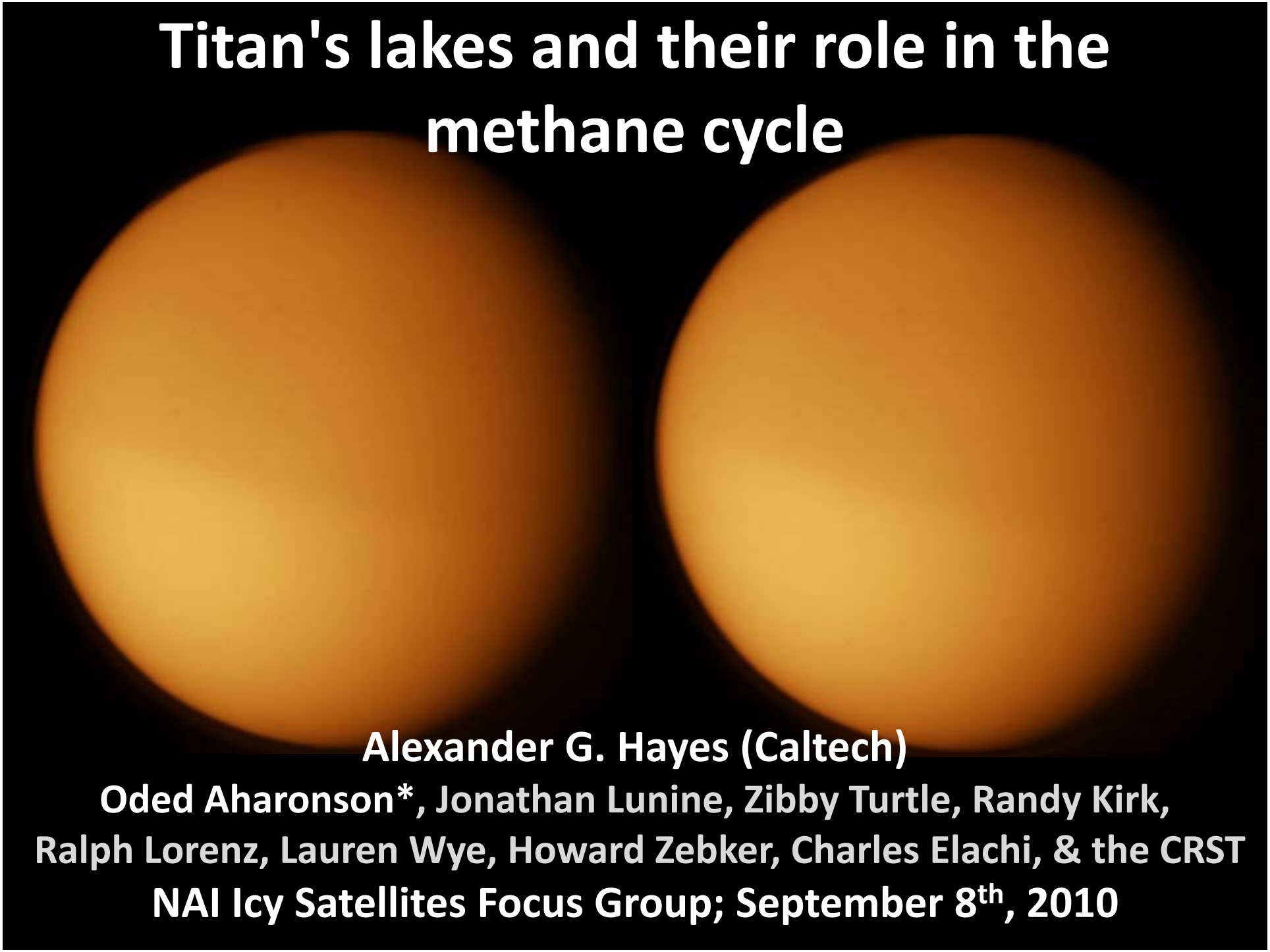
Titan's lakes and their role in the methane cycle



Alexander G. Hayes (Caltech)
Oded Aharonson*, Jonathan Lunine, Zibby Turtle, Randy Kirk, Ralph Lorenz, Lauren Wye, Howard Zebker, Charles Elachi, & the CRST
NAI Icy Satellites Focus Group; September 8th, 2010

