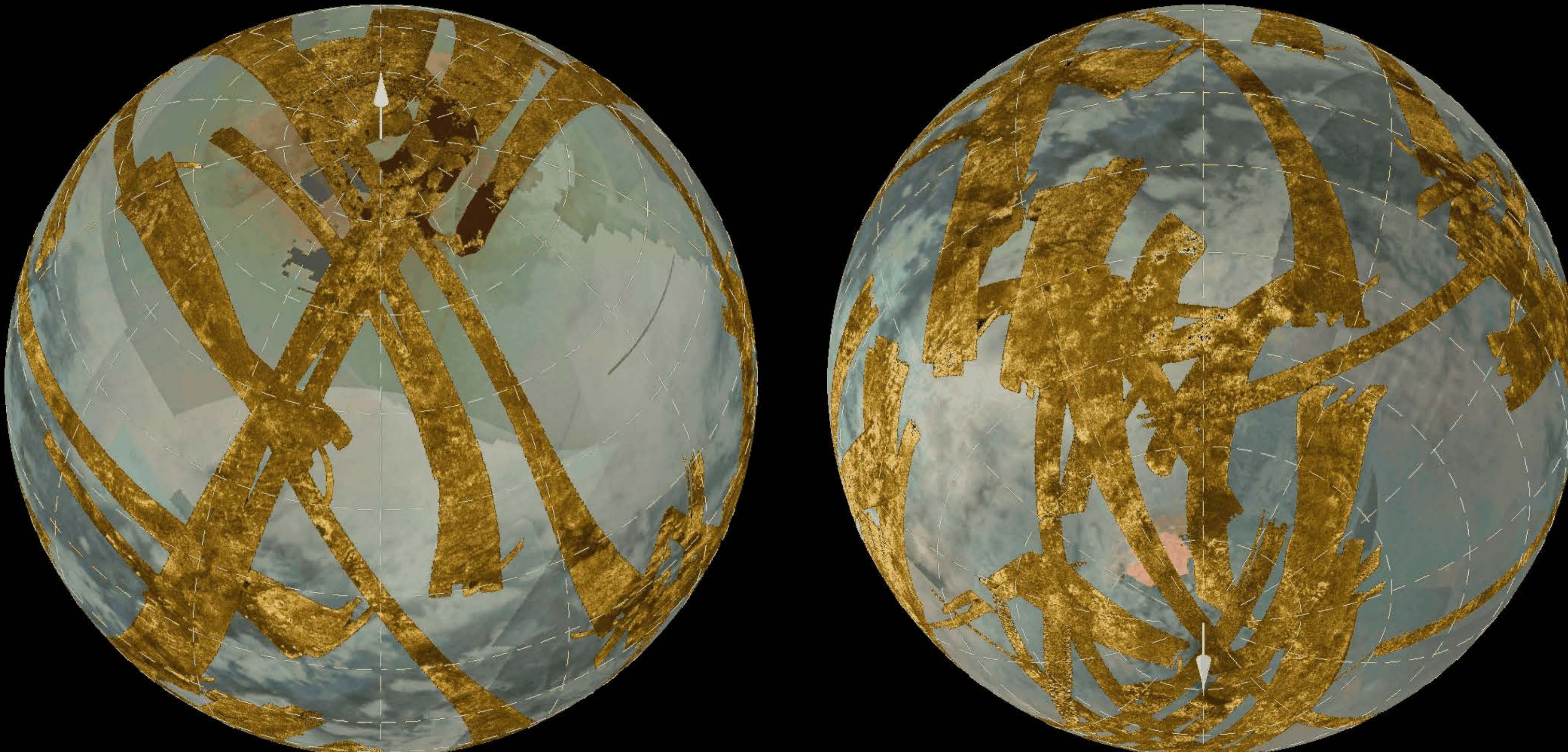
A Guide to Lakefront Vacationing on Titan: "Where to Go and When to Visit"

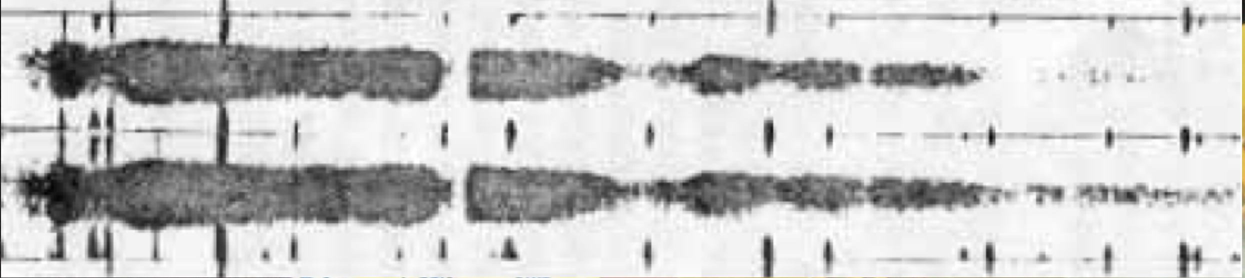


Alexander G. Hayes (Cornell)

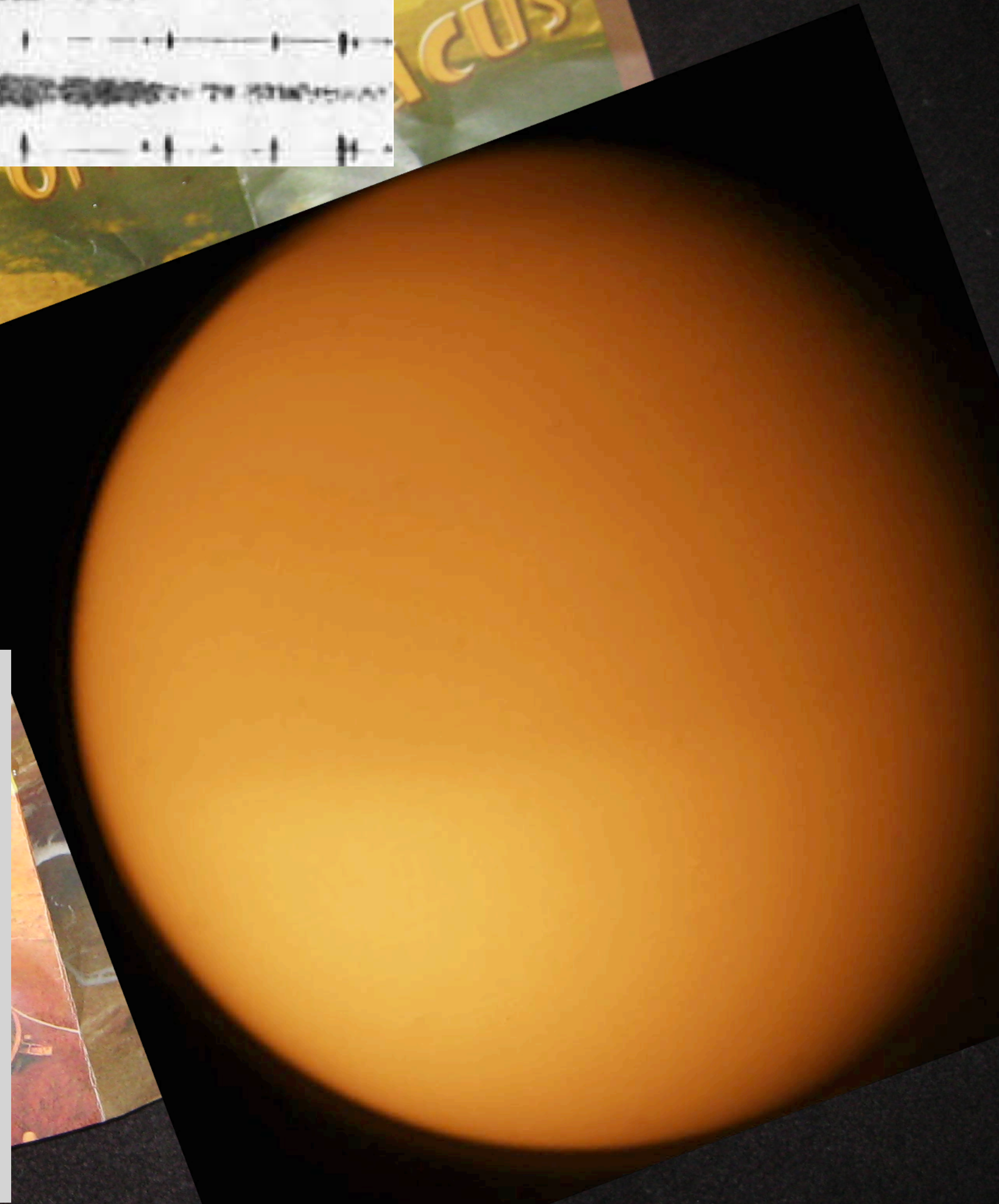
Collaborators: Oded Aharonson, Ryan Ewing, Jonathan Lunine, Bill Dietrich, Zibi Turtle, Randy Kirk, Ralph Lorenz, Michael Manga, Antoine Lucas, Lauren Wye, Mark Donelan, Howard Zebker, Dave Stevenson, Charles Elachi & the CRST

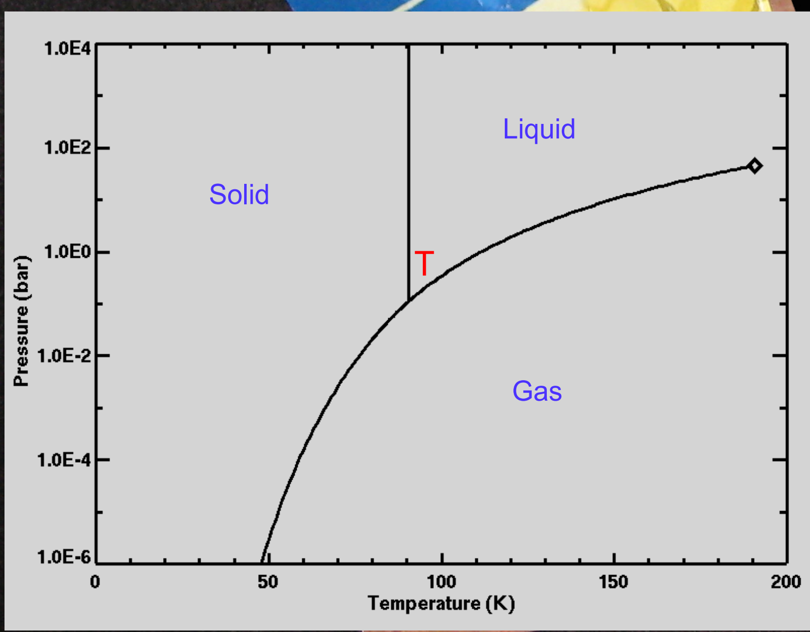
Cassini CHARM Telecon: January 30th, 2013

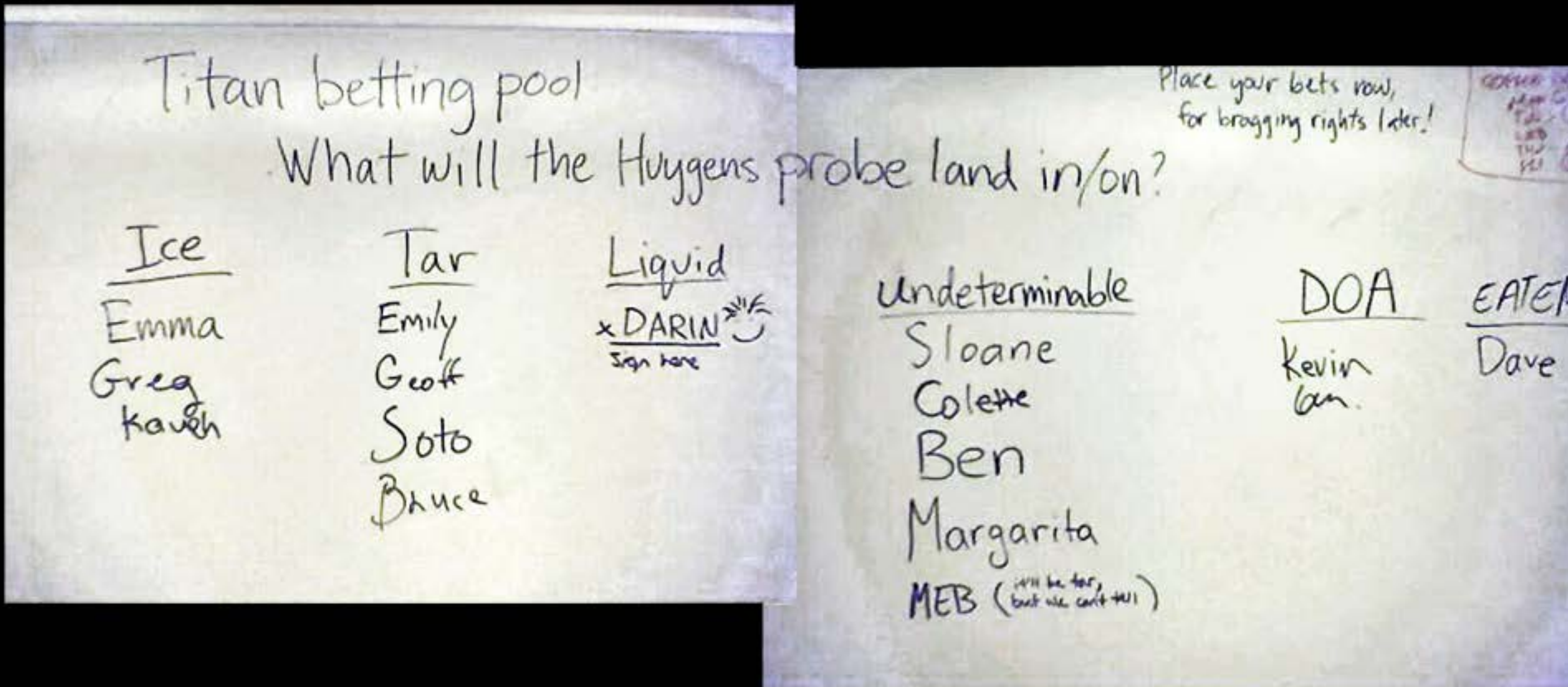
MEET THE RANGER DAILY
SAILING EXCURSIONS
KAYAKING TRIPS
SCUBA
WIND SURFING
NO-SMOKING
Image Credit:
The Planetary Society
TITAN SEASHORE
RECREATION AREA
LAND OF MANY USES
U.N. DEPARTMENT OF THE EXTERIOR
2007
Image Credit:
See Beautiful
ONTARIO LACUS
Image Credit:
JPL / Caltech
Come Visit Titan!
Image Credit:
Mike Caroll
Image Credit:
NASA / JPL
For More Information Contact Charles Frank Bolden, Jr.

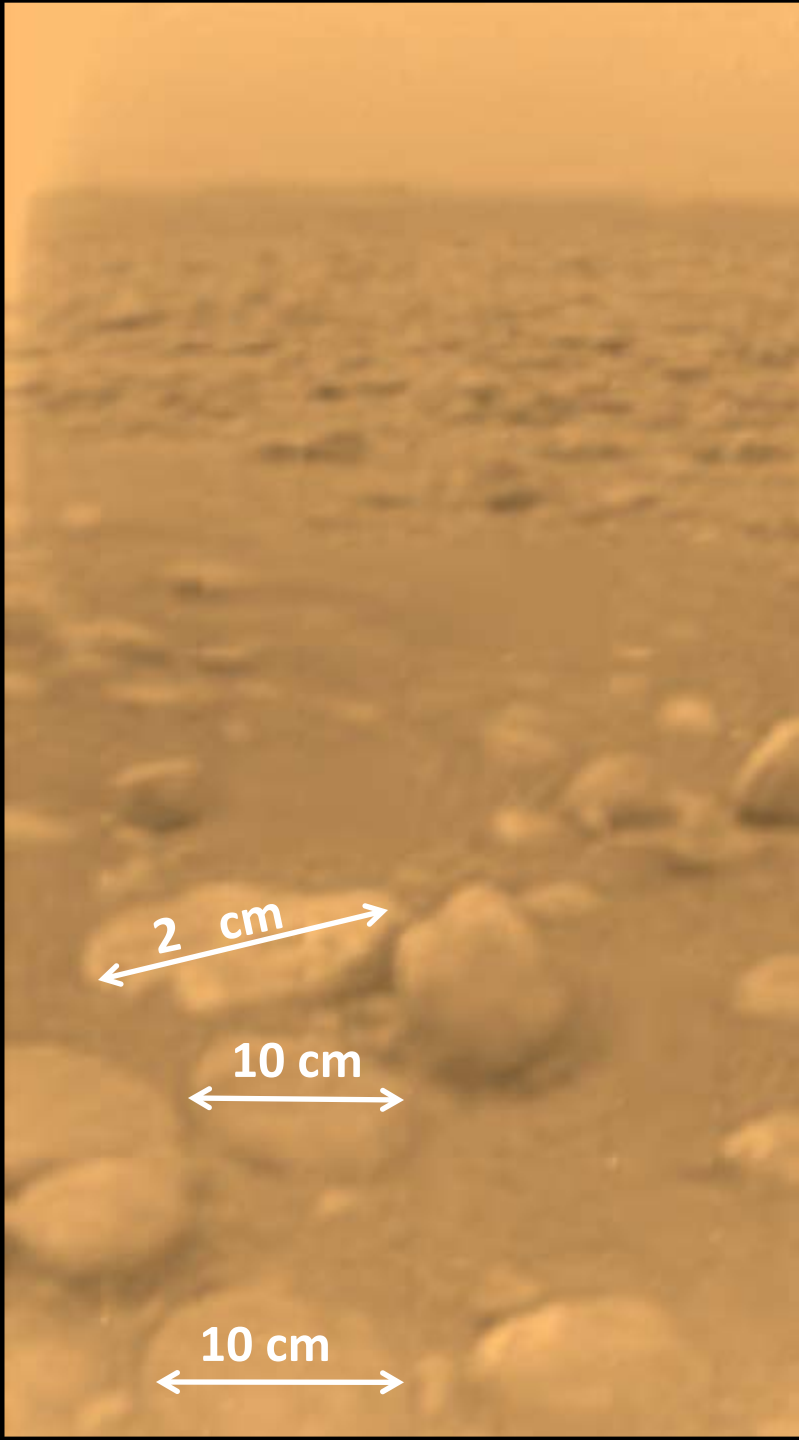


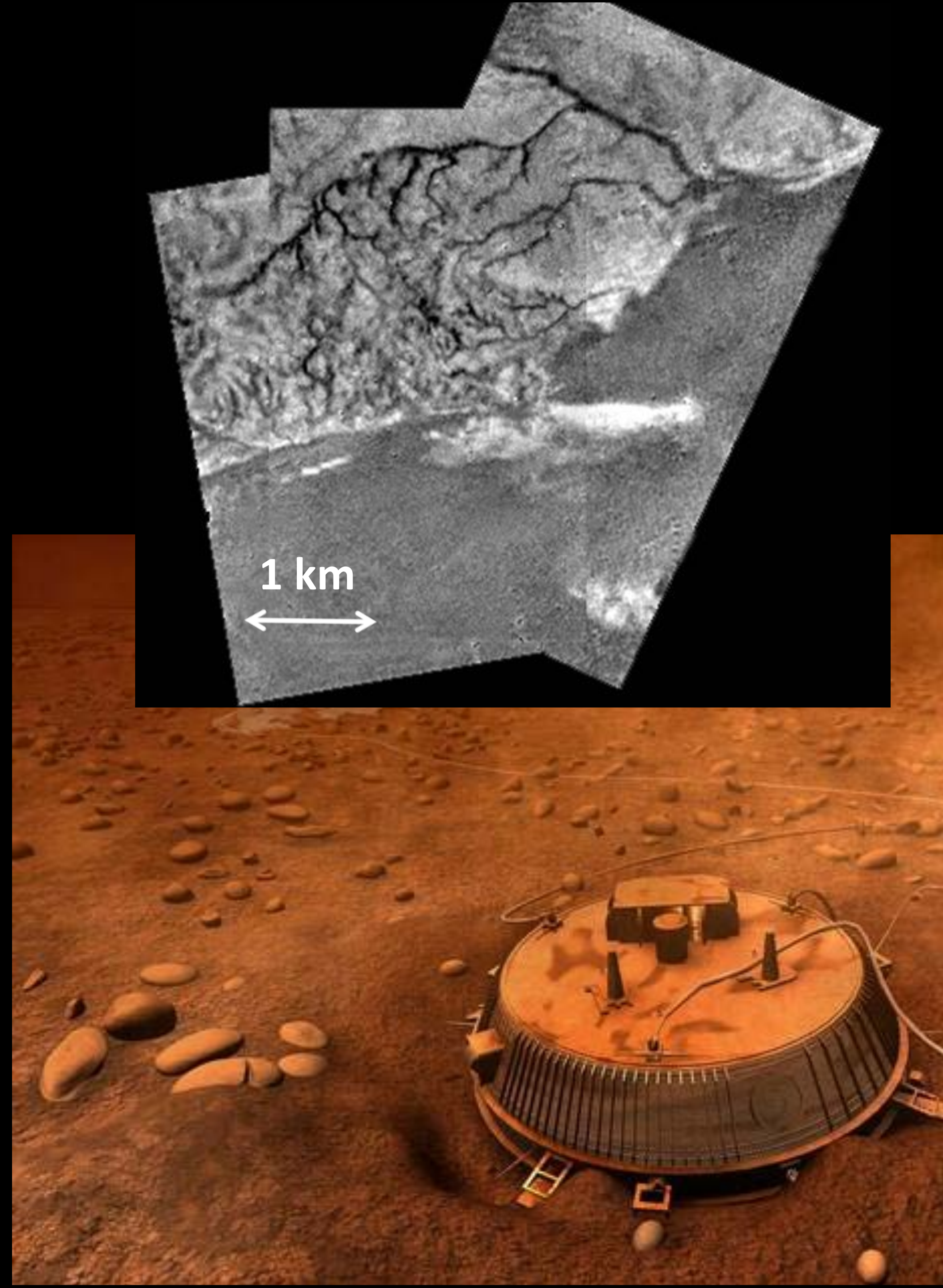
Kuiper ApJ 1944





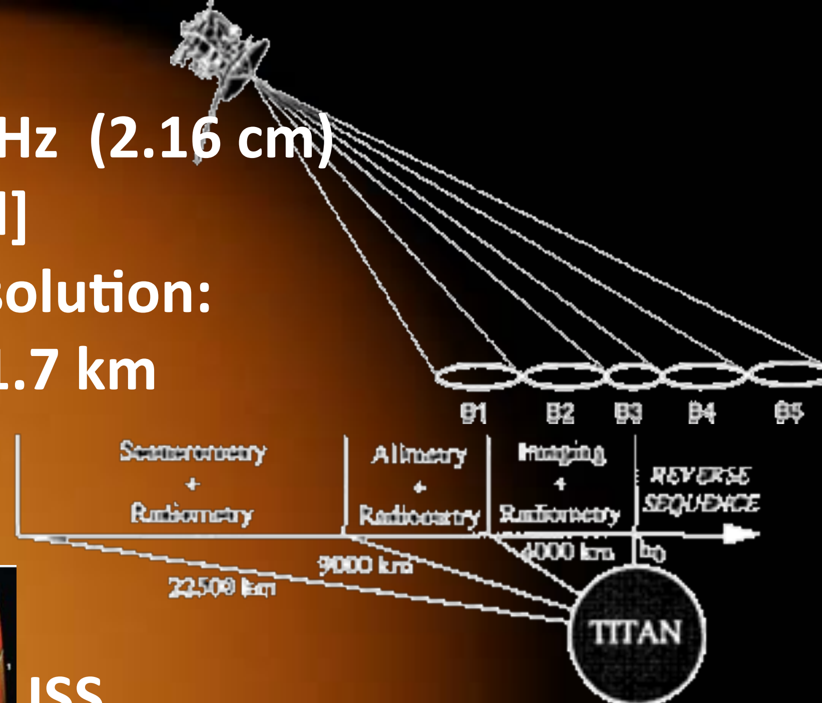

Titan betting pool
What will the Huygens probe land in/on?
Place your bets now, for bragging rights later!
Ice
Emma
Greg
Kaveh
Tar
Emily
Geoff
Soto
Bruce
Liquid
x DARIN
Sign here
Undeterminable
Sloane
Colette
Ben
Margarita
MEB
DOA
Kevin
EATEN
Dave

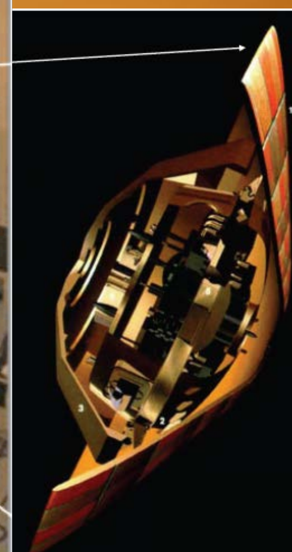

2 cm
10 cm
10 cm


1 km


Stephan et al., GRL 2010

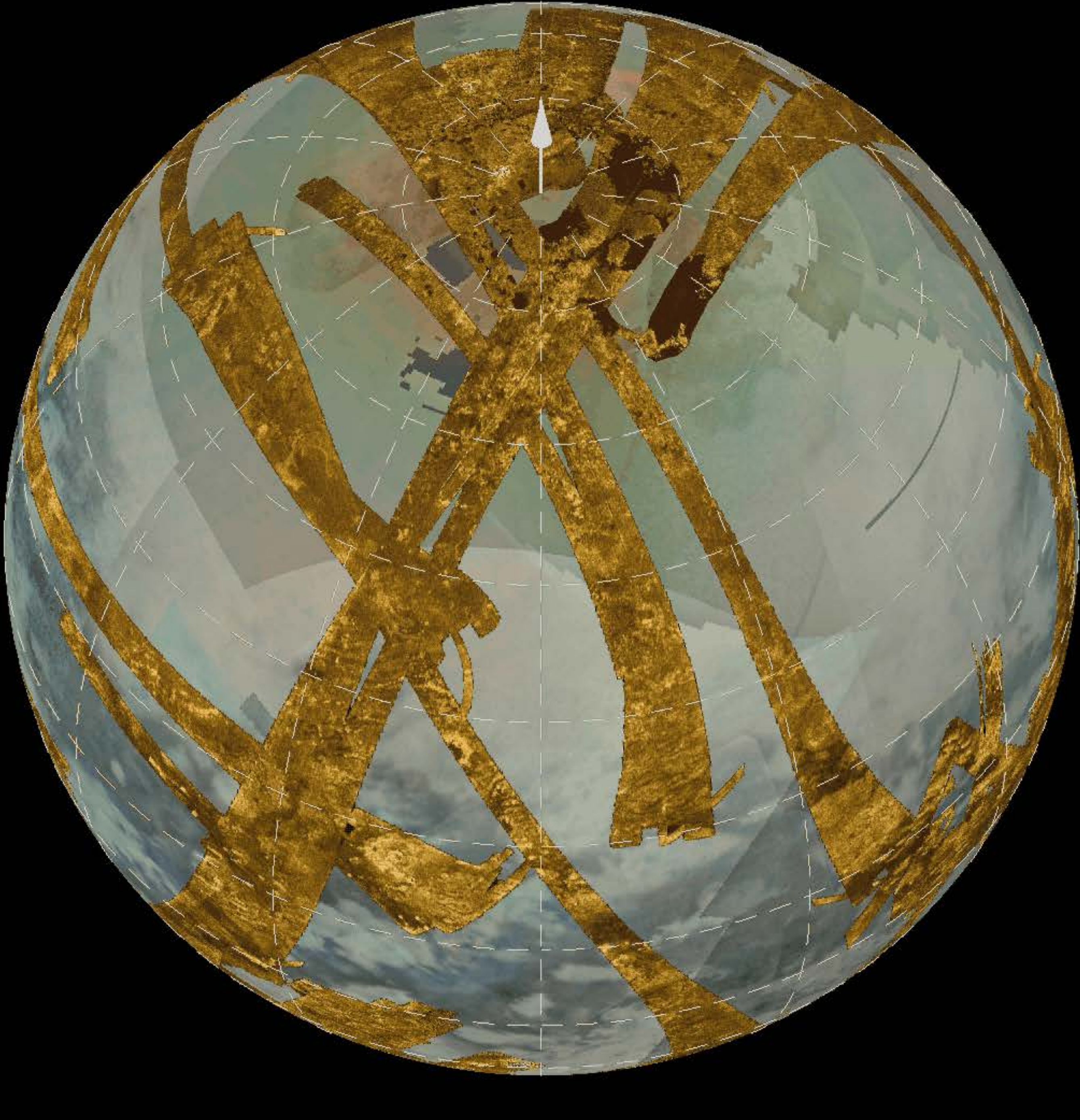
RADAR
- 13.78 GHz (2.16 cm)
  [Ku Band]
- SAR Resolution:
  300 m – 1.7 km



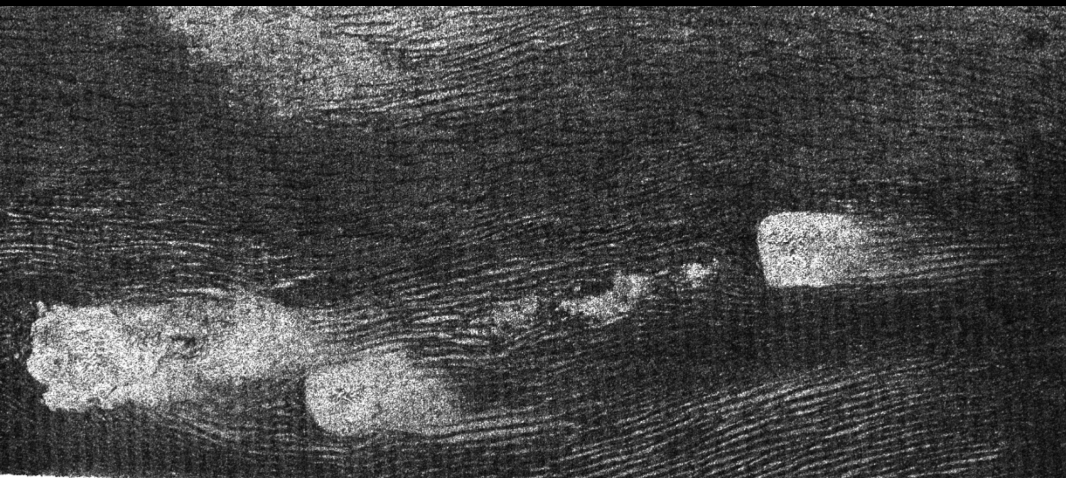


ISS
- VIS/NIR Telescope
  (0.2 – 1.1 μm)

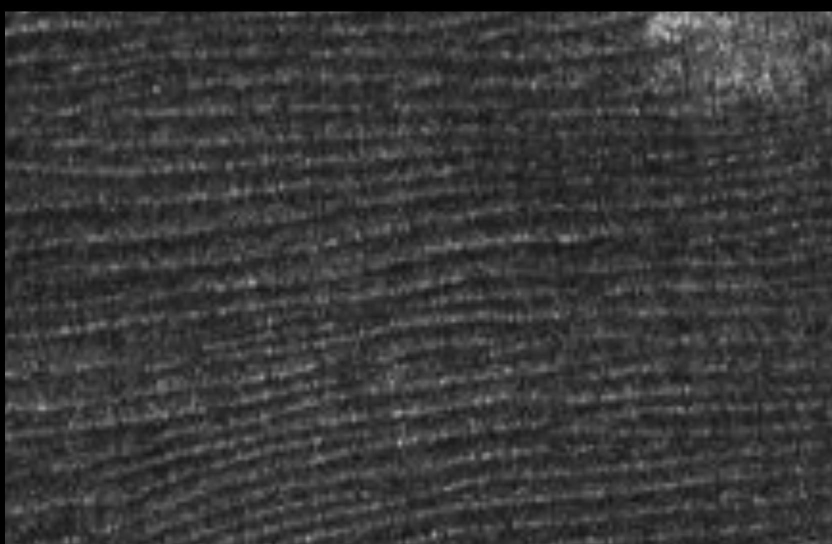
VIMS – IR
- Grating Spectrometer
  (0.84 - 5.1 μm n=264)



