Energy sources for Yotta-Tev iceberg showers

or

the physics of ice-shelf disintegration

Doug MacAyeal, University of Chicago
with
various colleagues in the Physics Department
at the University of Chicago

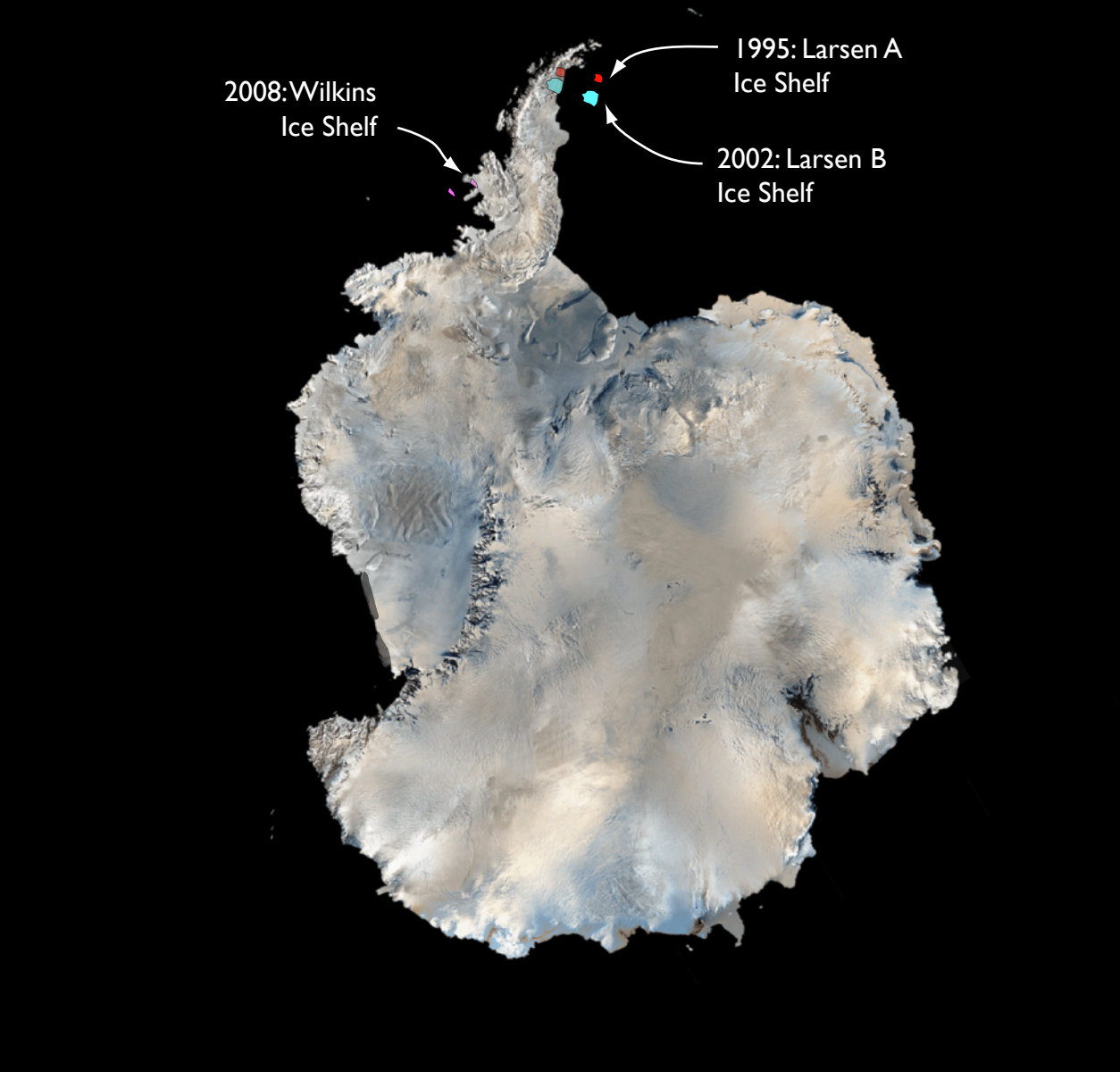
Premise: physicists like to think about problems that have not been solved...

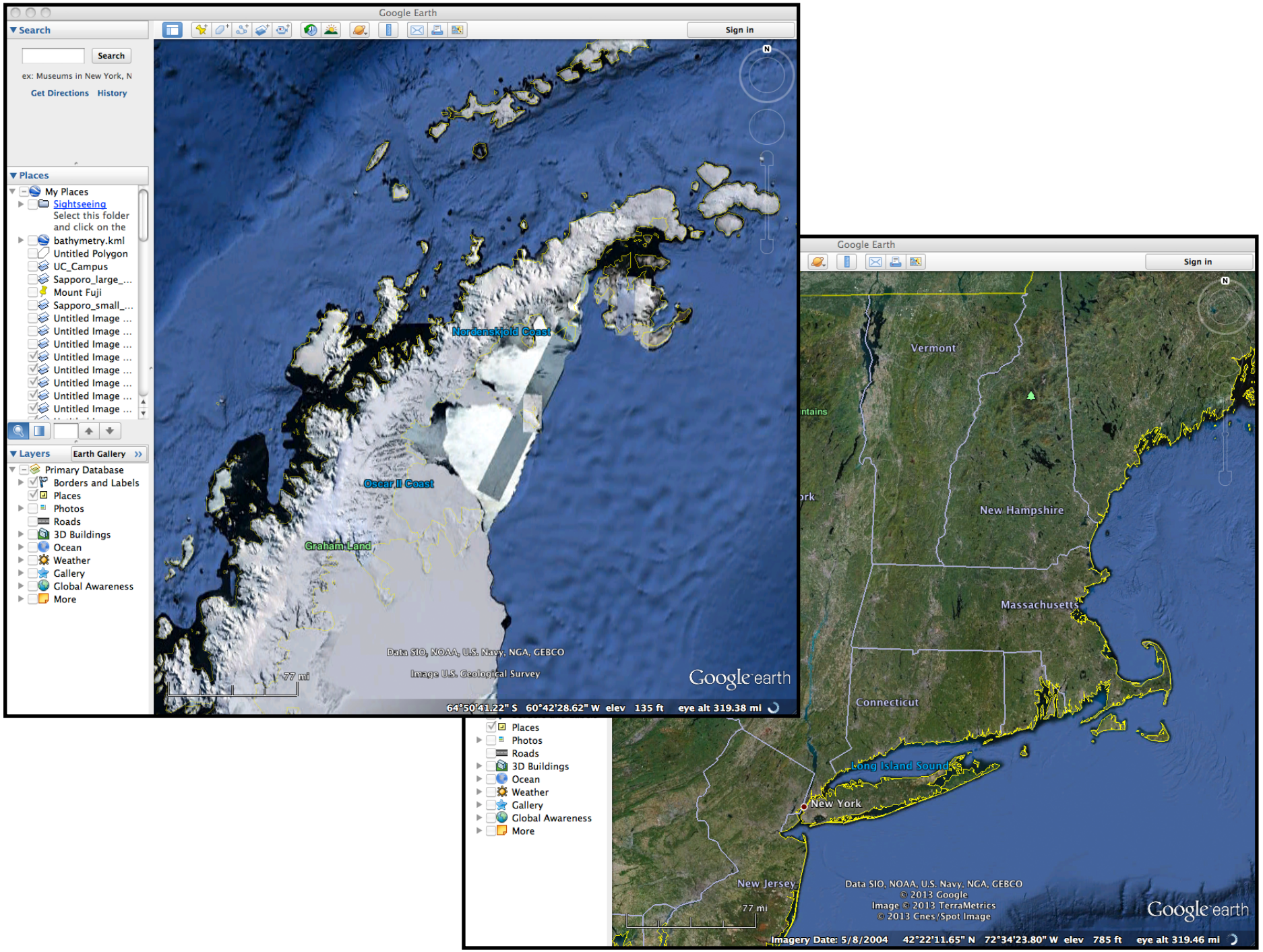
Plan of presentation:

- Explosive disintegration of Larsen B Ice Shelf (also Wilkins Ice Shelf)
- Physics A: iceberg-capsize experiments conducted in the lab
- Physics B: iceberg tsunamigenesis and ocean wave propagation...
- Physics C: elastic flexure and fracture below meltwater lake loads...

- Physics D: iterated maps and chain reactions

- Conclusion: an attept to use physics to tell the "story" of why ...


1995: Larsen A
Ice Shelf
2008: Wilkins
Ice Shelf
2002: Larsen B
Ice Shelf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Places
My Places
Sightseeing
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Sapporo_large_...
Mount Fuji
Sapporo_small_...
Untitled Image ...
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Primary Database
Borders and Labels
Places
Photos
Roads
3D Buildings
Ocean
Weather
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Vermont
New Hampshire
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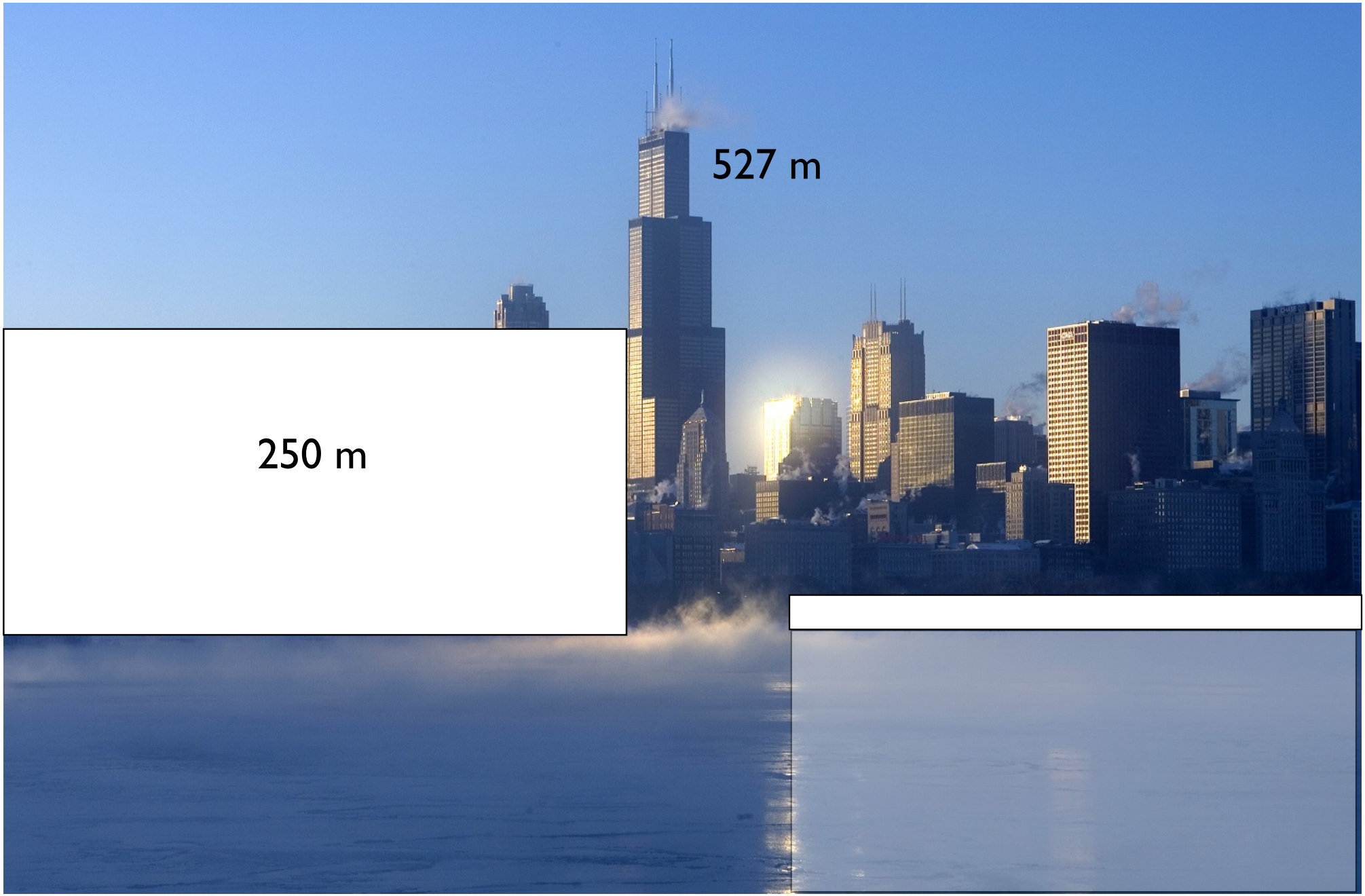
Long Island Sound
New York
New Jersey
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2013 Google
Image © 2013 TerraMetrics
© 2013 Cnes/Spot Image
Imagery Date: 5/8/2004 42°22'11.65" N 72°34'23.80" W elev 785 ft eye alt 319.46 mi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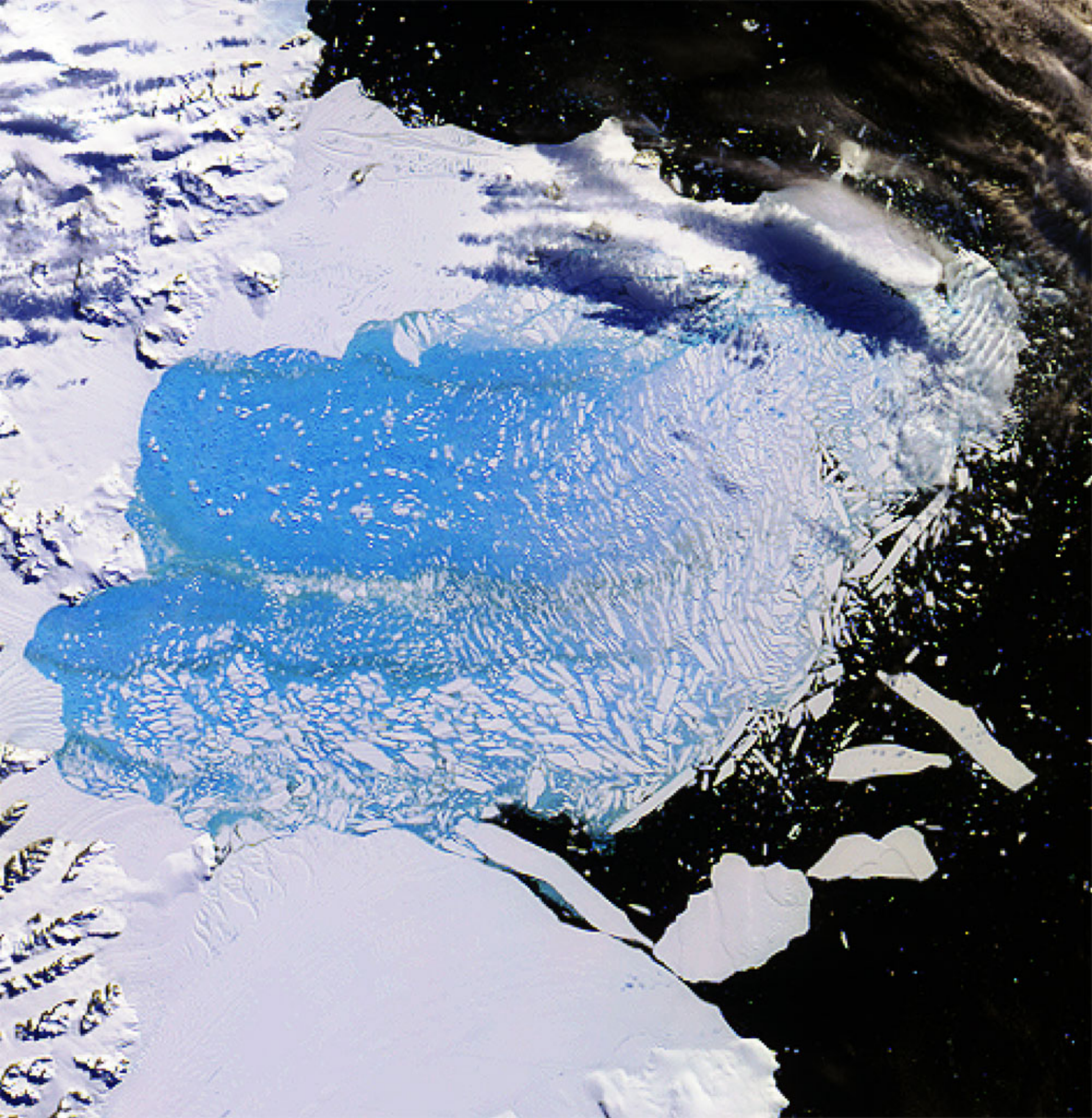

Phenomenology

Unexpectedness

Ice Shelf Breaks Up in a Fast-Warming Antarctic Region…

"All the News That's Fit to Print"

The New York Times

20 March, 2002

VOL. CLI . . . . No. 52,063

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WEDNESDAY, MARCH 20, 20

Printed in Colorado

Nation

Colorado: Part
Highs in the low
40's in the m
partly sunny sk
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S.E.C. Had Sought $500 Million In Failed Talks With Andersen

Negotiations Ended When Auditor Was Indicted

By KURT EICHENWALD

The Securities and Exchange Commission was demanding that Arthur Andersen pay $500 million to settle claims stemming from the Enron investigation, but the negotiations broke down after the firm was indicted by the Justice Department on charges of obstruction of justice, people involved in the case said yesterday.

