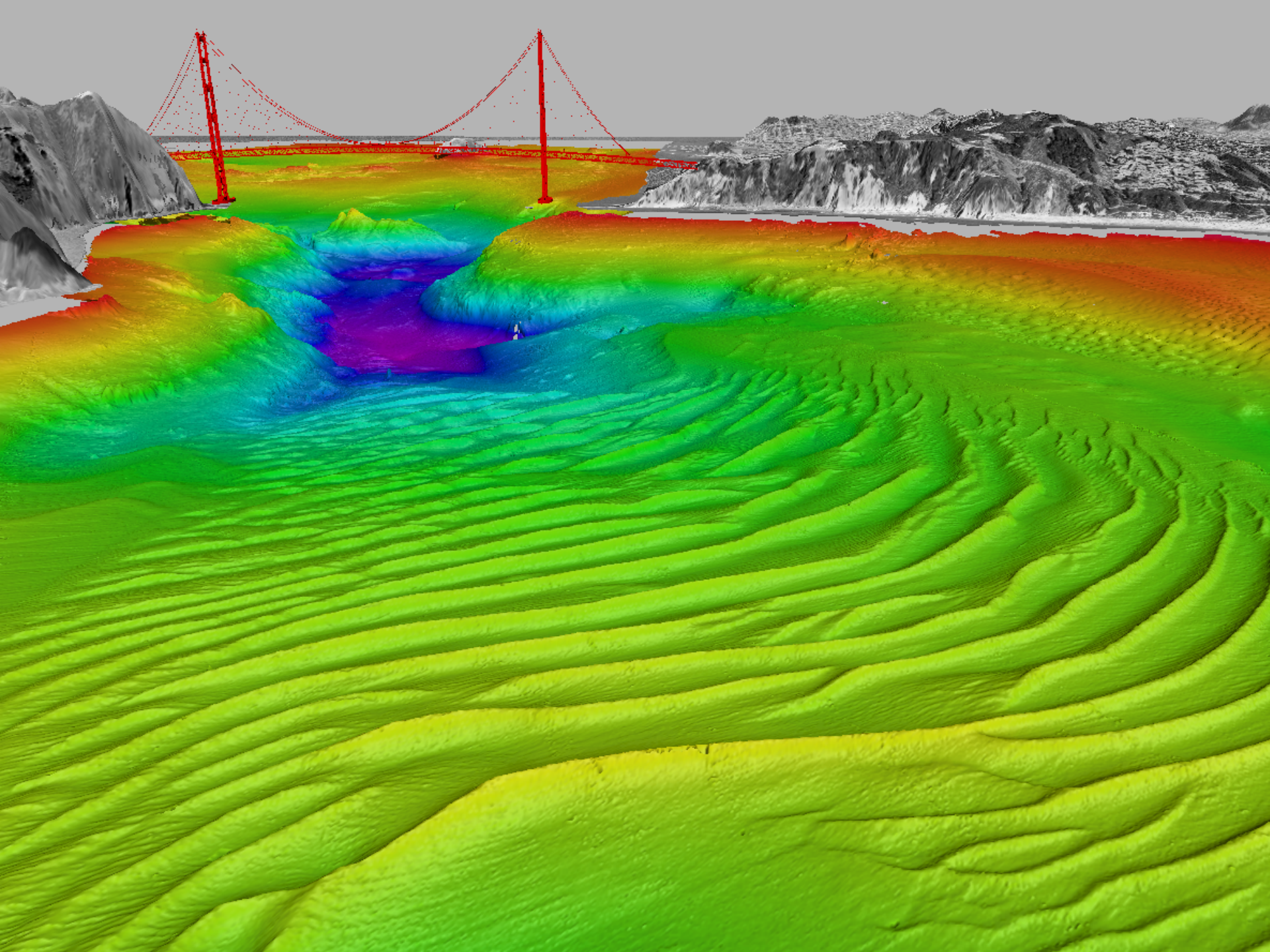
C) Sand waves, flood-dominated, 15-20 m scale.

D) Irregular, three-dimensional sand waves seaward of the main sand wave field.