Aeolian Processes

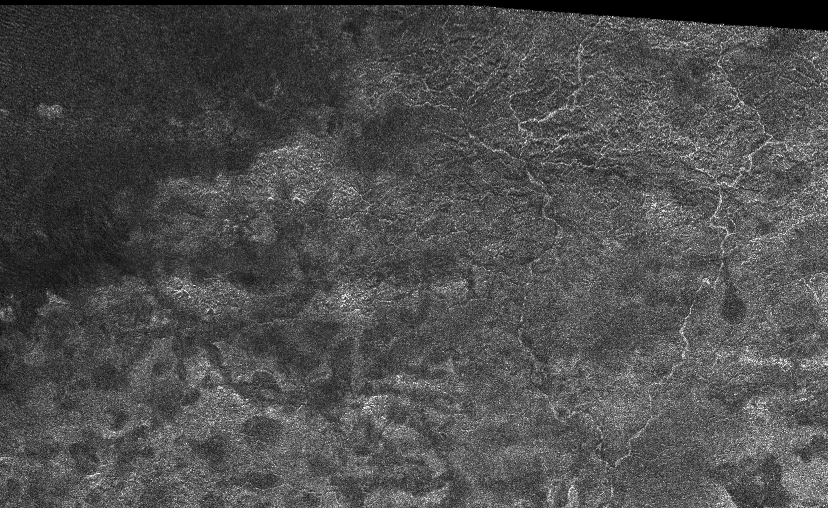


~50 km



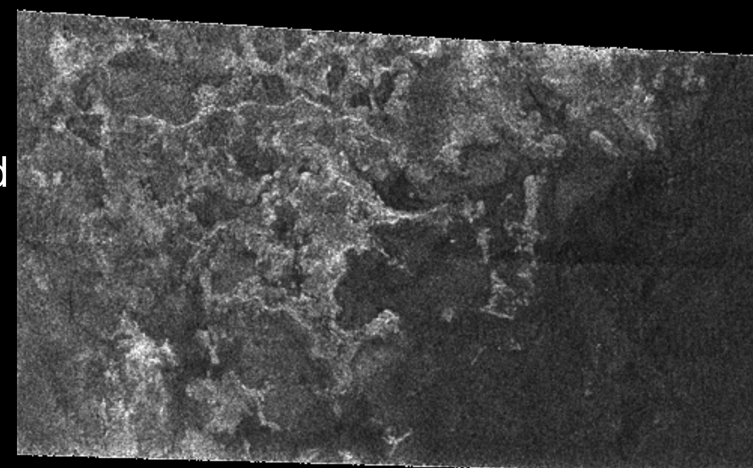
~15 km

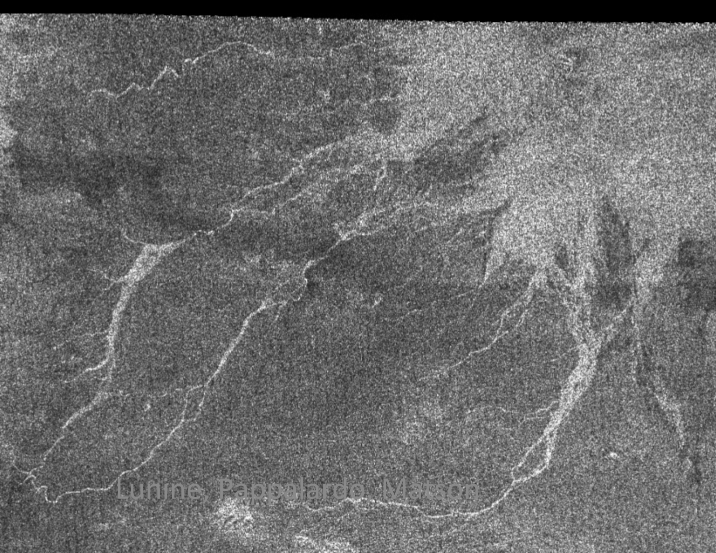
Fluvial Processes



Narrow, sinuous, radar-bright channels on the western portion of Xanadu extend for many hundreds of km. They may be river networks of methane that carry photochemical debris as sediment (image is ~ 80 km wide)

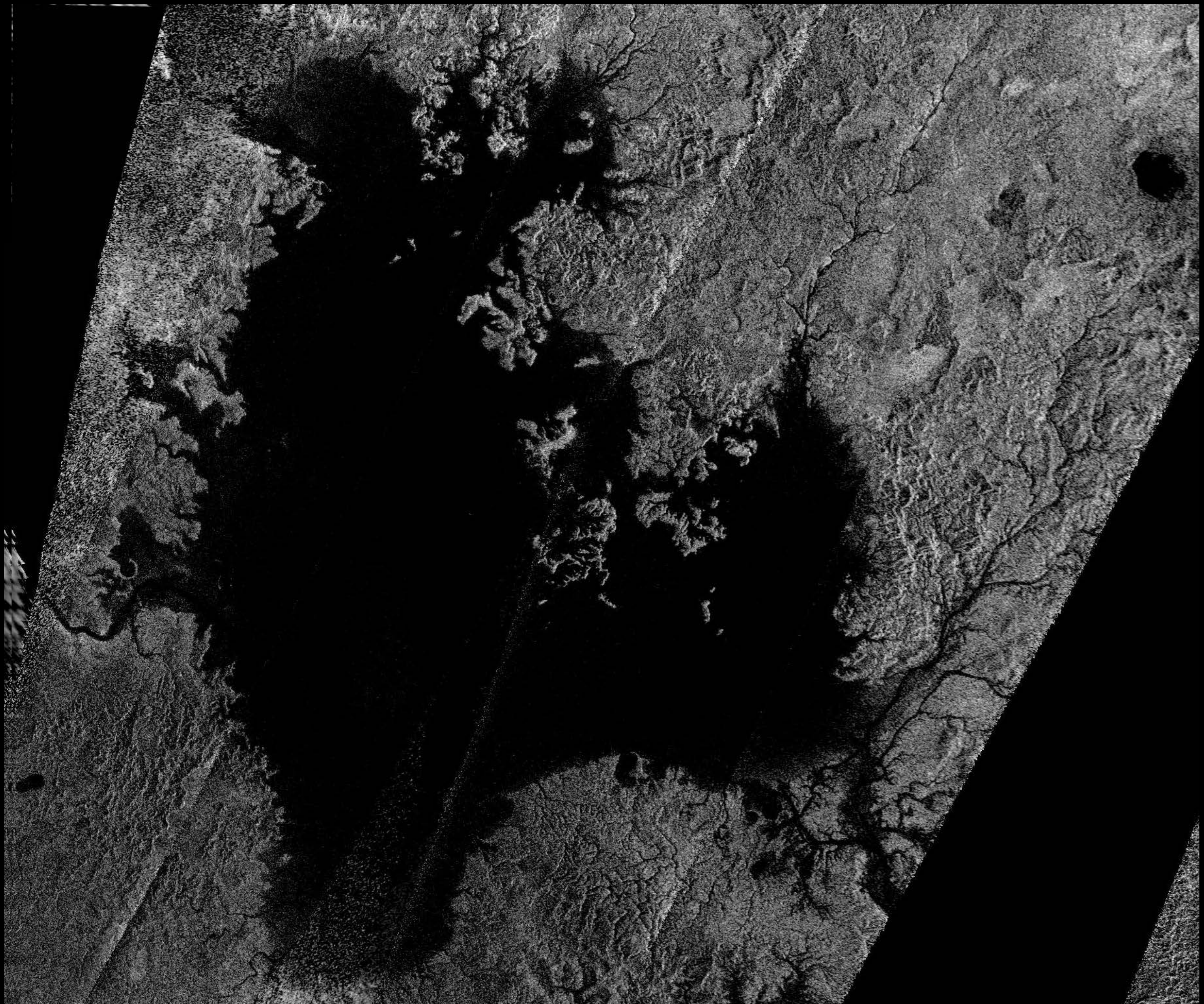
This southern-hemisphere "coastline" resembles terrestrial embayments and wetlands (~ 100 km wide)



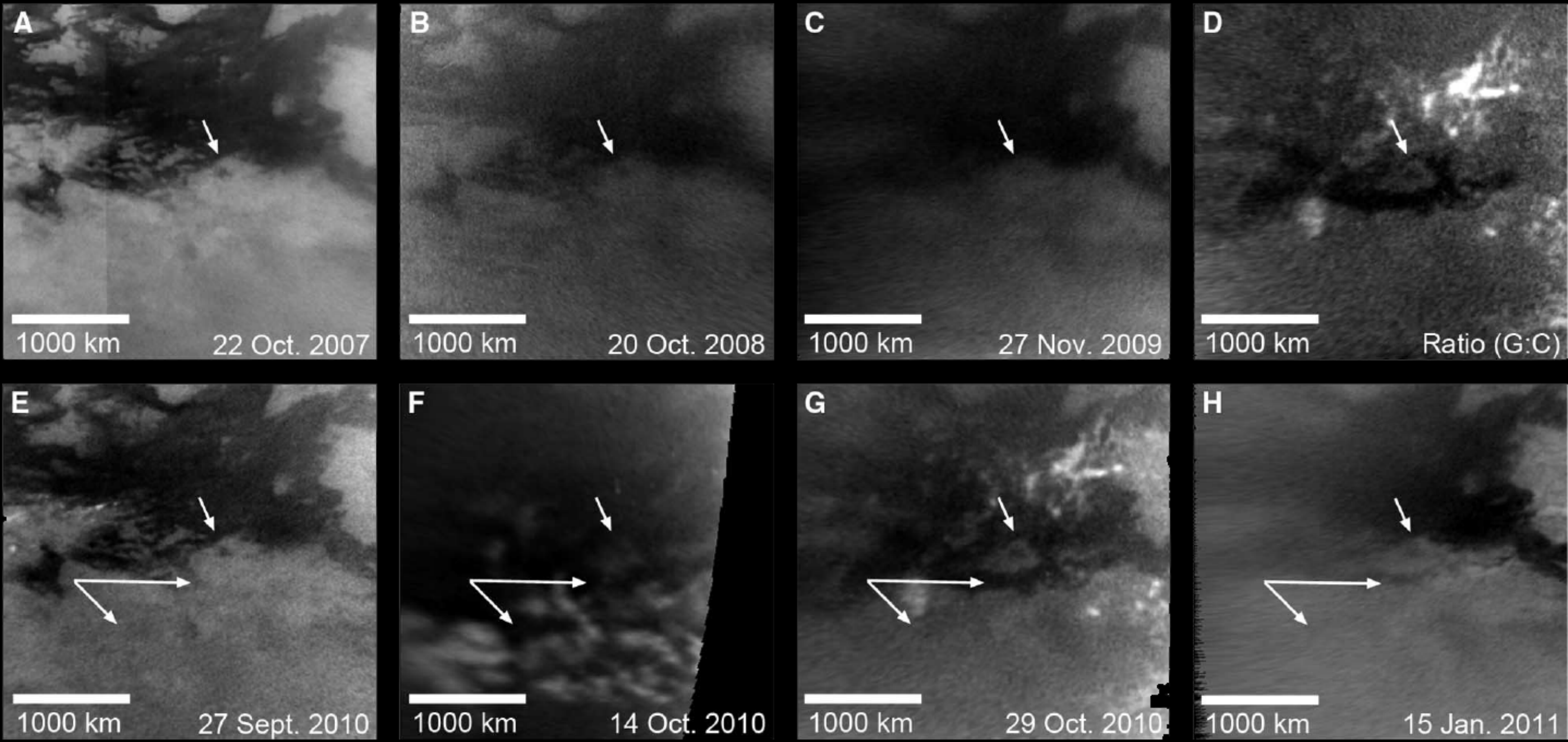


Networks of channels/valleys with high tortuosity near Menrva (T3) appear to drain > 10^4 km^2 into radar bright (rough?) regions (image is ~ 60 km wide) interpreted as alluvial fans.

Lacustrine Processes

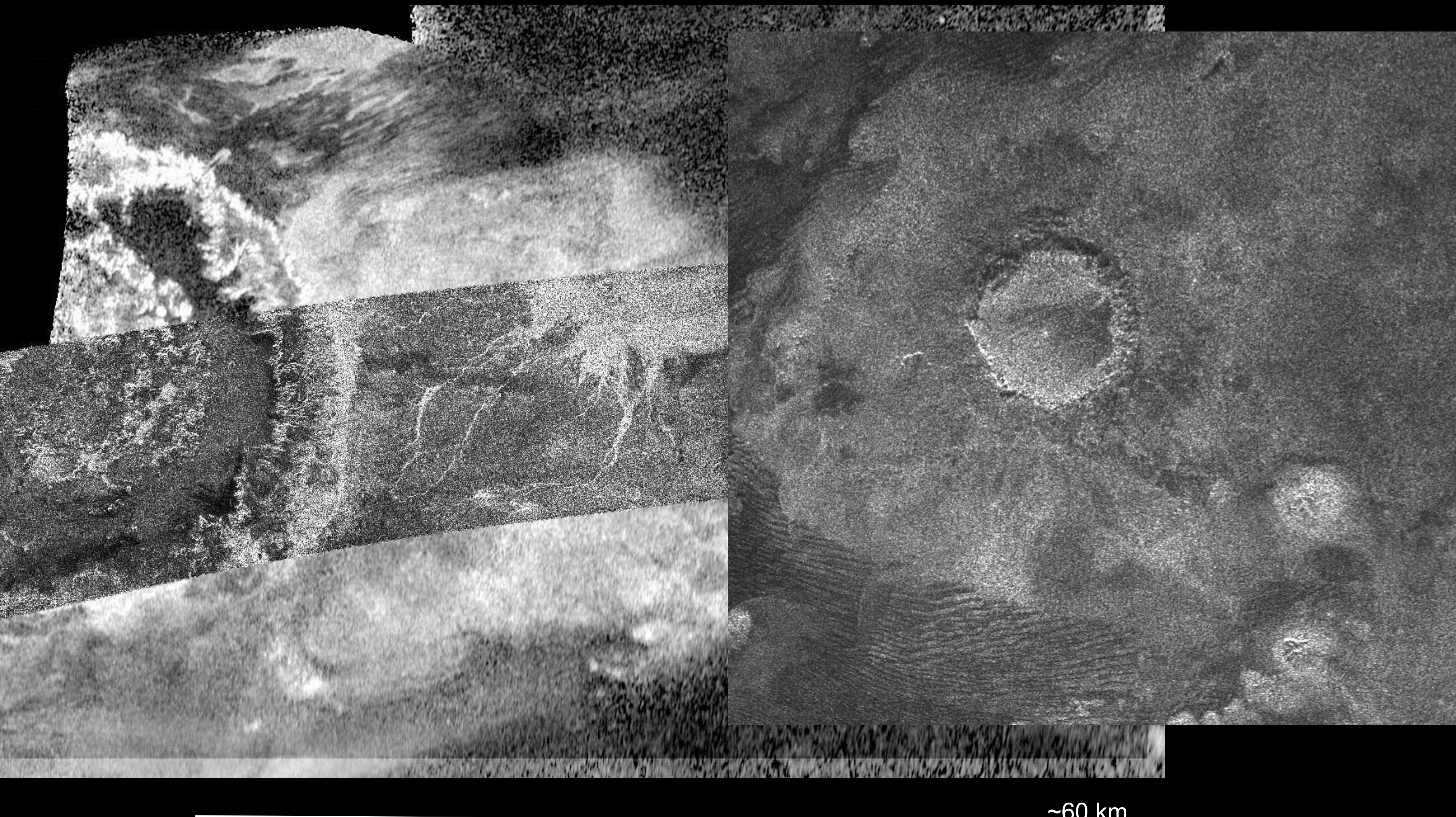


Pluvial Processes

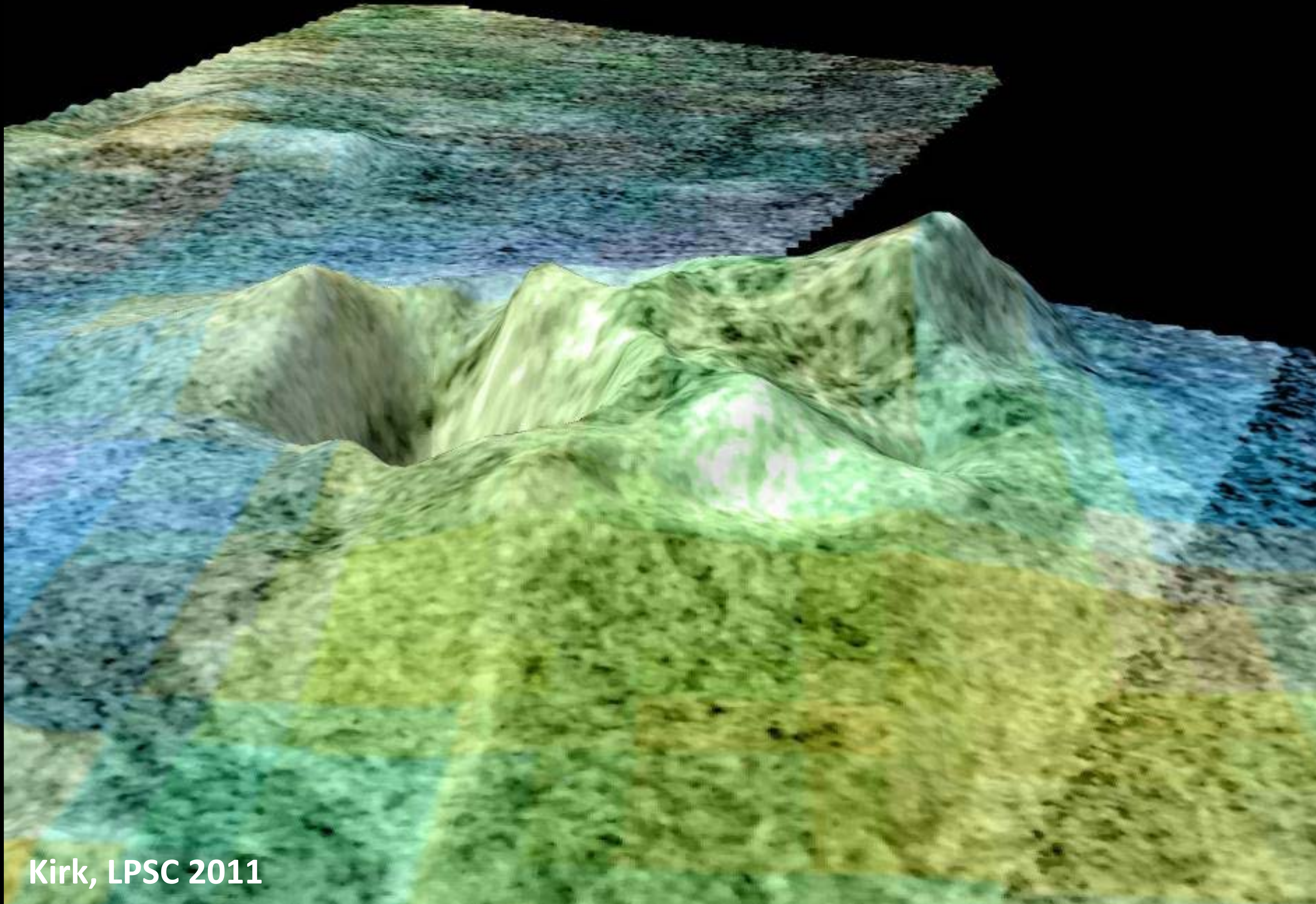


Turtle et al. , Science 2011

Impact Cratering

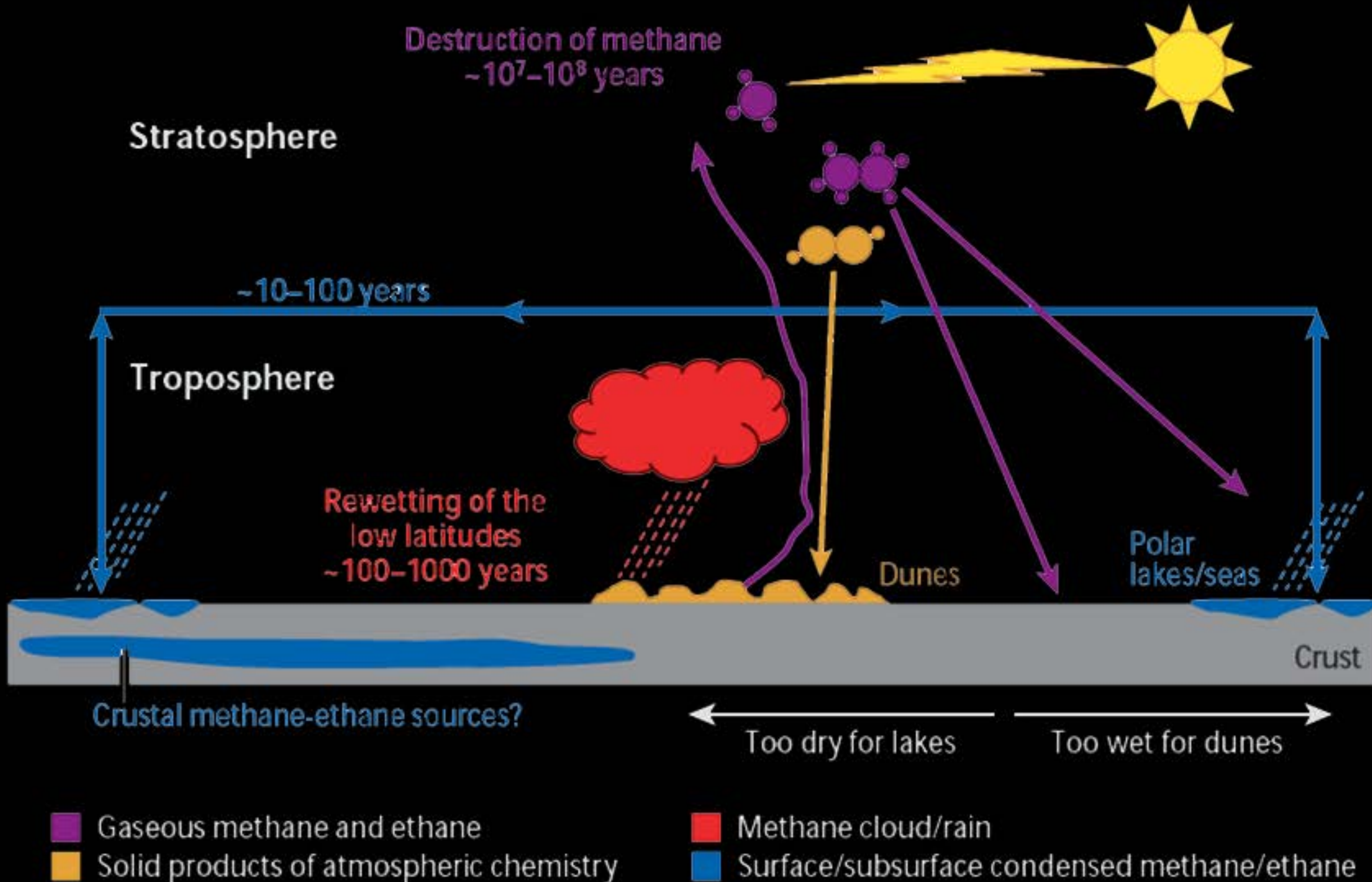


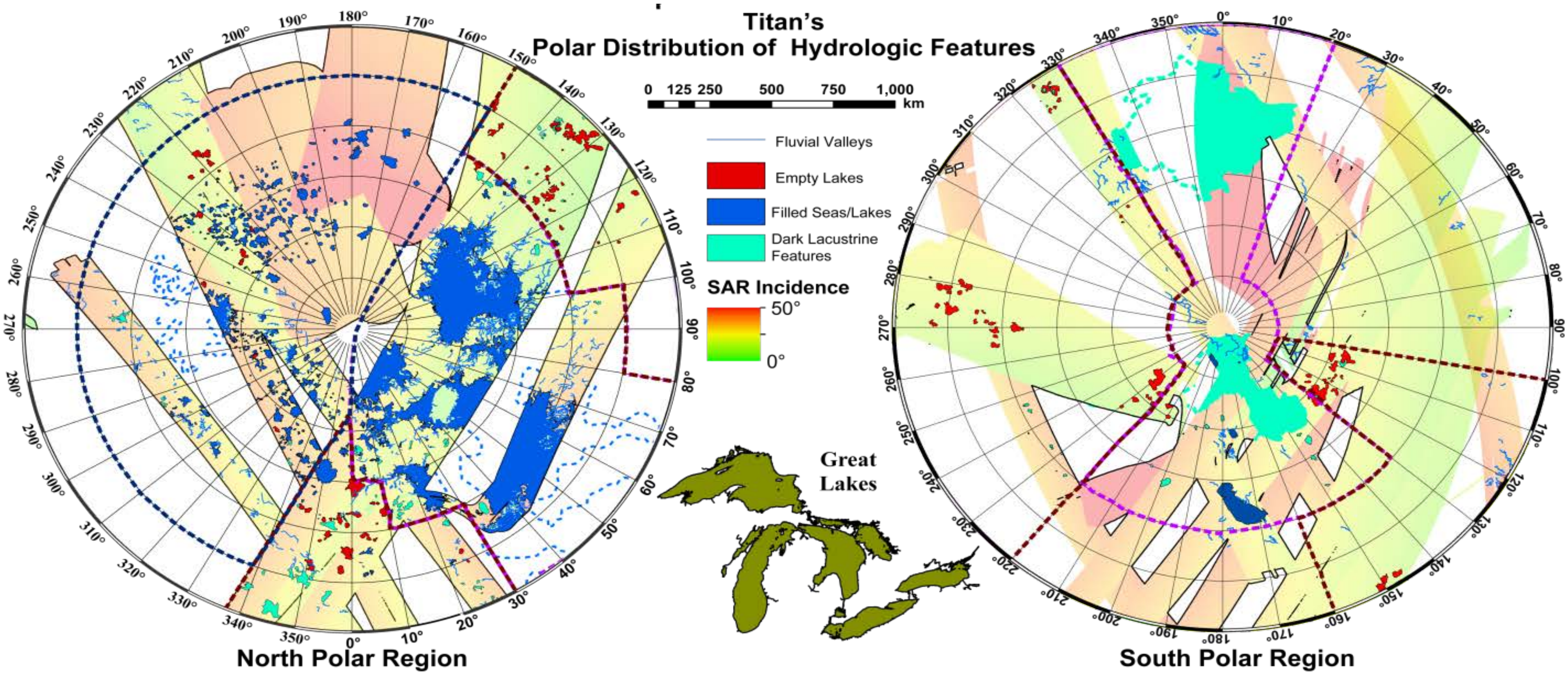
Endogenic Processes?



Kirk, LPSC 2011

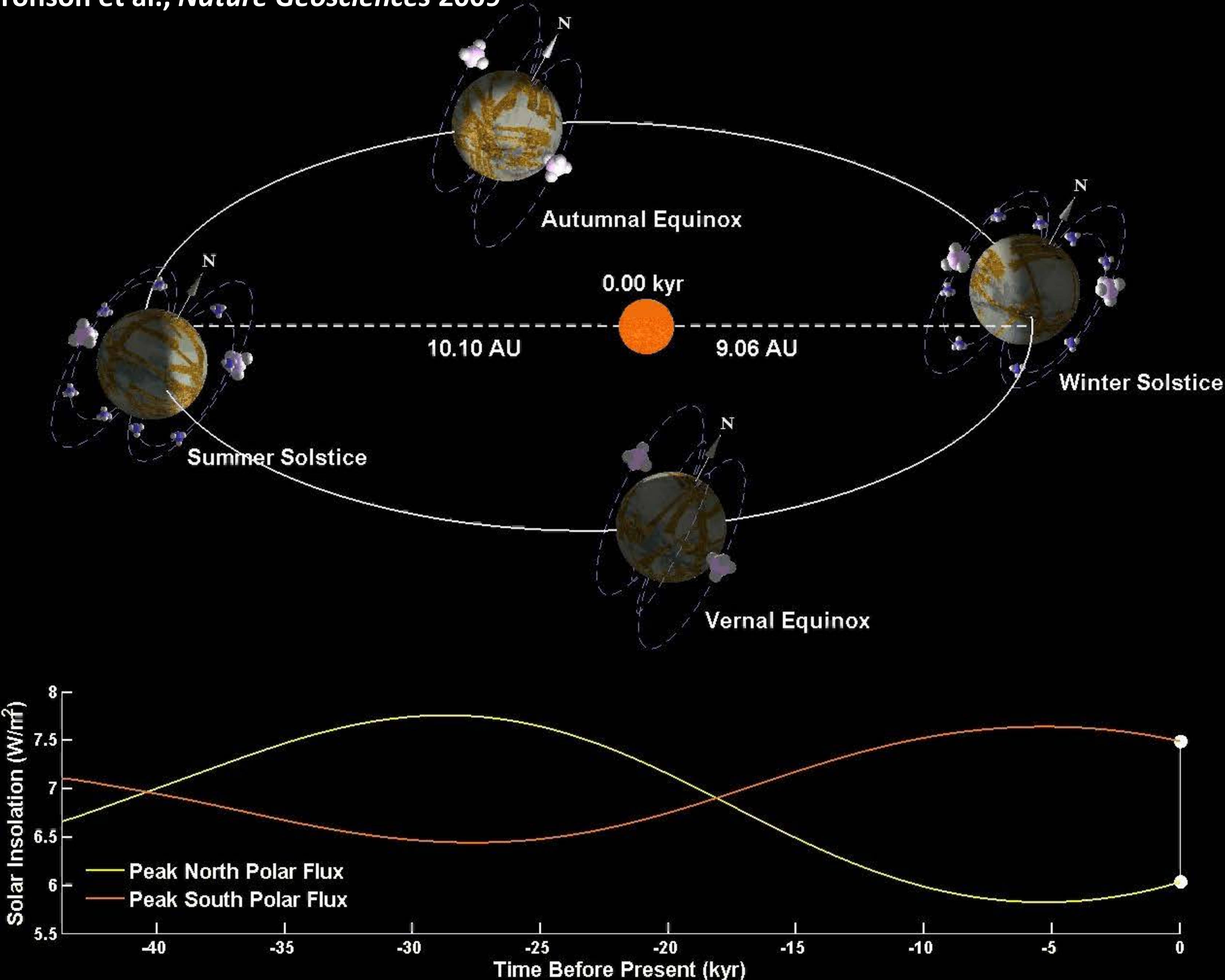
Titan: A New World


Destruction of methane
~10^7–10^8 years
Stratosphere
~10–100 years
Troposphere
Rewetting of the
low latitudes
~100–1000 years
Dunes
Polar
lakes/seas
Crust
Crustal methane-ethane sources?
Too dry for lakes
Too wet for dunes
Gaseous methane and ethane
Solid products of atmospheric chemistry
Methane cloud/rain
Surface/subsurface condensed methane/ethane