At the time that the talks between Andersen, the accounting giant, and securities regulators collapsed, the two sides were as much as $150 million apart on the amount of a financial settlement. But these people said that there were strong signs of progress. The firm had already indicated that other terms of a deal — including requirements that Andersen adopt wide-ranging reforms recommended by a committee led by Paul A. Volcker, the former chairman of the Federal Reserve — would be readily accepted.

The proposed settlement — roughly equal to two times the amount in fees that Andersen received over the last five years from Enron — was intended to finance a government-monitored compensation fund to reimburse investors who lost large sums of money in the collapse of Enron last December. Andersen was the longtime accountant to Enron and provided advice on its use of a series of partnerships that ultimately played a critical role in the company's downfall.

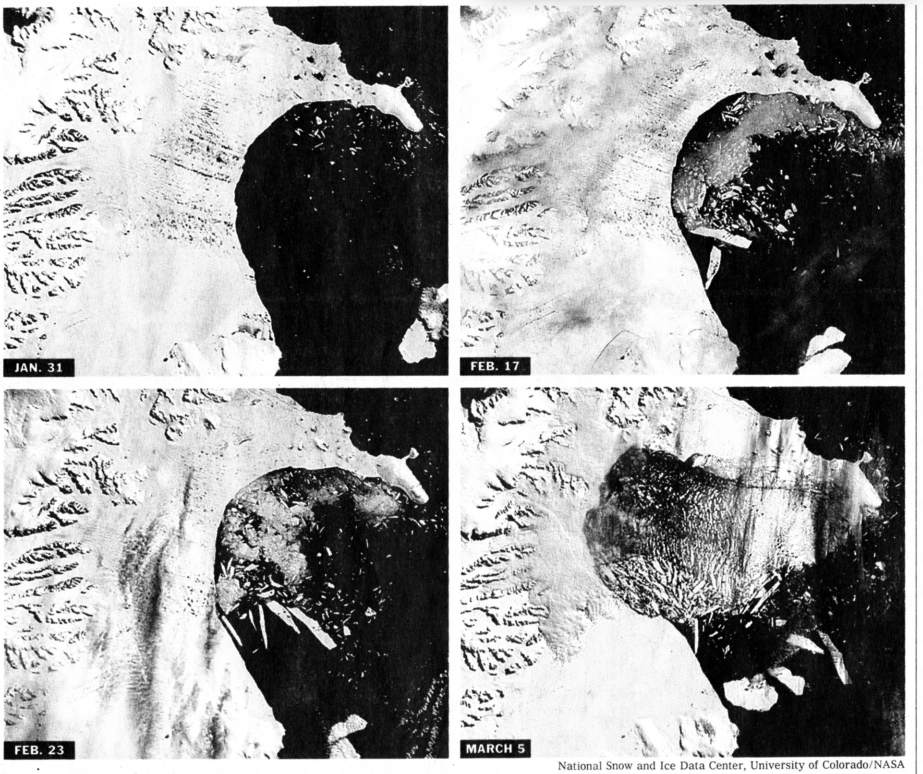
But with the company under indictment, its client base rapidly shrinking and its overseas offices likely to be sold to a competitor, the chances for the large-scale settlement incorporating significant reforms appear to have slipped away.

"There is little doubt that the settlement number would have been in the many hundreds of millions of dollars," one person involved in the case said yesterday. "But everything has changed very quickly, and now it's unlikely that those kinds of numbers will be in reach."

Another person involved in the case added: "It would have been an all-time world-shattering record. But now there aren't even talks in progress."

Throughout the negotiations, the S.E.C and the Justice Department were said to be in consultation. But the resulting criminal indictment

HEWLETT DECLARES



National Snow and Ice Data Center, University of Colorado/NASA

Ice Shelf Breaks Up in a Fast-Warming Antarctic Region

Satellite images over little more than a month show the disintegration of an ice shelf about the size of Rhode Island on the eastern side of the Antarctic Peninsula. The speed of the breakup stunned scientists. Page A11.

CHENEY,
SAYS HE
TO TALK

A TRUCE MU

Vice Preside
Says Meeti
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By MICHA
and JAM

JERUSALEM
shift of Bush
egy, Vice Pre
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steps to curb
and to impose
Mr. Cheney s
take place as ea
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to meet with M
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el indicated tha
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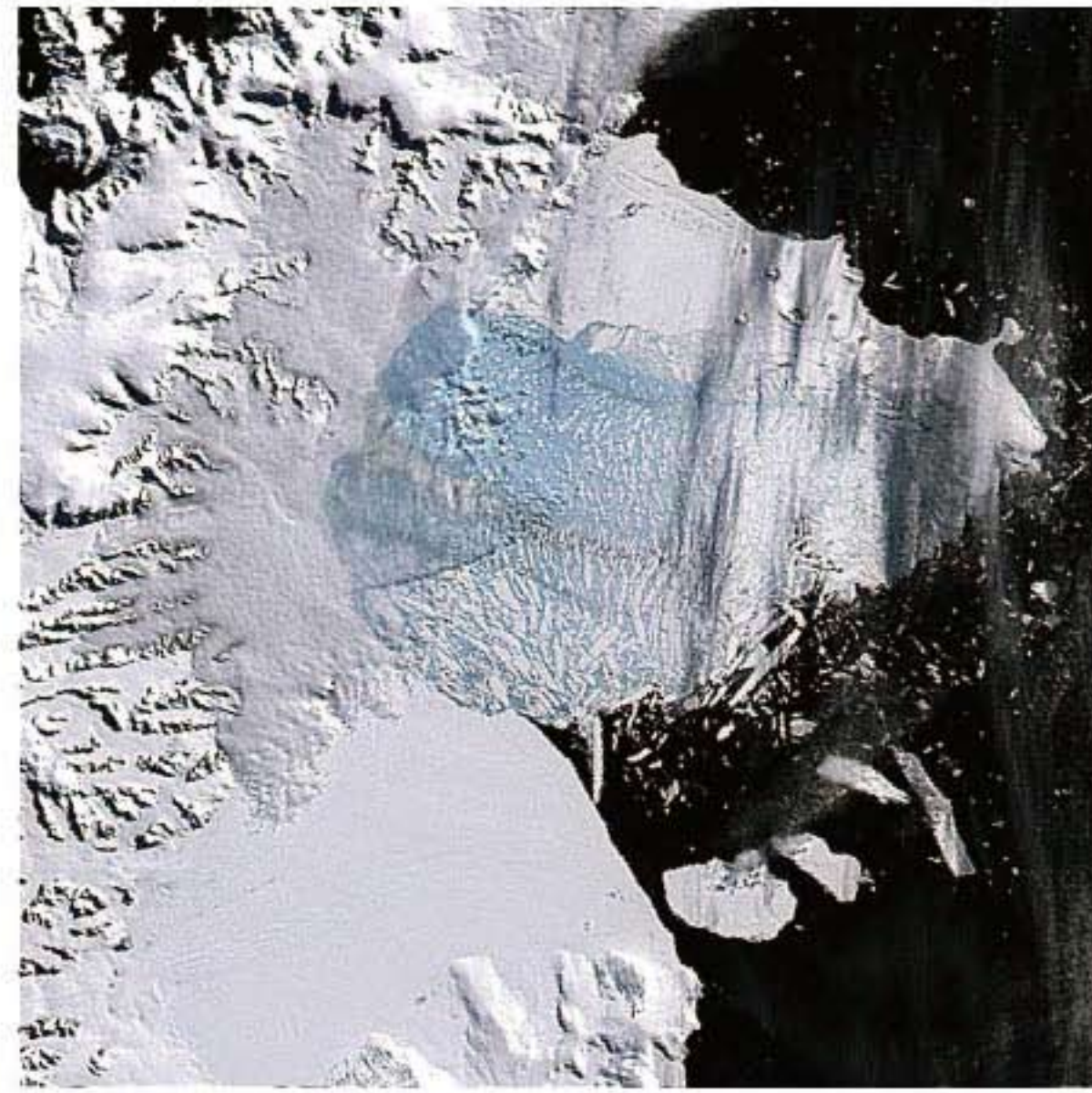
Explosiveness

31 Jan 2002

17 Feb 2002

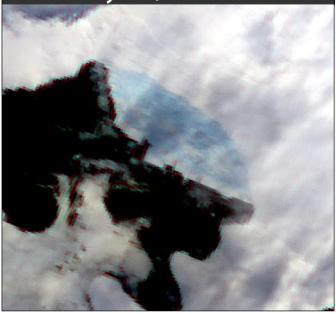
23 Feb 2002



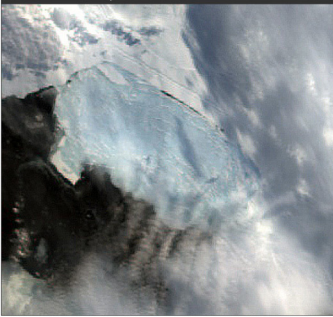
05 Mar 2002

February 28, 2008

February 29, 2008

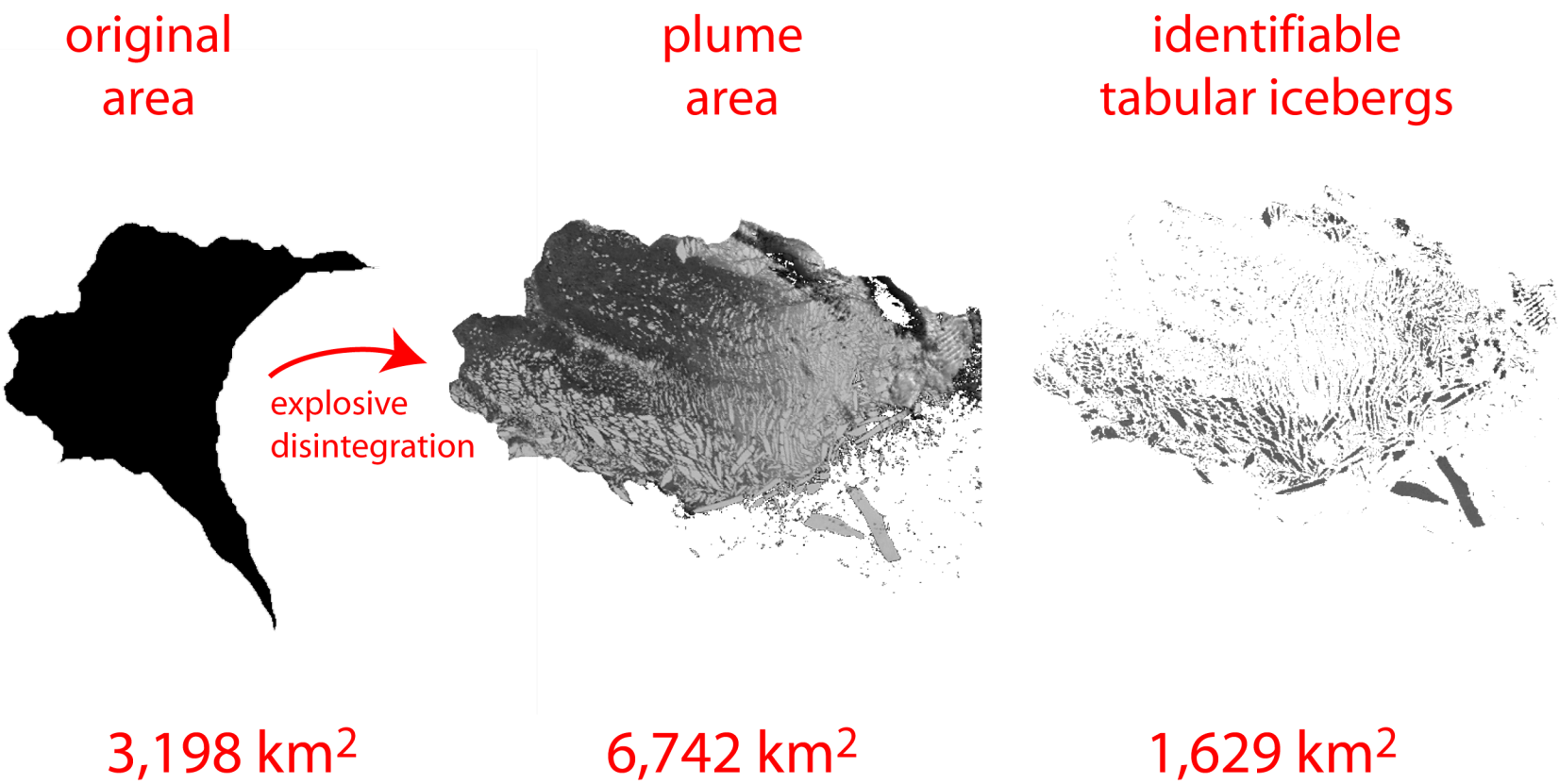


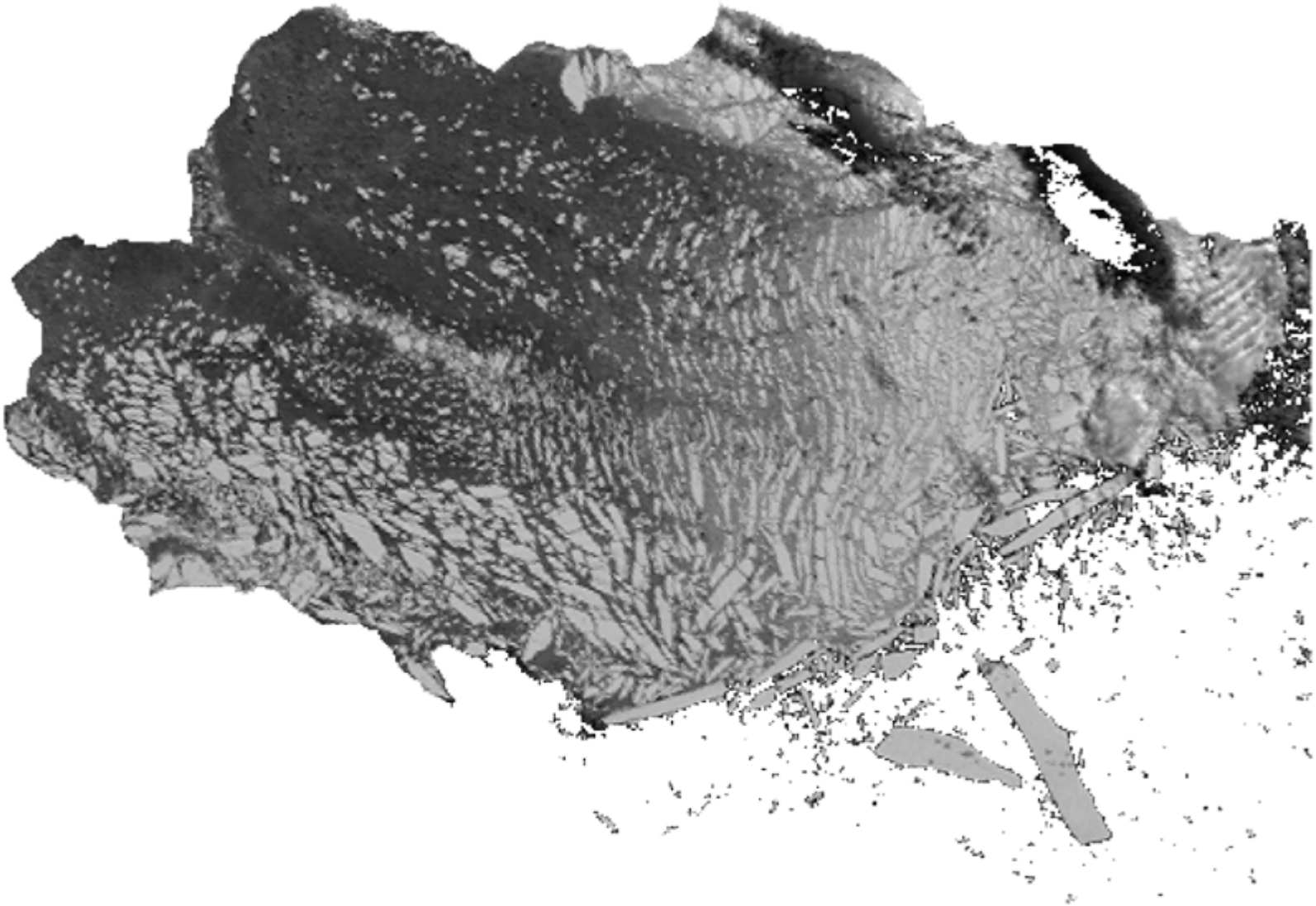
March 8, 2008



National Snow and Ice Data Center, Boulder, CO

Surface coverage


original area
plume area
identifiable tabular icebergs
explosive disintegration
3,198 km2
6,742 km2
1,629 km2