Complexity: Superimposed Bedforms

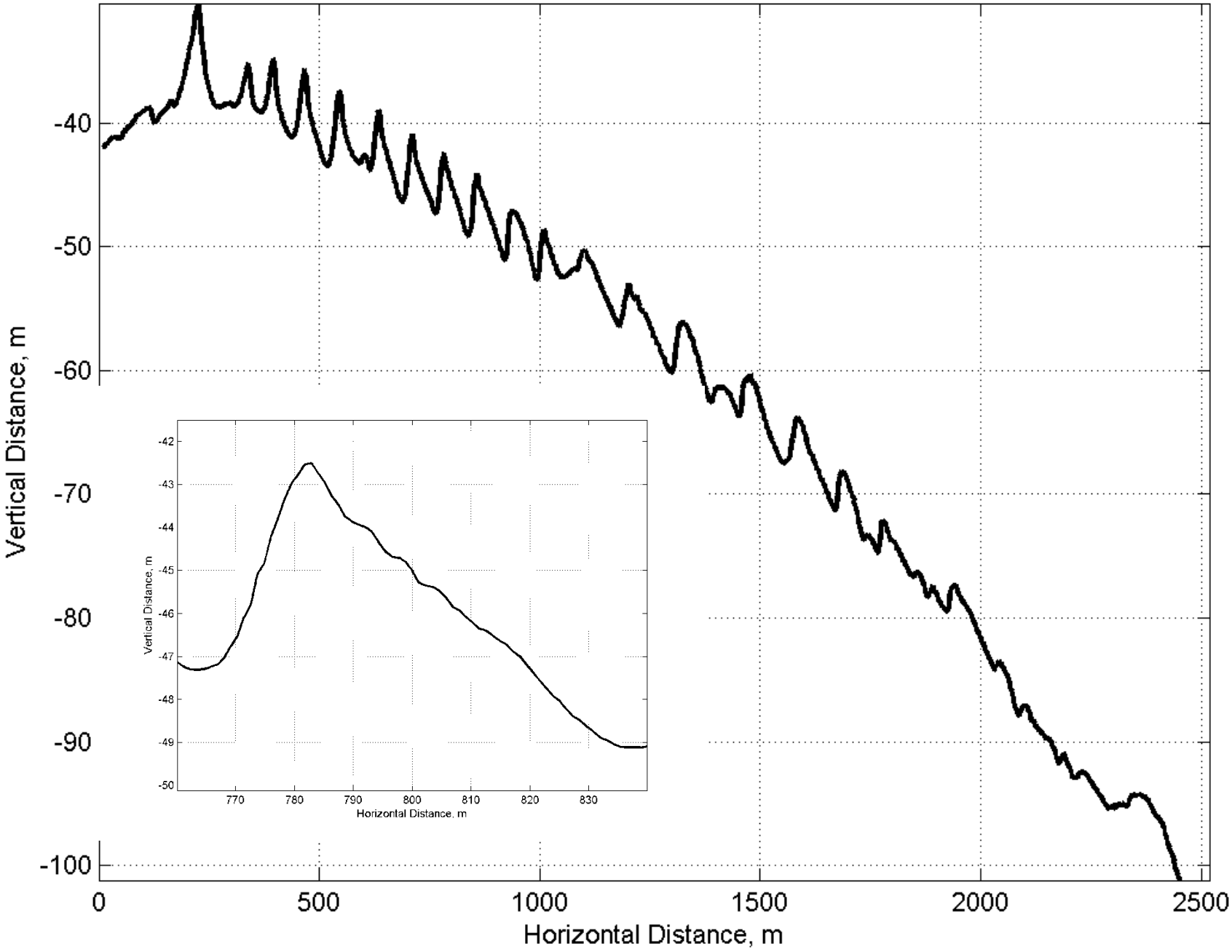




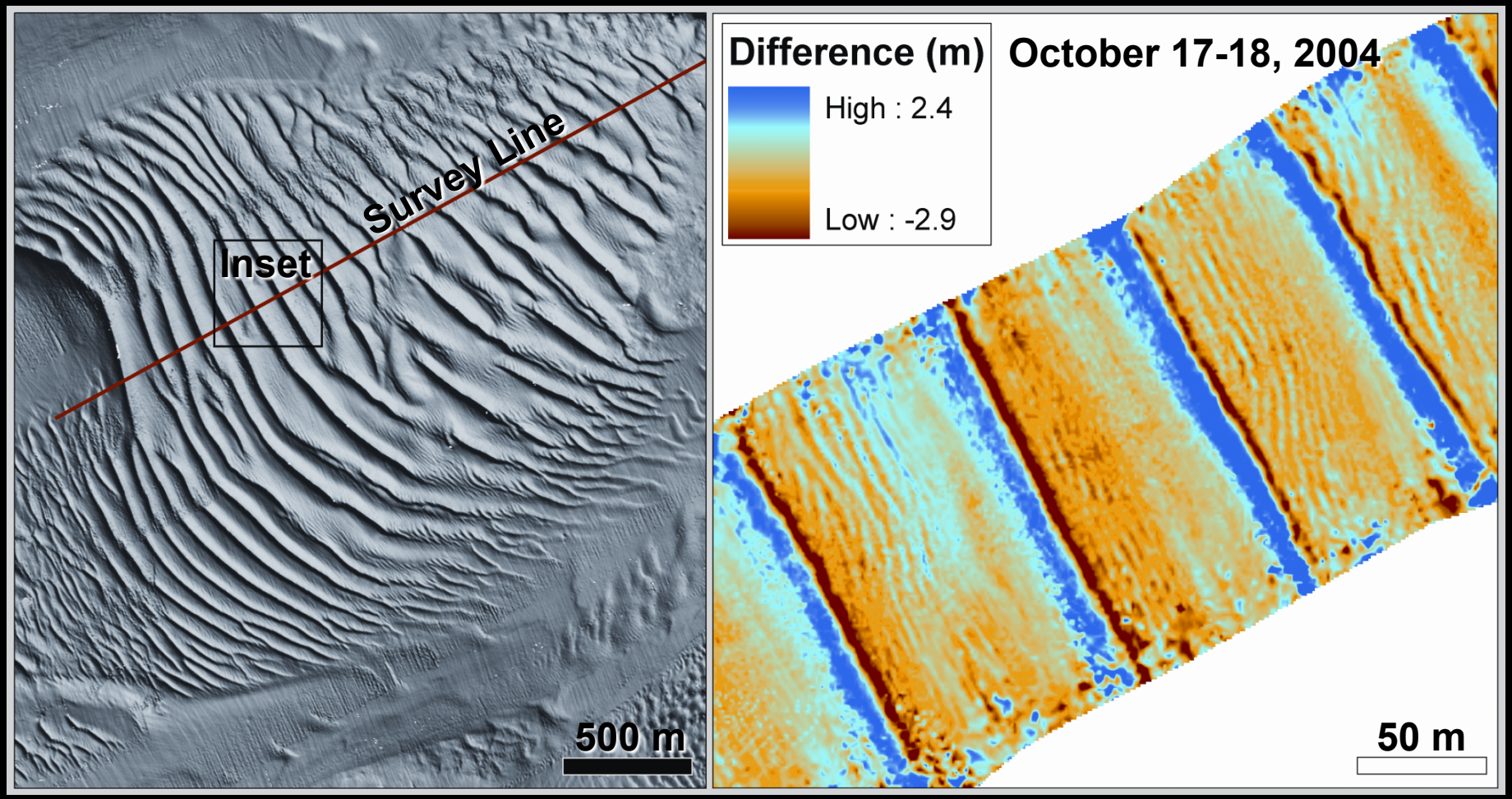
Sand Wave Highlights

- > 40 distinct sand waves
- Covers area over 4 km^2
- Up to 10 m high (avg. = 6 m)
- Wavelengths up to 220 m (avg. = 82 m)
- Depths range from to 30 to 106 m)
- Median grain size = 0.8 mm