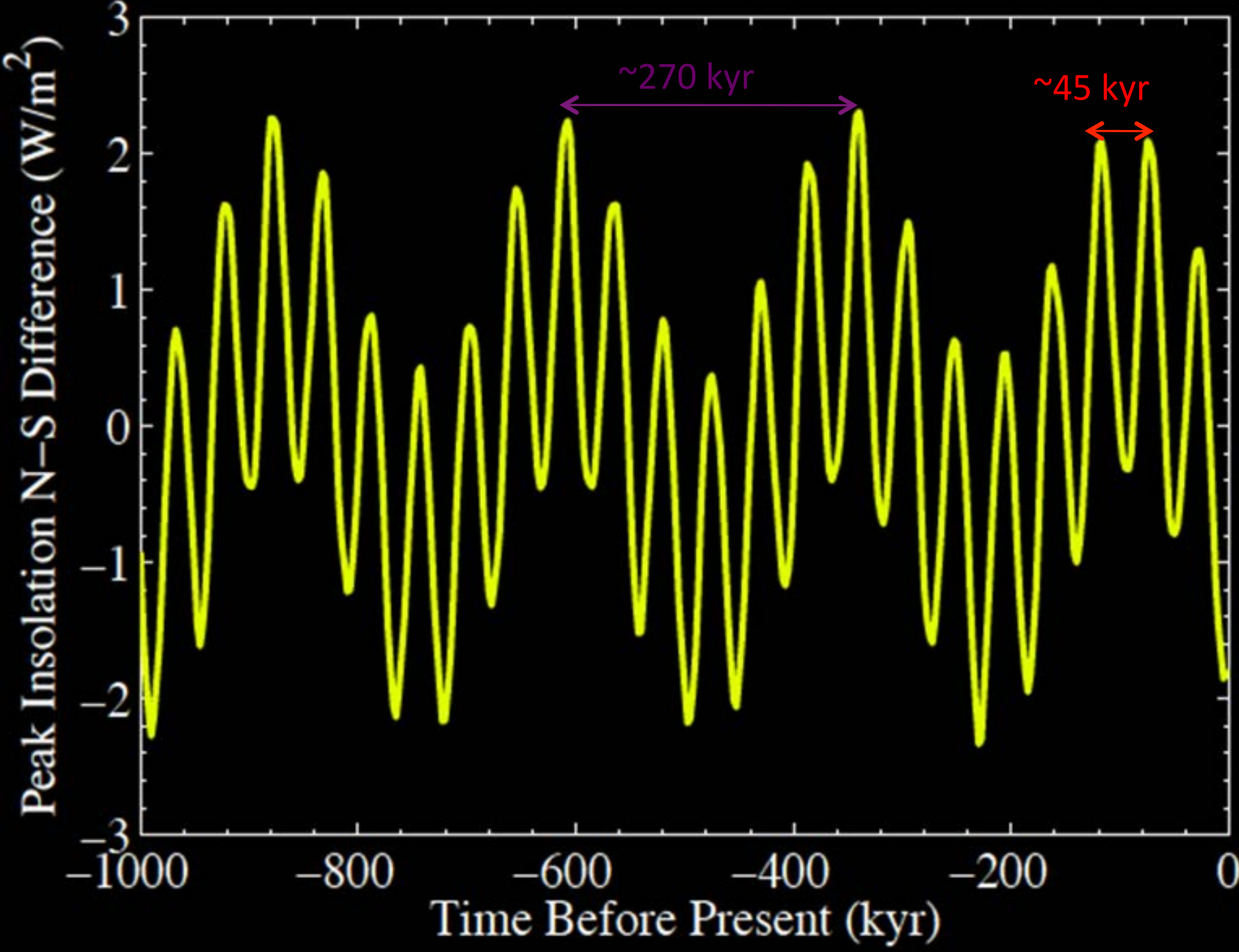


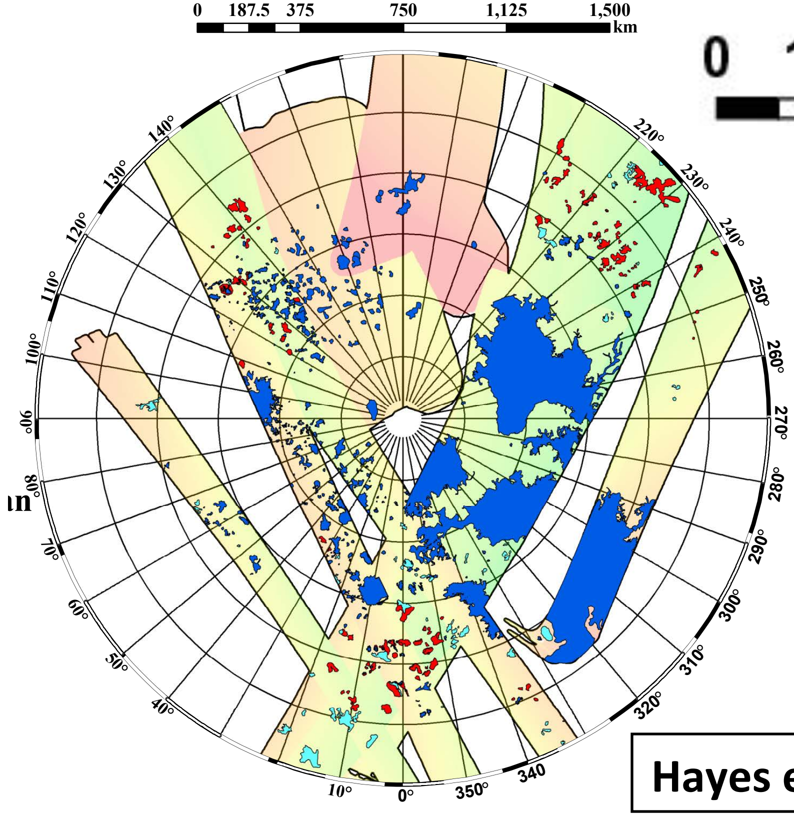
Lake Feature	Global	North (55°N-90°N)	South (55°S-90°S)
Swath Coverage	45.1%	56.5%	62.3%
Filled / Partially Filled / Empty	1.2% / 0.1% / 0.2%	10.5% / 0.7% / 1.2%	0.4% / 0.1% / 0.4%

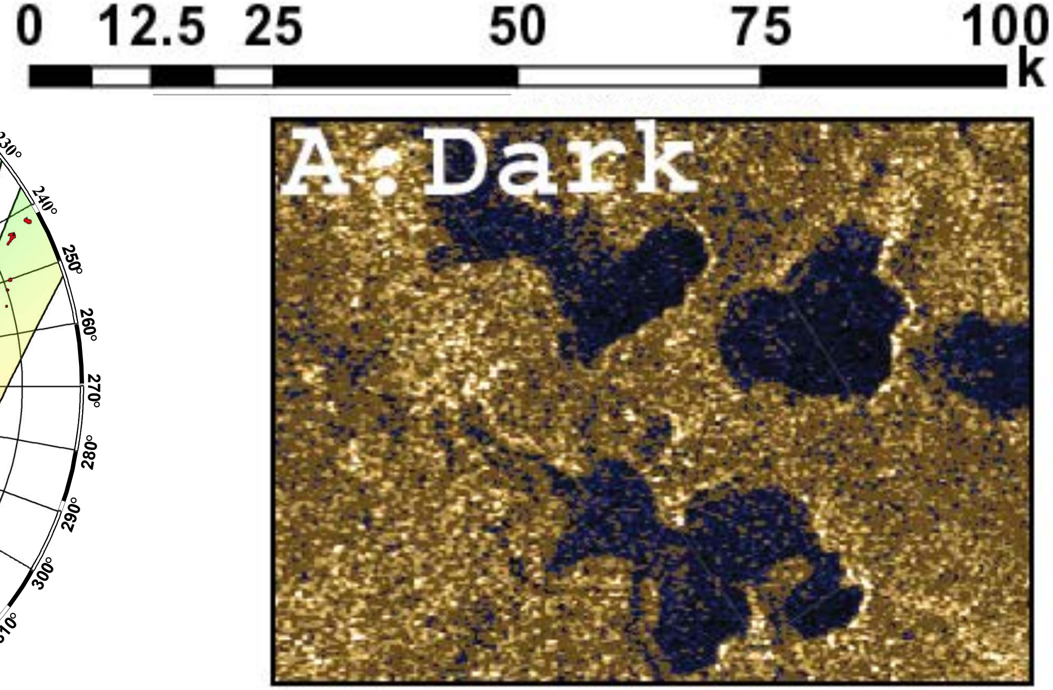
Aharonson et al., *Nature Geosciences* 2009



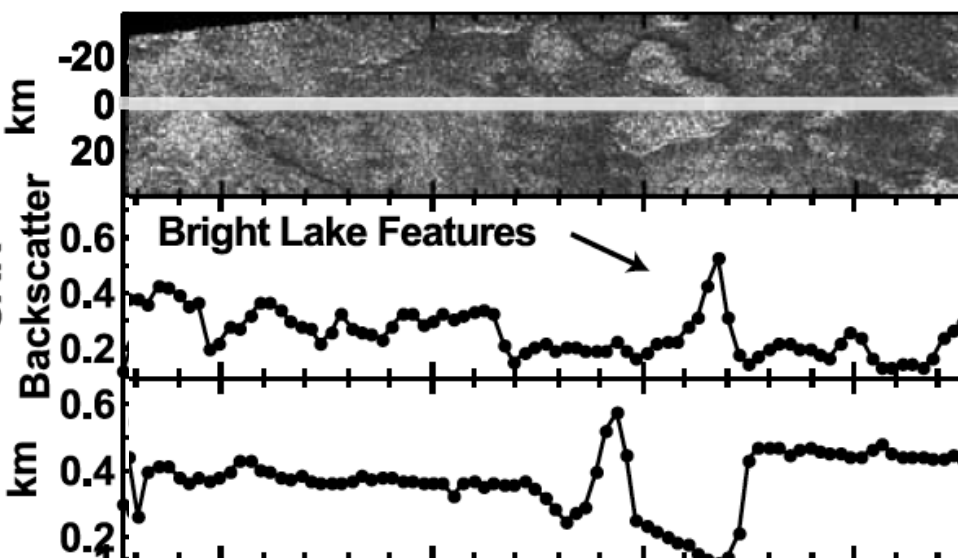
Titan's Milankovich Periods

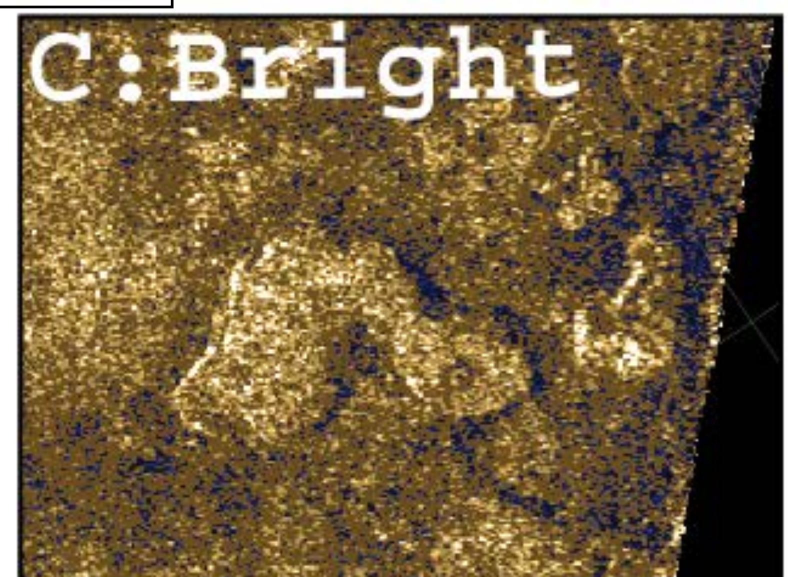


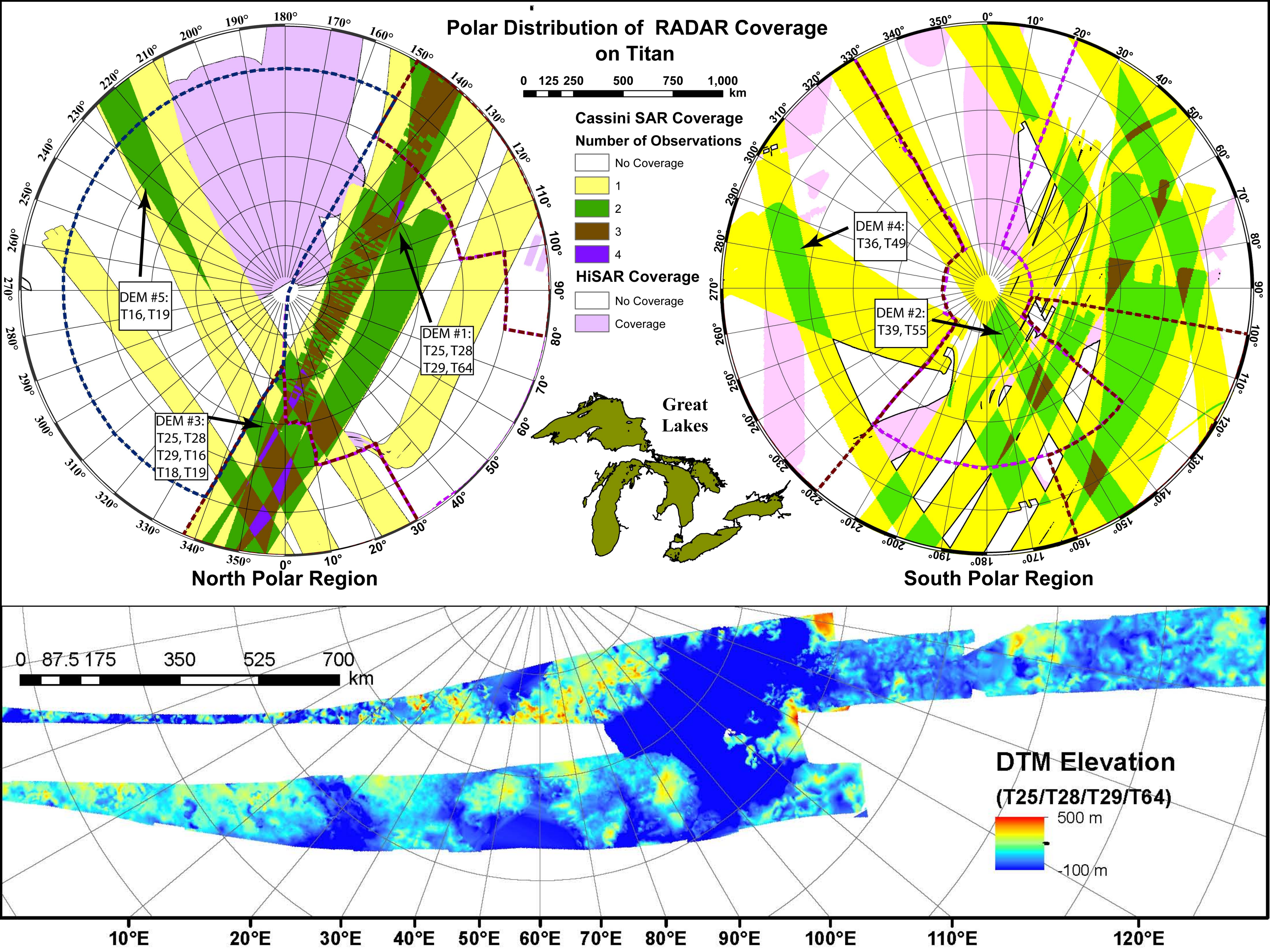




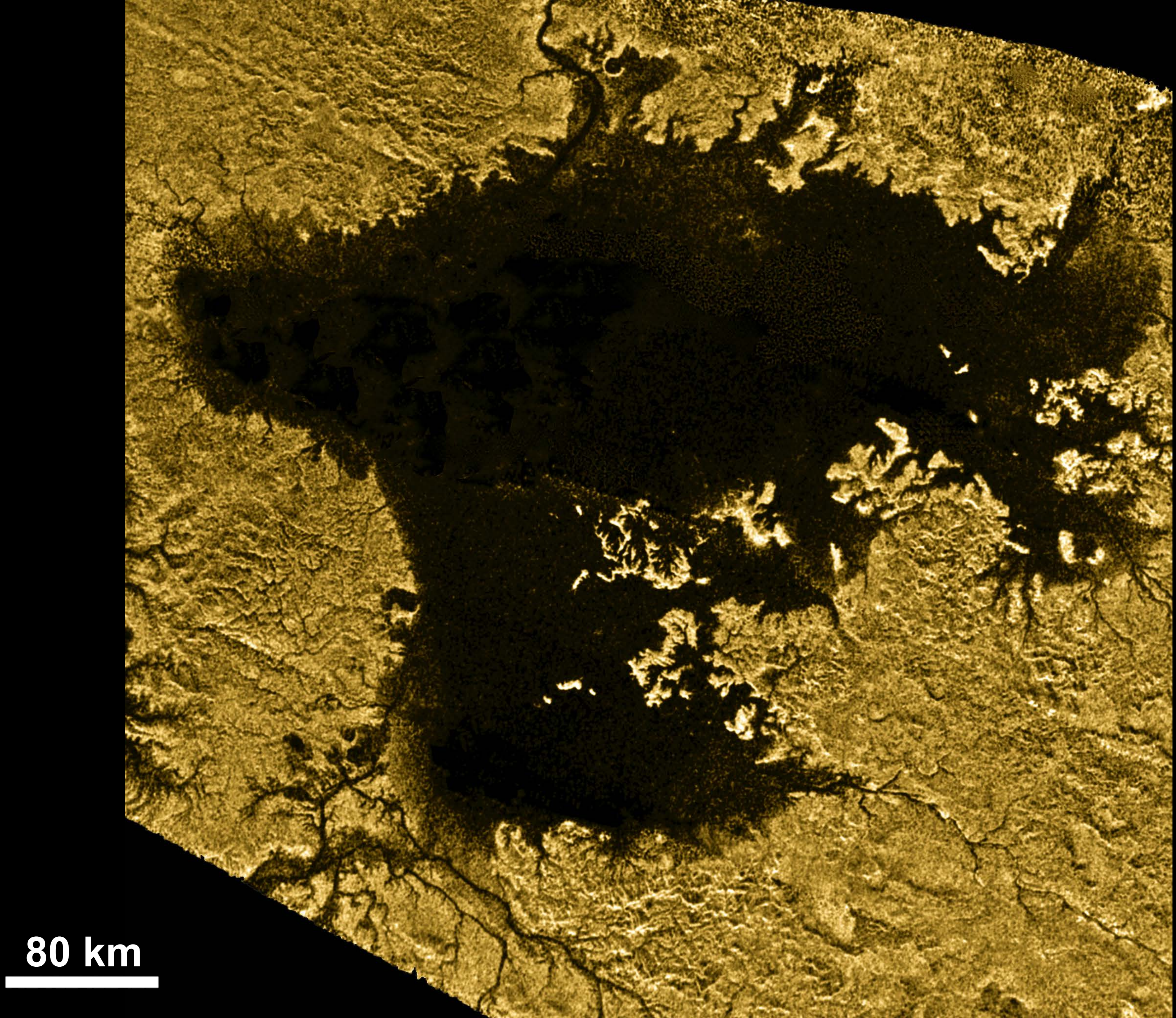
Hayes et al., *GRL* 2008

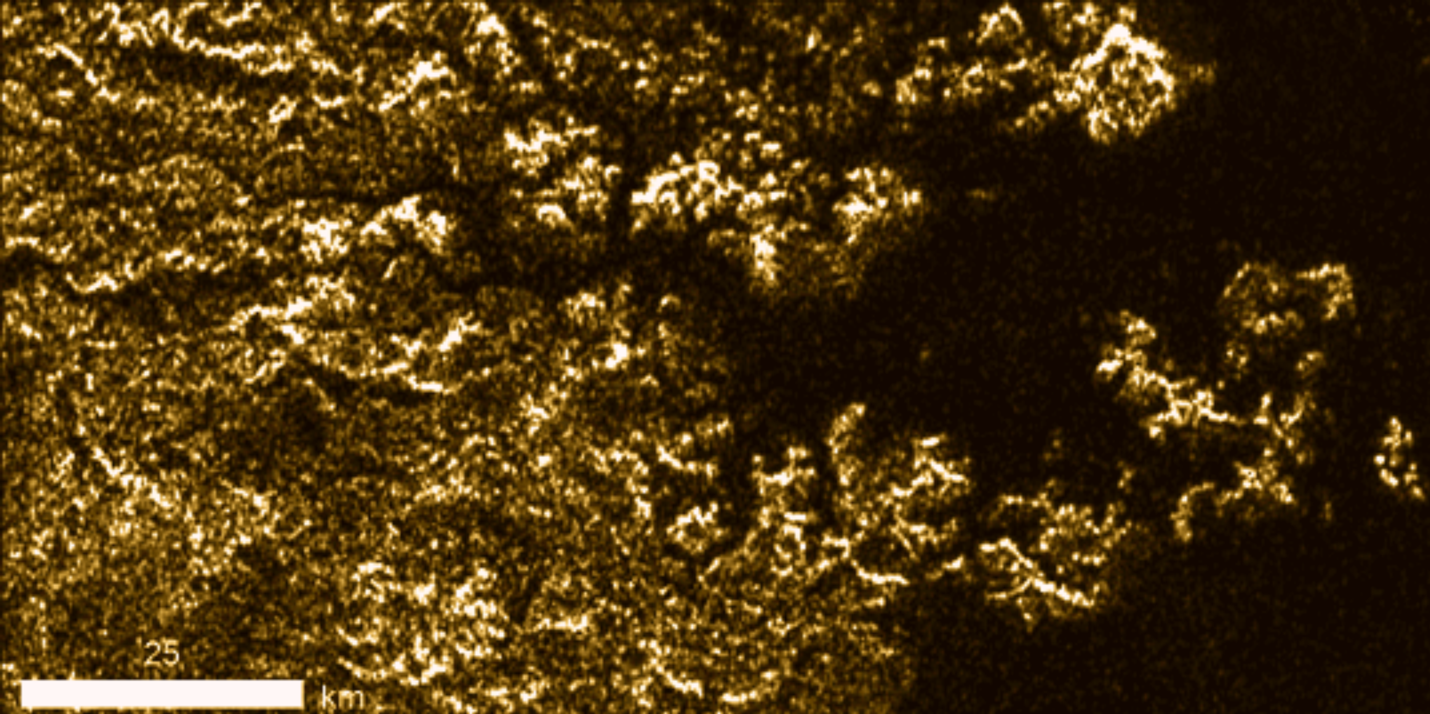




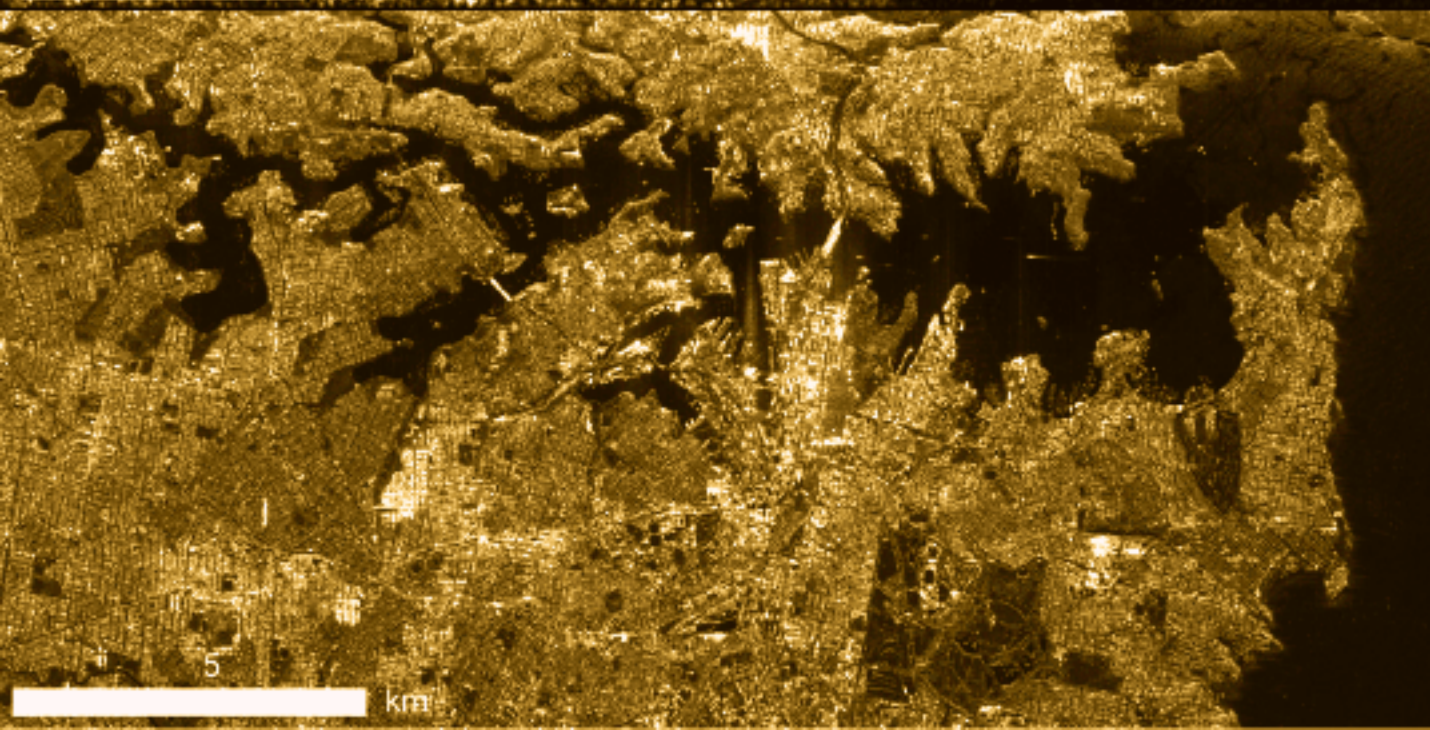


Polar Distribution of RADAR Coverage on Titan
0 125 250 500 750 1,000 km
Cassini SAR Coverage
Number of Observations
No Coverage
1
2
3
4
HiSAR Coverage
No Coverage
Coverage
DEM #5: T16, T19
DEM #1: T25, T28 T29, T64
DEM #3: T25, T28 T29, T16 T18, T19
DEM #4: T36, T49
DEM #2: T39, T55
Great Lakes
North Polar Region
South Polar Region
0 87.5 175 350 525 700 km
DTM Elevation
(T25/T28/T29/T64)
500 m
-100 m
10°E 20°E 30°E 40°E 50°E 60°E 70°E 80°E 90°E 100°E 110°E 120°E

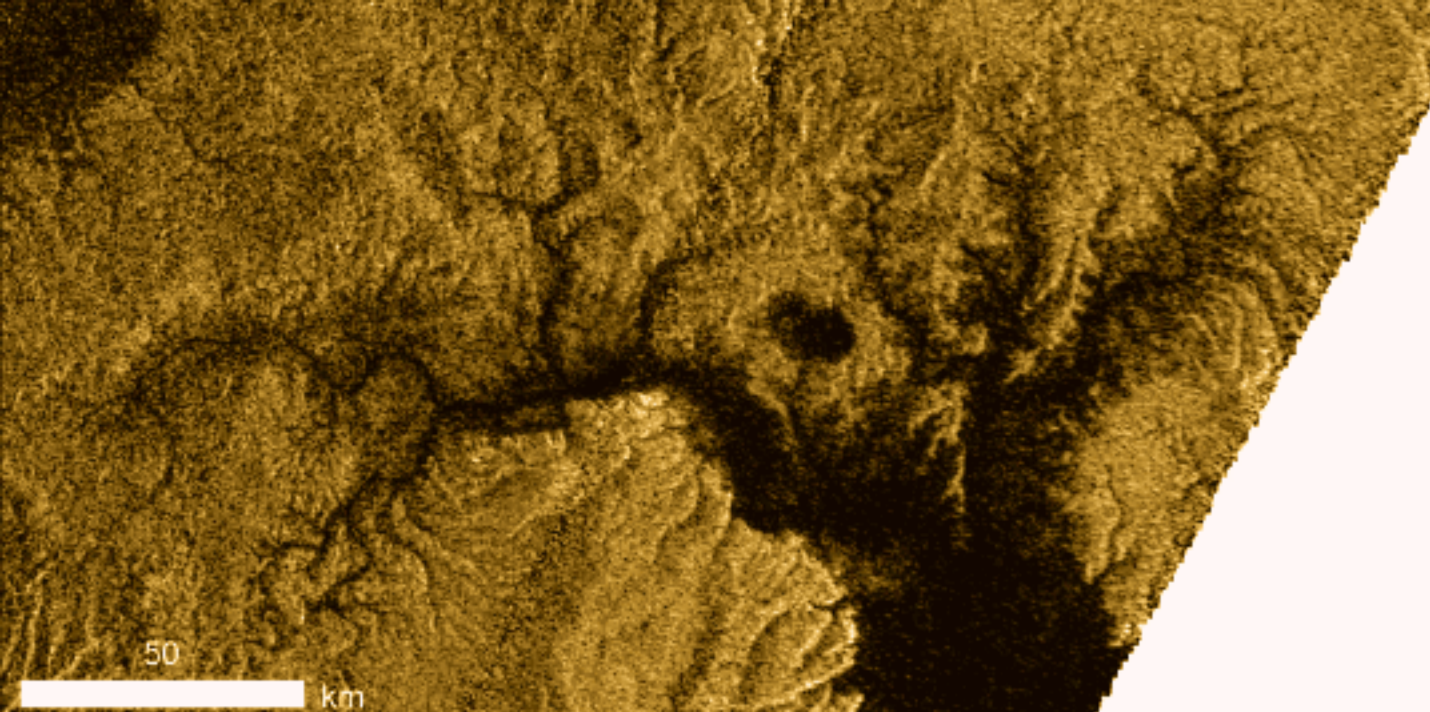

80 km



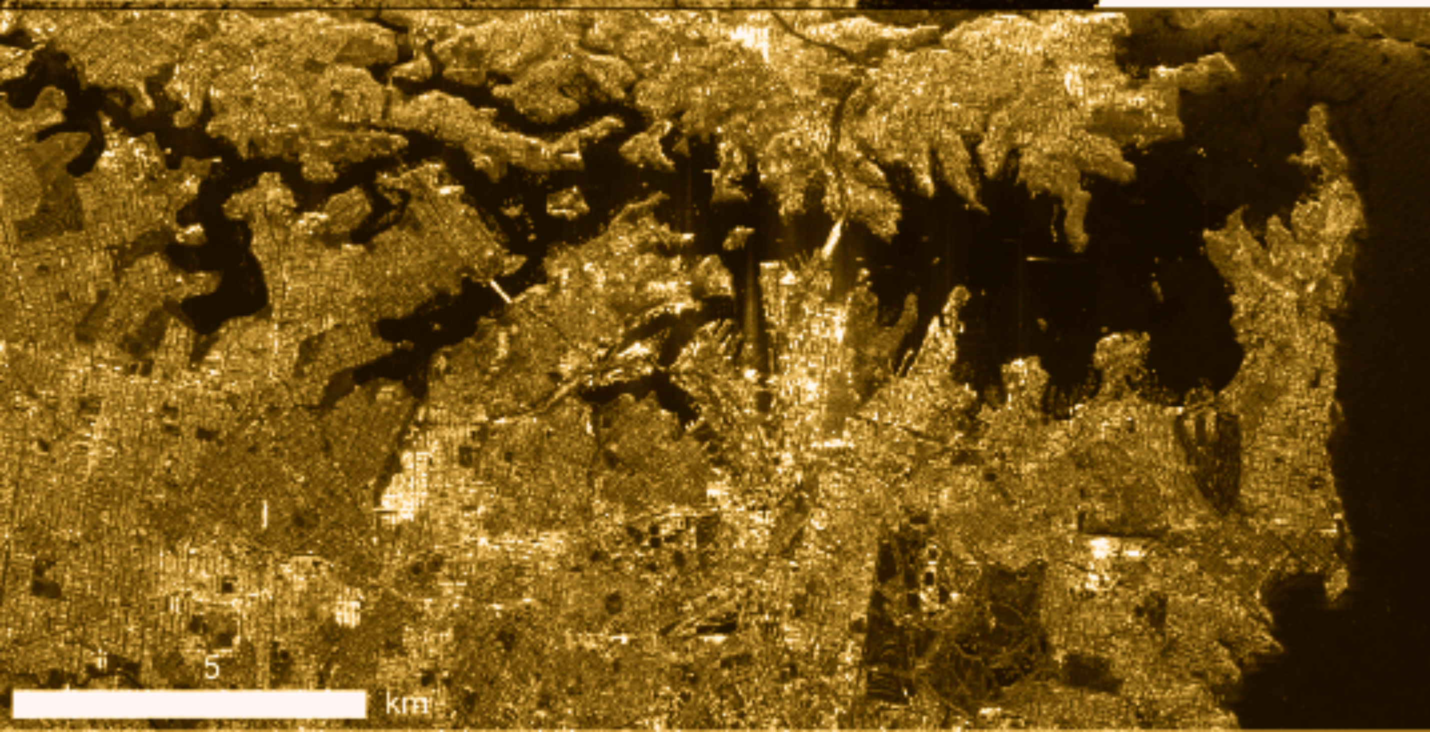
Ligeia Mare
Titan
Ku-Band
Cassini
SAR



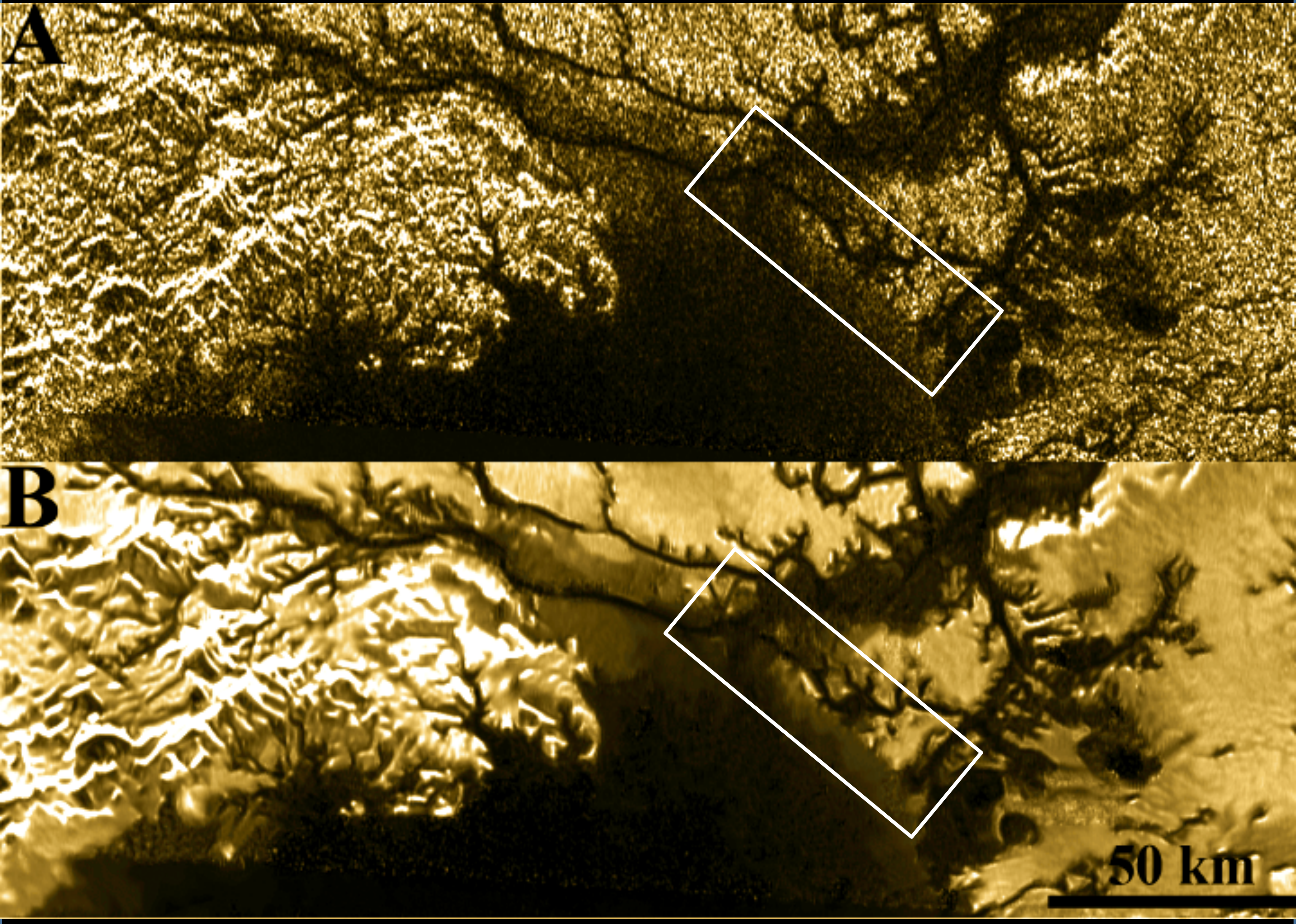
George’s River
Sydney,
Australia
C-Band
AIRSAR