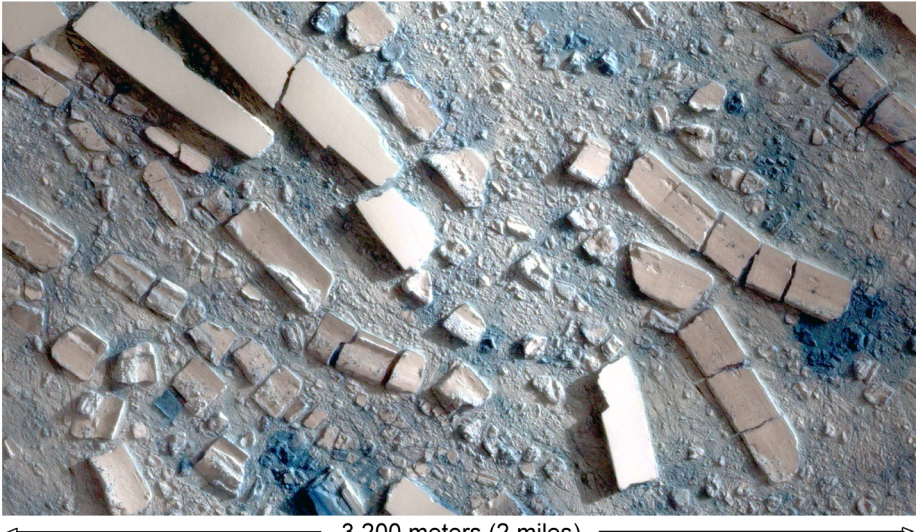
1,569 km^2 "lost" (about 1/2 of original ice shelf)

5,113 km^2 "space to hide in"

Taphonomy

taphos - Greek, 'grave'
-nomy - Greek, *nomos*, 'law' of knowledge, rules

High-resolution image (subscene)

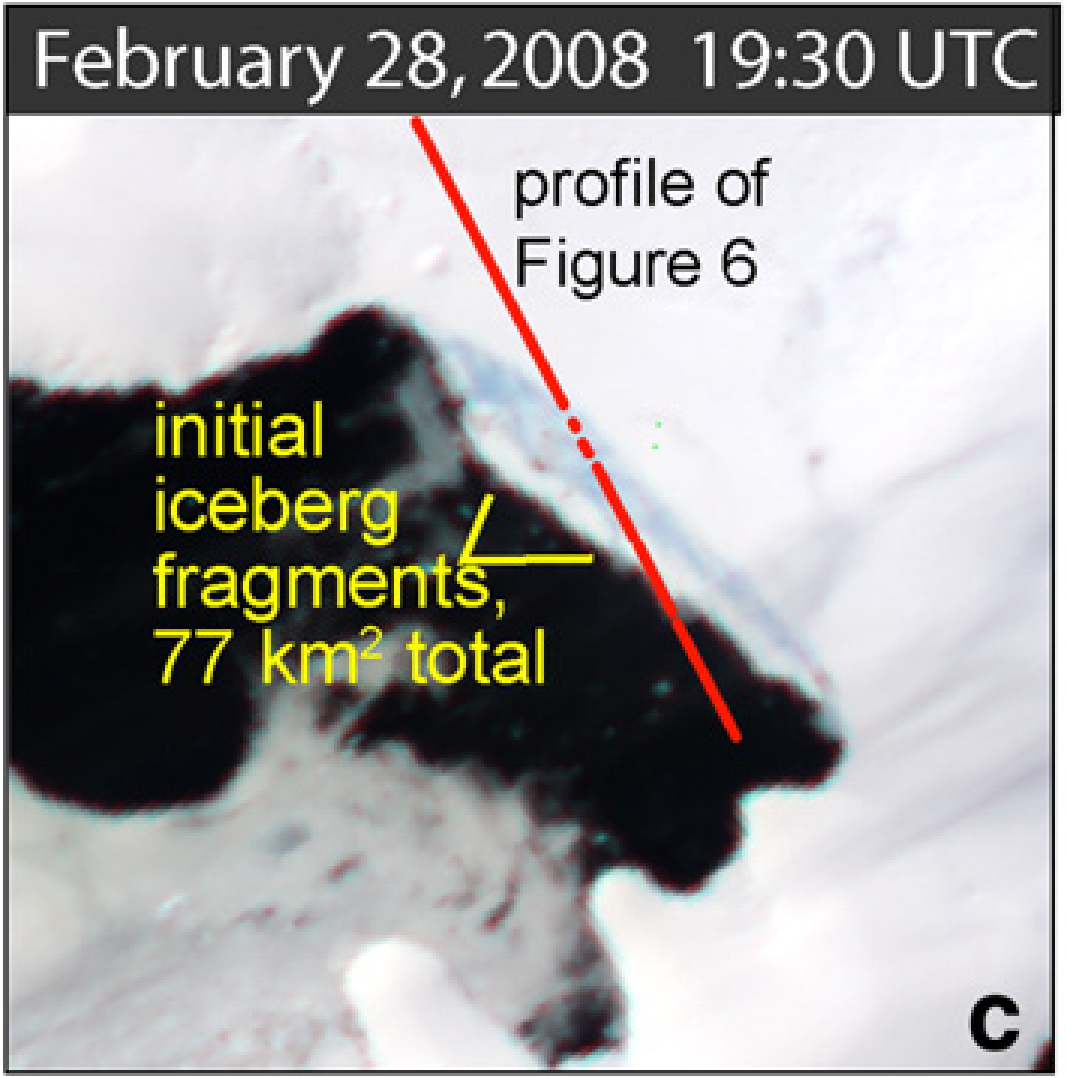


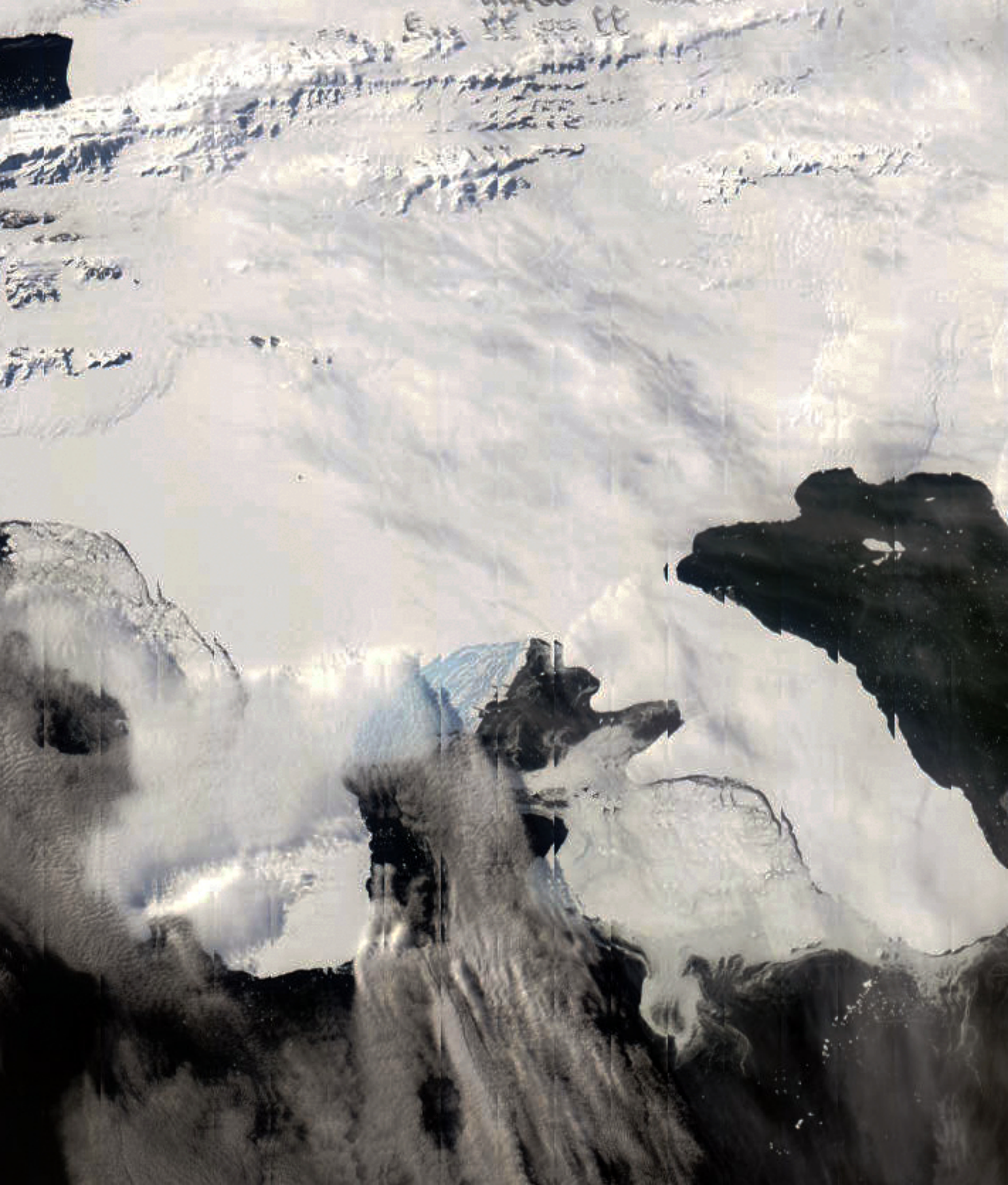
1,800 meters (1 mile)

3,200 meters (2 miles)

NSIDC/Courtesy Cheng-Chien Liu/NSPO

The phalanx


February 28, 2008 19:30 UTC
profile of
Figure 6
initial
iceberg
fragments,
77 km² total
c



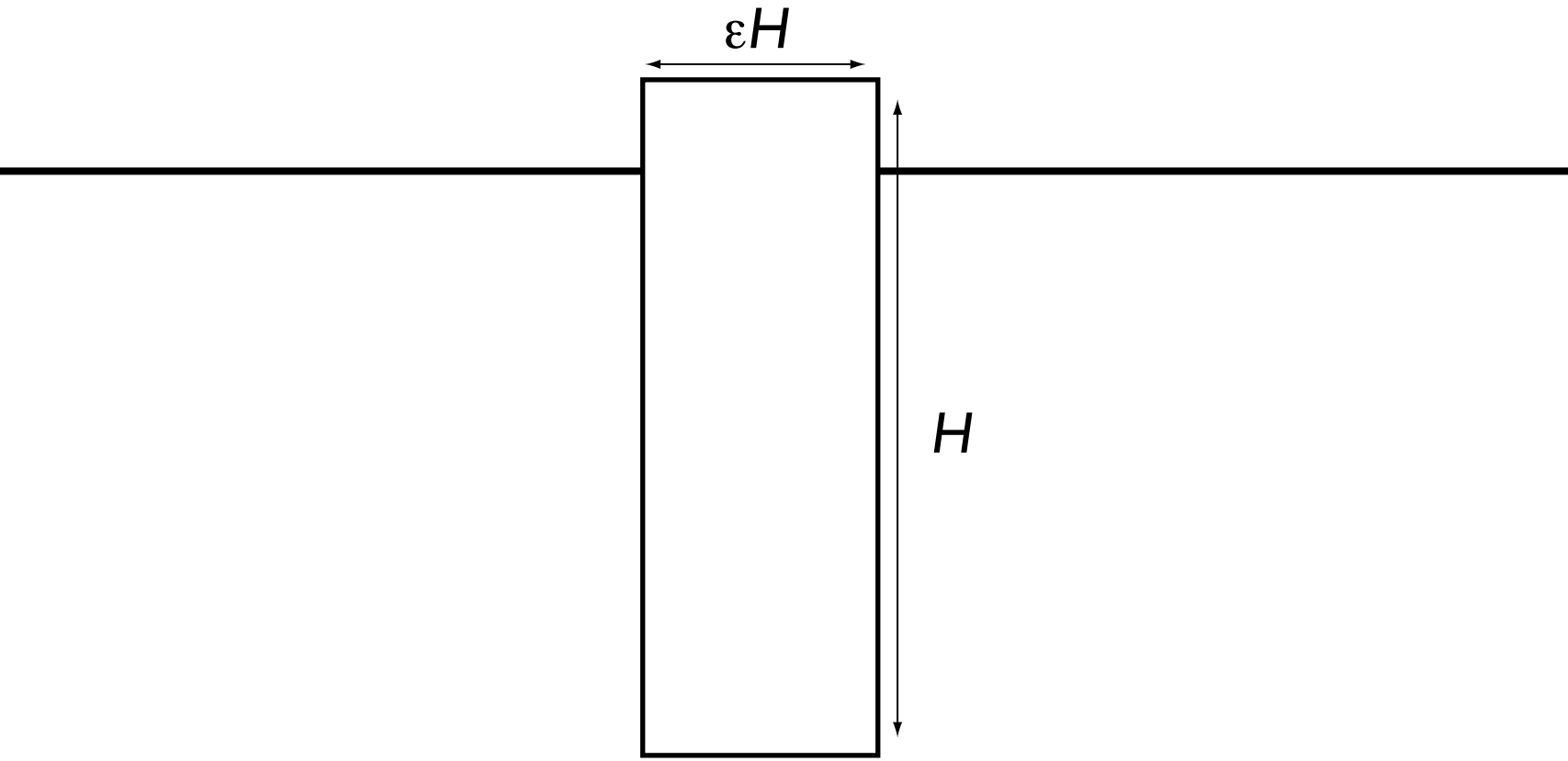
Physics A: iceberg capsize experiments

energetics

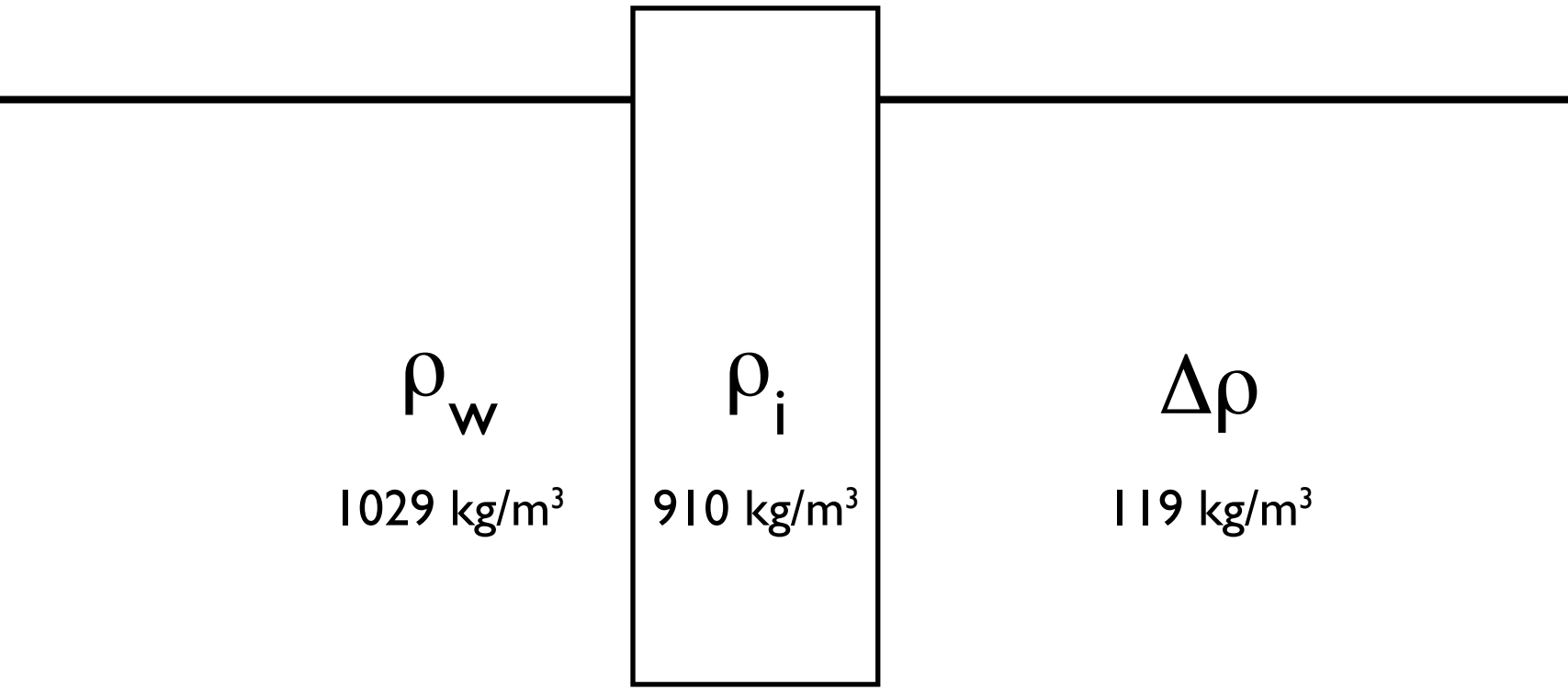
stability

It's best to idealize their geometry:

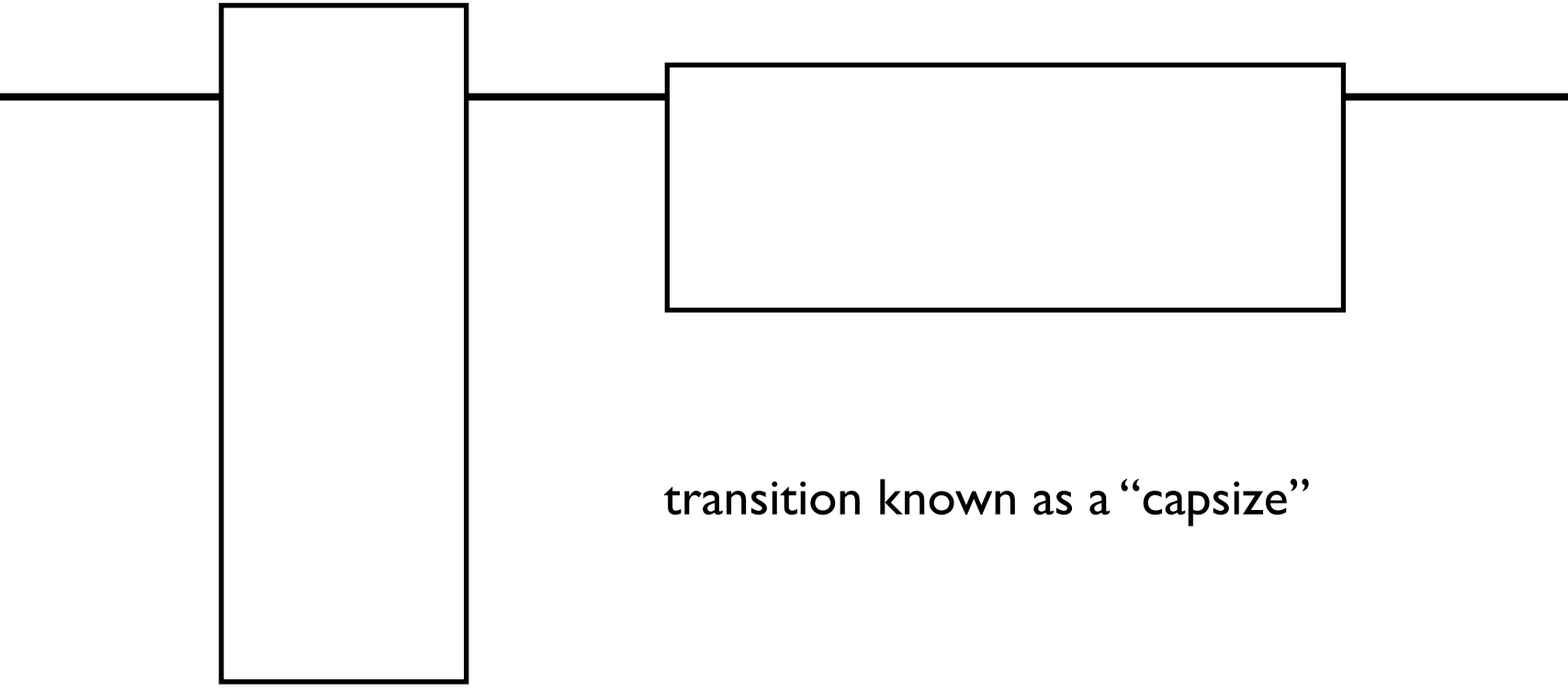
ε = aspect ratio



Available potential energy:



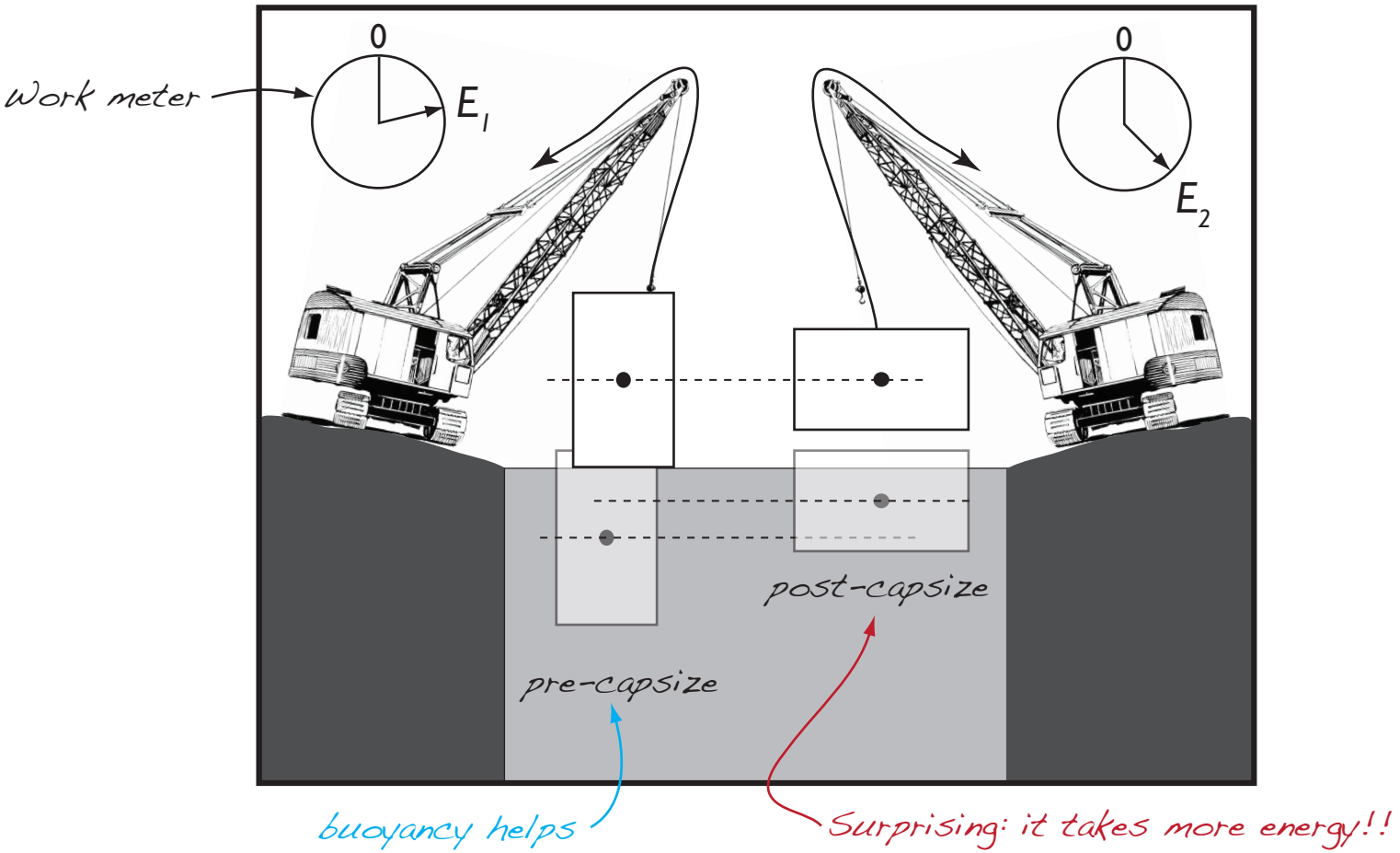
Two ways to float:



transition known as a “capsize”

How to quantify iceberg-capsize energy:

tsunami energy = E_1 - E_2



- Capsize ➜ impulsive and large potential energy release

A few facts and figures:

- An iceberg that is 150 m long, 150 m wide and 300 m deep can release 5.2×10^{11} J (126 tons of TNT).

- A typical iceberg in Greenland will release ~20 ktons TNT

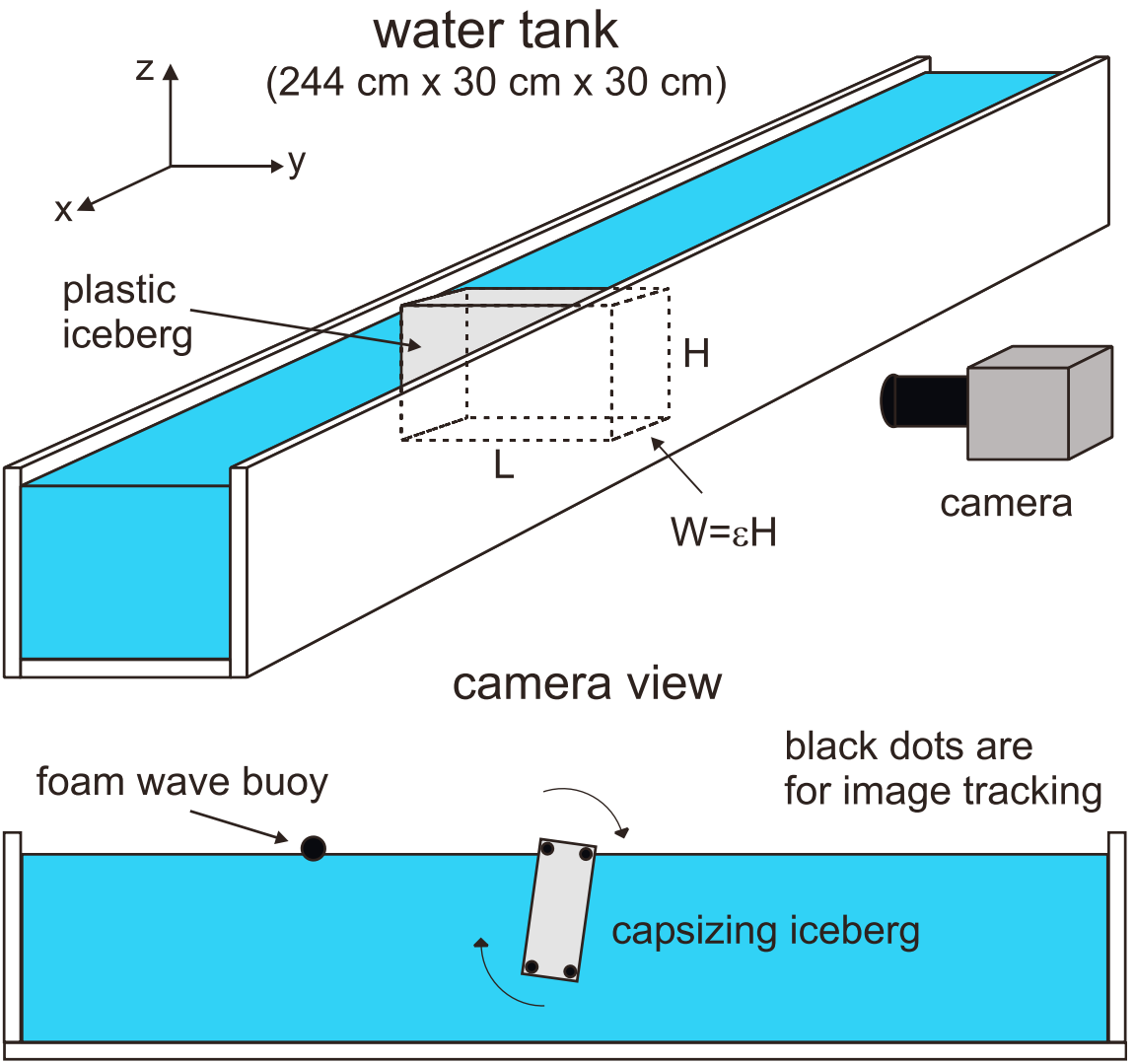
- Larsen B on March 6: 4000 km^2 iceberg fragments (Rack, 2004)... If all are composed of 300 m thick icebergs that capsized, then total energy released is 11.2 Mtons of TNT

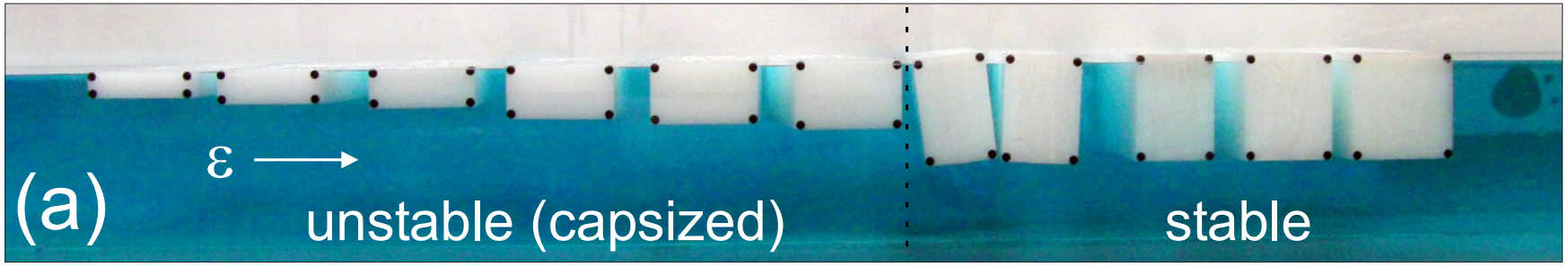
- (perspective: Sumatran tsunami of December 2004: 9 Ttons or 10^6 times more energy...)

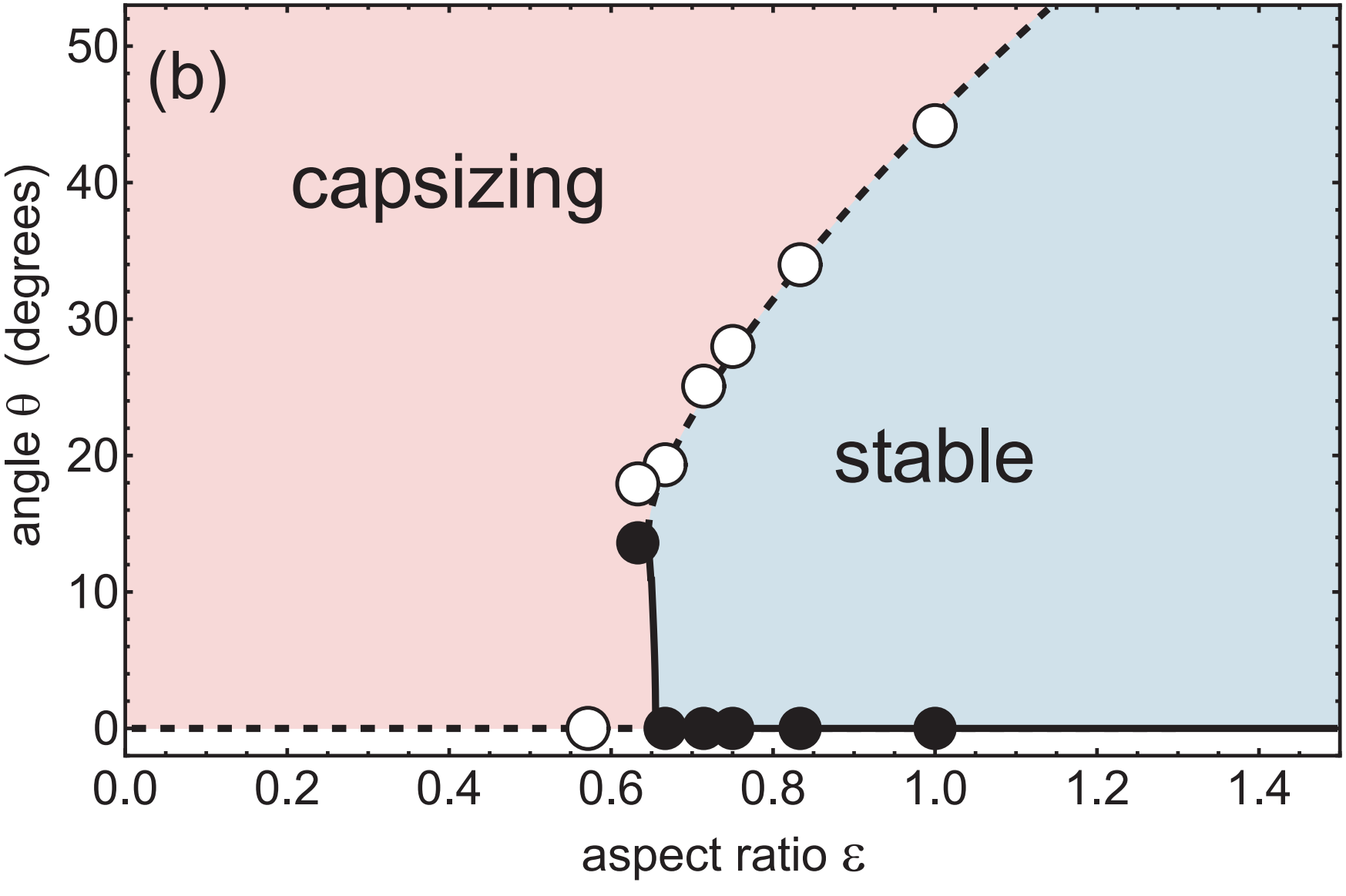
20 kilotons of TNT in 61 m of water ($\Delta t \approx 10^{-4}$ s)

Laboratory studies of iceberg capsize

- Scale-models of ice-shelf instability ➜ iceberg hydrodynamics

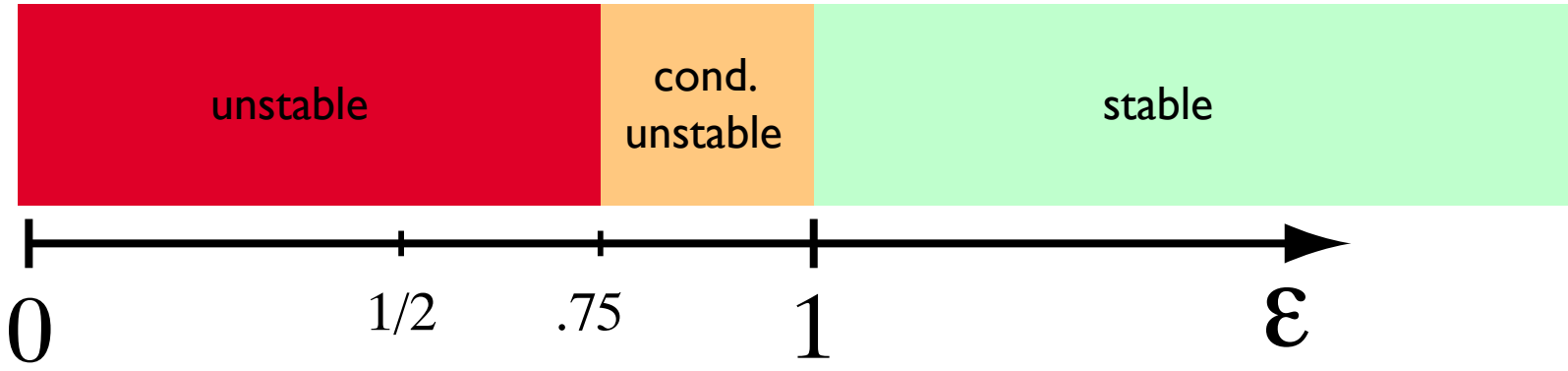



(a)
ε
unstable (capsized)
stable


(b)
capsizing
stable
angle θ (degrees)
aspect ratio ε
0
10
20
30
40
50
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Capsize stability:

(caveat: very much a function of rectangular geometry)



Physics B: iceberg tsunamigenesis and ocean wave propagation

Where does the energy of iceberg capsize go?