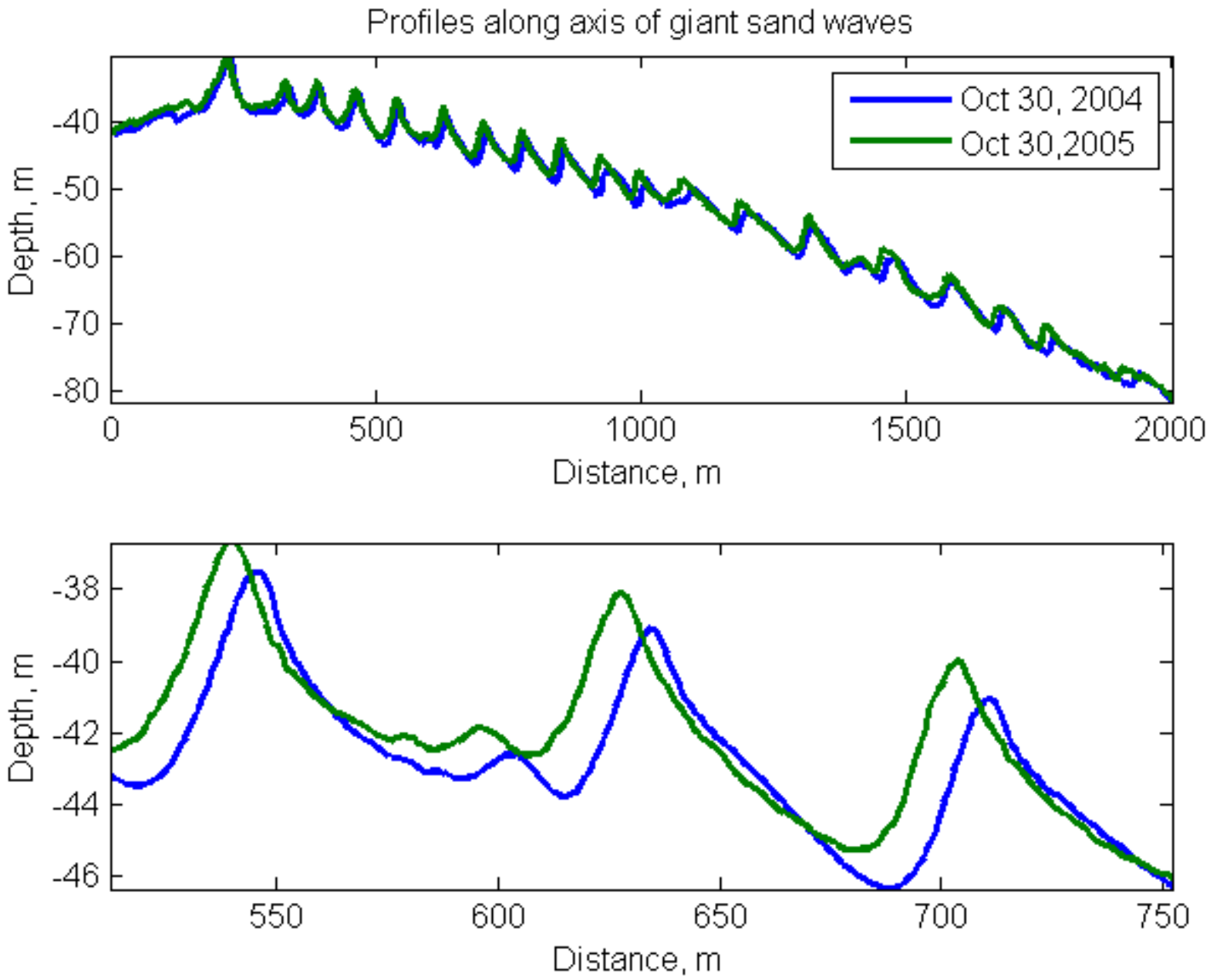
Cross sectional shape of the sandwaves



Sand Wave Movement (Barnard et. al, 2006)