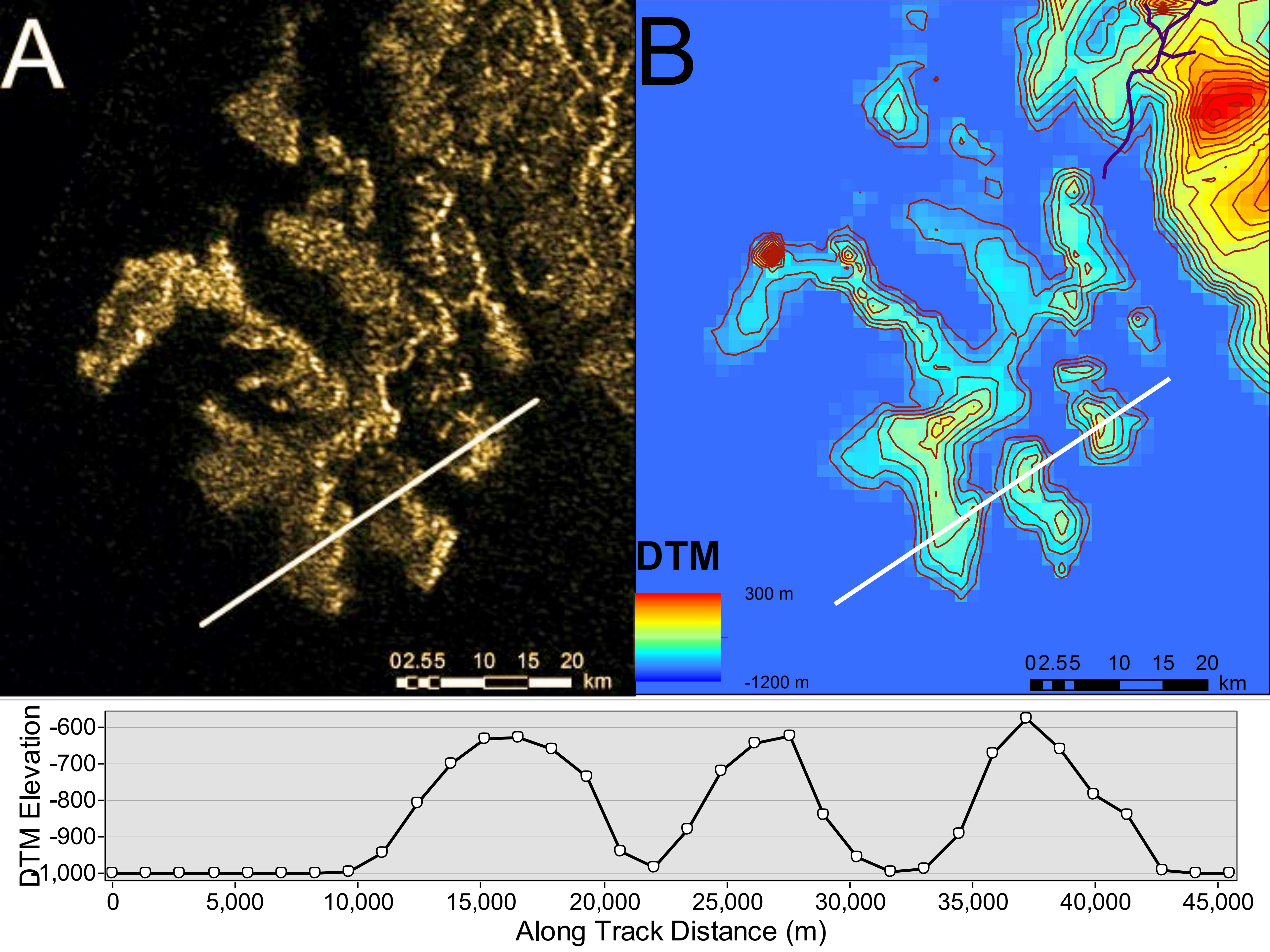


Kraken Mare
Titan
Ku-Band
Cassini
SAR

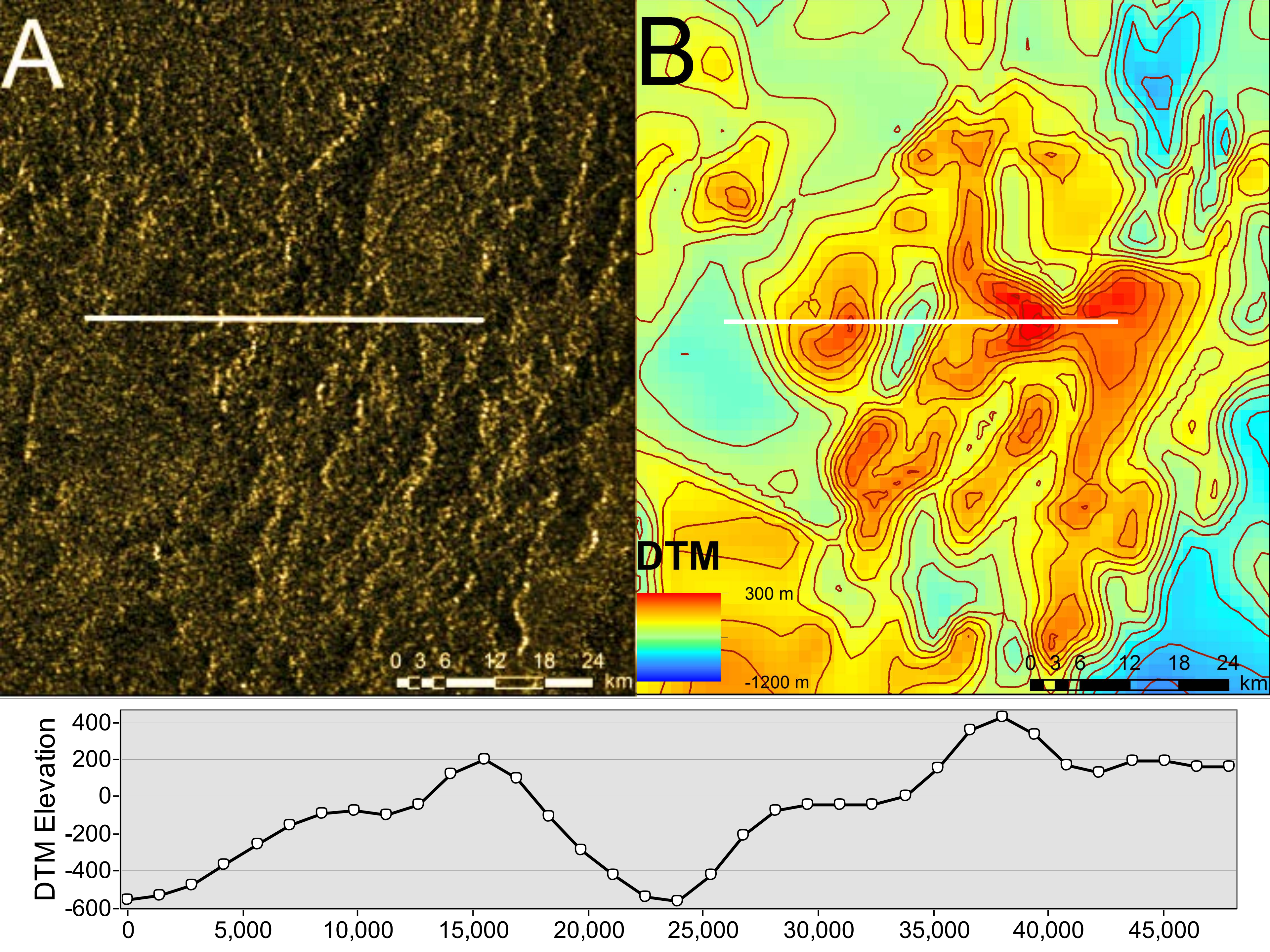


George's River
Sydney,
Australia
C-Band
AIRSAR

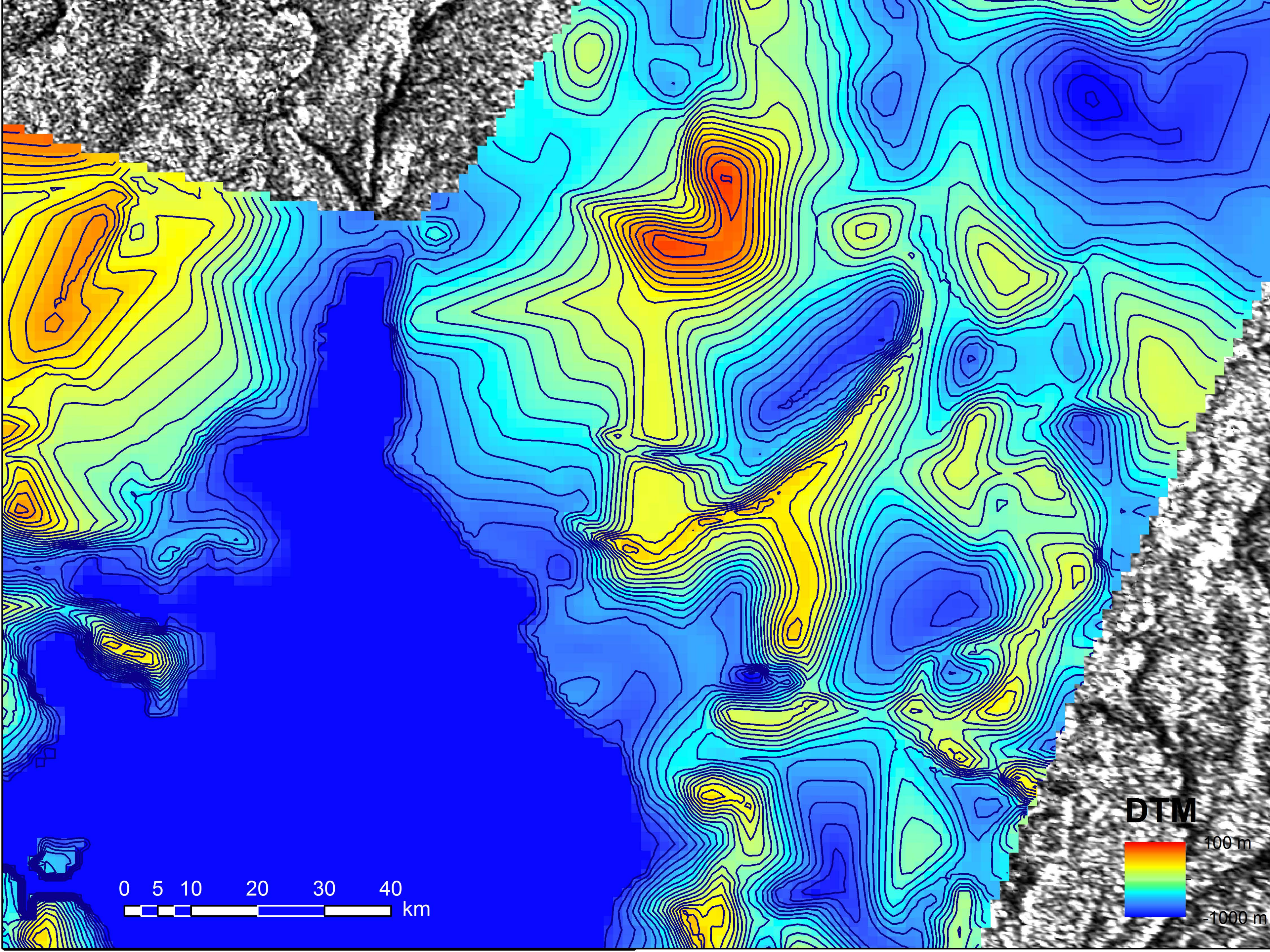

A
B
50 km



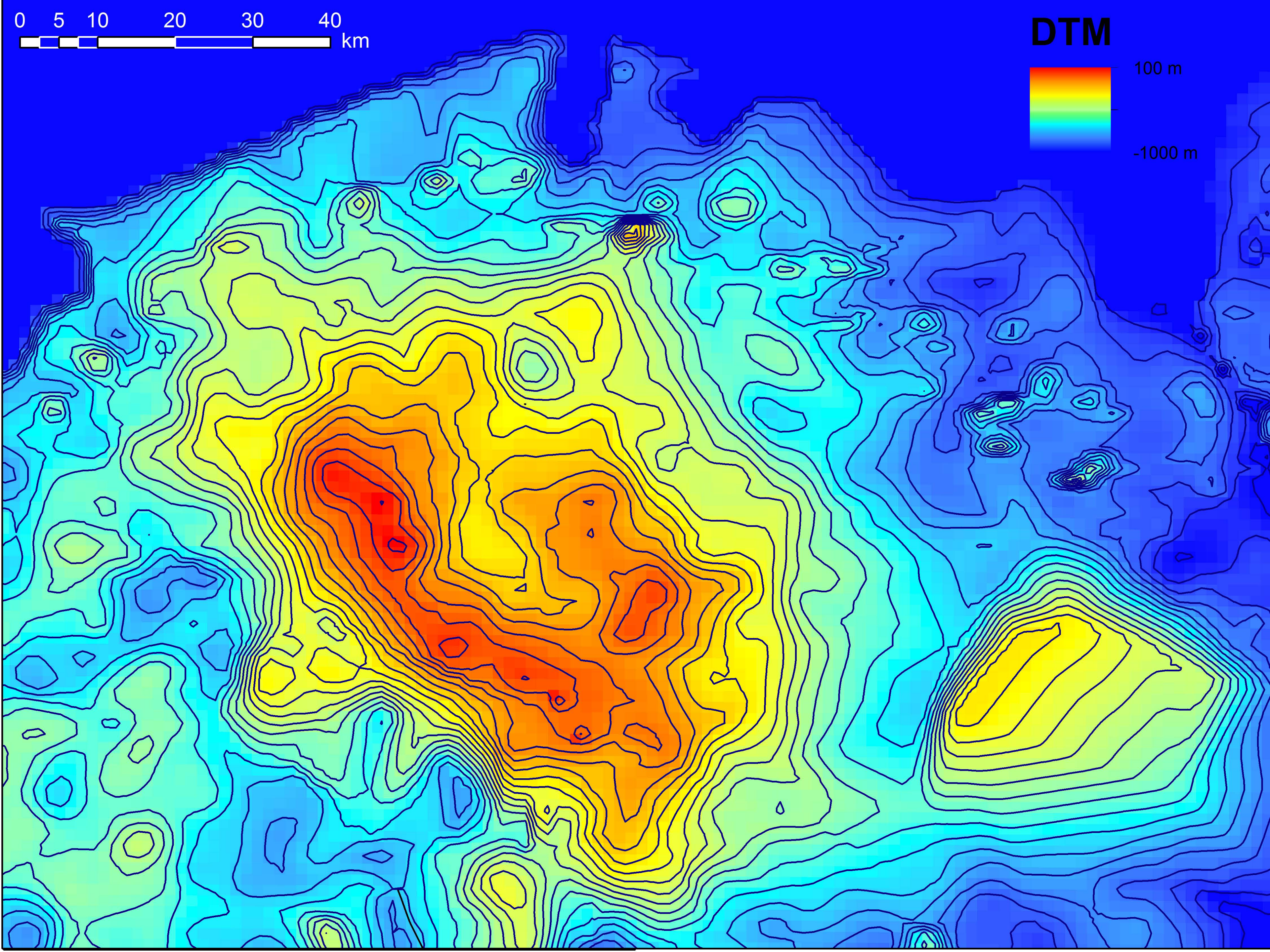
A
02.55 10 15 20
km
B
DTM
300 m
-1200 m
02.55 10 15 20
km
DTM Elevation
-600
-700
-800
-900
-1,000
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
Along Track Distance (m)

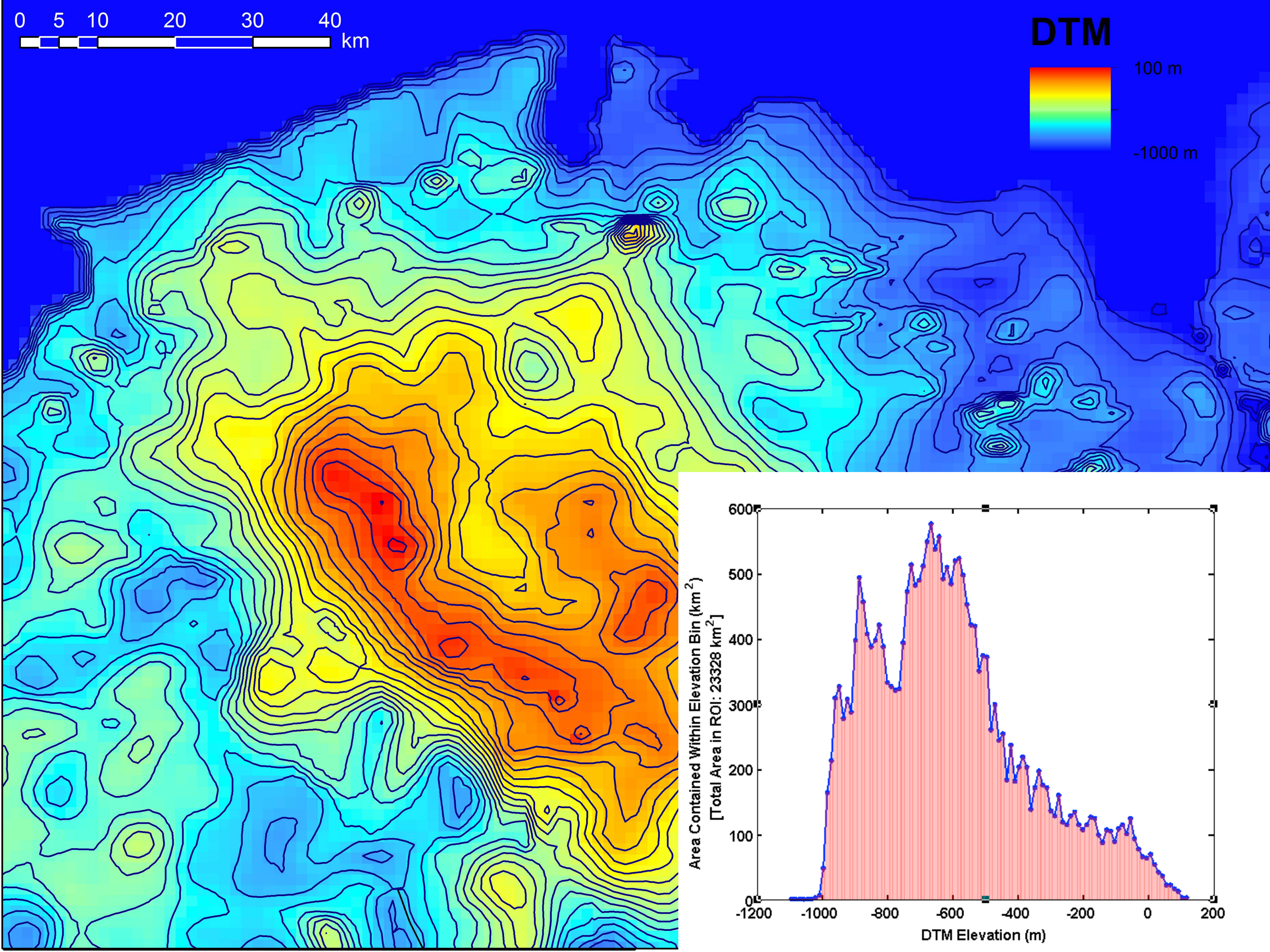


A
0 3 6 12 18 24
km
B
DTM
300 m
-1200 m
0 3 6 12 18 24
km
DTM Elevation
400
200
0
-200
-400
-600
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000

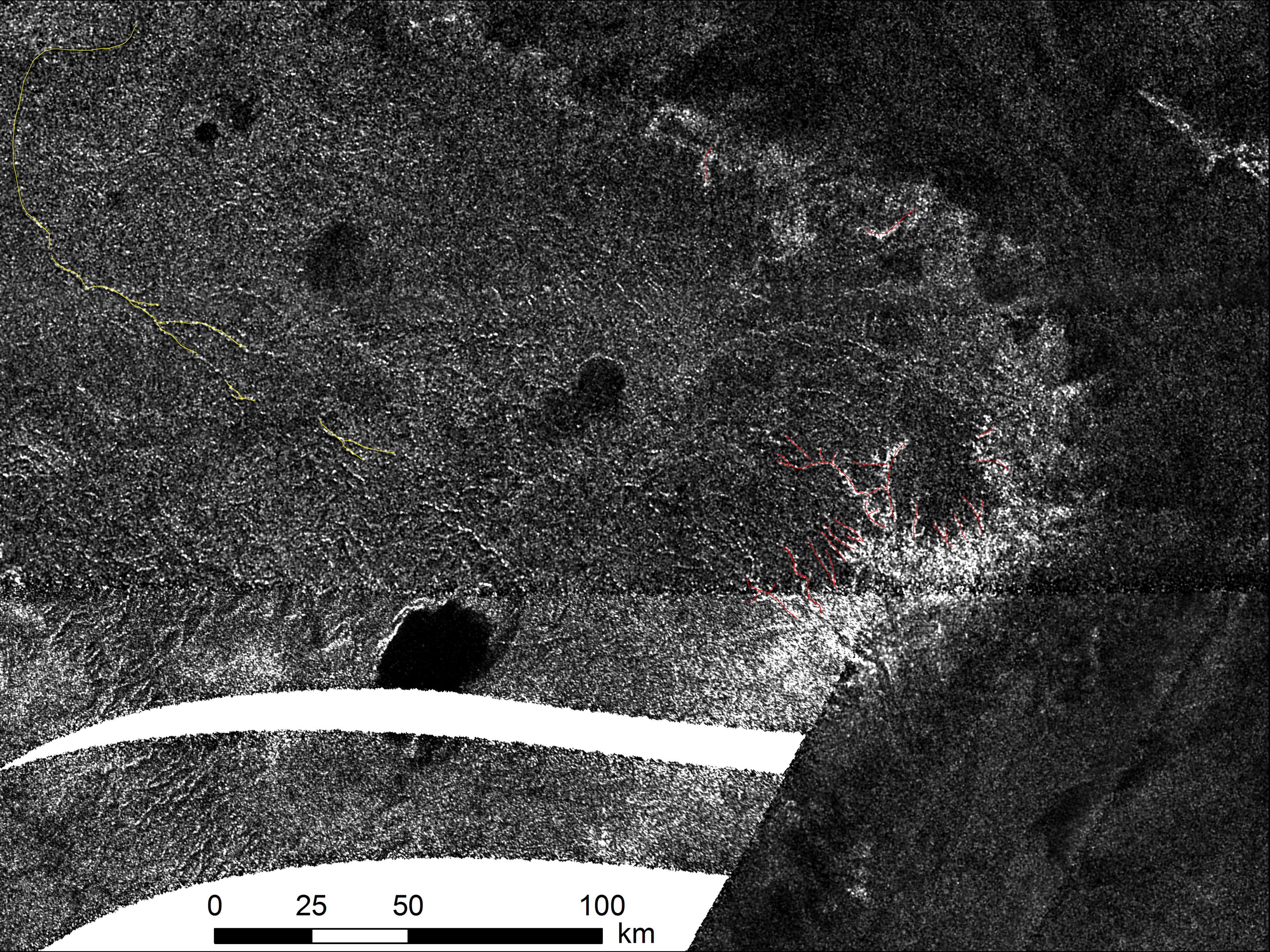


0 5 10 20 30 40
km
DTM
100 m
-1000 m

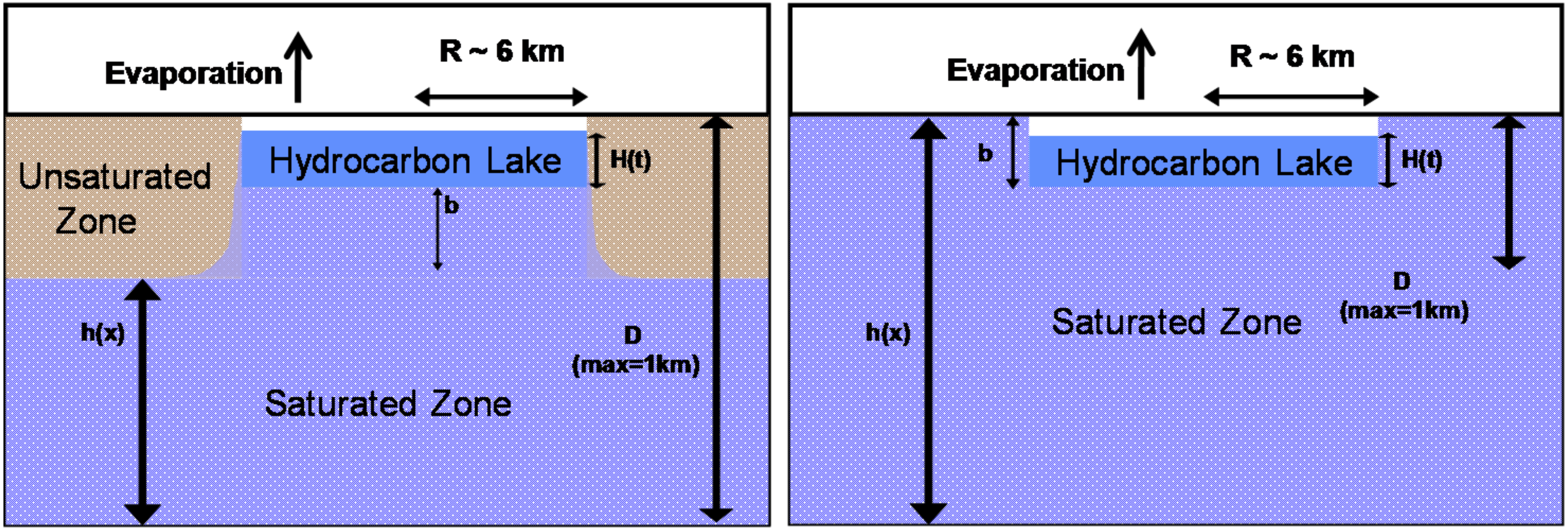

0
5
10
20
30
40
km
DTM
100 m
-1000 m


0 5 10 20 30 40
km
DTM
100 m
-1000 m
Area Contained Within Elevation Bin (km^2)
[Total Area in ROI: 23328 km^2]
DTM Elevation (m)
0 100 200 300 400 500 600
-1200 -1000 -800 -600 -400 -200 0 200