Can ocean waves influence ice shelf break up?

EXTREME DANGER!

Do not walk on the beach. Death or serious injury might occur.
Risk of sudden tsunami waves, caused by calving icebergs.

LIVSFARE!

Færdsel på stranden er livsfarlig.
Tsunami bølger opstår uden forvarsel, når isfjeldene kælver.

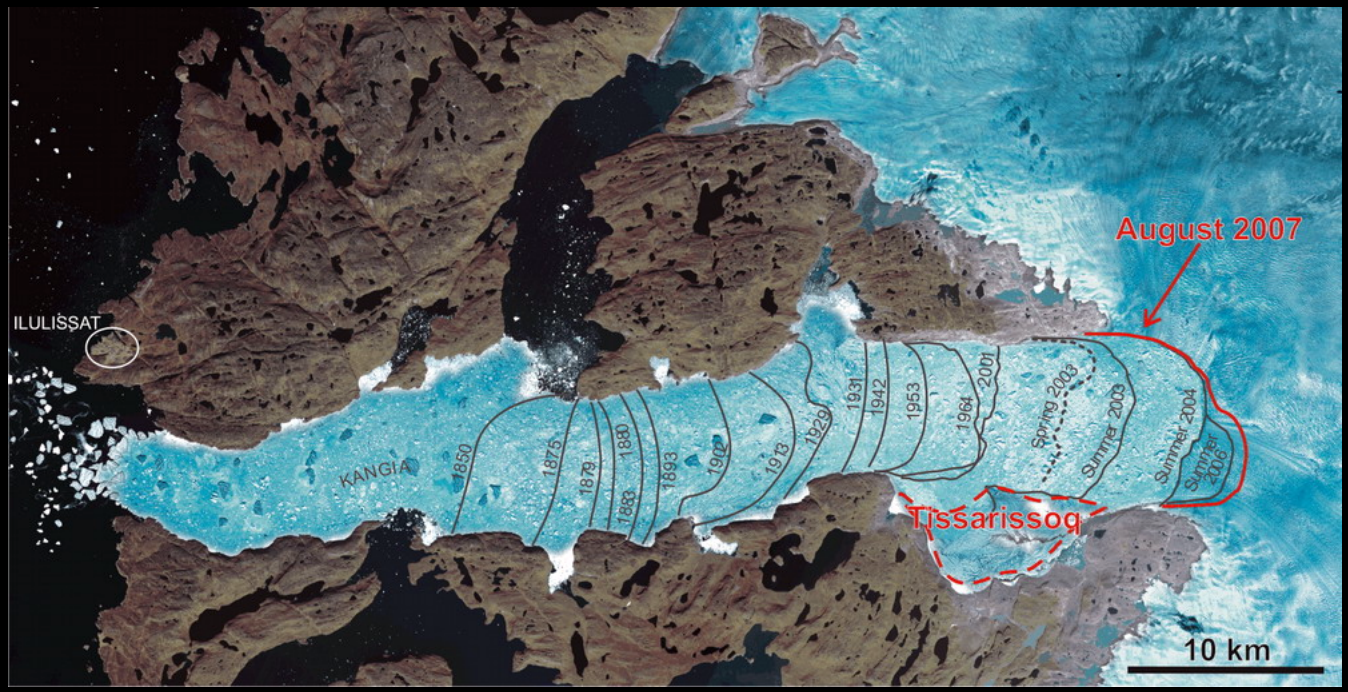
MIANERSOQQUSSUT!

Sissami pisunneq inuunermik ulorianartorsiortitsisinnaavoq
iisaqusattarnera pissutaalluni.

Ilulissat Municipality · Ilulissat Kommune · Ilulissat Kommuneat

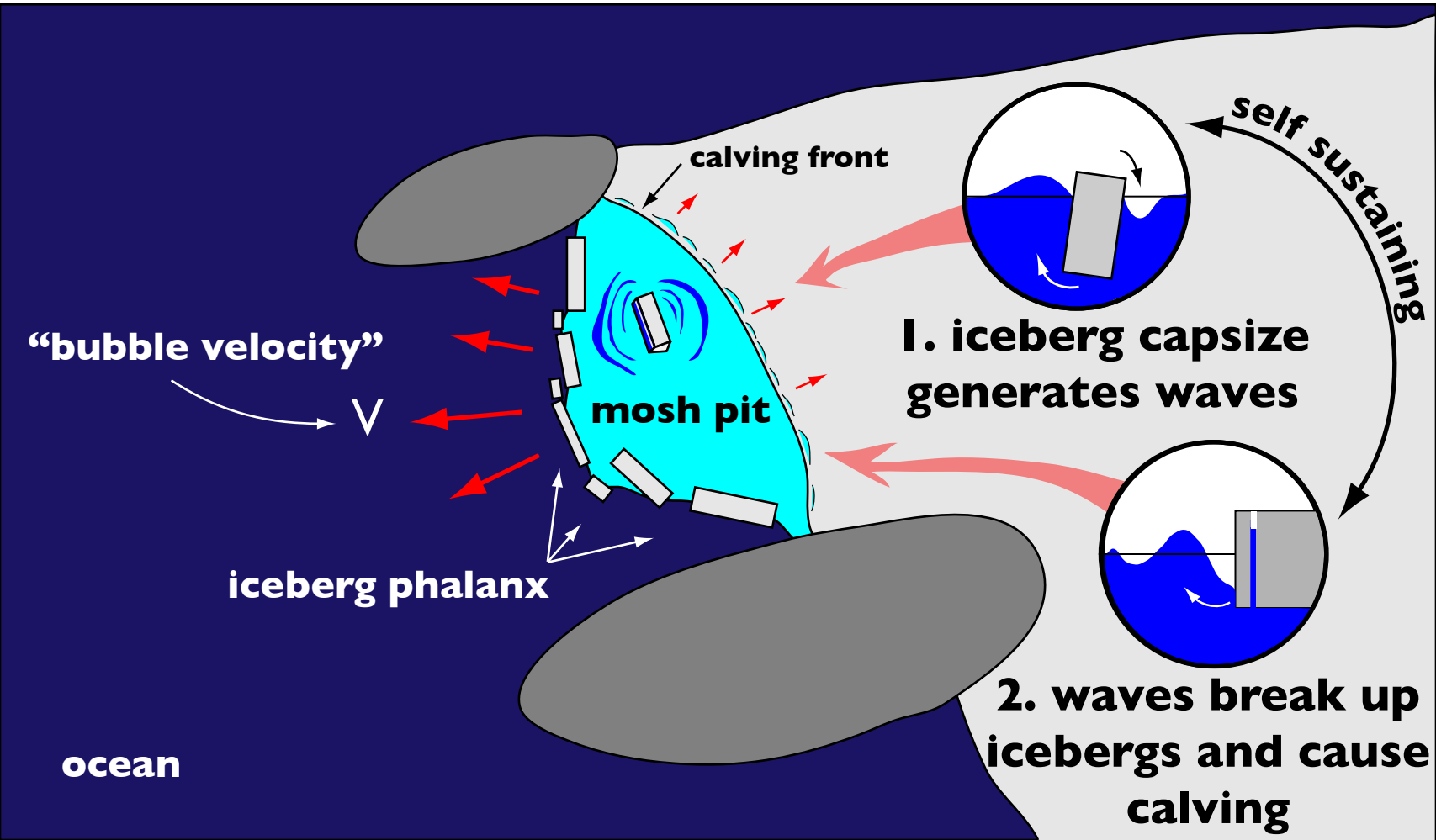
Tsunami Greenland - Tsunami Groelândia 1995

Qummannaq
Ilulissat
Qeqertarsuaq
Kangerlussuaq
Tasiilaq
Kap Farvel


ILULISSAT
KANGIA
1850
1875
1879
1883
1880
1893
1902
1913
1929
1931
1942
1953
1964
2001
Spring 2003
Summer 2003
Summer 2004
Summer 2006
August 2007
Tissarissoq
10 km

Conceptual model:

Mosh Pit



Physics C: elastic flexure due to meltwater lakes

fracture mechanics

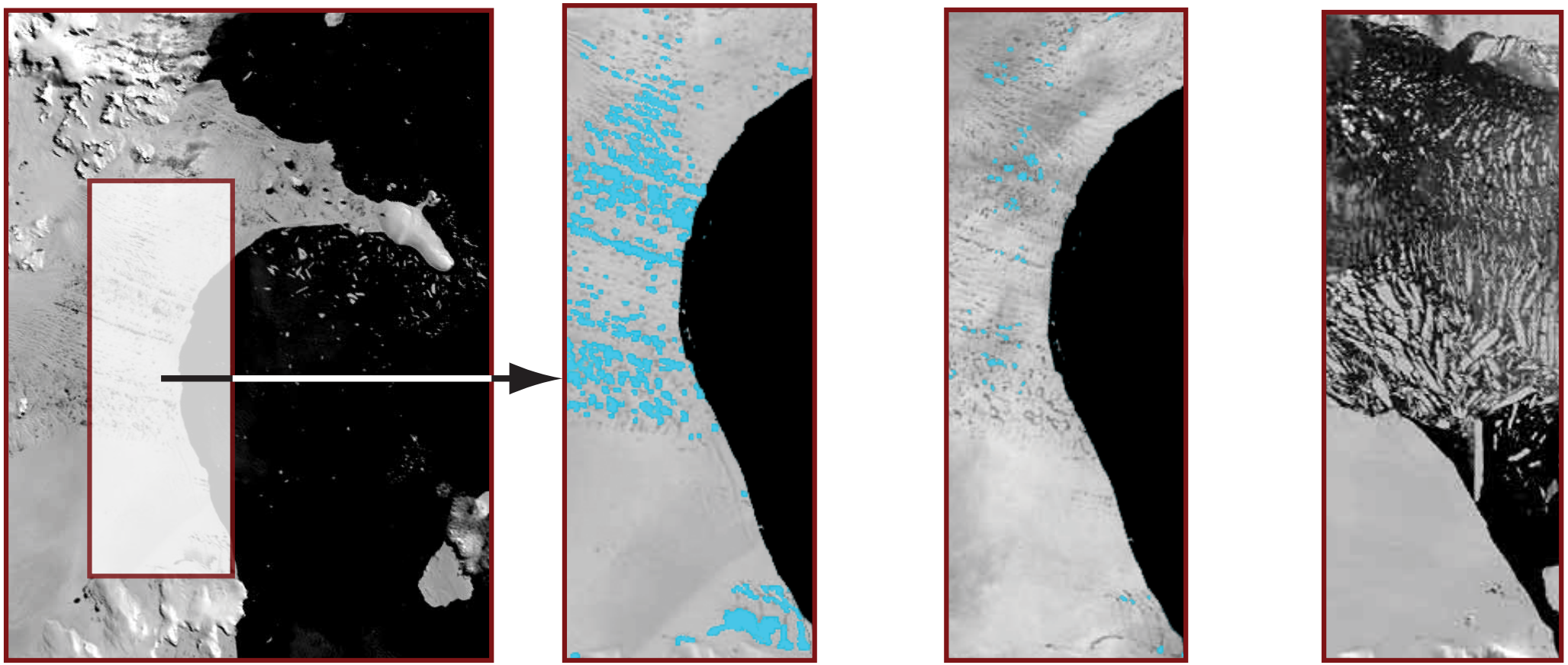
scale selection

Antarctica...

lakes usually, but also dolines:

Christina Hulbe's study of ice-shelf lakes:

ponding → ***the water vanishes!*** → ***collapse***

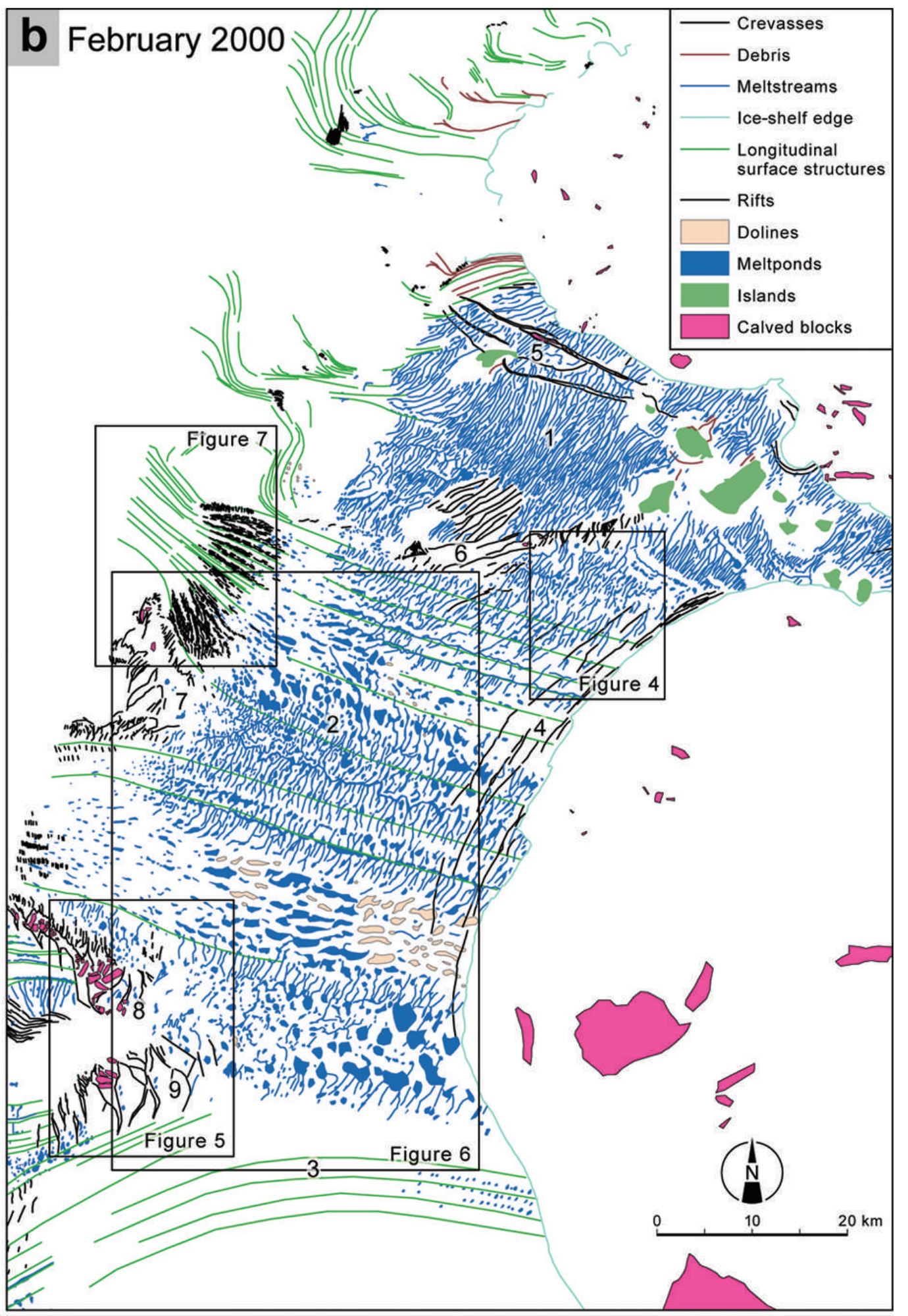


Larsen B Ice Shelf
early 2002

31 January

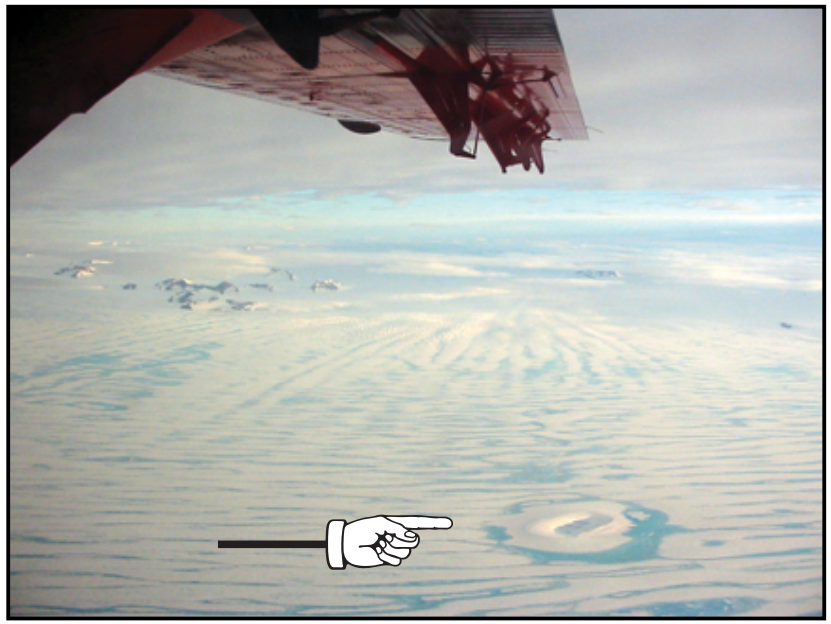
17 February

5 March


b February 2000
Crevasses
Debris
Meltstreams
Ice-shelf edge
Longitudinal surface structures
Rifts
Dolines
Meltponds
Islands
Calved blocks
Figure 7
Figure 4
Figure 5
Figure 6
1
2
3
4
5
6
7
8
9
N
0
10
20 km