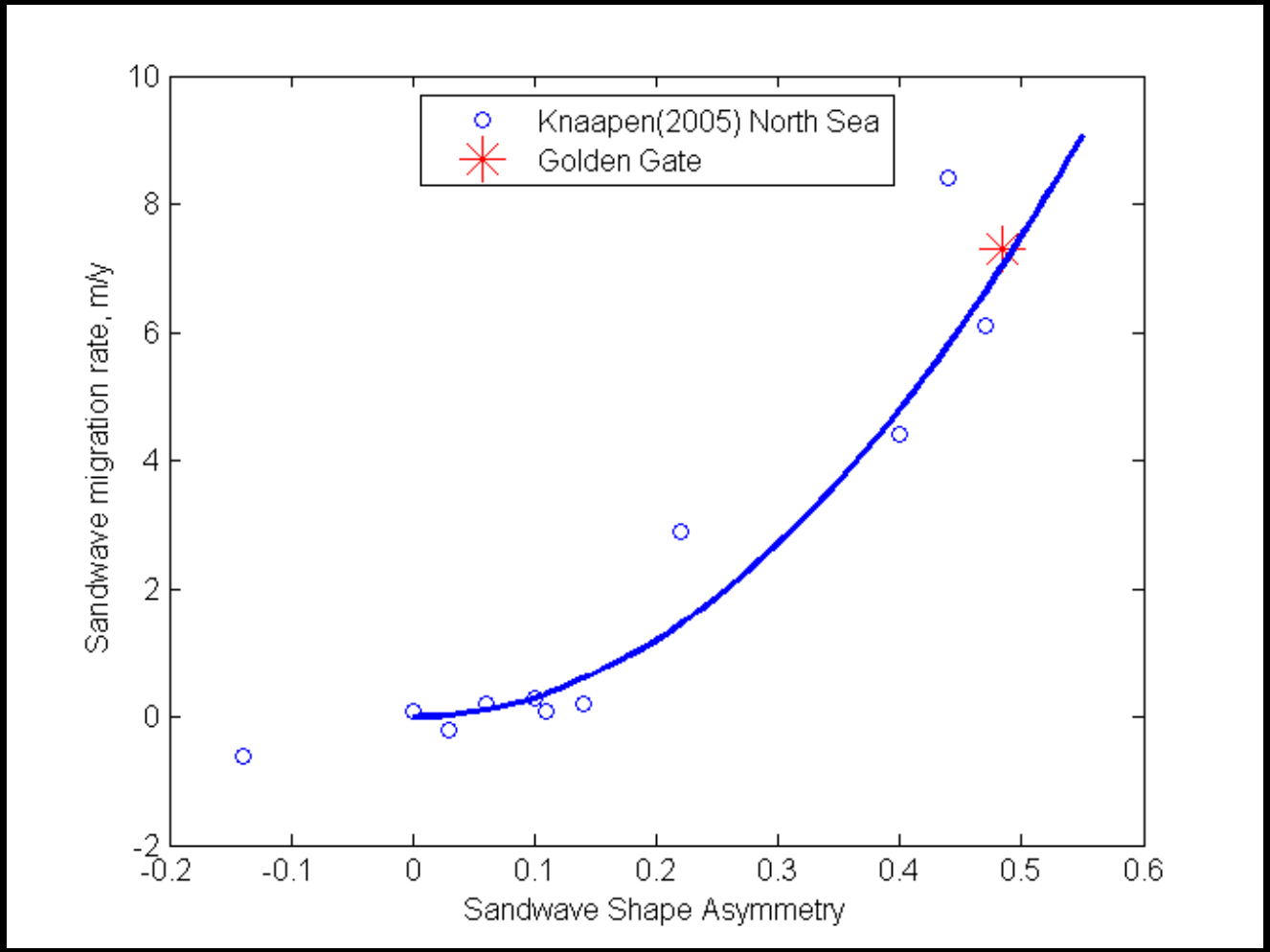


Migration over one year

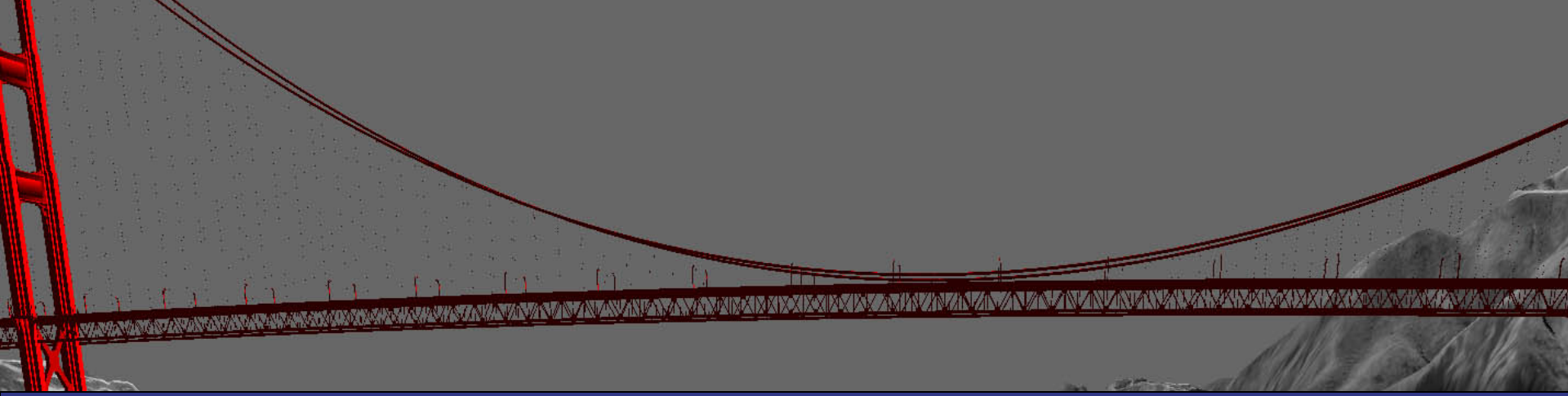


Migration rate verses shape predictors

(following Knaapen, JGR 2005)