0 25 50 100
km

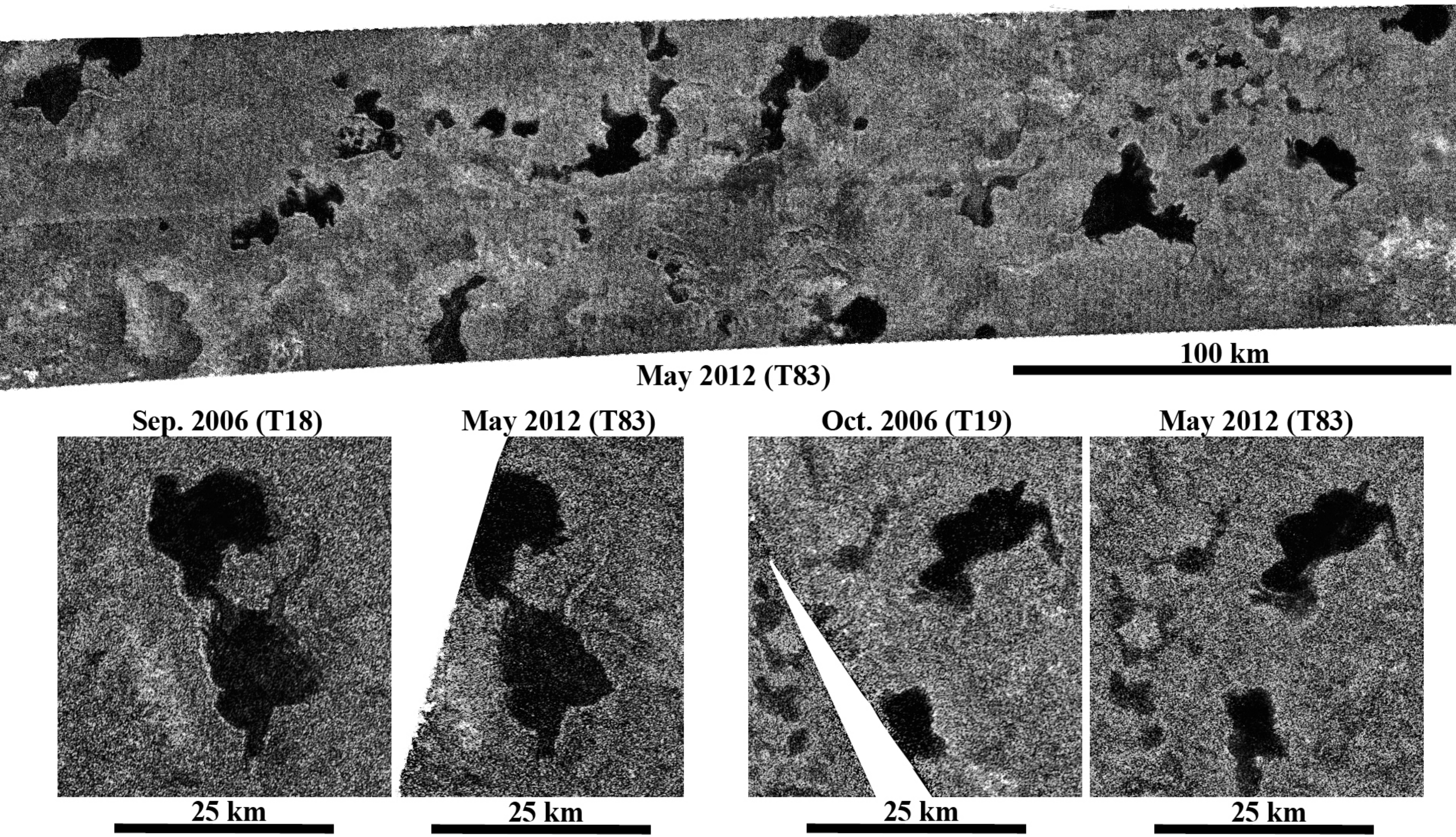

0
25
50
100
km

Flow Through Porous Media: Case Studies

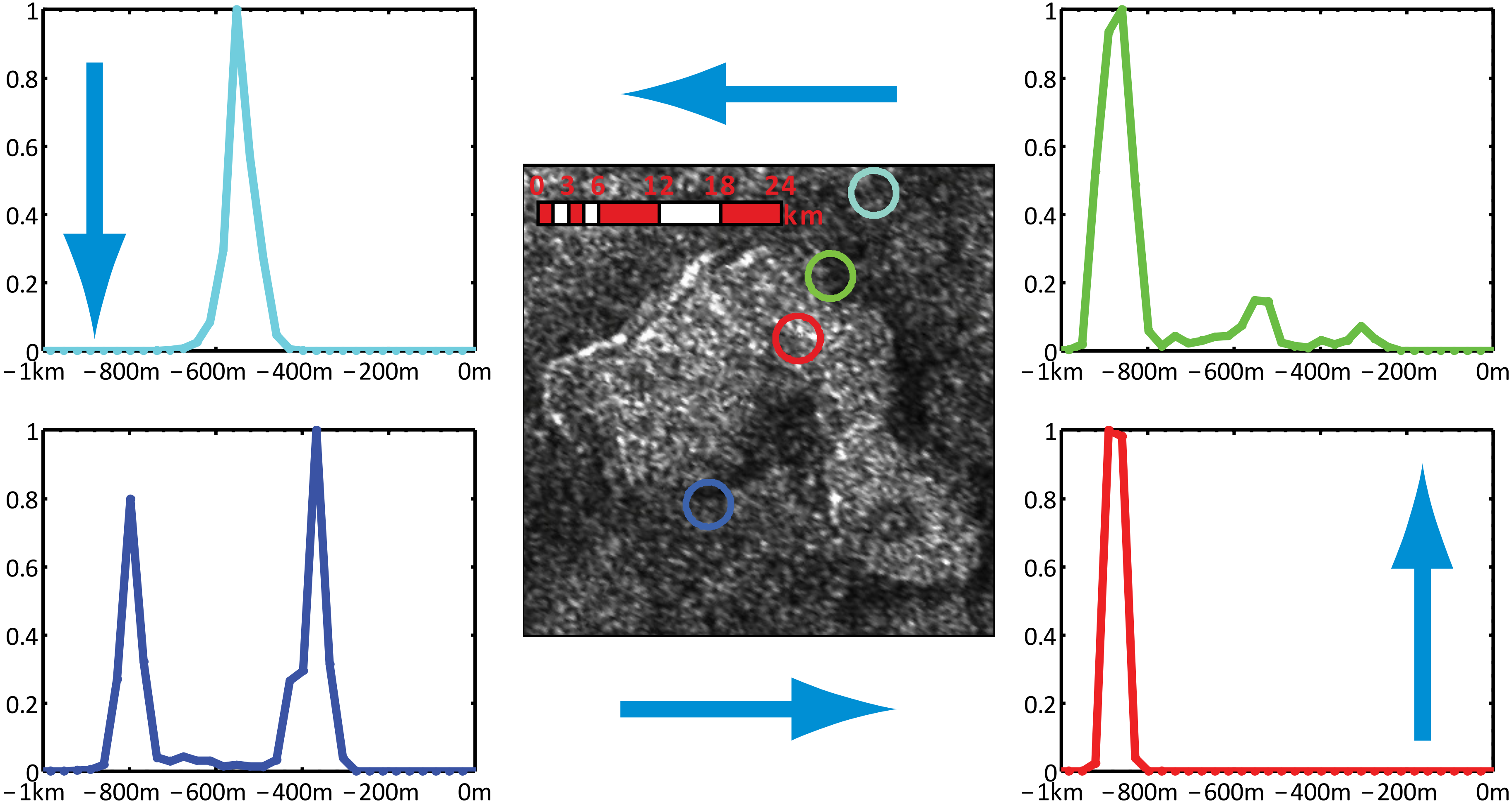


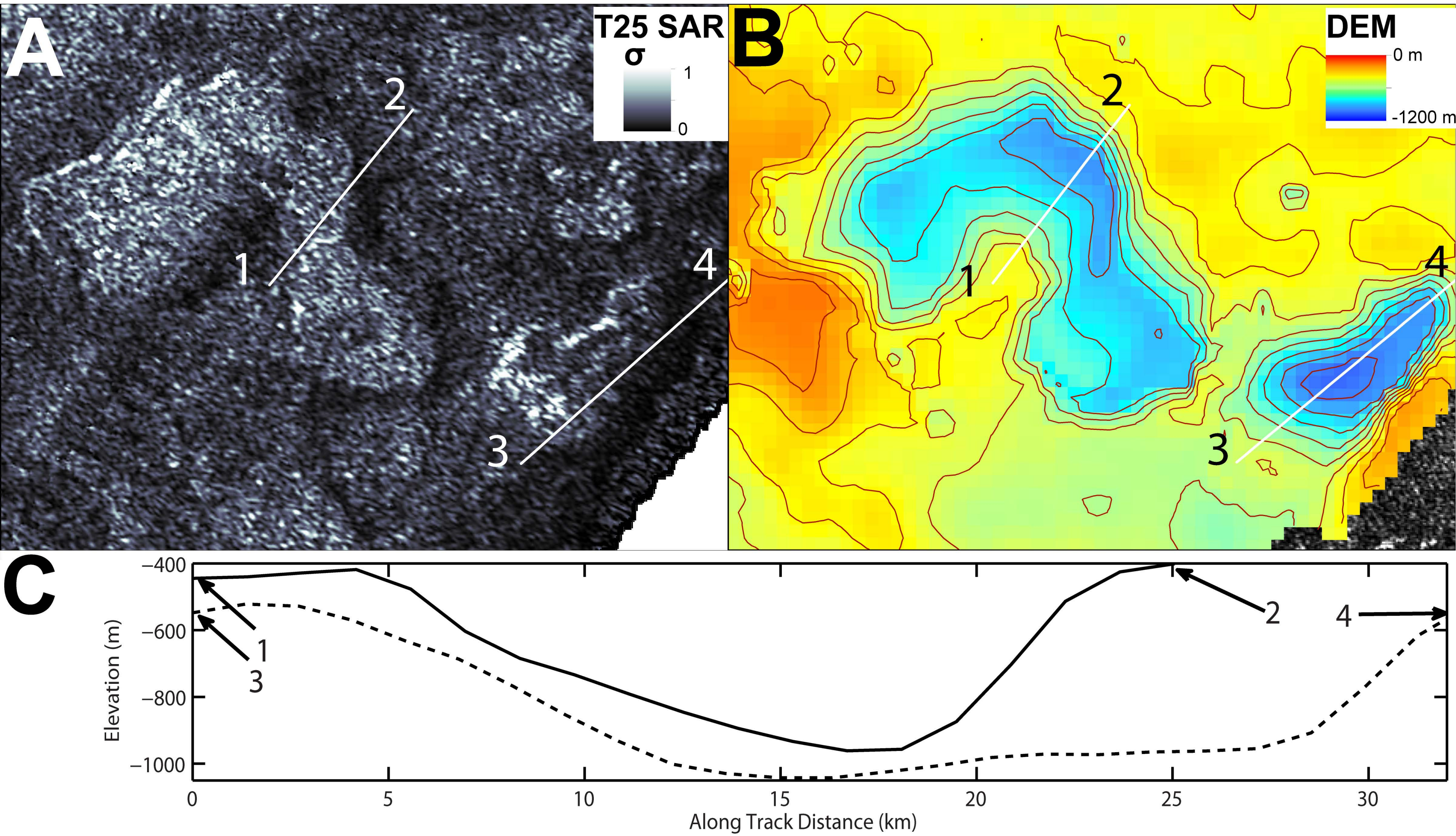
Symbol	Parameter
R	Radius (1-300 km)
H	Height (10-100 m)
b	Depth to Aquifer (1-10 m)
S	Local Slope (0.001-0.01)
E	Evaporation Rate (0.3 – 3 m/yr)

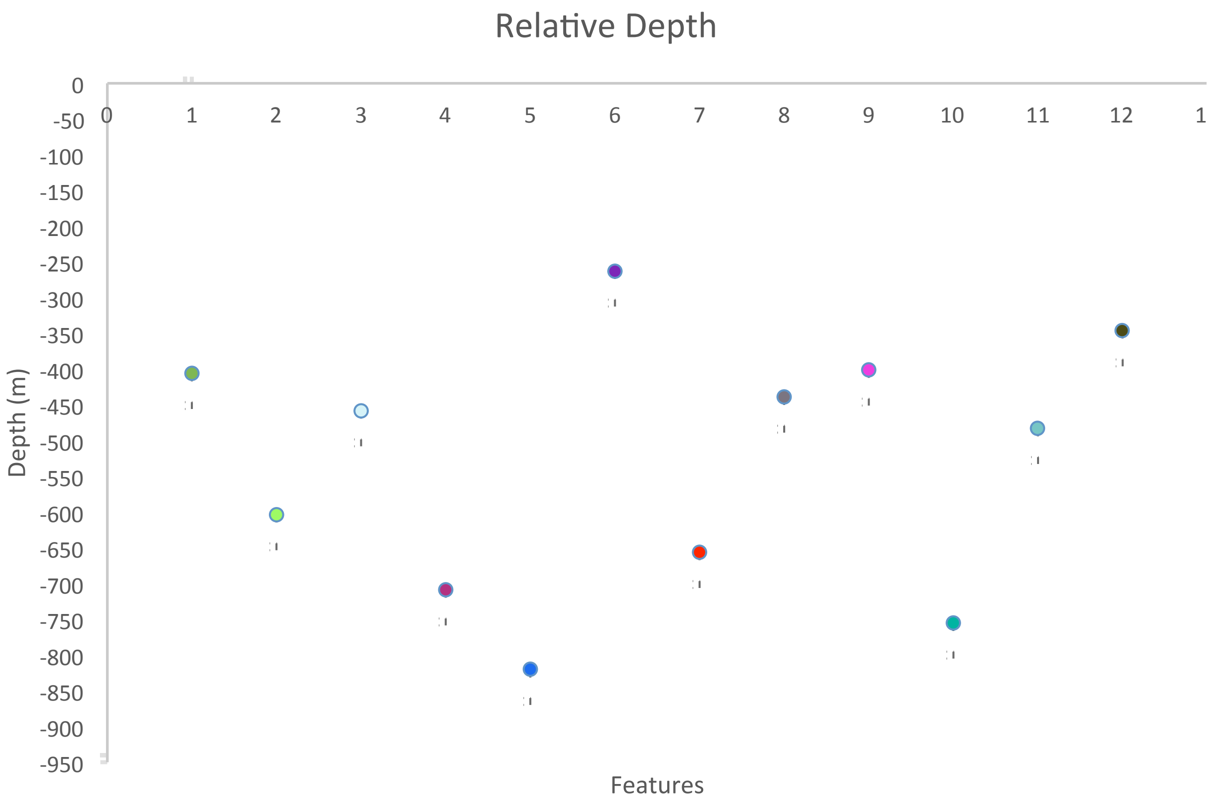
Hayes et al., *GRL* 2008


100 km
May 2012 (T83)
Sep. 2006 (T18)
May 2012 (T83)
Oct. 2006 (T19)
May 2012 (T83)
25 km
25 km
25 km
25 km

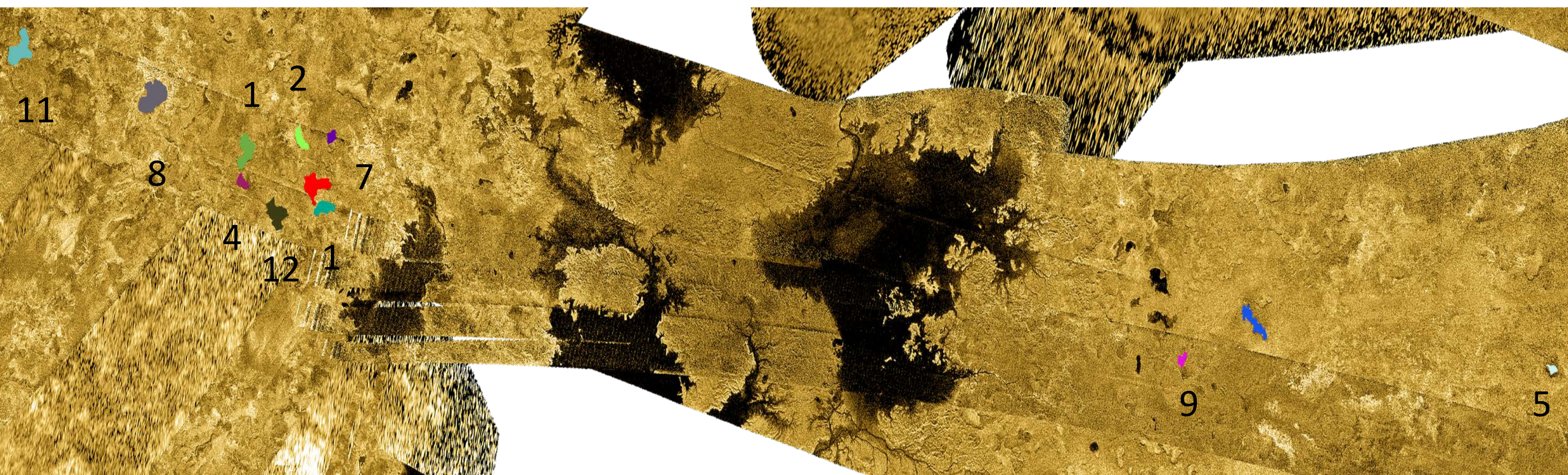
Titan's Paleolake Basins

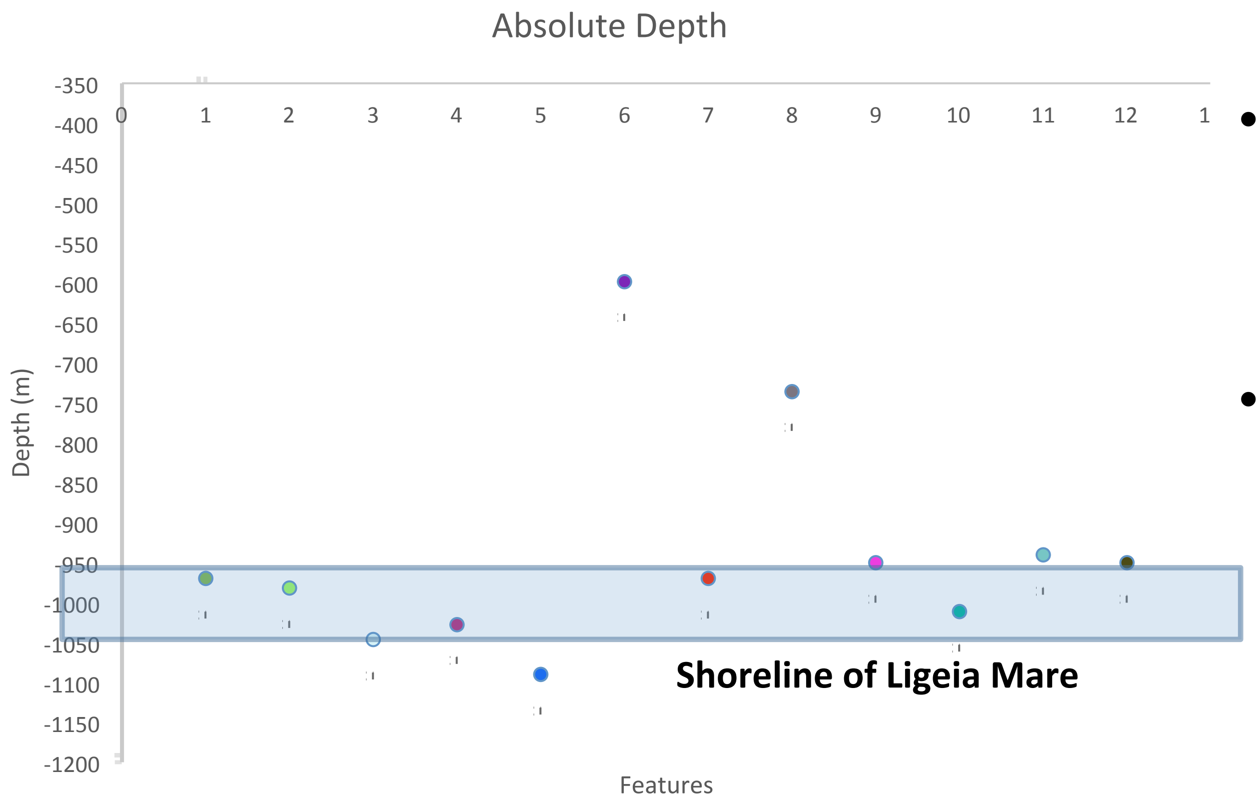



A
T25 SAR
σ
1
0
1
2
3
4
B
DEM
0 m
-1200 m
1
2
3
4
C
Elevation (m)
−400
−600
−800
−1000
0
5
10
15
20
25
30
Along Track Distance (km)
1
3
2
4

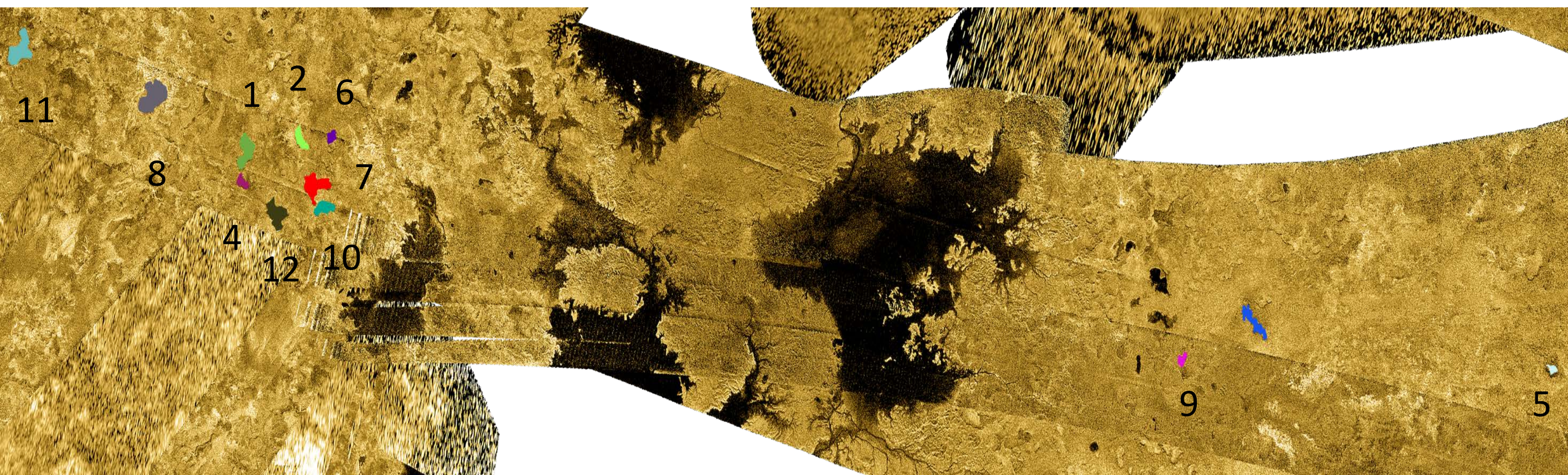


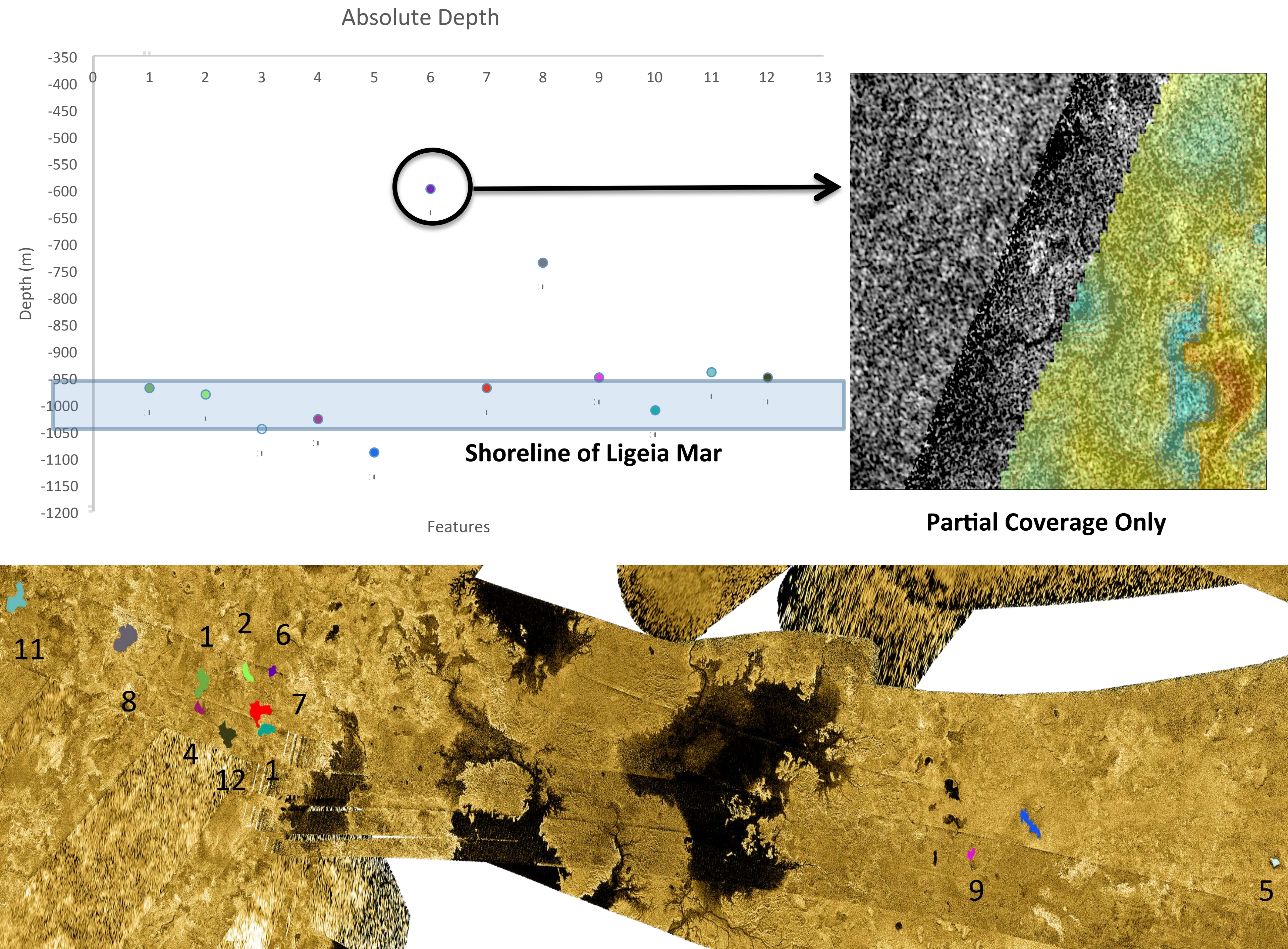
- Twelve empty lake features overla current DTM coverage
- Basin depths rang from 250 m to 820 m.



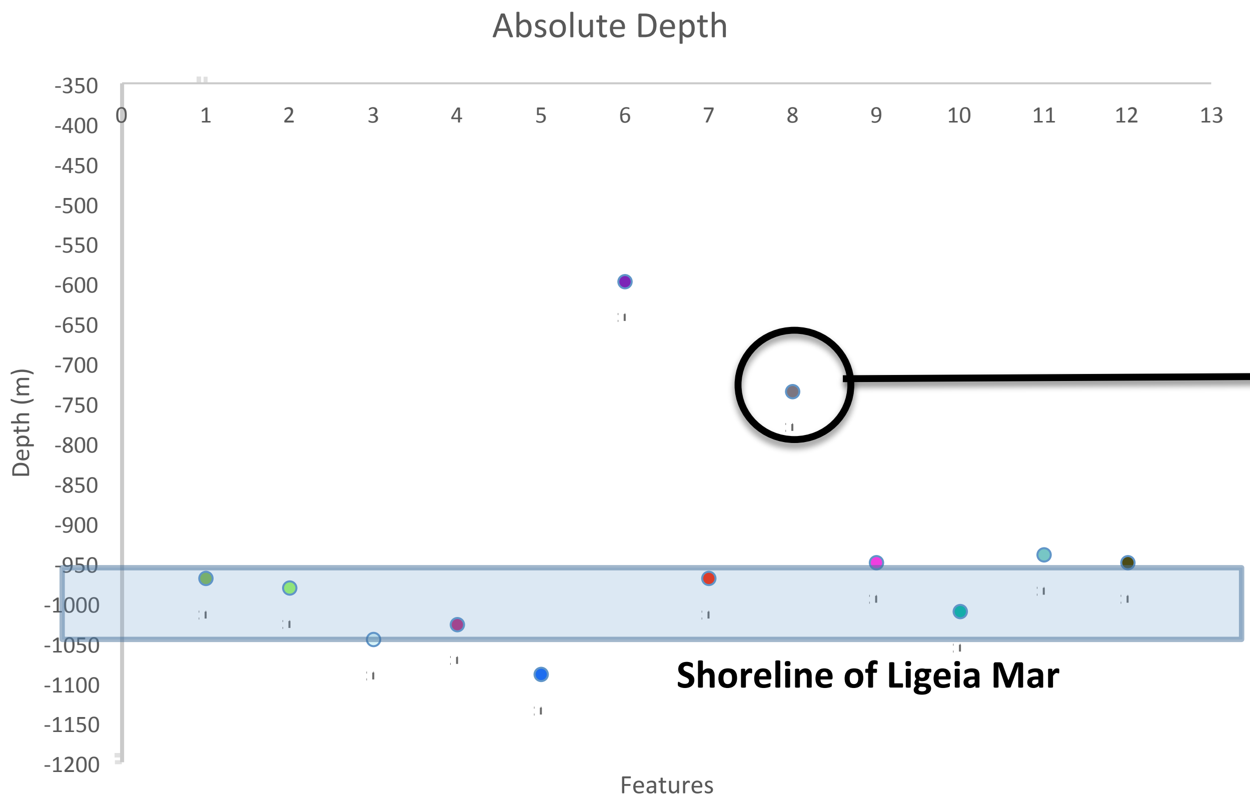


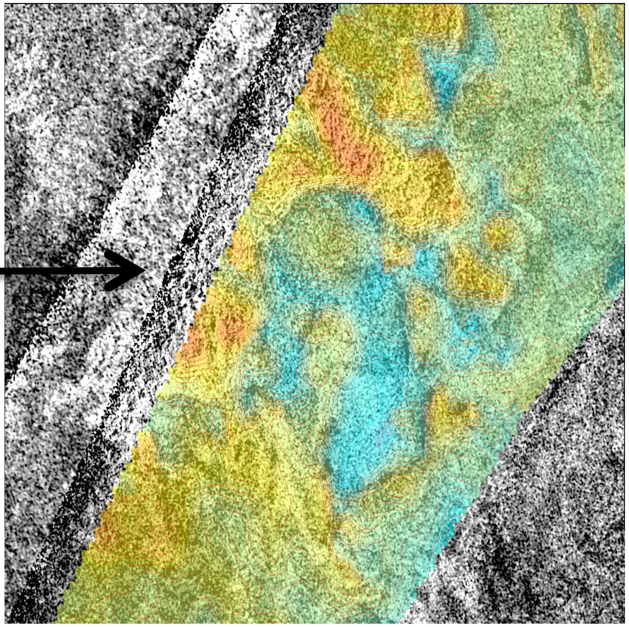
- Twelve empty lake features overlap current DTM coverage
- Absolute depths are clustered around the elevation of Ligeia Mare' shoreline.