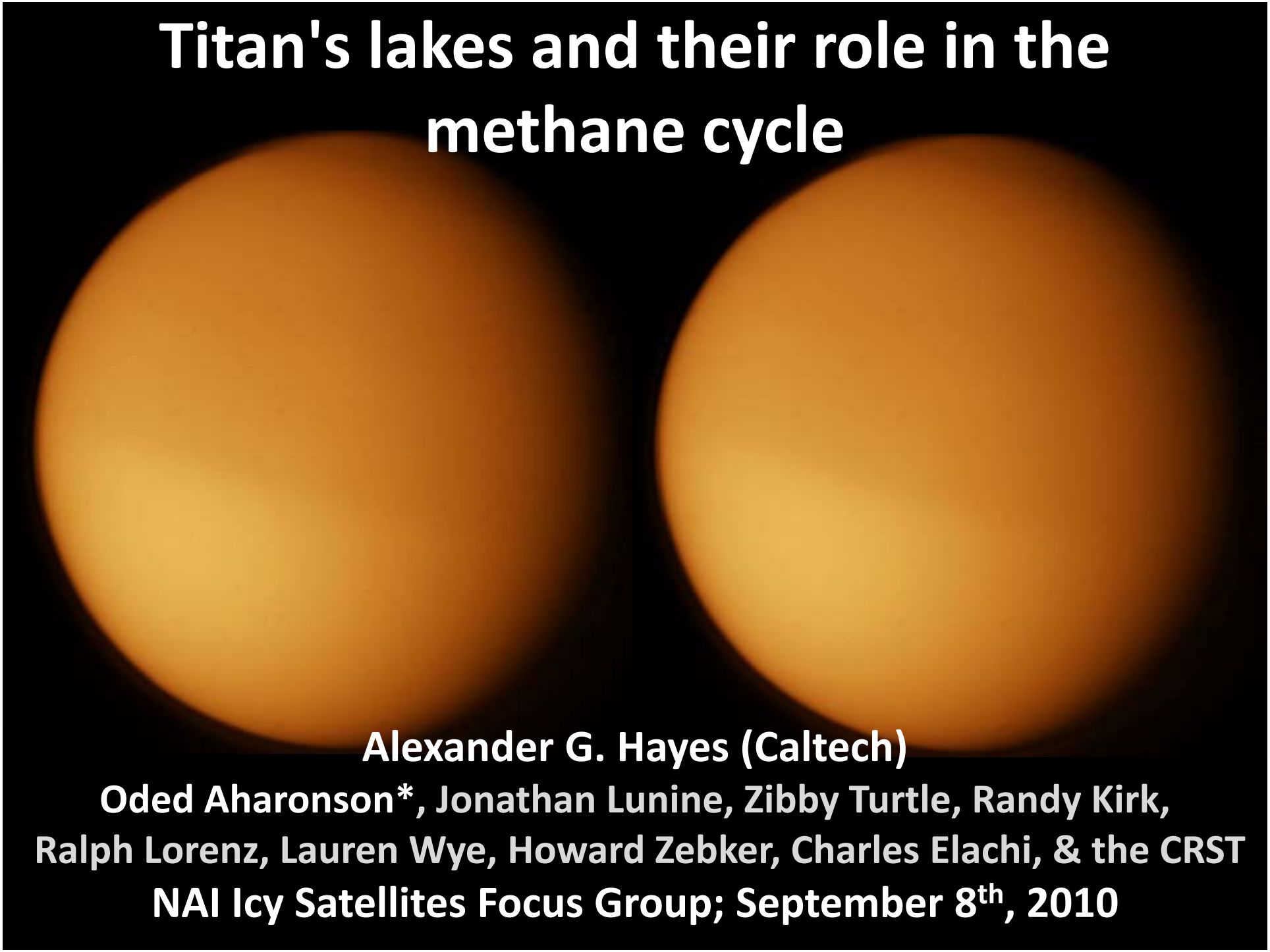
Titan betting pool

What will the Huygens probe land in/on?