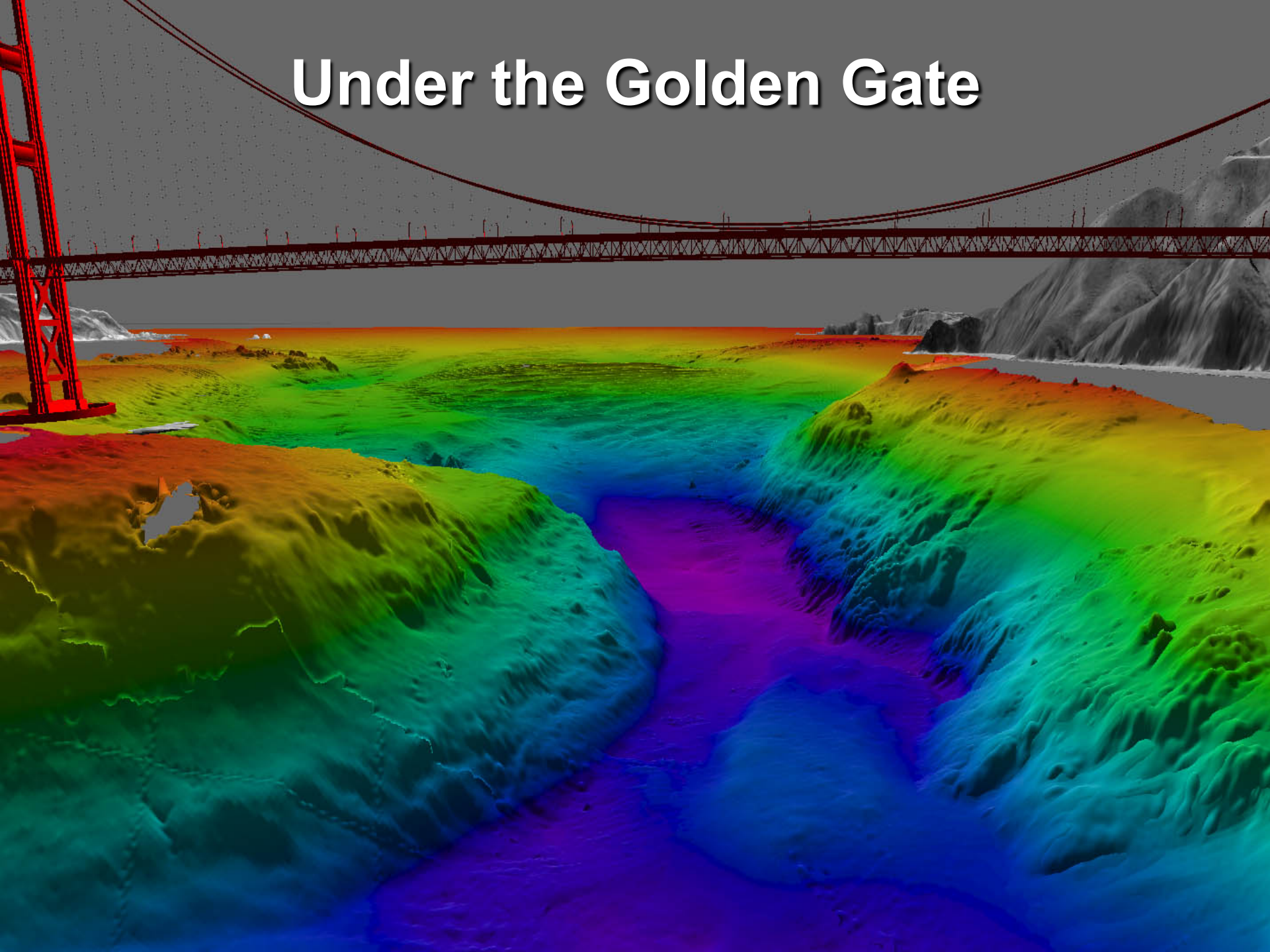


$$Rate\ \alpha\,(Assymetry)^2$$



The key to the strong ebb tidal jet lies under the Golden Gate

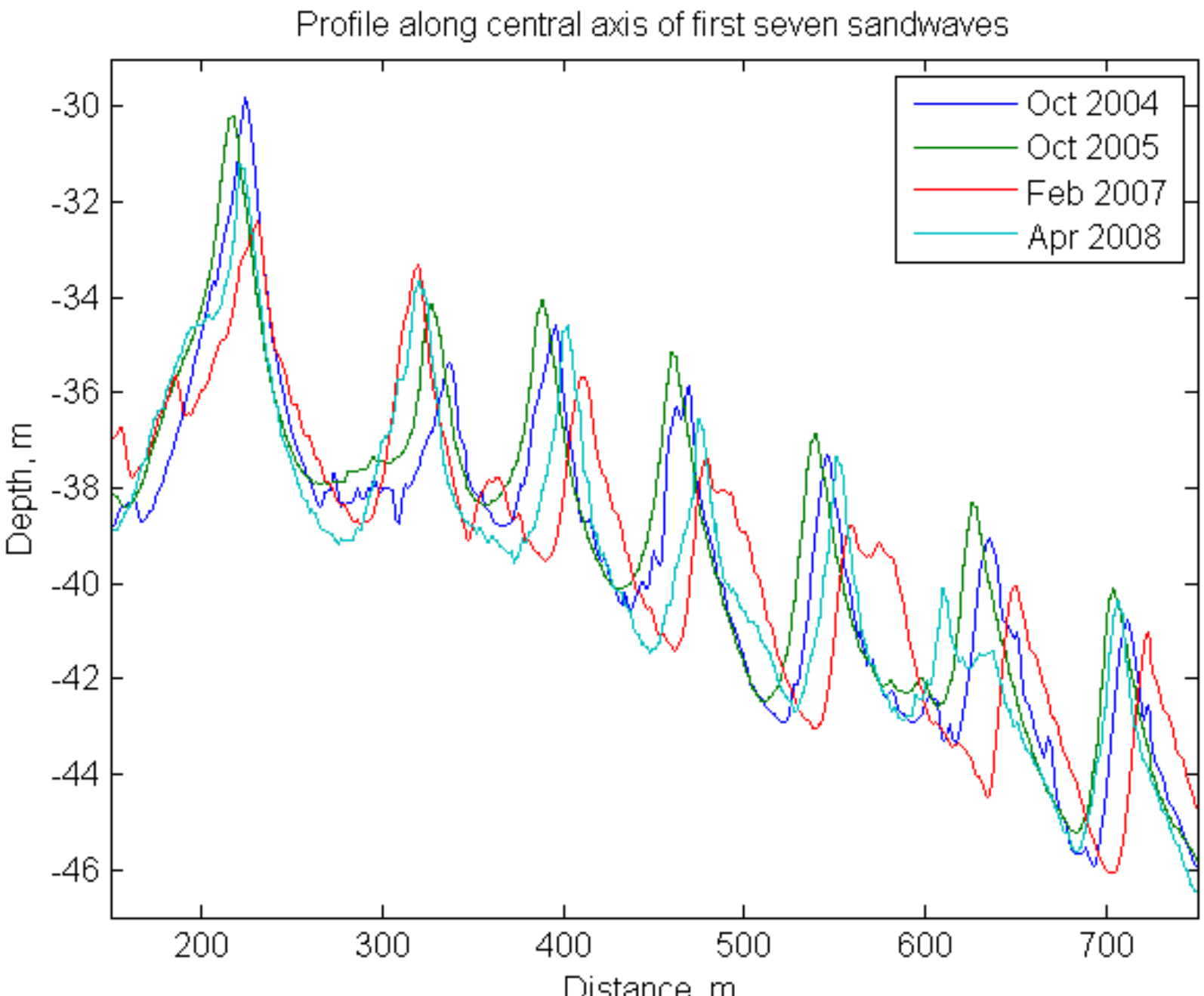
Under the Golden Gate

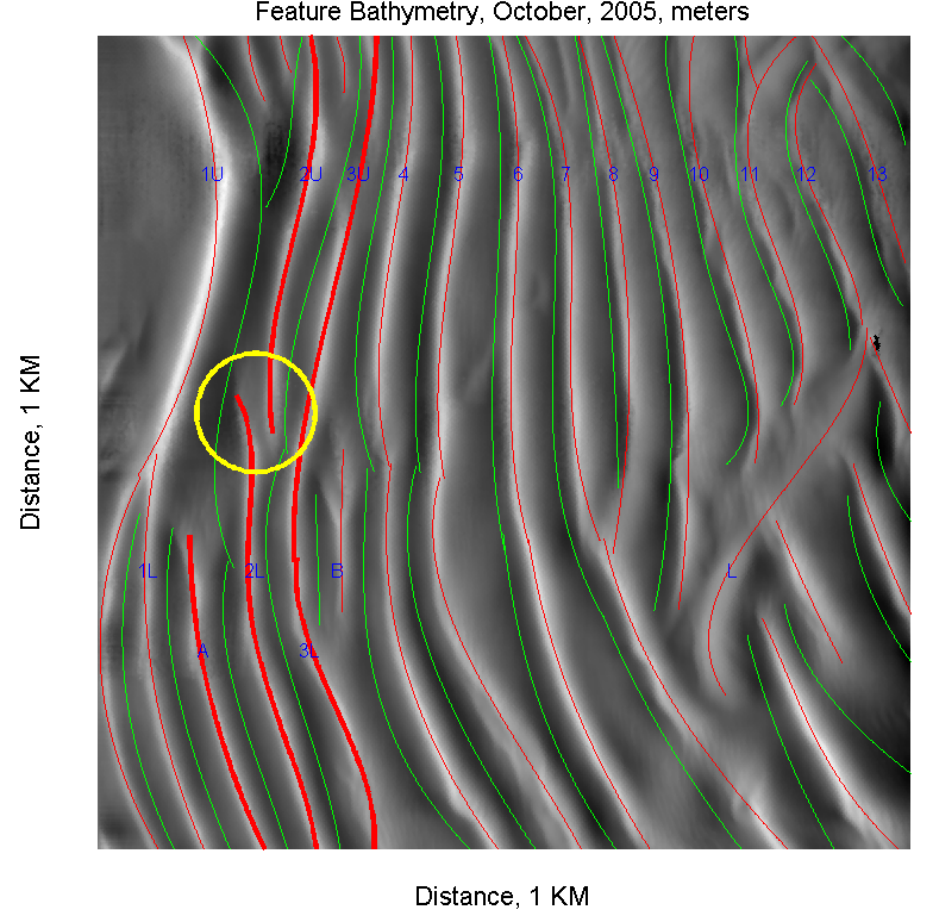


Sand Wave Movement
(conclusions as of 2005/2006)

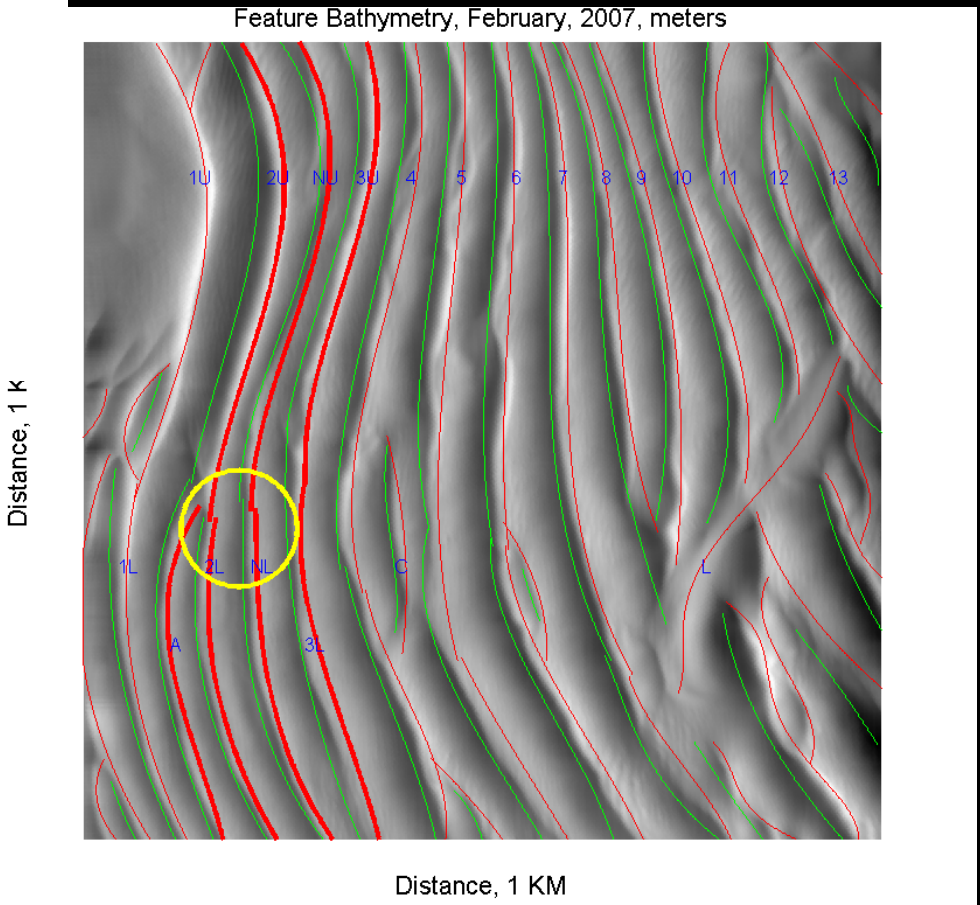