Antarctica...

lakes usually, but also dolines:



a doline on George VI Ice Shelf

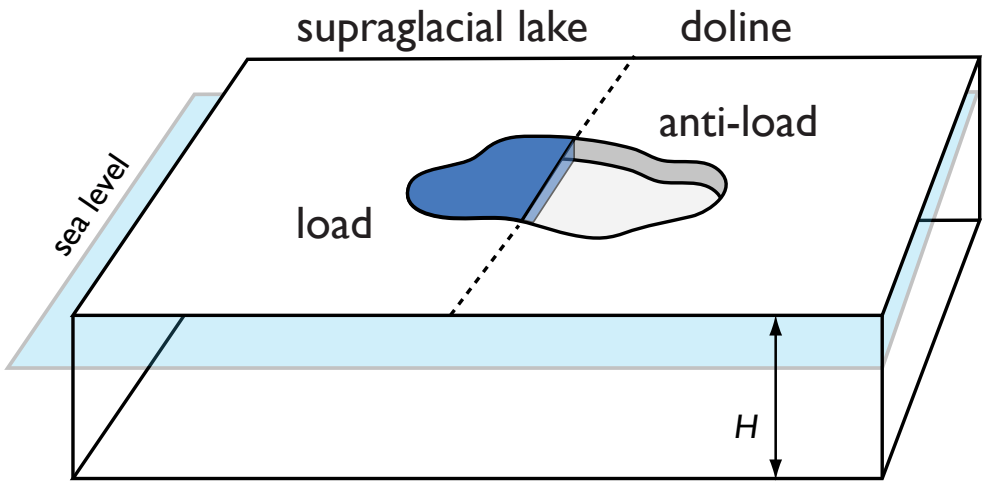


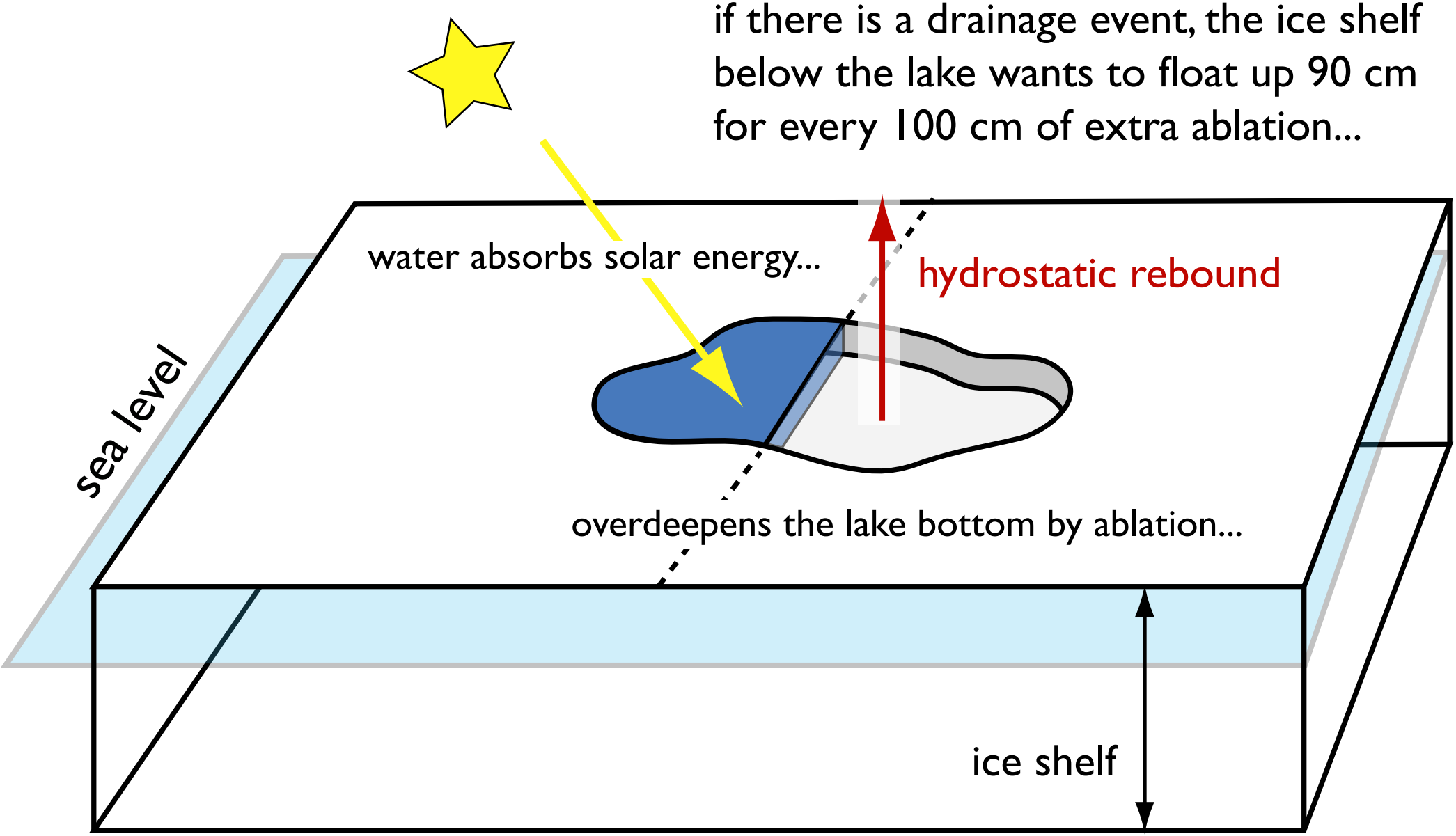
Fig. 2. The large ice doline (also called the ice caldera) on George VI Sound, Antarctica, taken from the air in January 1967. The doline is about 1.5 km in diameter. Uranus Glacier at top left and Eros Glacier from the upper right are shown entering the ice shelf. The dark streaks are meltwater lakes. Notice the similarity in shape to the ice blister in Figure 1 but the great difference in size. (Photograph by courtesy of C. W. M. Swithinbank.)

Fig. 3. Vertical air photograph of an ice doline at 71°20′ S, 68°40′ E near the southern edge of the Amery Ice Shelf, Antarctica. The doline is about 3 km long by 1.3 km wide and stereo-pair photography gives a depth for the doline of 80 m below the surrounding ice surface (Mellor and McKinnon, 1960). (Photograph by courtesy of ANARE.)

Antarctica...

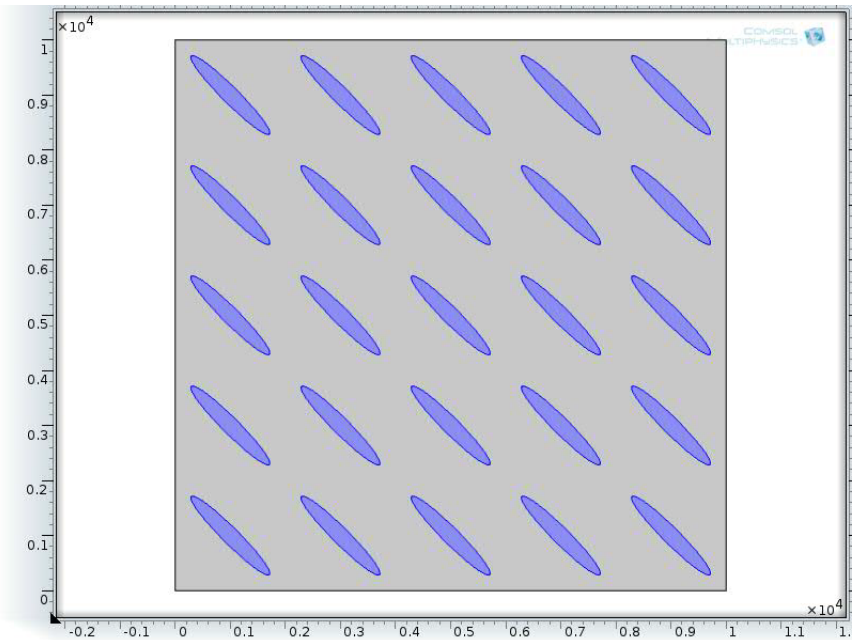
What happens when ice-shelf lakes drain?

if there is a drainage event, the ice shelf below the lake wants to float up 90 cm for every 100 cm of extra ablation...



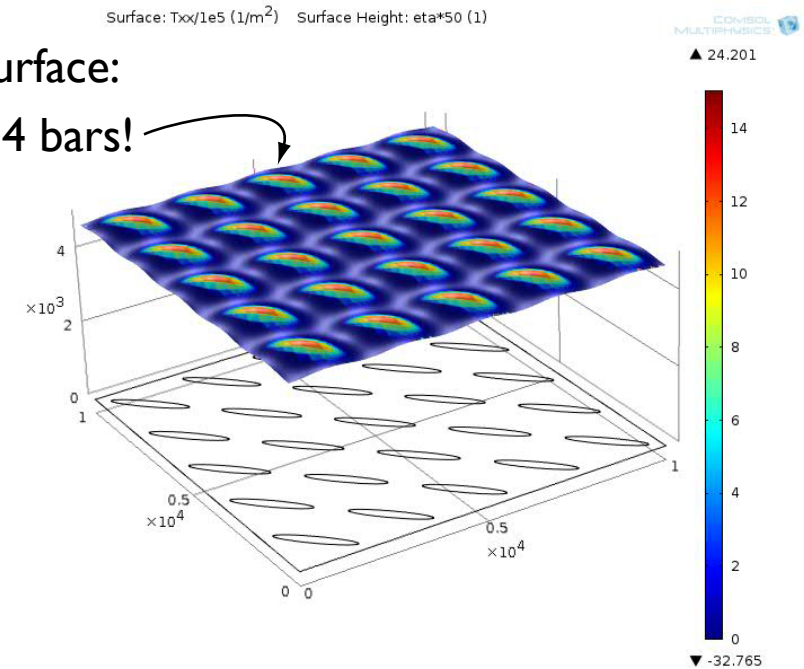
numerical solution:

arrayed lake pattern
(ellipses)



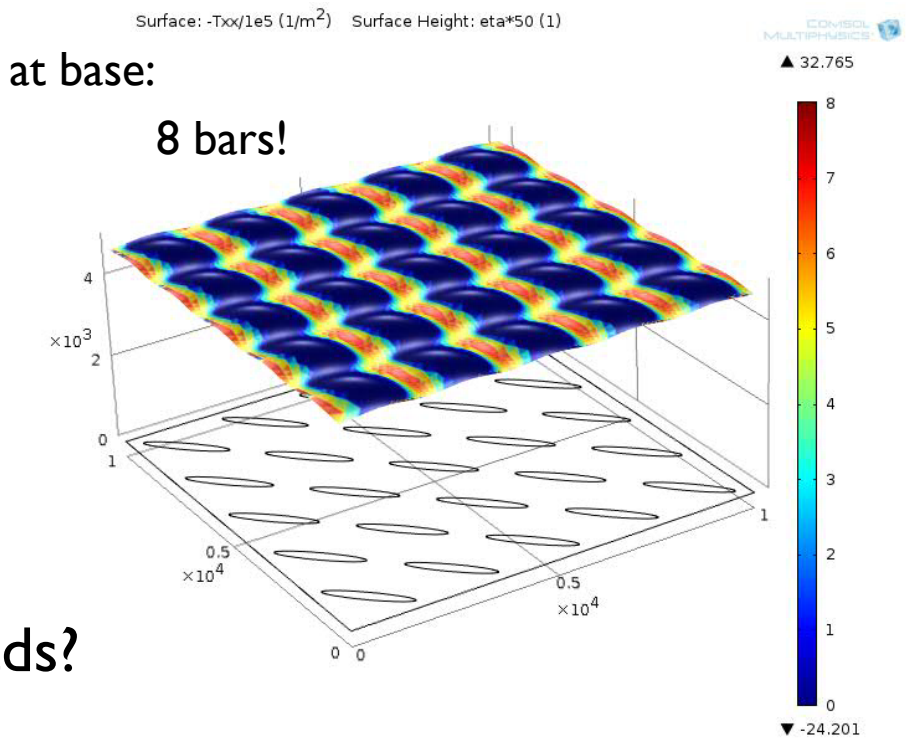
at surface:

14 bars!



at base:

8 bars!



Does lake drainage ultimately lead to
a fragmented ice shelf due to flexure loads?

Physics D: iterated maps and chain reactions

self-sustaining iceberg capsize

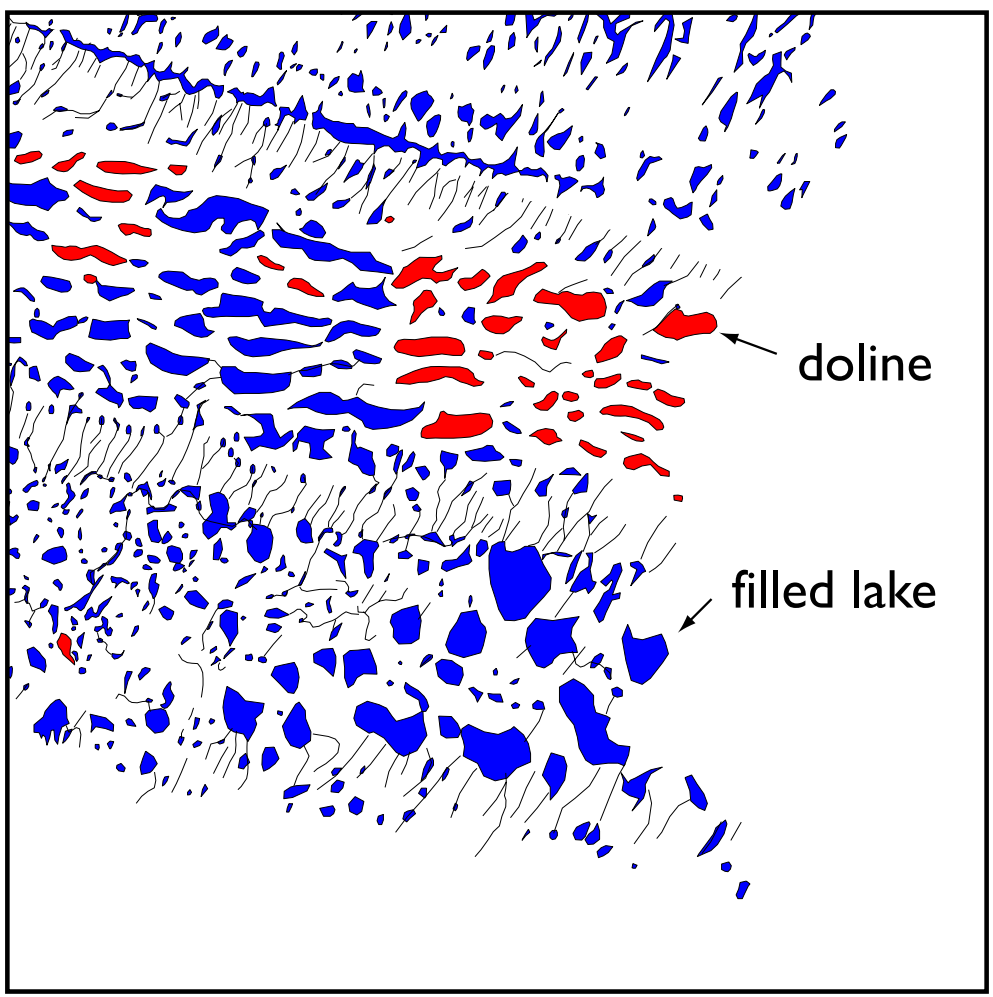
cooperative behavior of meltwater lake drainage