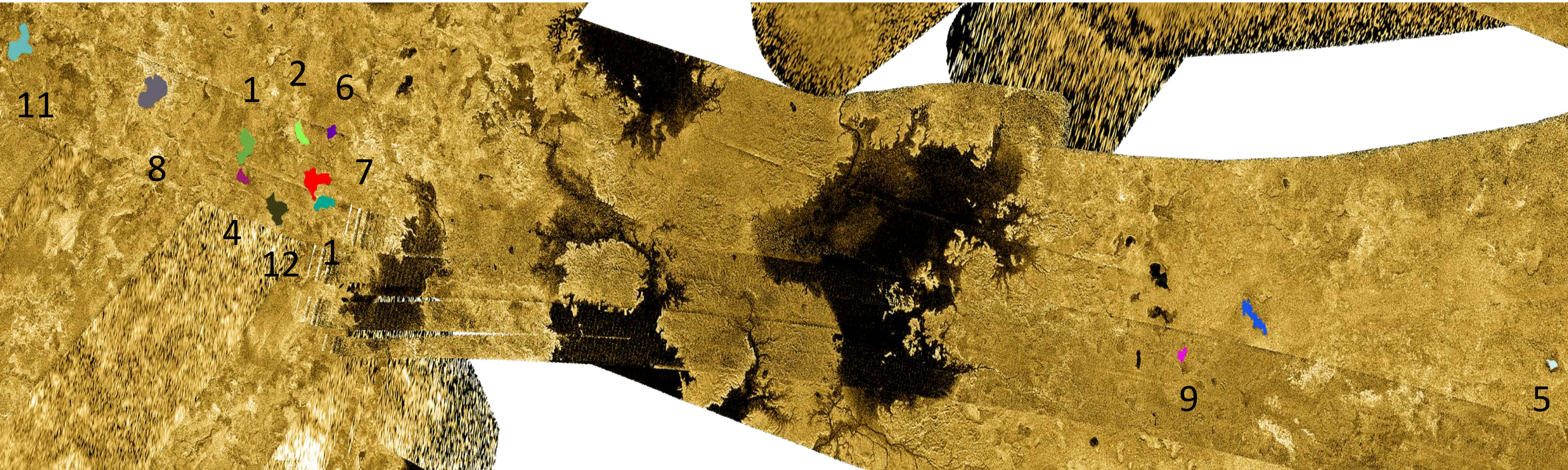


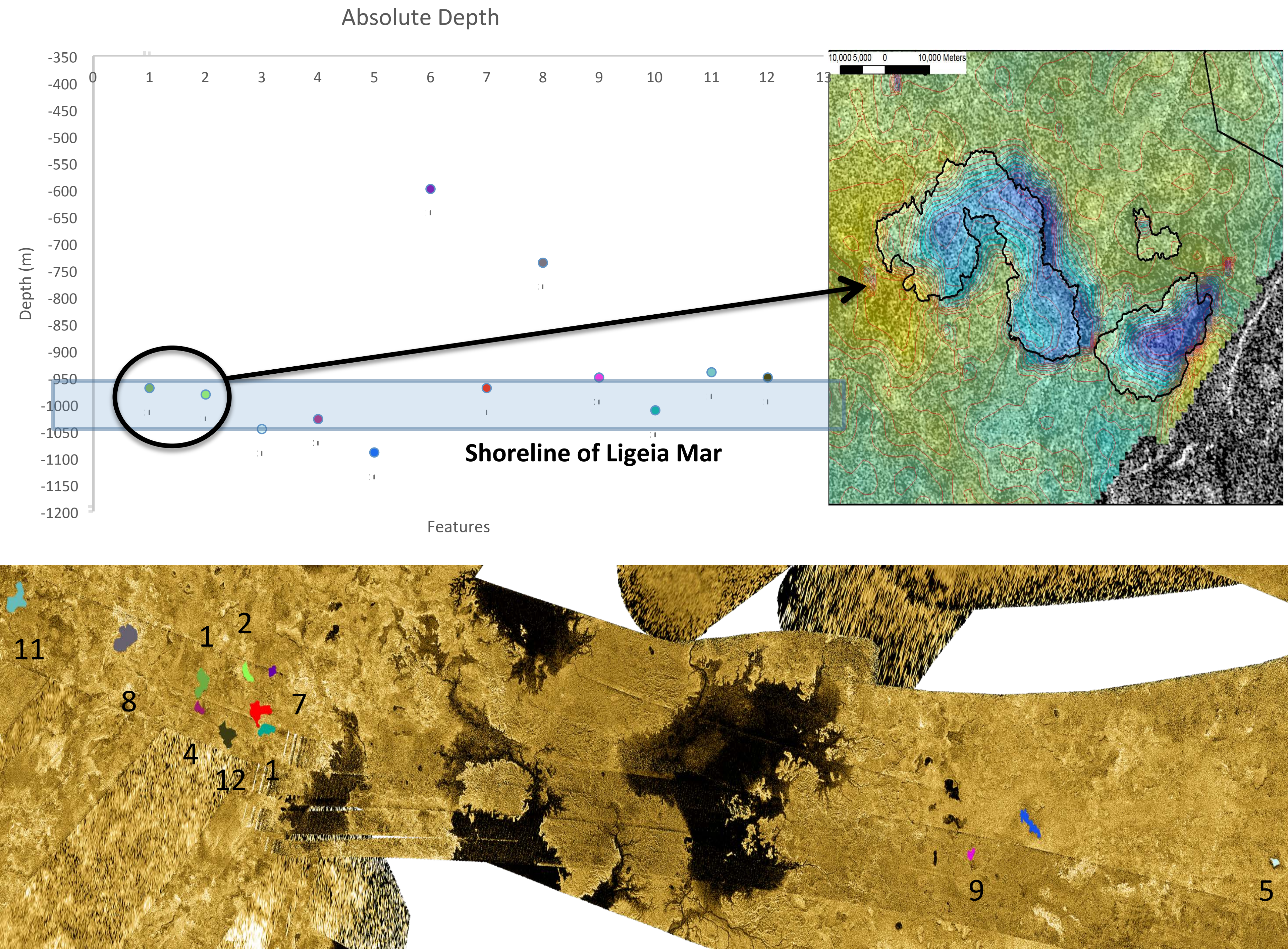
Absolute Depth
Depth (m)
-350
-400
-450
-500
-550
-600
-650
-700
-750
-800
-850
-900
-950
-1000
-1050
-1100
-1150
-1200
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Features
Shoreline of Ligeia Mar
Partial Coverage Only
11
1
2
6
8
7
4
12
1
9
5

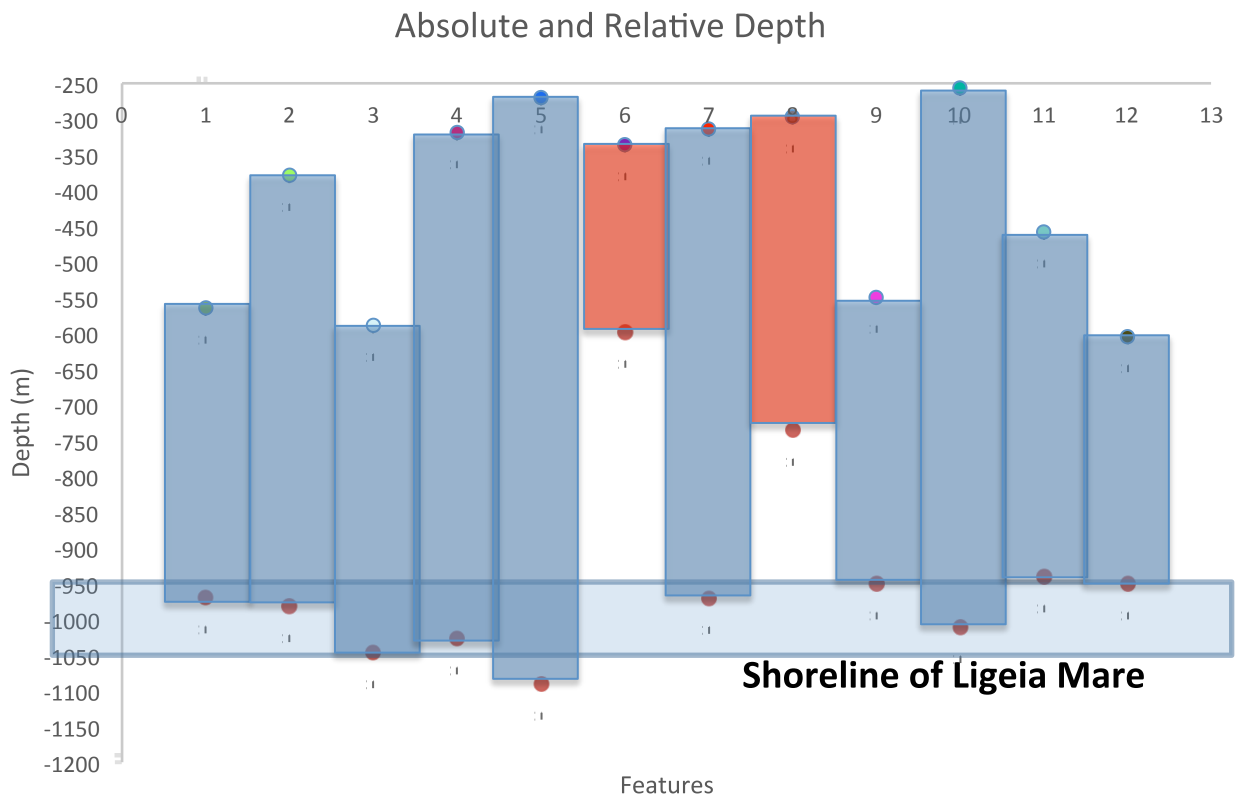


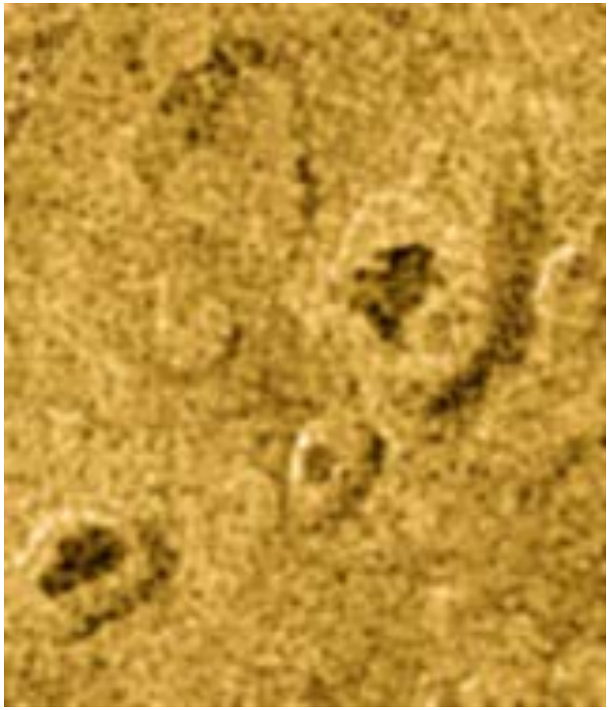


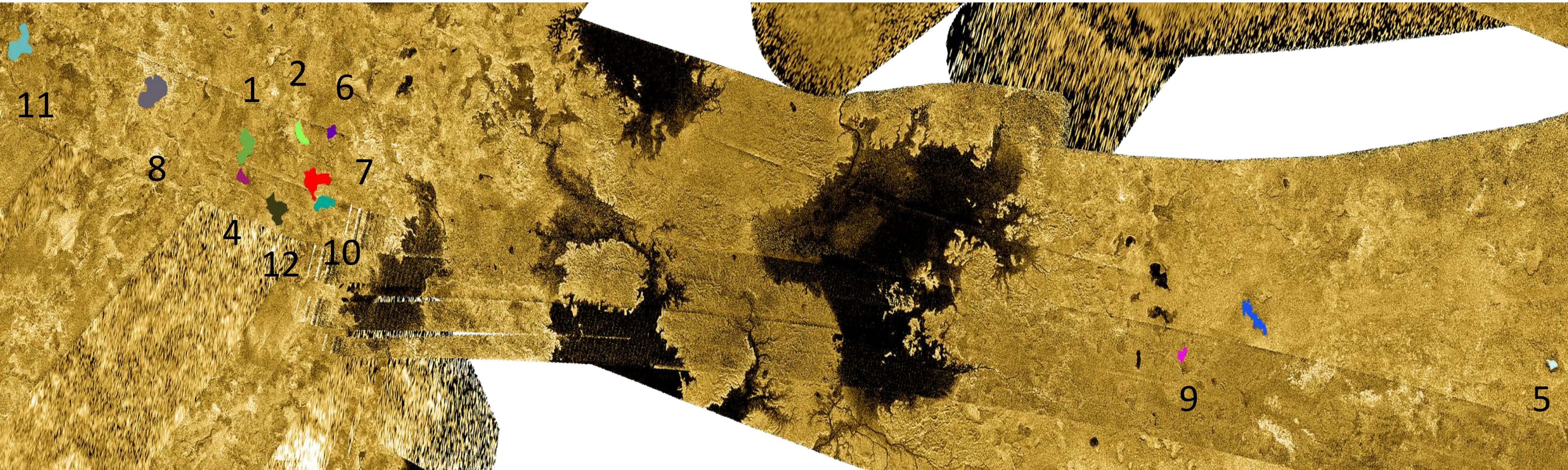
Complex Terrain, Inset in Mountainous Region




Absolute Depth
Depth (m)
Features
-350
-400
-450
-500
-550
-600
-650
-700
-750
-800
-850
-900
-950
-1000
-1050
-1100
-1150
-1200
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Shoreline of Ligeia Mar
10,000 5,000 0 10,000 Meters
11
1
2
8
7
4
12
1
9
5


Absolute and Relative Depth
Depth (m)
-250
-300
-350
-400
-450
-500
-550
-600
-650
-700
-750
-800
-850
-900
-950
-1000
-1050
-1100
-1150
-1200
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Features
Shoreline of Ligeia Mare



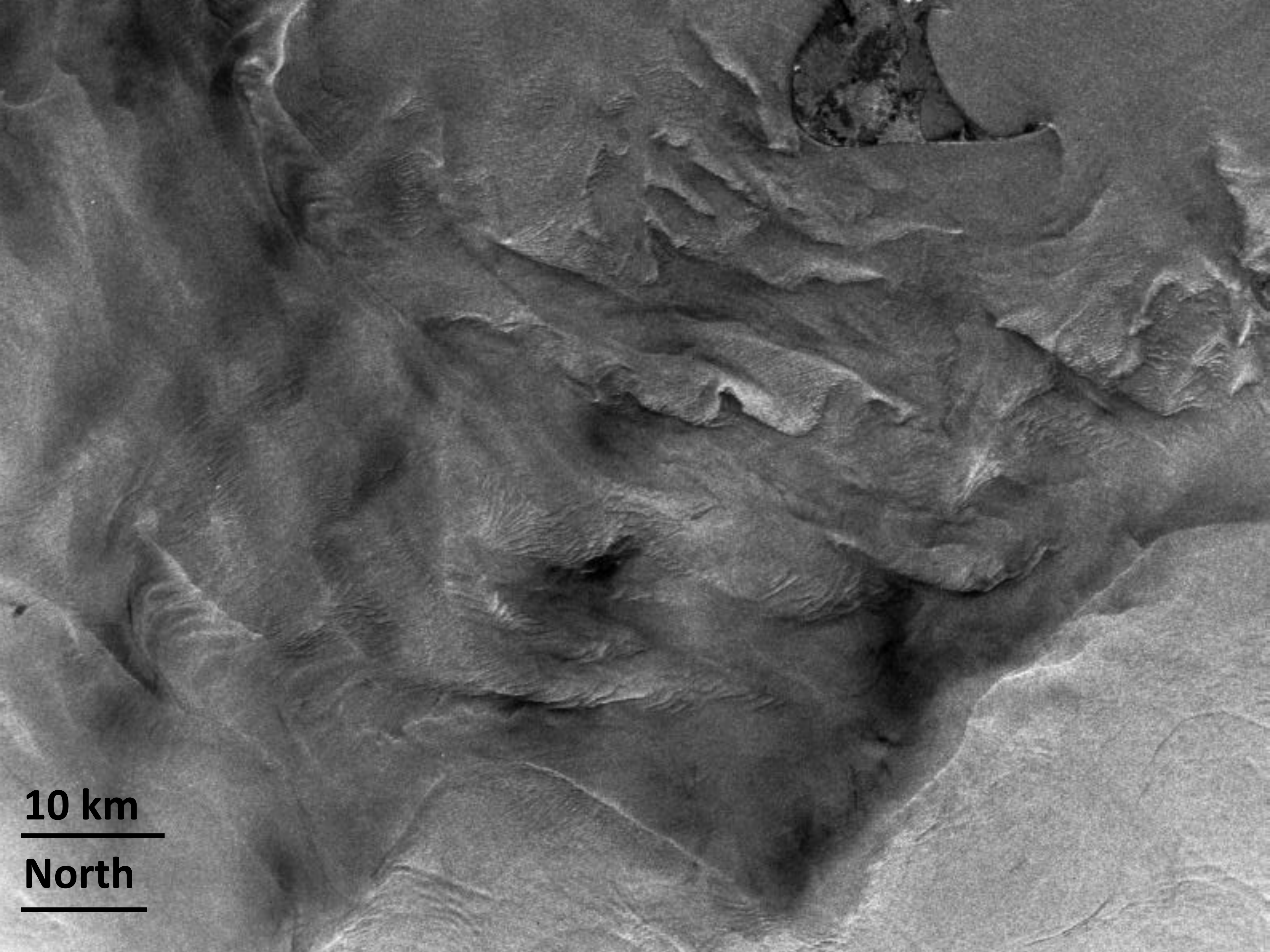

11
1
2
6
8
7
4
12
10
9
5

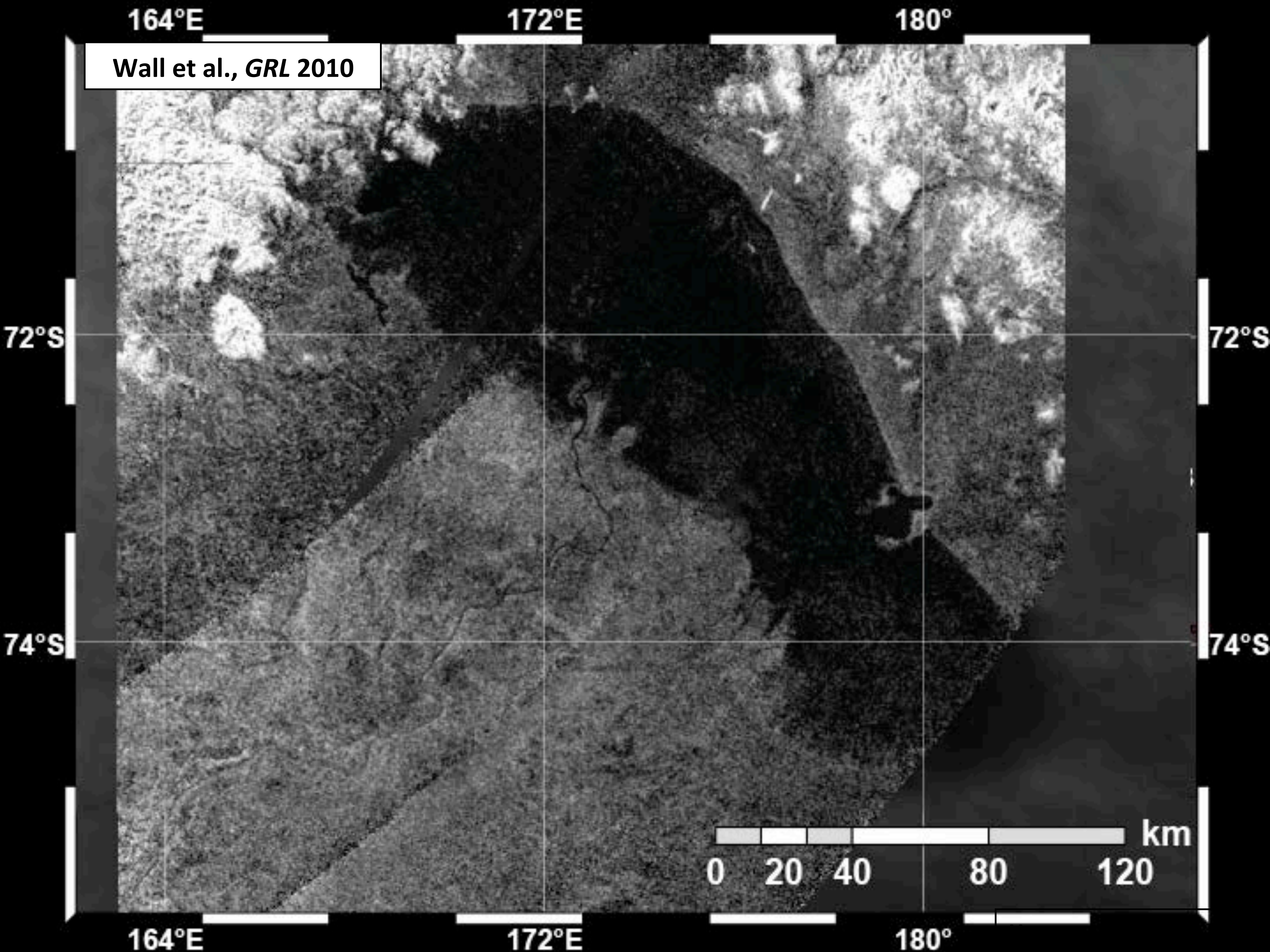
- **Drowned topography reveals both a dynamic and passive evolutionary history.**
  - Rising base level is currently outpacing sedimentation in the North
  - At times, fluid level persists long enough to leave behind topographic legacy

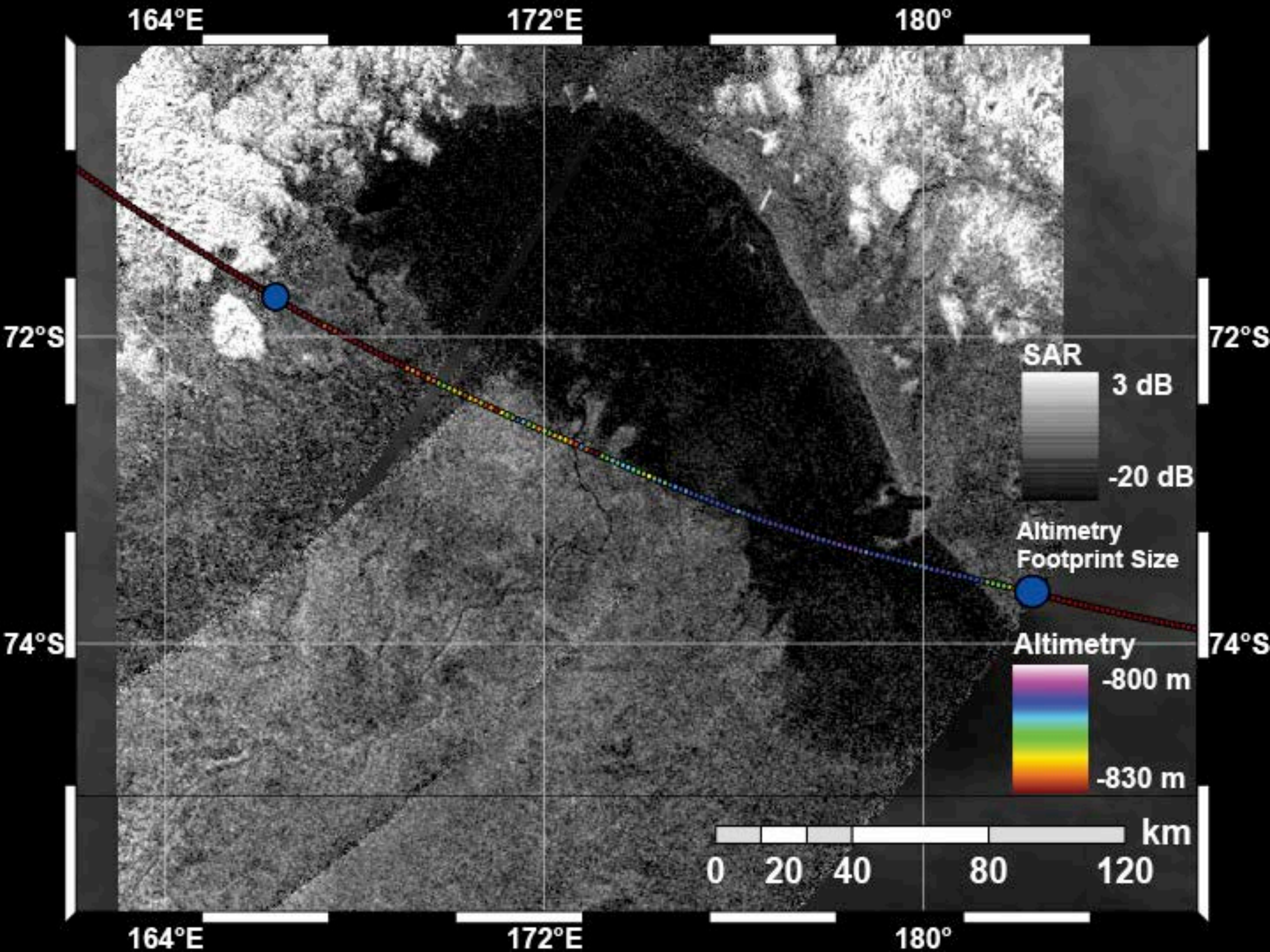
- **Multi-layered plateaus suggest episodic erosional processes**
  - Landscape history of flat surface building followed by dissection

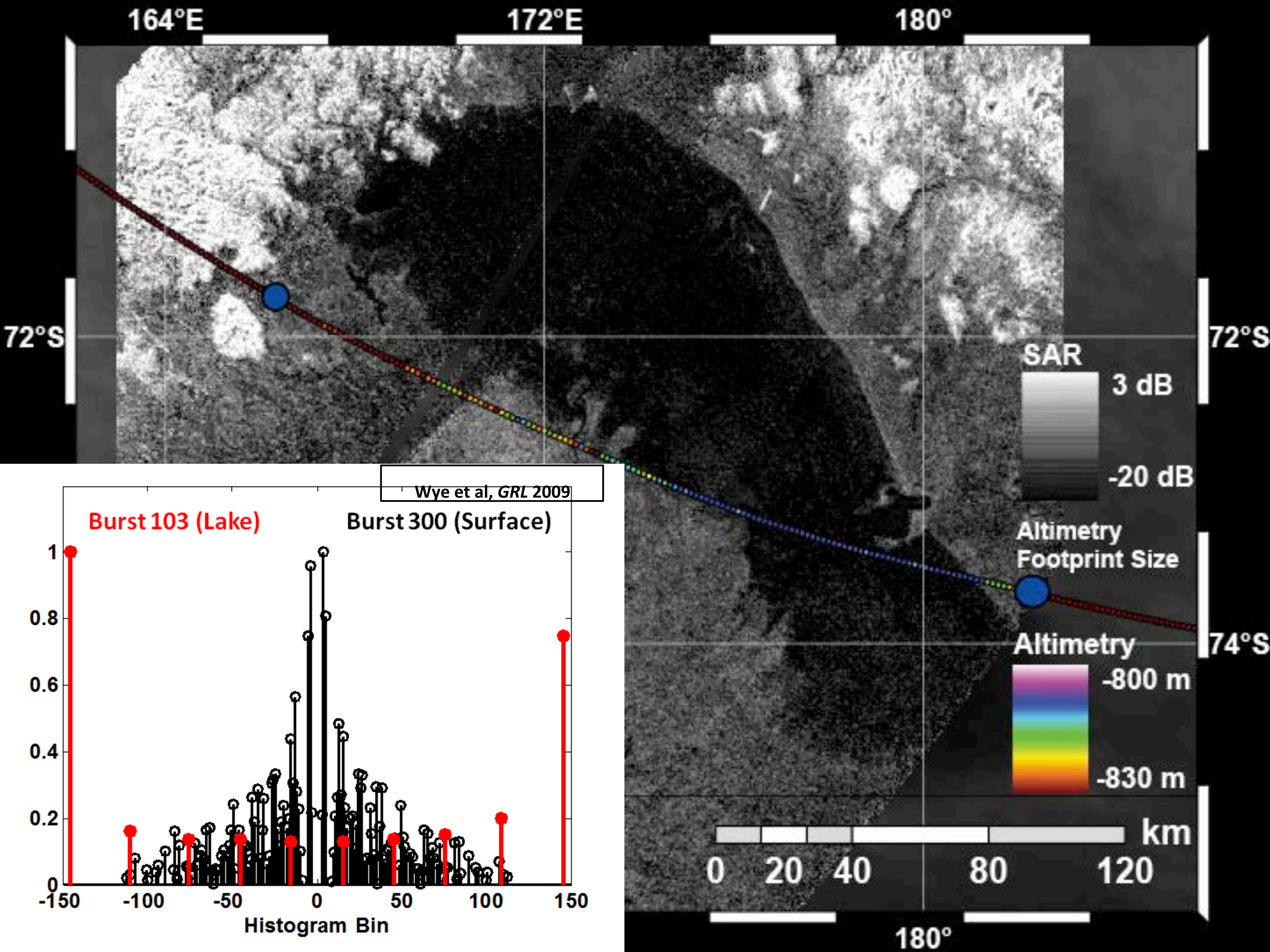
- **Conical depressions are not consistent with fluvial erosion**
  - Most consistent with kartic dissolution
    (must explain shallow slopes and mass transport issues).

- **Bright lake morphometrics constrain formation mechanism**
  - Relative depths range from 250 m – 850 m
  - Absolute elevations are comparable to seas shorelines
  - Compositionally distinct from surrounding terrain


10 km
North


Wall et al., *GRL* 2010
164°E
172°E
180°
72°S
74°S
km
0
20
40
80
120

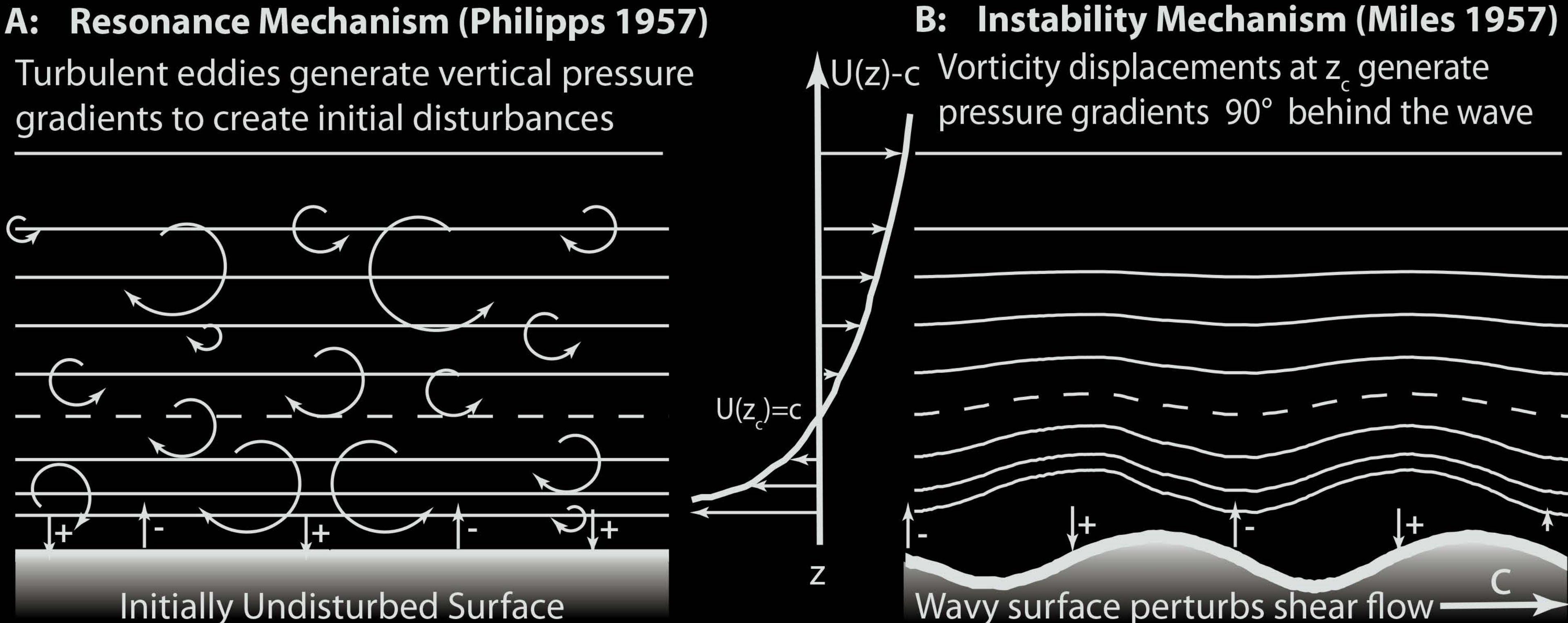

164°E
172°E
180°
72°S
74°S
SAR
3 dB
-20 dB
Altimetry
Footprint Size
Altimetry
-800 m
-830 m
km
0
20
40
80
120


164°E
172°E
180°
72°S
72°S
74°S
SAR
3 dB
-20 dB
Altimetry
Footprint Size
Altimetry
-800 m
-830 m
km
0
20
40
80
120
180°
Wye et al, GRL 2009
Burst 103 (Lake)
Burst 300 (Surface)
1
0.8
0.6
0.4
0.2
0
-150
-100
-50
0
50
100
150
Histogram Bin

- How do you **generate** waves?
- Do we expect to **observe** waves?
- Can we **detect** waves?