- Crests oscillate up to 3 m during a tidal cycle
- Net movement consistent with shape asymmetry ~ 7 m/year along the central axis
- Net sediment transport of ~ 32,000 m^3/yr extrapolated from migration along the central axis

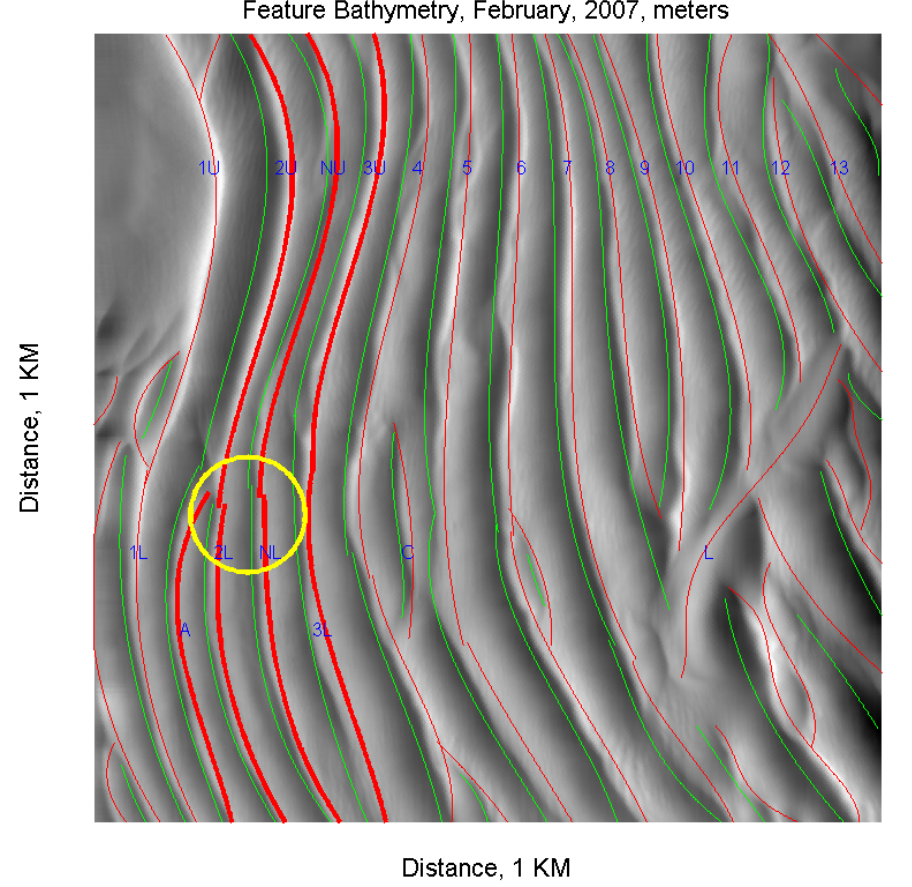
Migration over 3.5 years; It gets more interesting!