Place your bets now, for bragging rights later!

Ice	Tar	Liquid	Undeterminable	DOA	EATEN
Emma	Emily	x DARIN	Sloane	Kevin	Dave
Greg	Geoff	Sign here	Colette		
Kaveh	Soto		Ben		
	Bruce		Margarita		
			MEB (will be tar, but we can't tell)		

Titan's lakes and their role in the methane cycle



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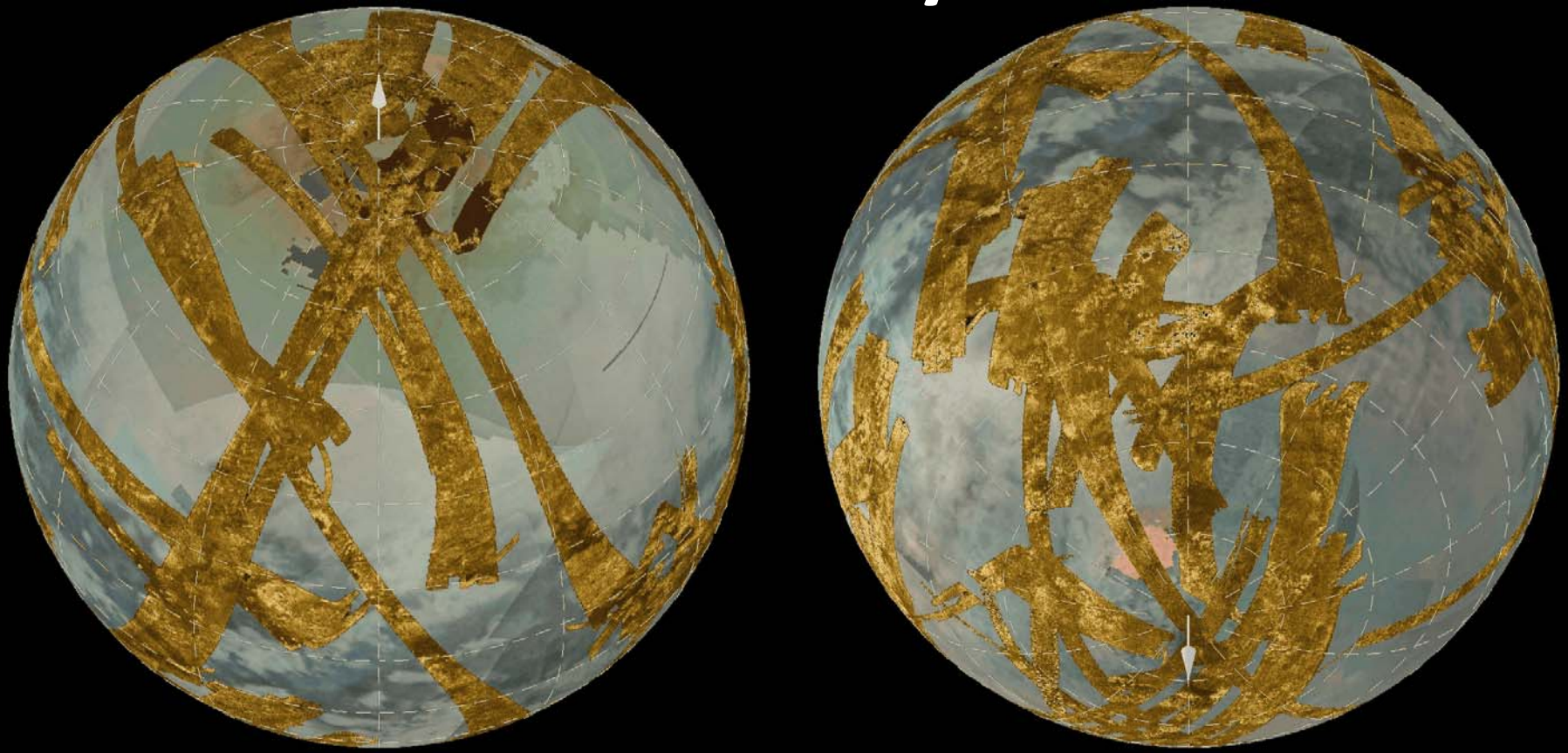