"Wind blowing over a water surface generate waves in the water by a physical process that can not be regarde as known"

F. Ursell, 1956



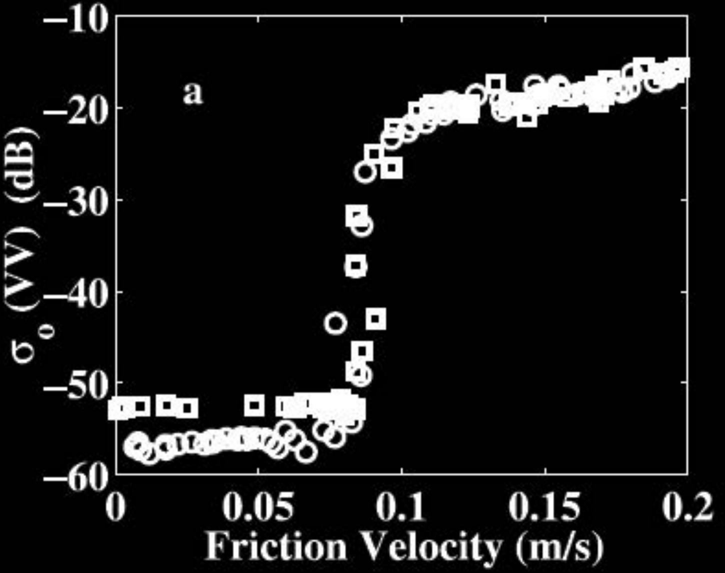
Growth Rate:

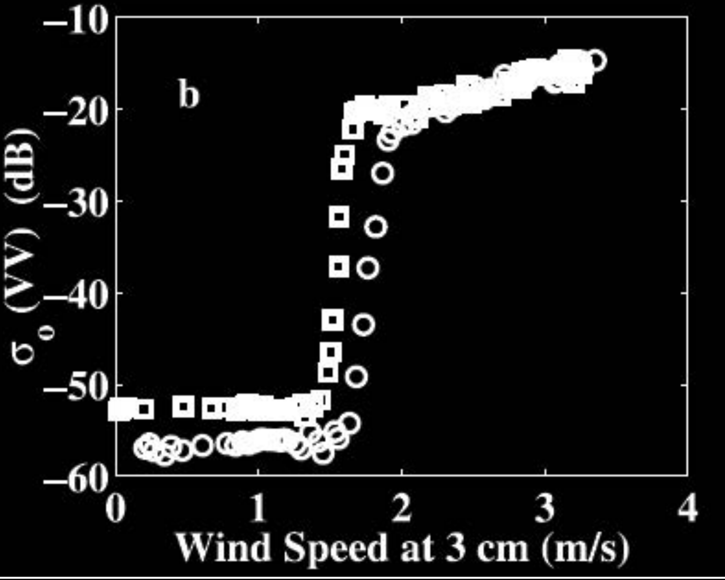
$$(\beta_g/\omega)_{Donelan} = 0.194\frac{\rho_a}{\rho_f}\left[(U_{\lambda/2}/c)\cos(\chi - \bar{\chi}) - 1\right]^2$$

$$\beta_{\nu_l}/\omega = 4\nu_l k/c$$ **(Viscous Dissipation)**

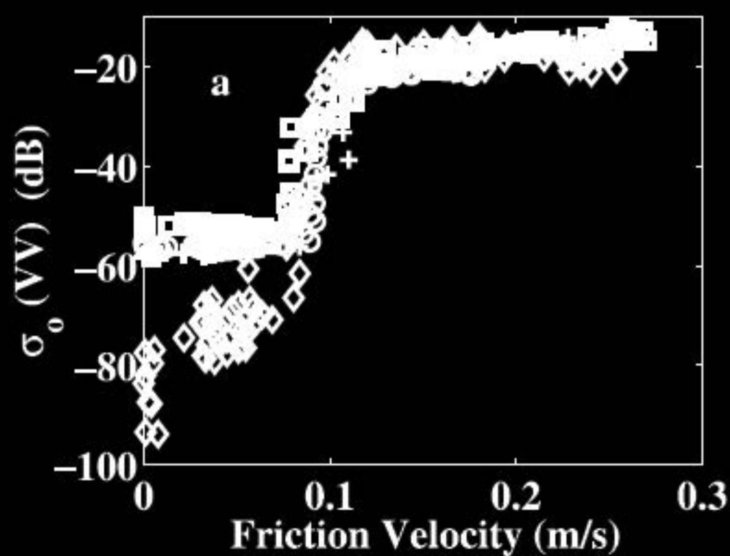
$$c^2 \approx \gamma k/\rho_f + g/k$$ **(Dispersion Relation)**

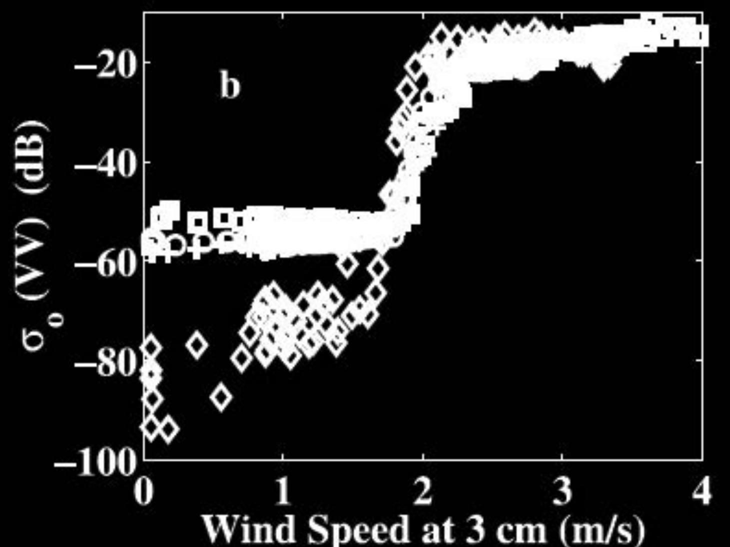
A Threshold for Wind-Wave Growth (Donelan and Plant, JGR 2009)



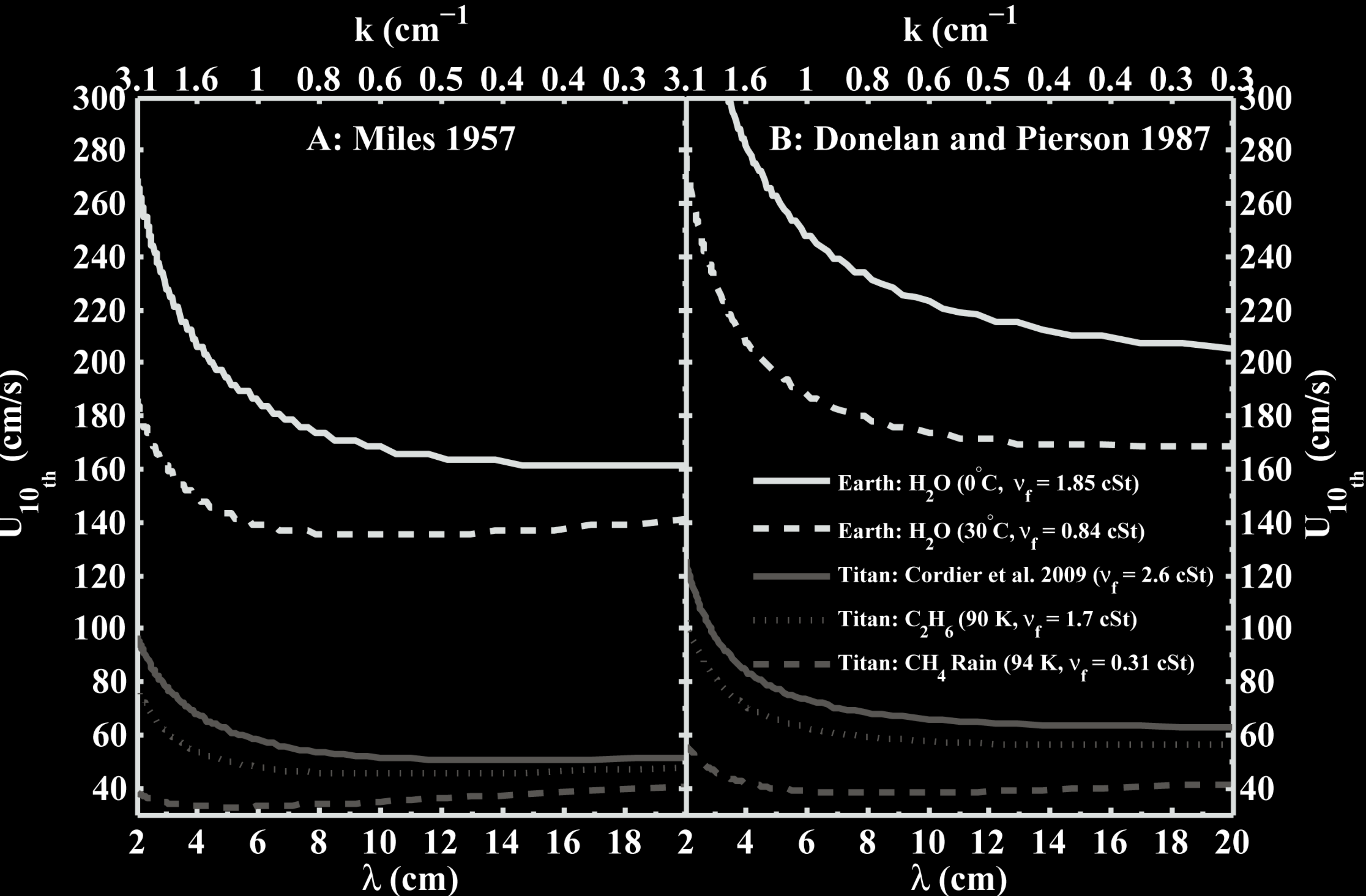


Changing Water Temperature (Viscosity)

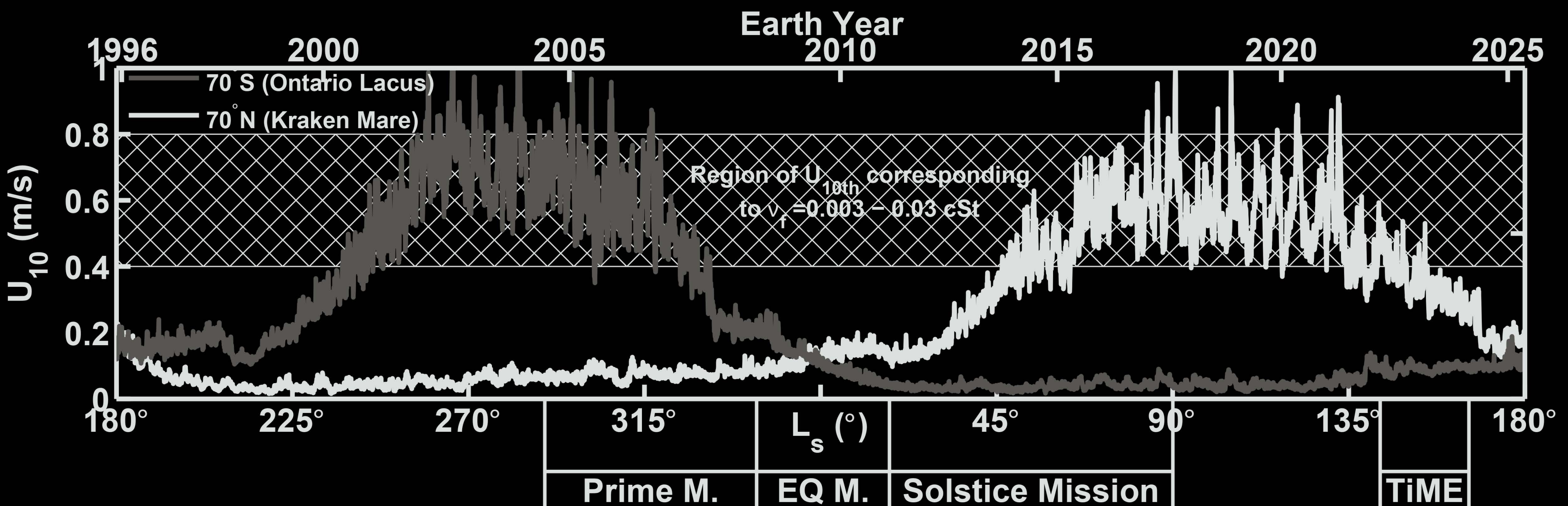




generate observe detect



generate observe detect



Growth Rate:

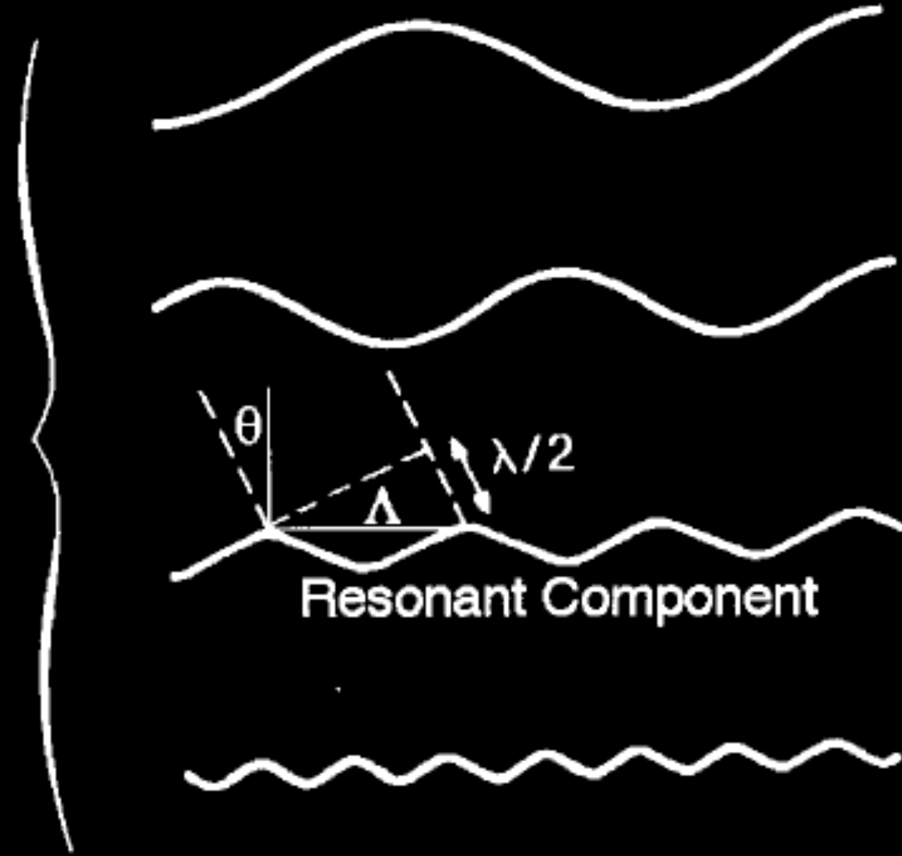
$$(\beta_g/\omega)_{Donelan} = 0.194\frac{\rho_a}{\rho_f}\left[(U_{\lambda/2}/c)\cos(\chi - \bar{\chi}) - 1\right]^2$$

$$\beta_{\nu_l}/\omega = 4\nu_l k/c$$ **(Viscous Dissipation)**

$$c^2 \approx \gamma k/\rho_f + g/k$$ **(Dispersion Relation)**

generate	**observe**	**detect**

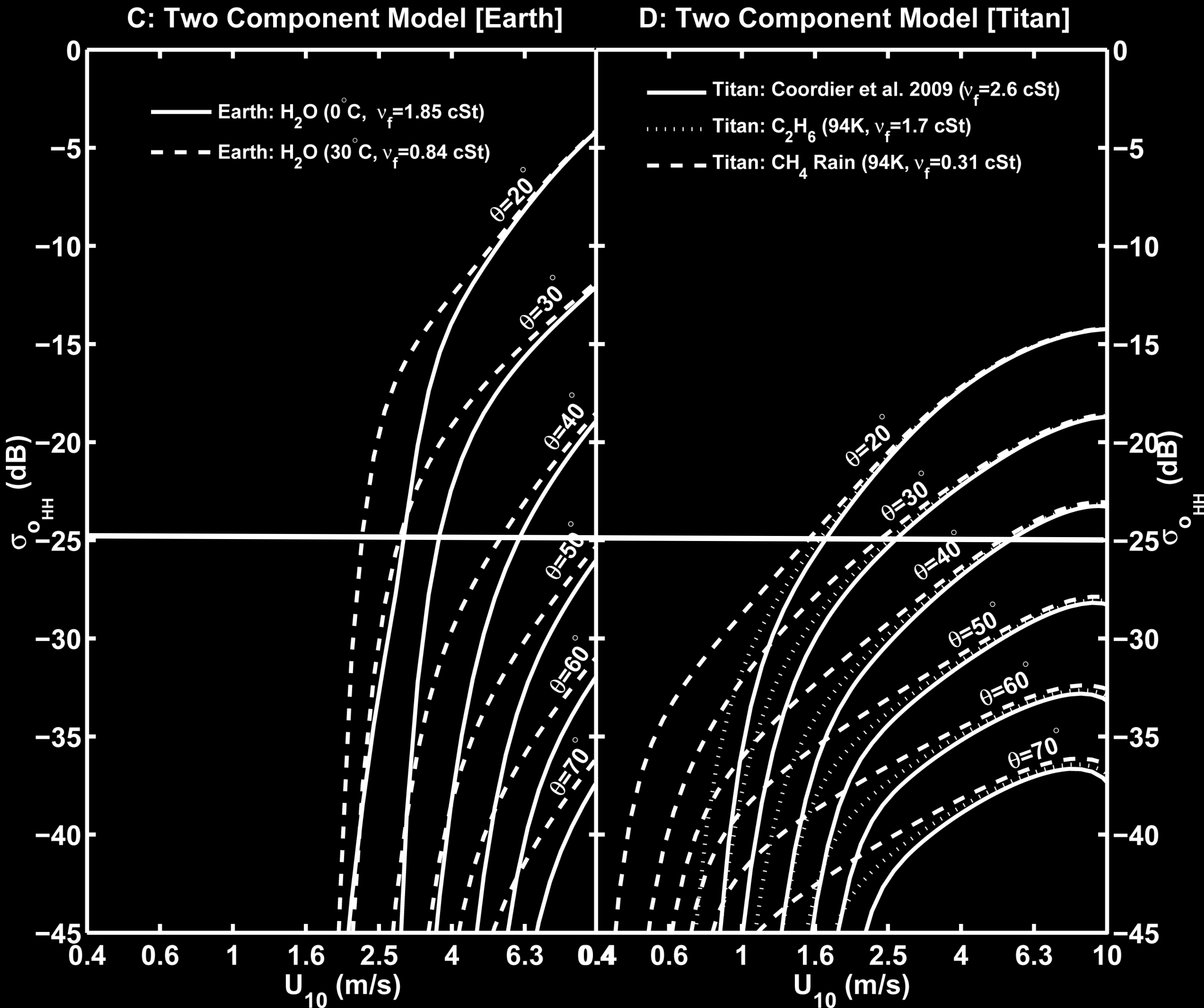
Bragg Backscatter:



$$k_{bragg} = \left(2k\sin(\theta)\right)$$

$$\lambda_{bragg} = \lambda / 2\sin(\theta)$$

Collyer, 1994

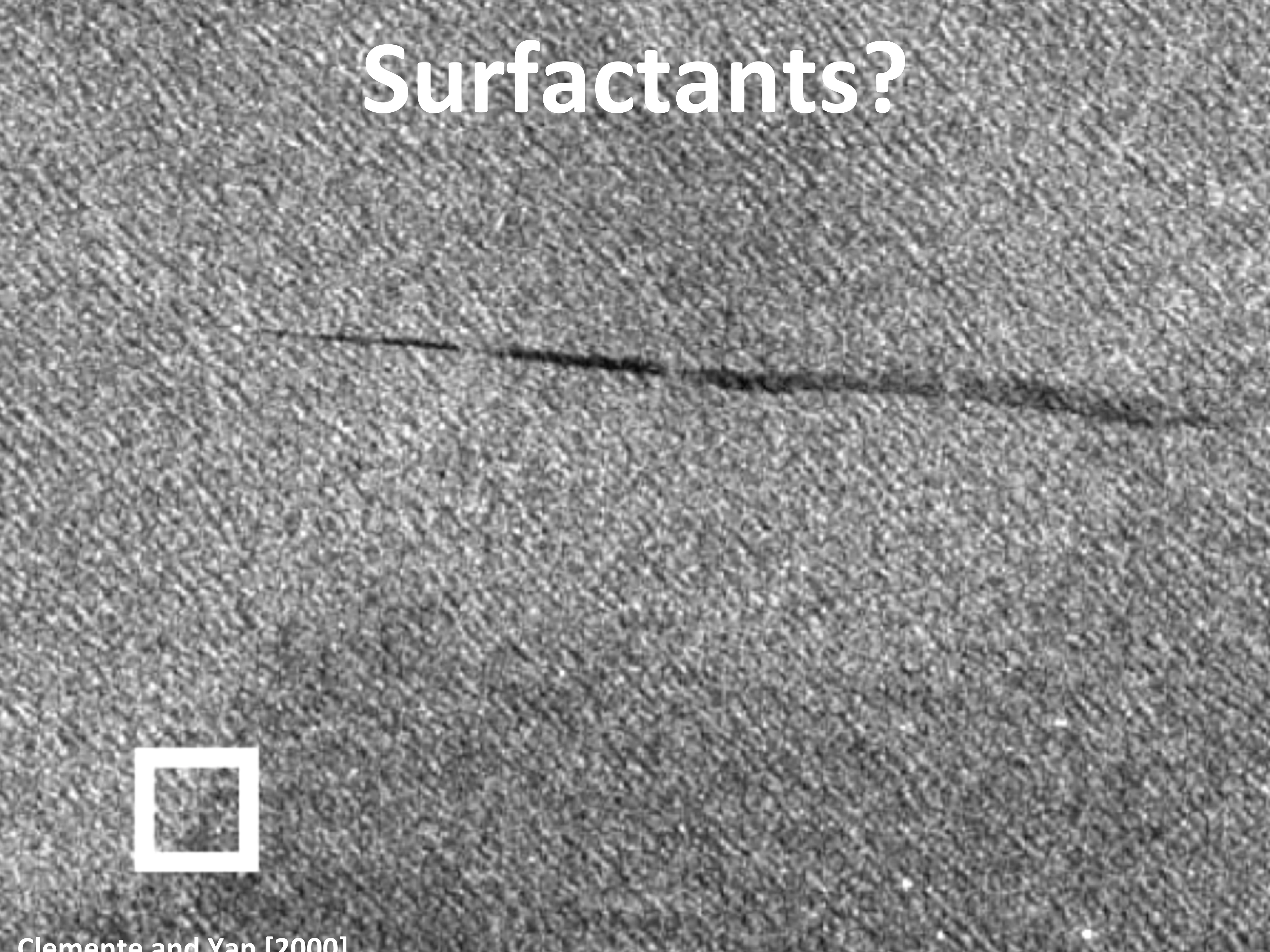


generate observe detect

Conclusions

- Threshold wind speeds (for scatterometry) on Titan are expected to be between 2.5-4 times lower than earth
  - Scatter is primary driven by viscosity
- Current GCM models suggest that wind speeds vary seasonally, and may exceed threshold during spring and summer
- Bragg backscatte on Hydrocarbon lakes is reduced by a lower dielectric constant, but enhanced by increased spectral power at the resonant Bragg wavelengths
  - Models predic returns near or below the SAR noise-equivalent backscatter (single pixel) for expected winds
- The presence (or absence) of waves during the Cassini Solstice mission may provide a constraint on allowable wind speed / liquid viscosity (composition) [surfactants?]

Surfactants?



Clemente and Yan [2000]

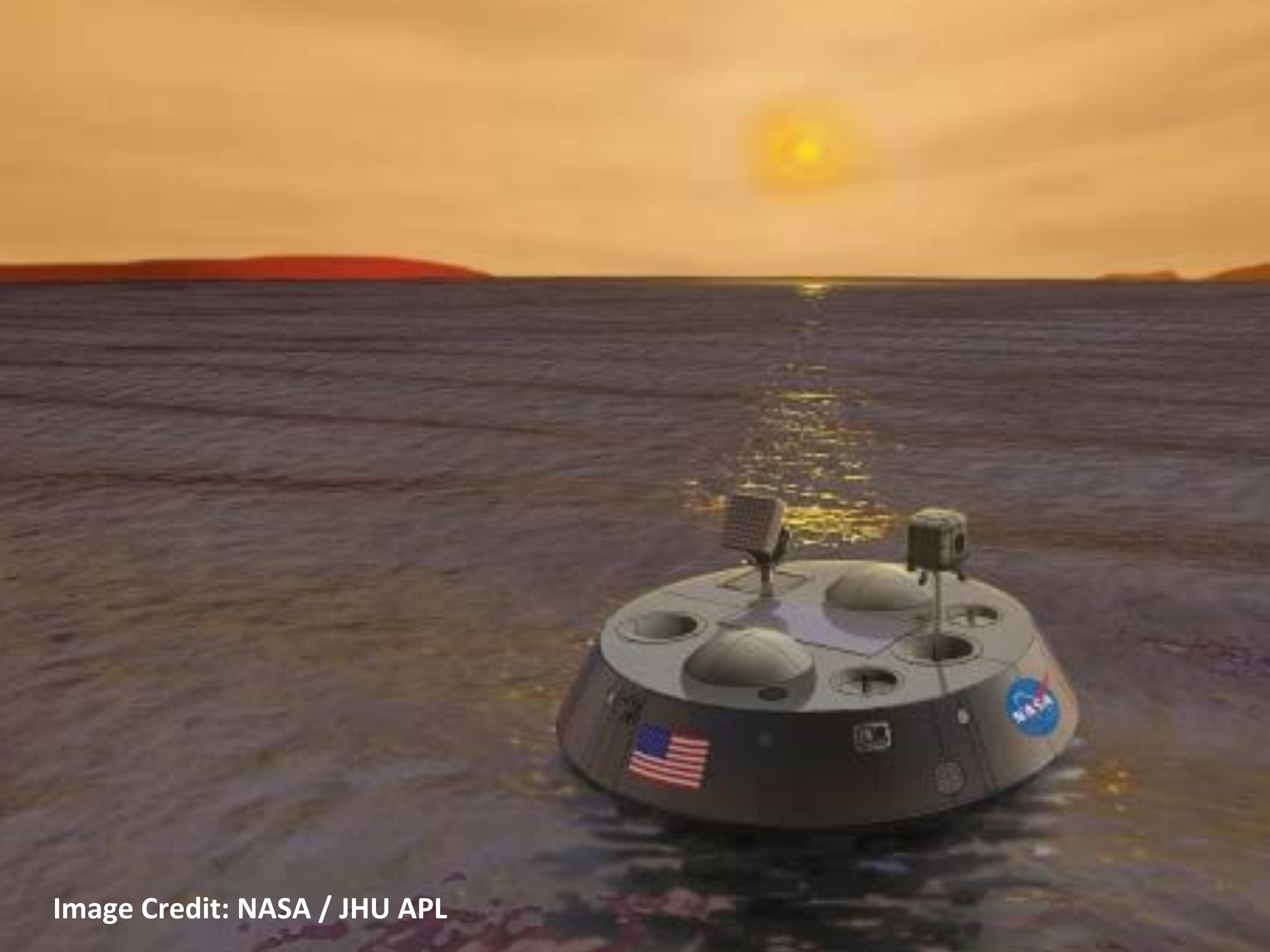
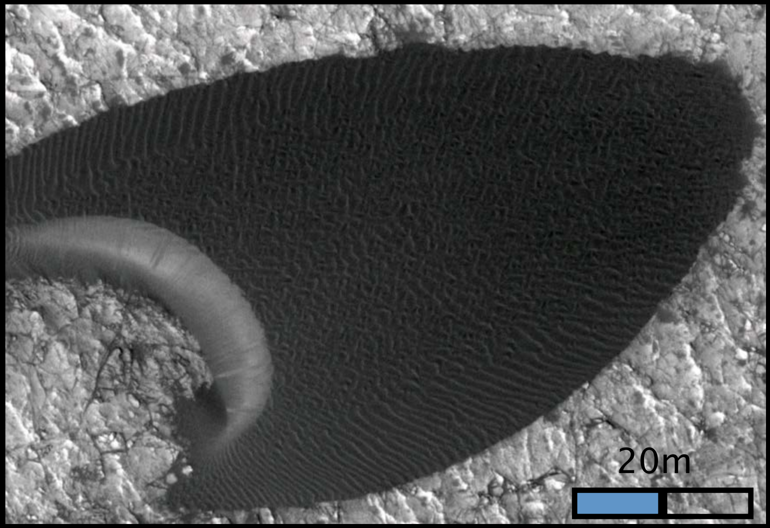


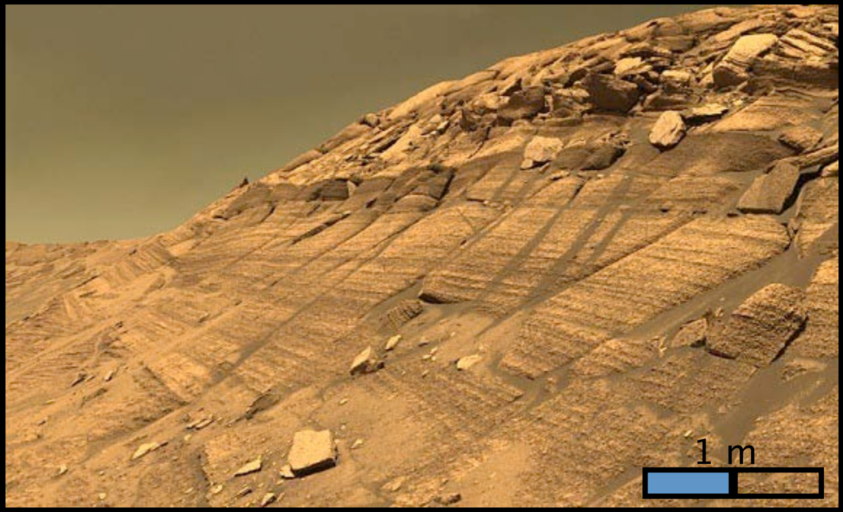
Image Credit: NASA / JHU APL

A Guide to Desert Vacationing for the Hydrophobic

Dune and ripples in Nili Patera, Mars

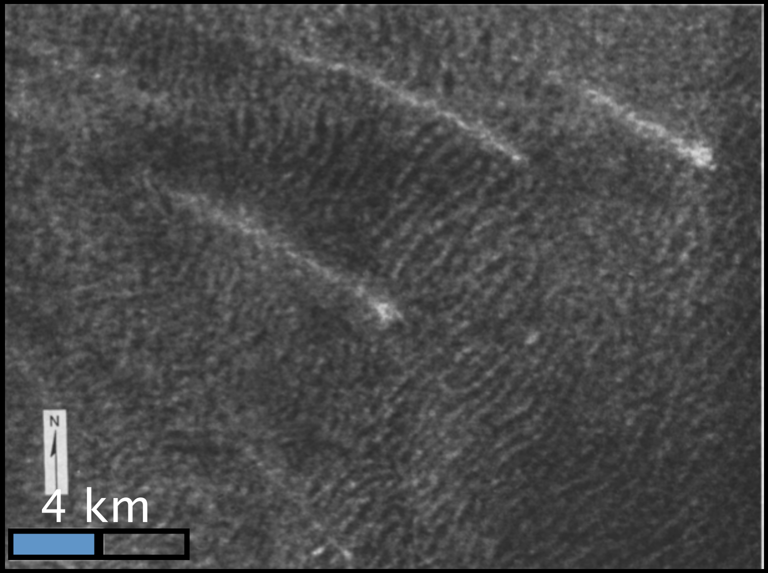


Burns Fm., Mars



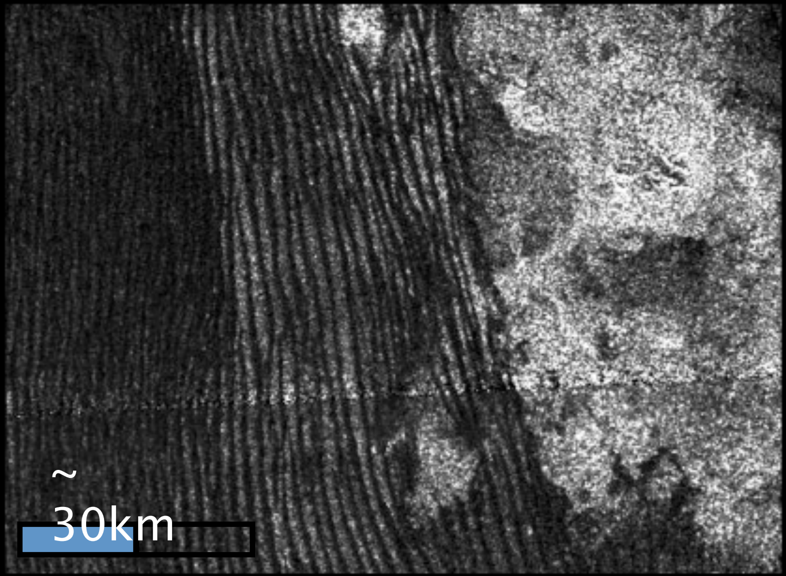
http://marsrover.nasa.gov/home/

Dunes on Venus

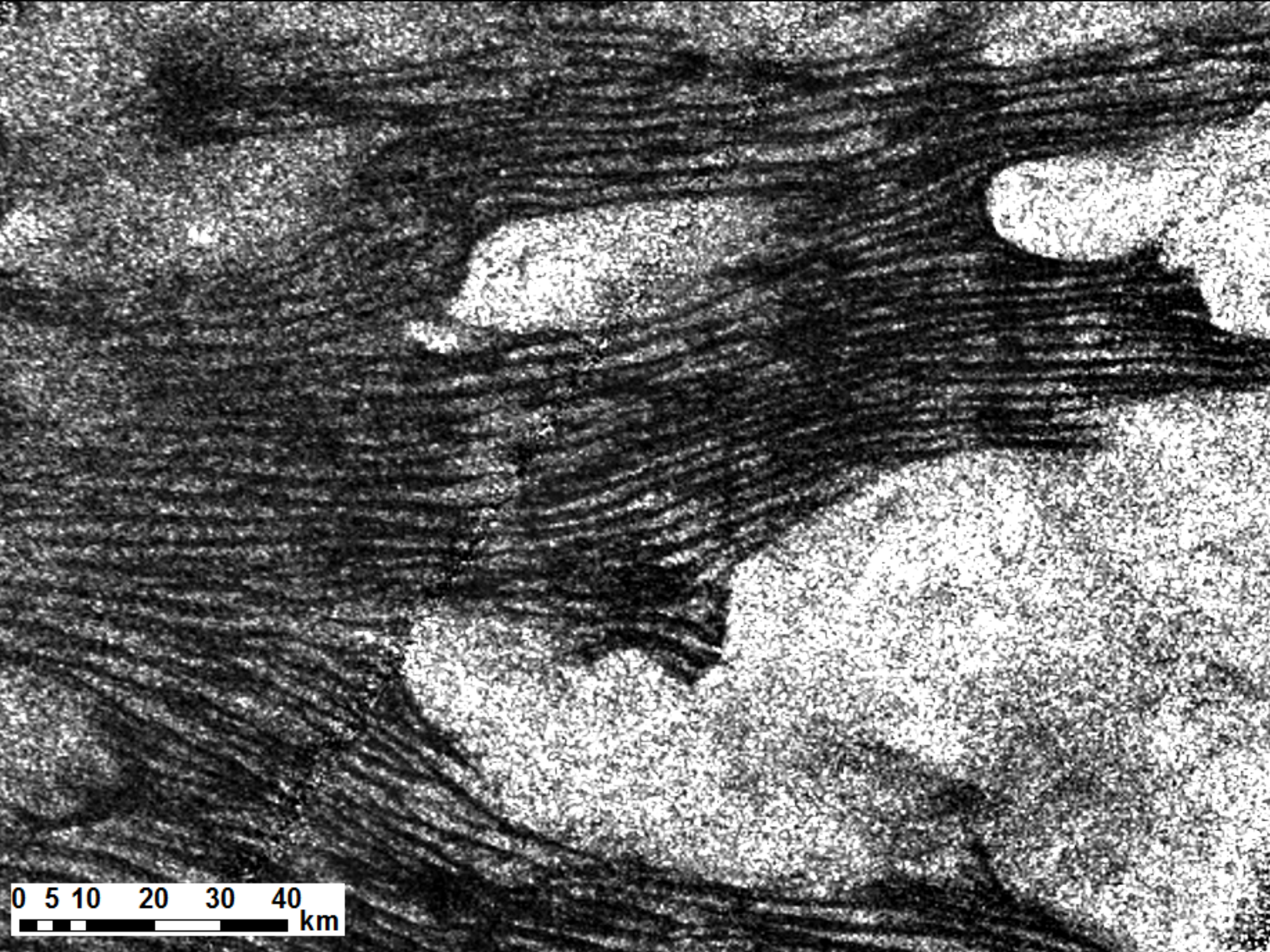


Greeley et al., 1992

Linear dunes on Titan

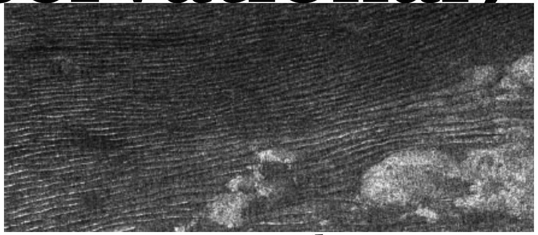


http://www.nasa.gov/mission_pages/cassini/


0 5 10 20 30 40
km

Previous Dune Studies (Observational)