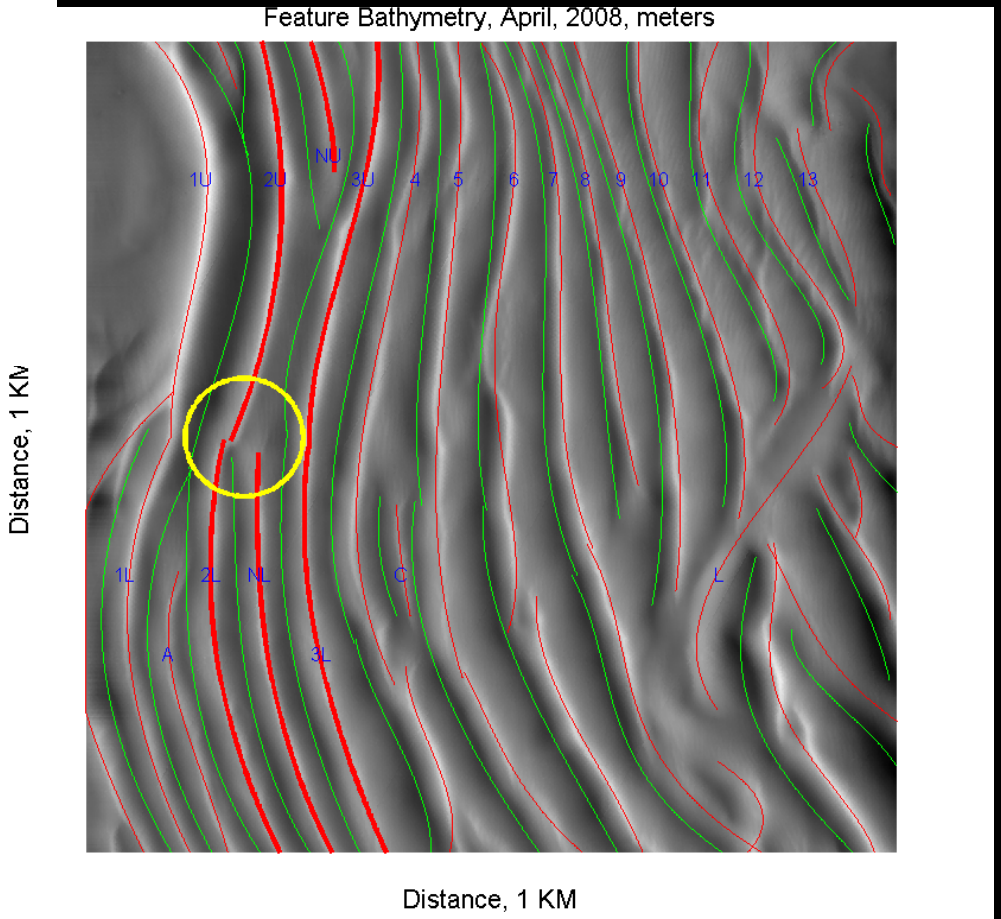


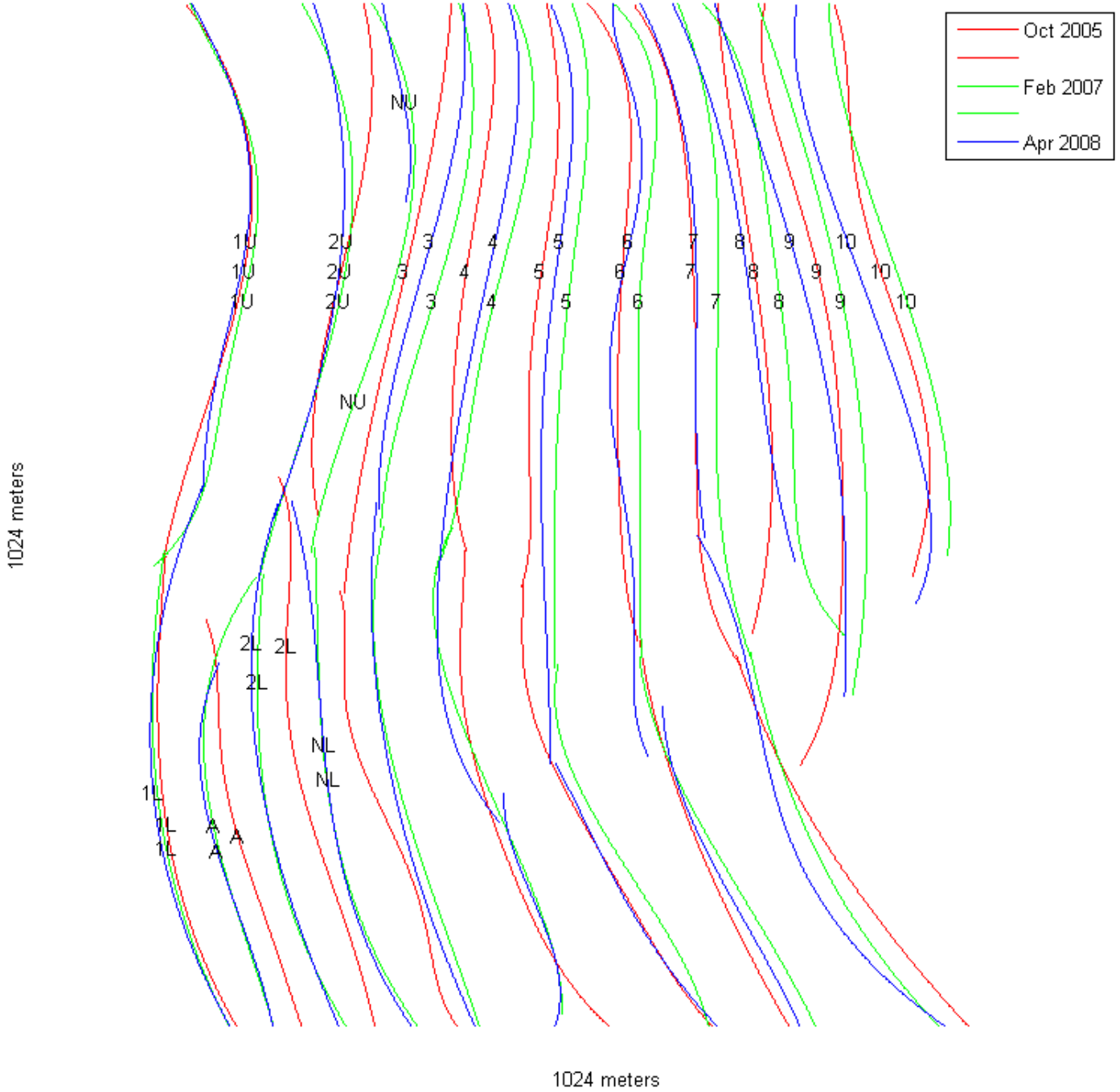
Between Oct., 2005 and Feb., 2007 a new crest developed between crests number 2 and 3. Neighboring crests migrated in the “opposite” direction to accommodate new crest.