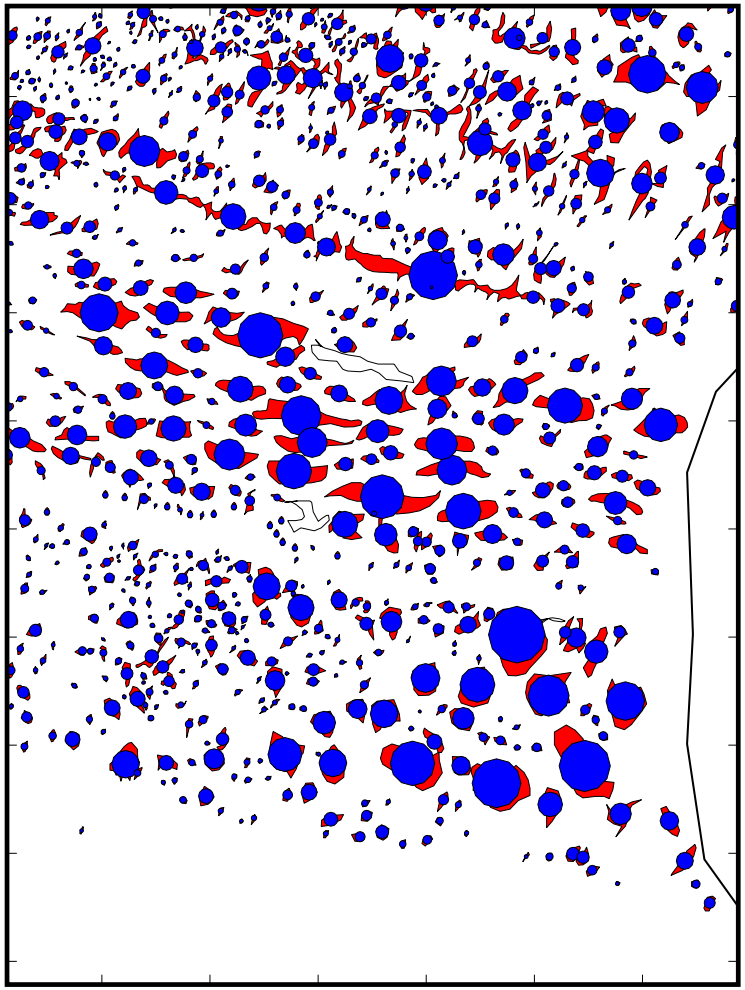
Larsen B digitized lakes:

disk load

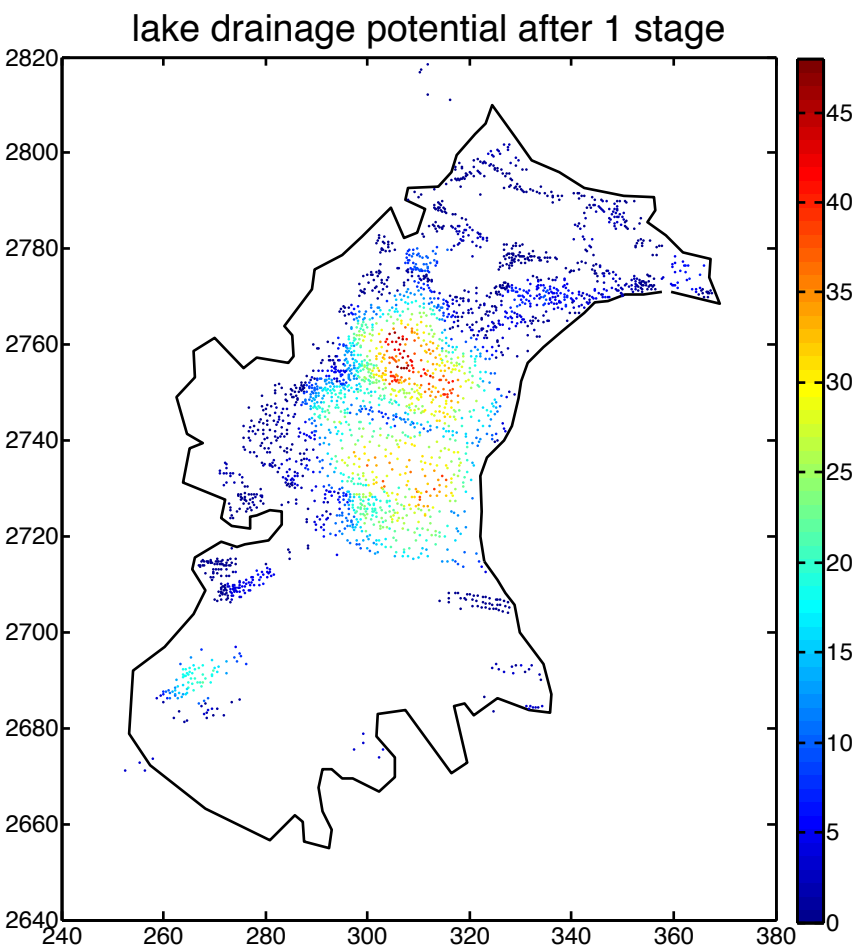
actual lake/doline

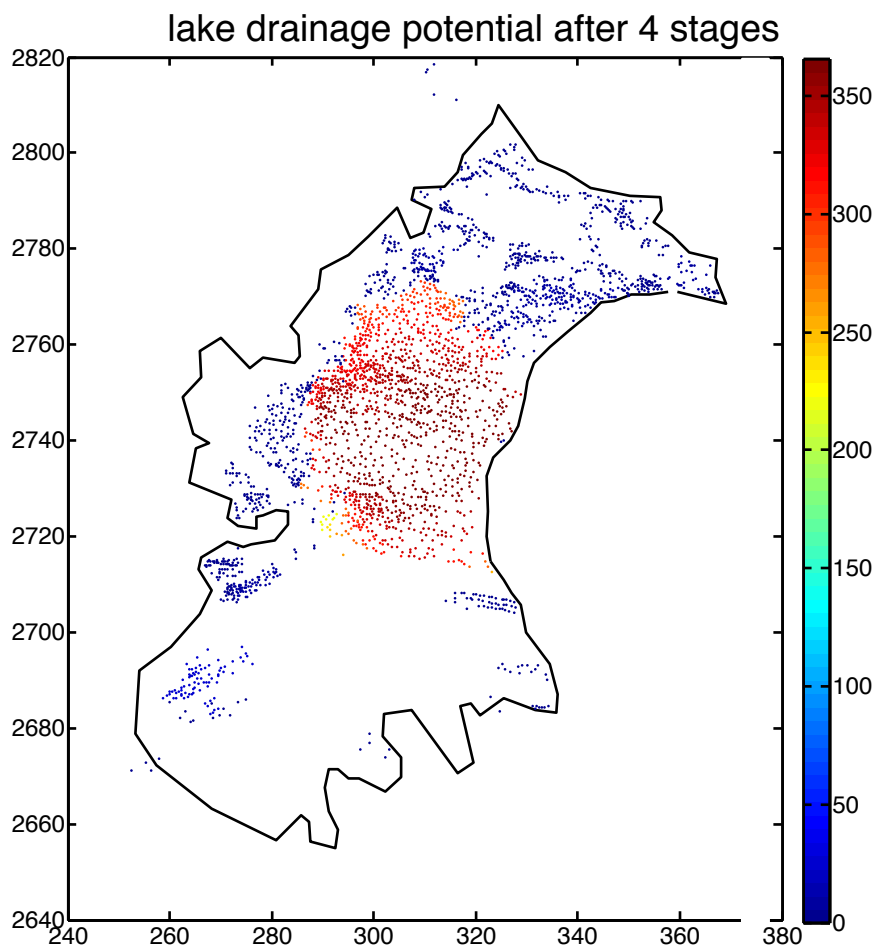
...analytic solution for circular lakes



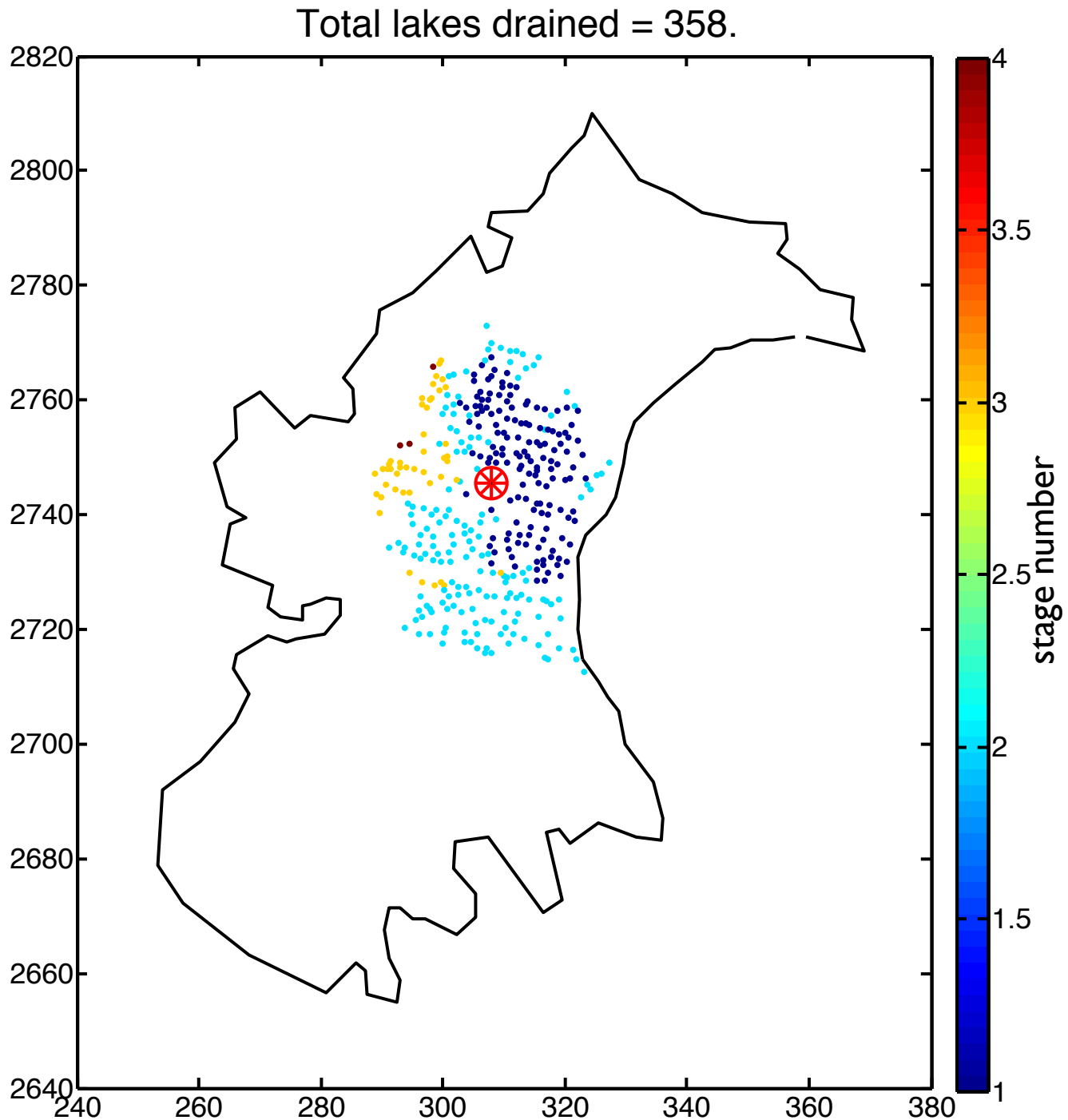


Draining one lake causes other lakes to drain:



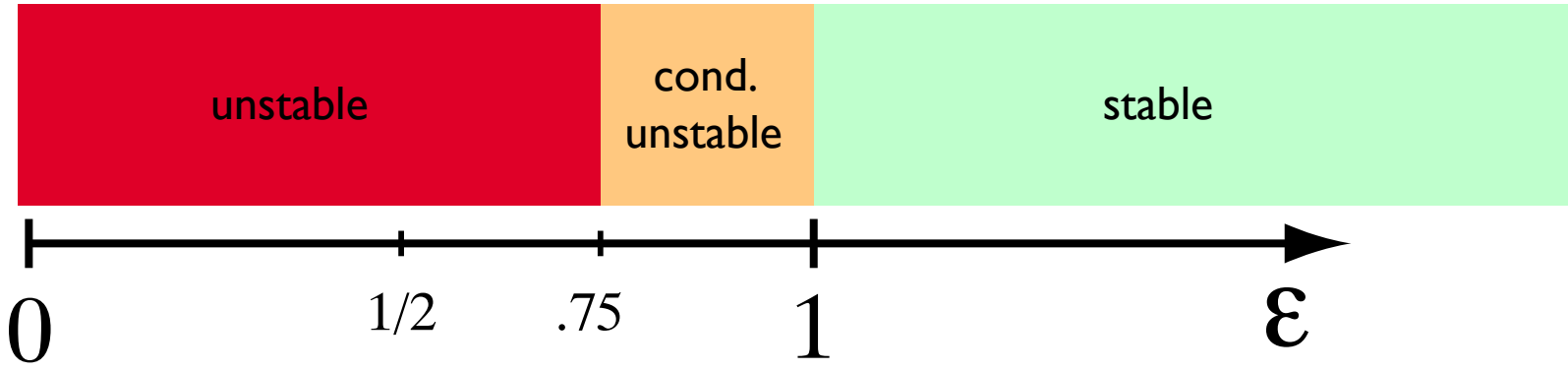


Draining one lake causes other lakes to drain:



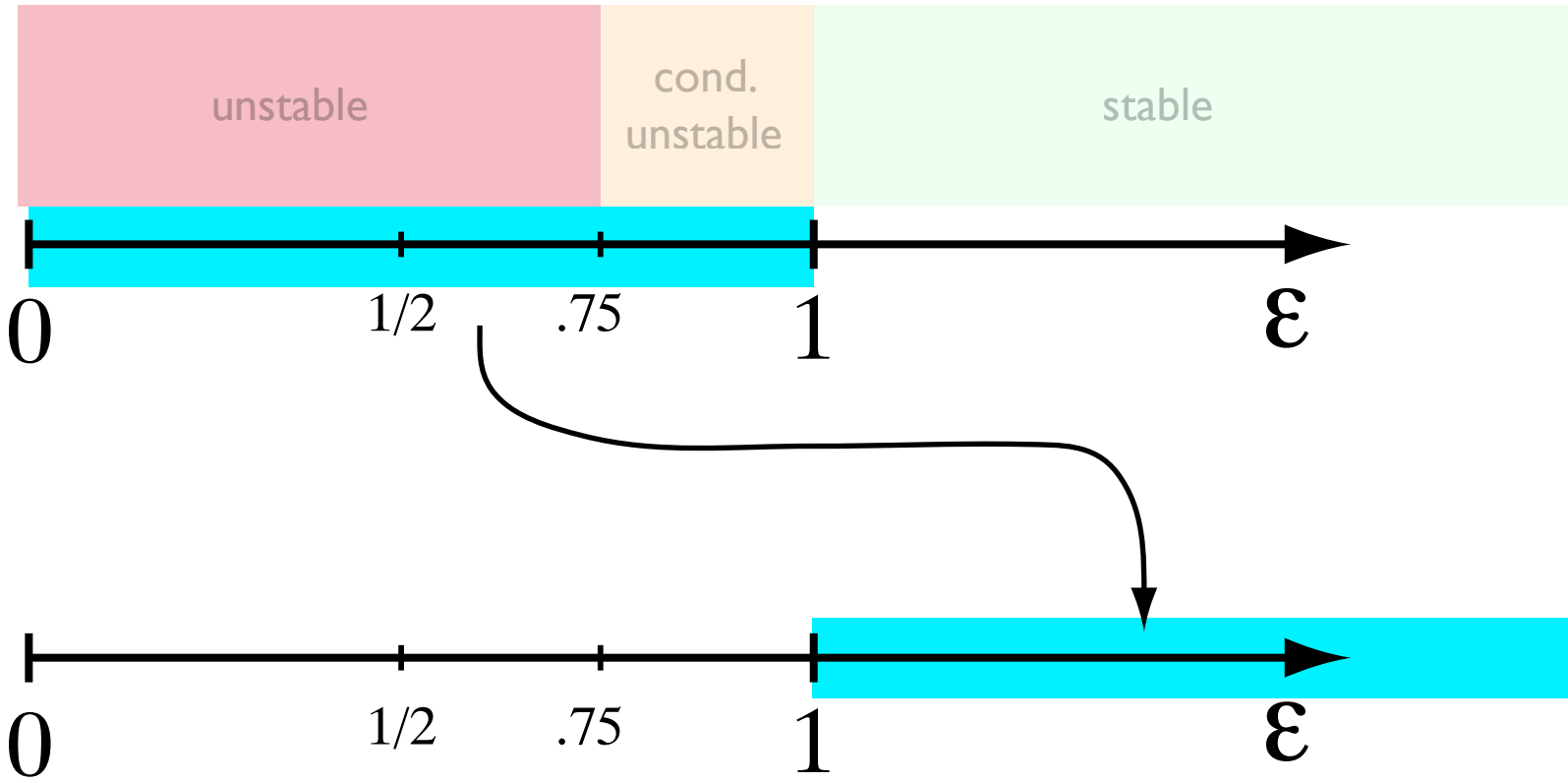
Capsize stability:

(caveat: very much a function of rectangular geometry)

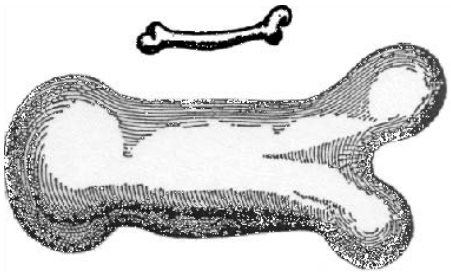


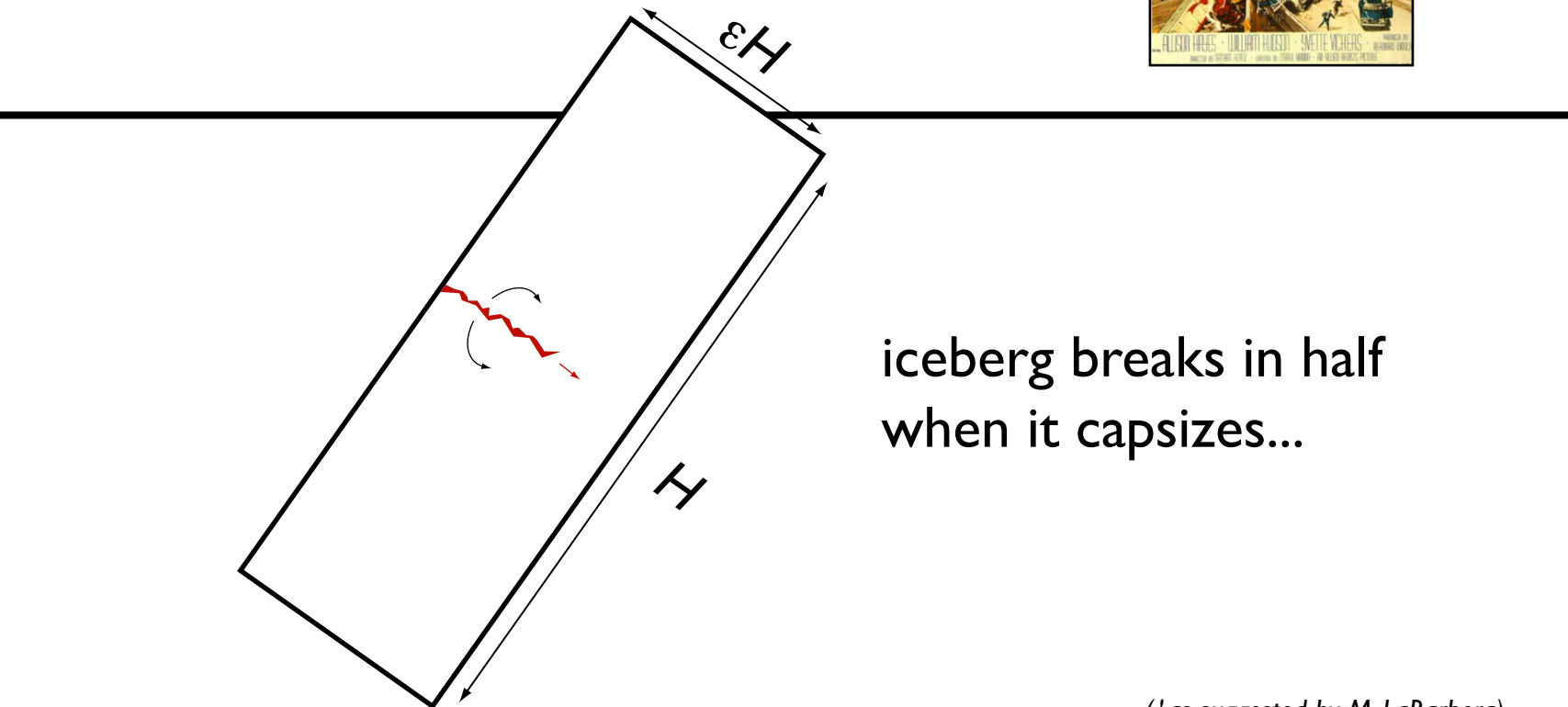
How capsize changes aspect ratio:

$$\varepsilon \Rightarrow 1/\varepsilon$$



The "50-foot woman effect†":



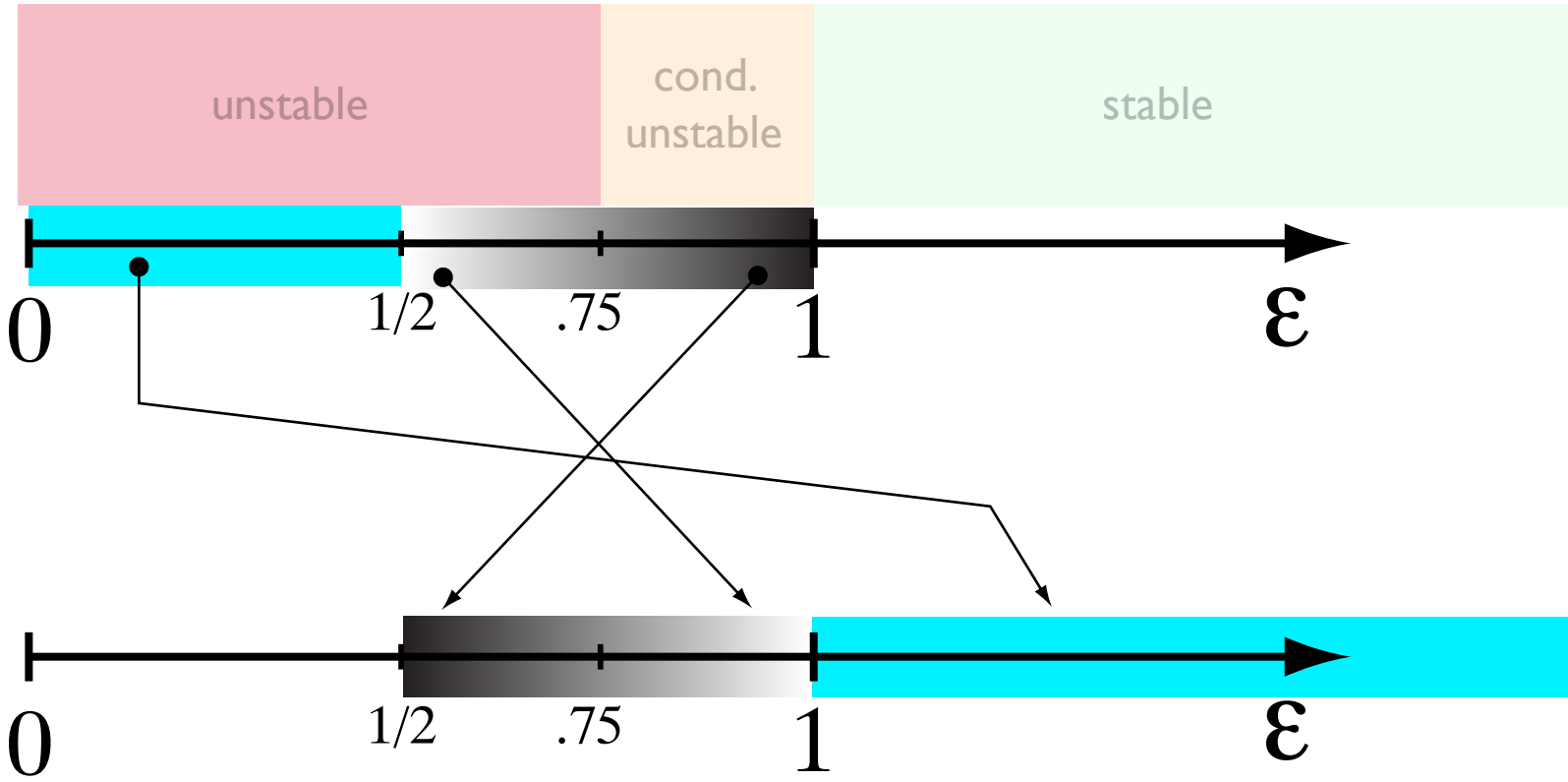


iceberg breaks in half when it capsizes...

(†as suggested by M. LaBarbera)

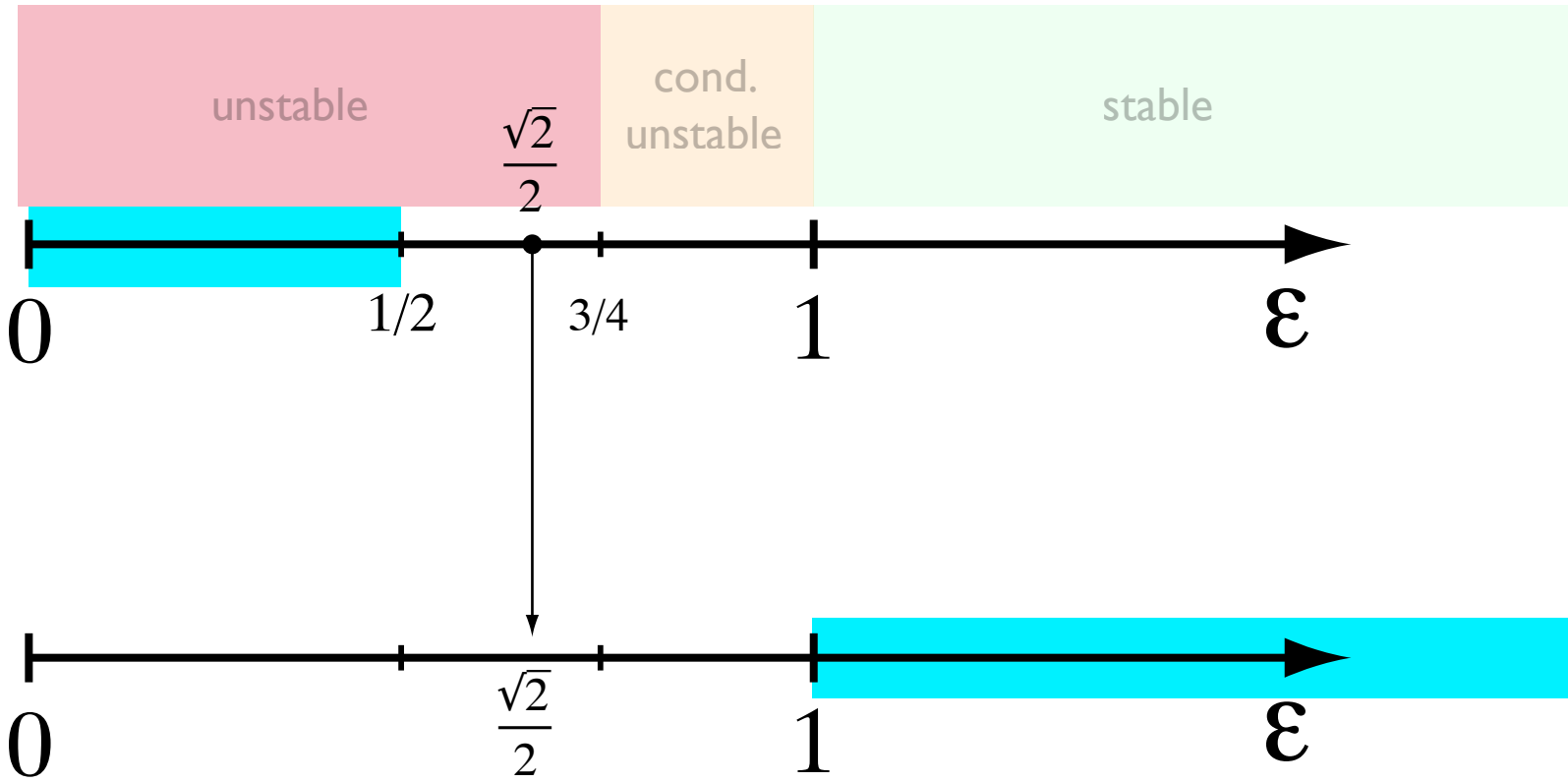
... with iceberg breaking in half:

$$\varepsilon_2 \rightarrow (1/2)/\varepsilon_1$$



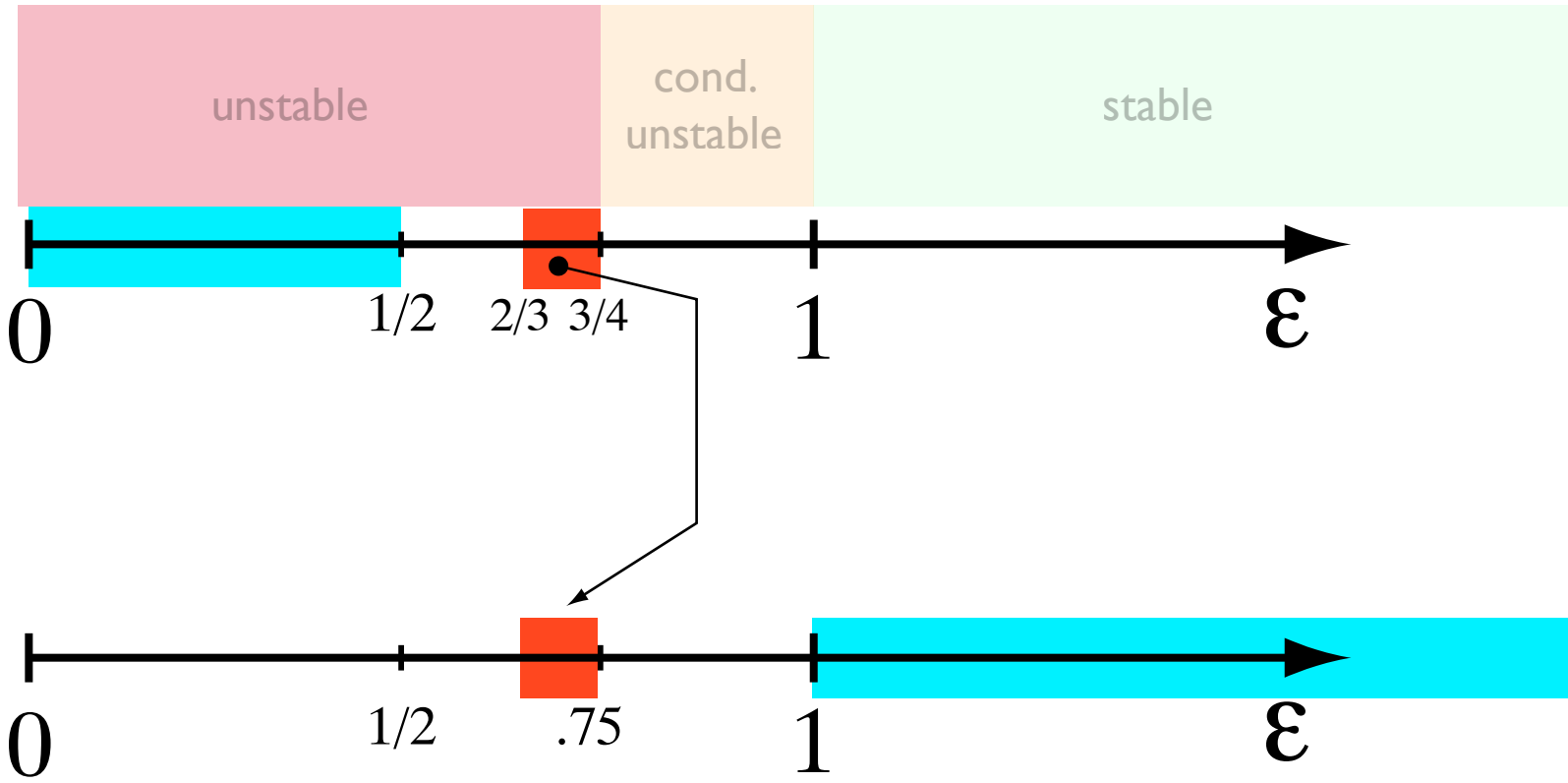
a fixed point:

$$\varepsilon_2 \to (1/2)/\varepsilon_1$$



... some aspect ratios keep getting mapped to the same unstable zone:

$$\varepsilon_2 \rightarrow (1/2)/\varepsilon_1$$



Conclusion: attempt to put the physics together

environmental warming → meltwater lakes
meltwater lakes → widespread fracture events
widespread fracture events → iceberg calving
iceberg calving → iceberg capsize
iceberg capsize → tsunamigenesis
tsunamigenesis (+ band gap) → localization of wave energy
localization of wave energy → iceberg calving