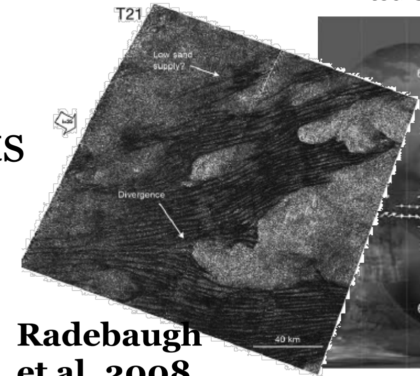
- **Morphology**
  (Lorenz 2006; Radebough 2008, 2010)
  - Evidence for both linear (longitdunal) and crescentic (barchan) forms
  - Different dune forms associated with variations in sediment availability



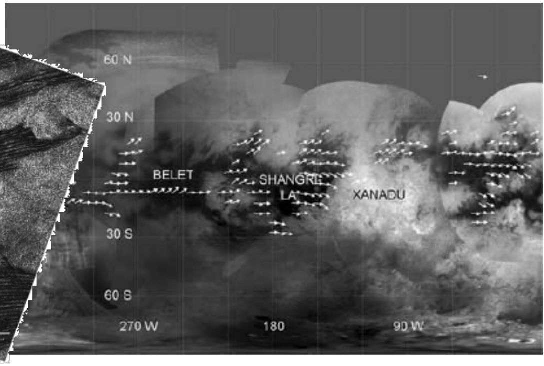
Lorenz et al. 2006

Radebaugh et al. 2010

- **Orientation**
  (Lorenz 2006, 2009; Radebough 2008)
  - Dune forms distinct patterns
  - Interaction with topography suggests west-east elongation direction (opposite of expected trade winds)

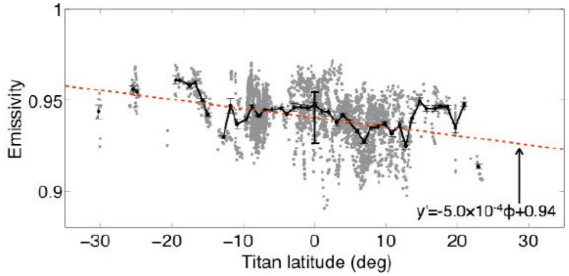


Radebaugh et al. 2008



Lorenz et al. 2009

- **Global Variation**
  (Savage 2010; LeGall 2010, 2011, in-press)
  - Morphometric variations with latitude/ altitude
  - Crest spacing and dune/interdune fraction increase with both latitude and altitude
  - Inferred through radiometric parameters



Le Gall et al. in-press

Dunes Form Patterns

It is difficult to NOT to form a line in the sand

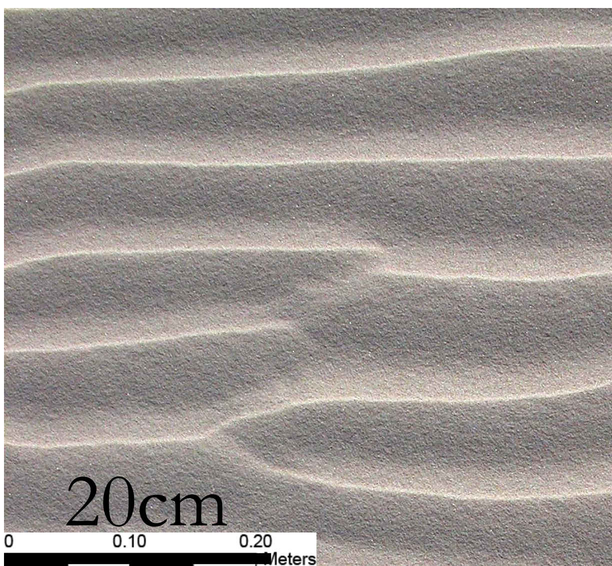
Similar line geometry patterns form under very different flow regimes and at very different scales.

transverse

reversing

obtuse bimodal

Rubin & Hunter 1987

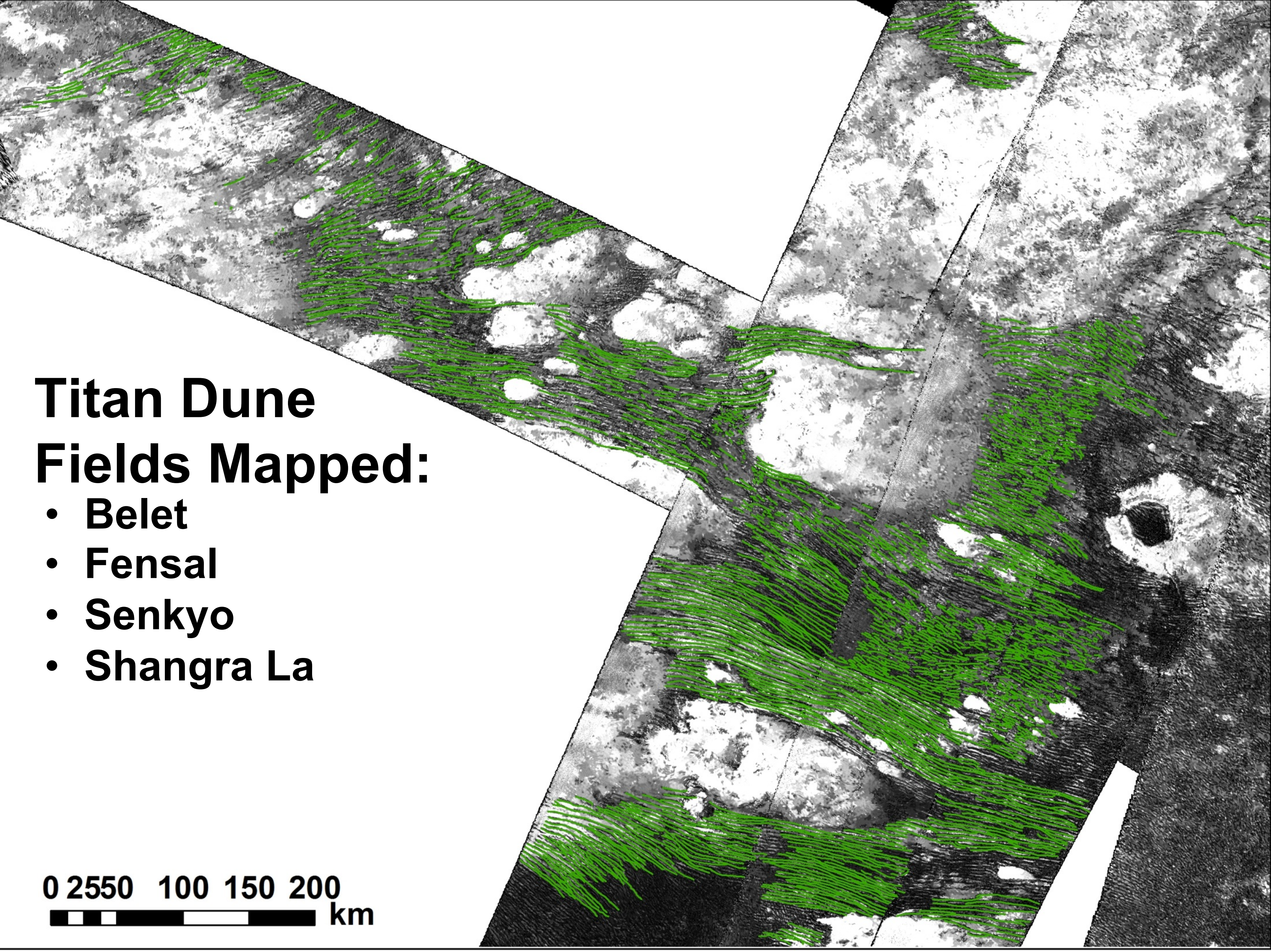


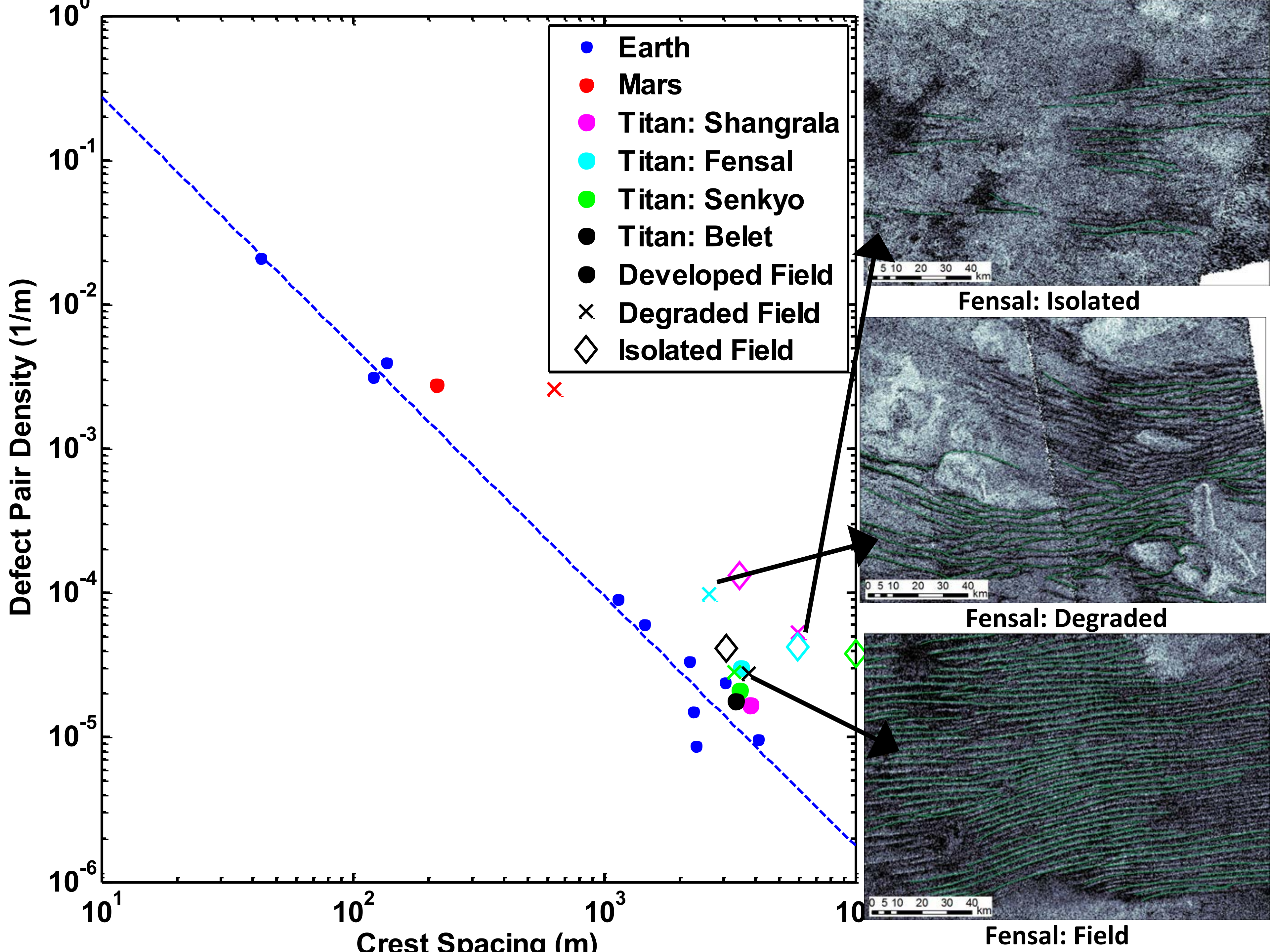
8km

Wind ripple
Padre Island, T

Titan Dune Fields Mapped:

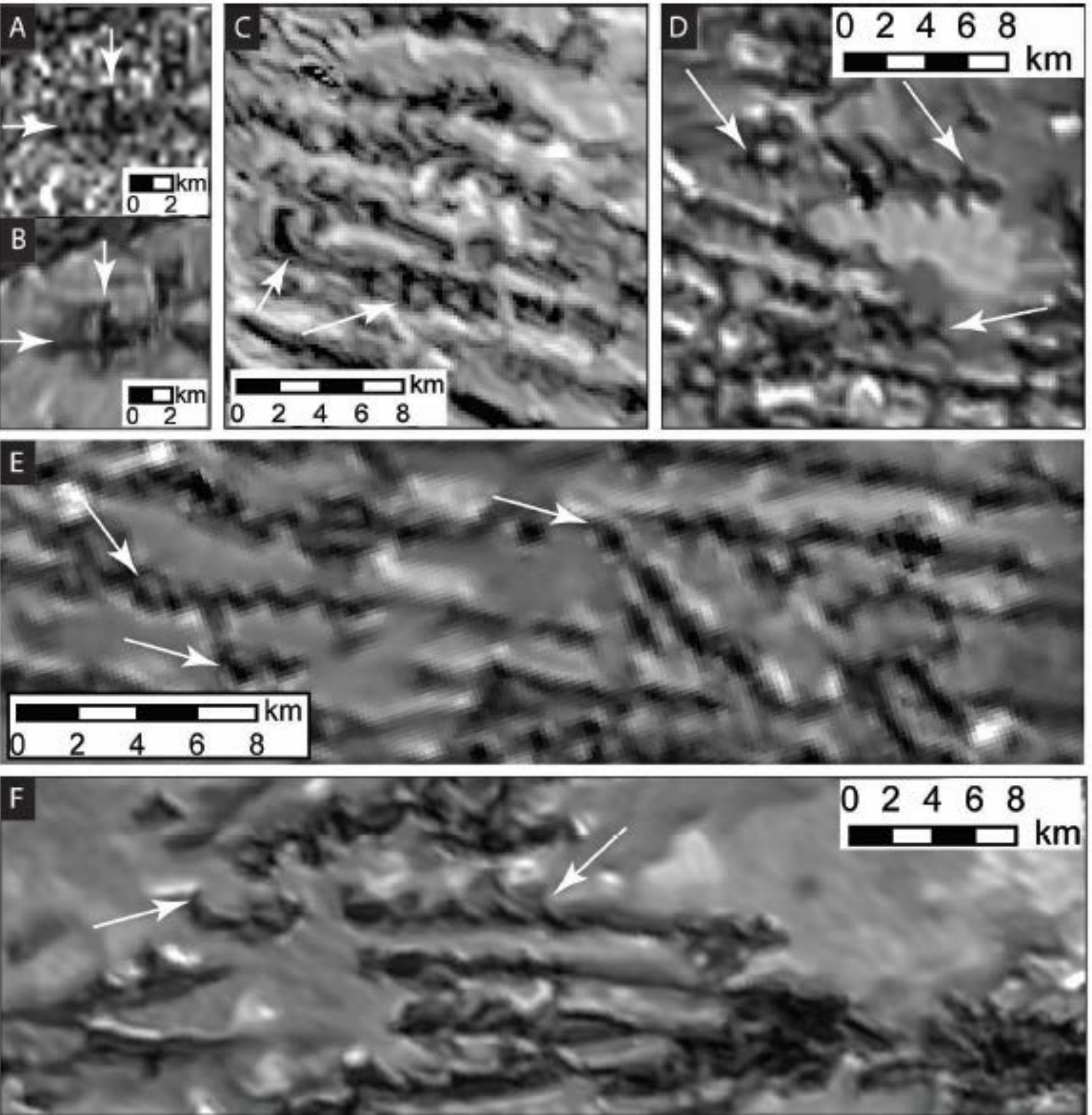
- Belet
- Fensal
- Senkyo
- Shangra La




Earth
Mars
Titan: Shangrala
Titan: Fensal
Titan: Senkyo
Titan: Belet
Developed Field
Degraded Field
Isolated Field
Defect Pair Density (1/m)
Crest Spacing (m)
Fensal: Isolated
Fensal: Degraded
Fensal: Field
0 5 10 20 30 40 km

New Types of Dunes Discovered on Titan

Distinctive Dune Forms Constrain Titan's Wind Regimes



Newly processed Cassini RADAR images reveal a second dune pattern that "overprints" the dominant east-west linear dunes. Their existence points to some important shifts in Titan winds over time.

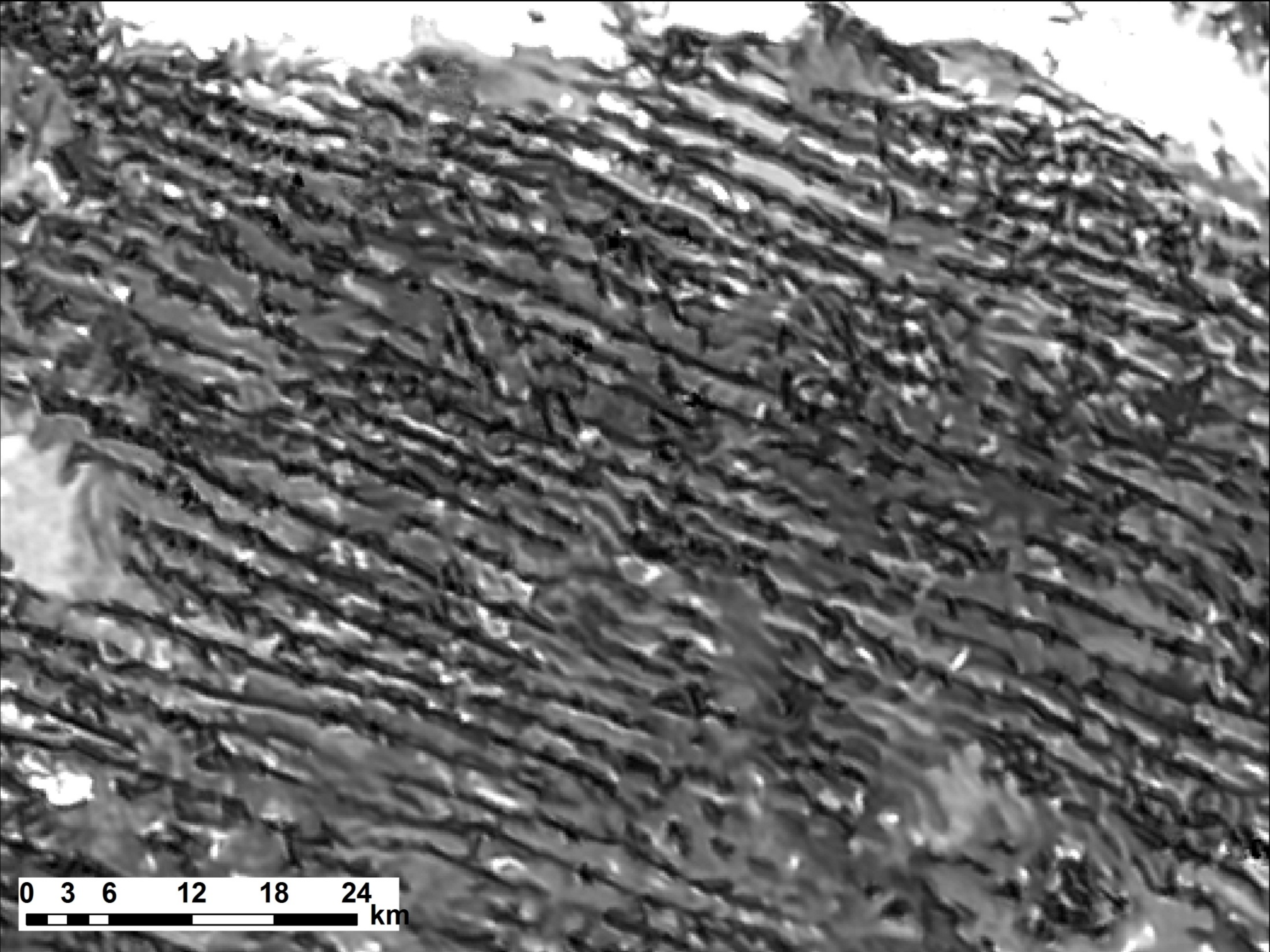
(A) Standard SAR image

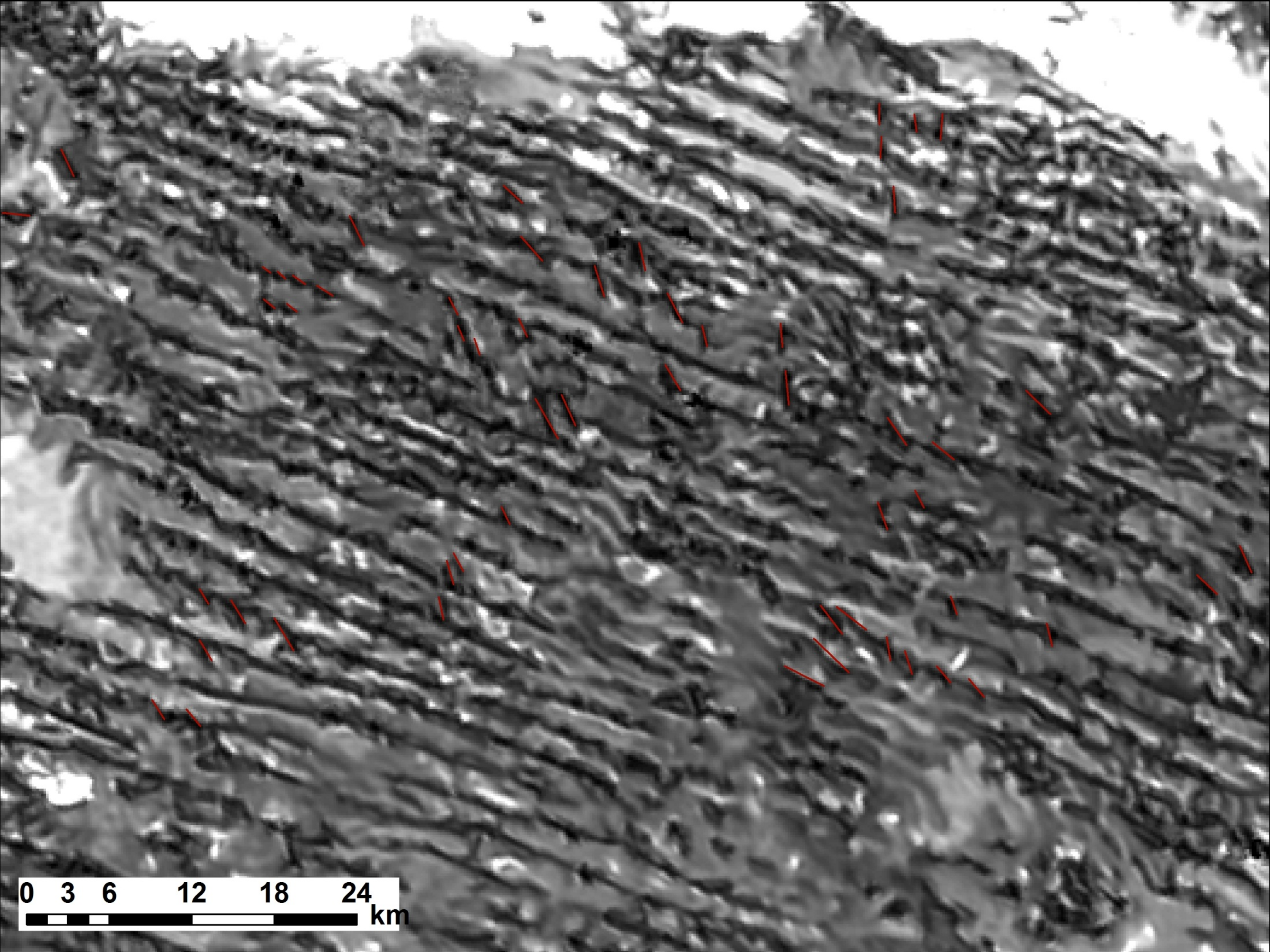
(B) SAR image with noise removed showing star dune. Star Dunes require the presence of winds from multiple directions to form.

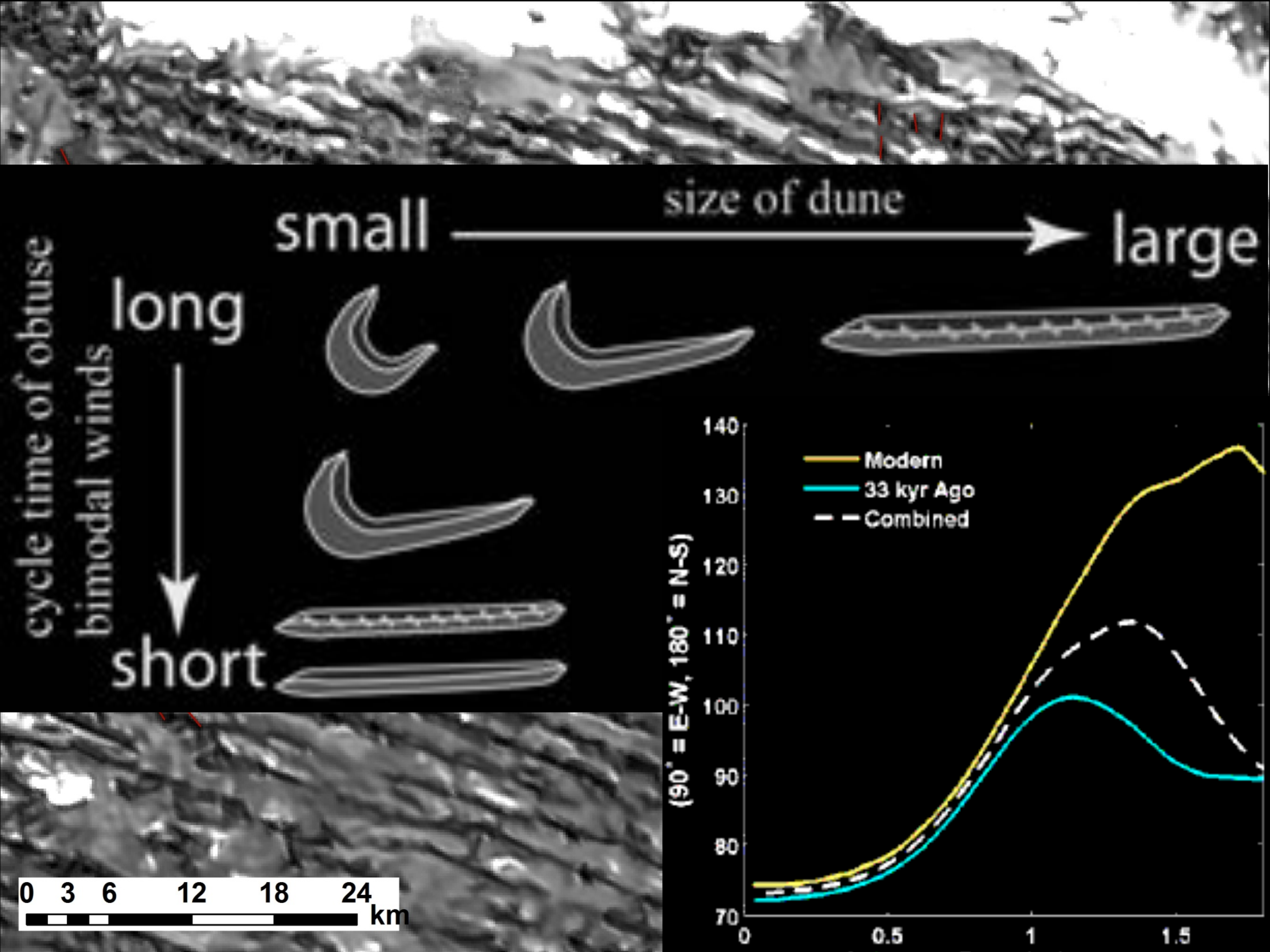
(C) Barchans dunes with elongate southern horns indicating the influence of a second wind.

(D) Star dunes forming in areas where the supply of sediments is poor, which is common on Earth.

(E) Barchanoid and reoriented crestlines imply that dunes respond to winds varying over different time scales.


0 3 6 12 18 24
km


0 3 6 12 18 24
km


size of dune
small
large
cycle time of obtuse bimodal winds
long
short
140
130
120
110
100
90
80
70
Modern
33 kyr Ago
Combined
(90° = E-W, 180° = N-S)
0
0.5
1
1.5
0 3 6 12 18 24
km