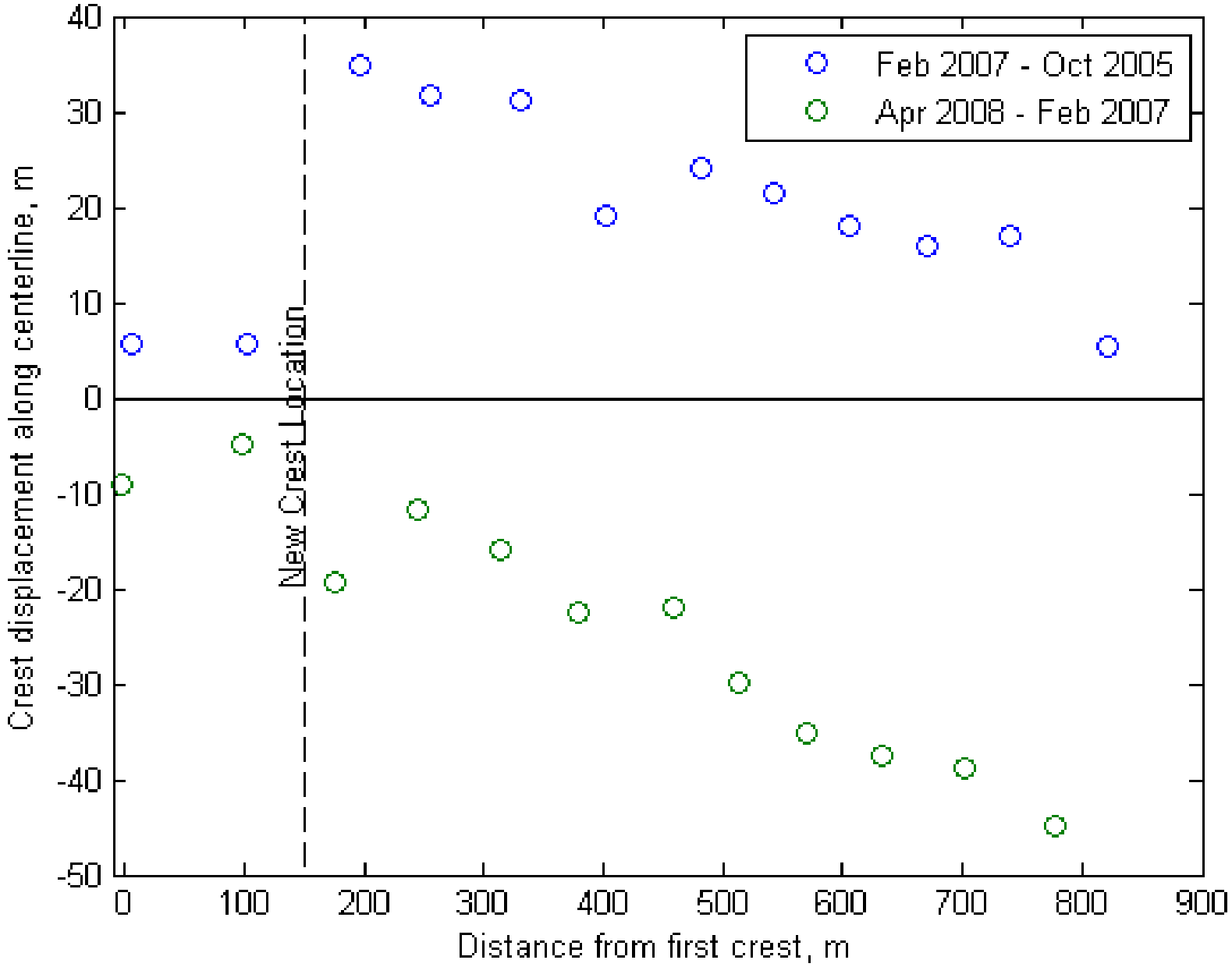




Between Feb., 2007 and Apr., 2008 much of the new crest disappeared, and neighboring crests moved back to fill the empty space.




Oct 2005
Feb 2007
Apr 2008
1024 meters
1024 meters
NU
NU
1U
1U
1U
2U
2U
2U
3
3
3
4
4
4
5
5
5
6
6
6
7
7
7
8
8
8
9
9
9
10
10
10
2L
2L
2L
NL
NL
1L
1L
1L
A
A
A


Feb 2007 - Oct 2005
Apr 2008 - Feb 2007
New Crest Location
Crest displacement along centerline, m
Distance from first crest, m
40
30
20
10
0
-10
-20
-30
-40
-50
0
100
200
300
400
500
600
700
800
900

These observations raise many perplexing questions:

How and why did the new crest form inside the field of sandwaves?

How did the field-scale migration occur to accommodated the new crest?

Some sandwaves migrated in the direction opposite to that indicated by their shape asymmetry! How does this happen? I've never seen "anti-asymmetry" migration before, have you?

No conclusions, so instead, some poetry!

L.F. Richardson famous poem on the cascading scales of hydrodynamics :

Great whirls have little whirls
That feed on their velocity
And little whirls have lesser whirls
And so on to viscosity

Inspired by Richardson's poem, here's one about the coalescing scales of particle flows:

Grains move to and fro

Forming wiggles and bumps that grow

Into ripples, dunes, and swales

Merging and bridging scales

From the grain coefficient of restitution

Up to landscape evolution