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LETTERS

The lakes of Titan

E. R. Stofan[1,2], C. Elachi[3], J. I. Lunine[4], R. D. Lorenz[5], B. Stiles[3], K. L. Mitchell[3], S. Ostro[3], L. Soderblom[6], C. Wood[7], H. Zebker[8], S. Wall[3], M. Janssen[3], R. Kirk[6], R. Lopes[3], F. Paganelli[3], J. Radebaugh[4], L. Wye[8], Y. Anderson[3], M. Allison[9], R. Boehmer[3], P. Callahan[3], P. Encrenaz[10], E. Flamini[11], G. Francescetti[12], Y. Gim[3], G. Hamilton[3], S. Hensley[3], W. T. K. Johnson[3], K. Kelleher[3], D. Muhleman[13], P. Paillou[14], G. Picardi[15], F. Posa[16], L. Roth[3], R. Seu[15], S. Shaffer[3], S. Vetrella[12] & R. West[3]

The surface of Saturn's haze-shrouded moon Titan has long been proposed to have oceans or lakes, on the basis of the stability of liquid methane at the surface[1,2]. Initial visible[3] and radar[4,5] imaging failed to find any evidence of an ocean, although abundant evidence was found that flowing liquids have existed on the surface[5,6]. Here we provide definitive evidence for the presence of lakes on the surface of Titan, obtained during the Cassini Radar flyby of Titan on 22 July 2006 (T_{16}). The radar imaging polewards of 70° north shows more than 75 circular to irregular radar-dark patches, in a region where liquid methane and ethane are expected to be abundant and stable on the surface[2,7]. The radar-dark patches are interpreted as lakes on the basis of their very low radar reflectivity and morphological similarities to lakes, including associated channels and location in topographic depressions. Some of the lakes do not completely fill the depressions in which they lie, and apparently dry depressions are present. We interpret this to indicate that lakes are present in a number of states, including partly dry and liquid-filled. These northern-hemisphere lakes constitute the strongest evidence yet that a condensable-liquid hydrological cycle is active in Titan's surface and atmosphere, in which the lakes are filled through rainfall and/or intersection with the subsurface 'liquid methane' table.

Liquid methane is a thermodynamically allowed phase anywhere on the surface of Titan today. However, at all except the highest latitudes, the methane relative humidity (amount of methane relative to the saturated value) is less than 100%, and so standing bodies of methane must evaporate into the atmosphere. There is no methane ocean in contact with the atmosphere[8], and the timescale for saturating the atmosphere by evaporation of methane from the surface (about 10^3 years (ref. 9)) is much longer than the seasonal cycle of just under 30 years. Hence methane precipitation near the poles should dominate the 'hydrology' of methane on Titan[10]. Thus, lakes will be stable from the poles down to a latitude determined by the abundance of methane in the surface–atmosphere system and by the possible intersection of such surface methane fluids with putative subterranean 'methanifers', analogous to terrestrial aquifers.

An additional factor in establishing and stabilizing the presence of lakes at high latitude is the preferential deposition of ethane in polar regions (see, for example, ref. 11). This in turn may be controlled by the availability of cloud condensation nuclei in the stratosphere enhanced by the sedimentation of heavier organics such as C_4N_2 (ref. 12) in the seasonal polar hood. This feature, imaged nearly a Titan year ago by Voyager in the north and now also seen to be present (se for example, ref. 13), forms during polar winter. Observations an modelling suggest that high-latitude clouds poleward of 75° sout are methane but include an ethane mist[8]. Ethane is fairly involatile a Titan surface conditions, and hence if present would form a perman ent component to lakes. With the observations currently availabl the condensed-phase surface methane-to-ethane ratio cannot b constrained. Even if the as yet unmeasured surface temperature above 75° north latitude are 3–5 K below the equatorial 93.6 K (re 14), as suggested by Voyager observations[11], dissolved nitrogen i binary methane–nitrogen lakes will depress the freezing point suffi ciently, and ternary methane–ethane–nitrogen lakes will hav strongly depressed freezing points.

The Cassini Titan Radar Mapper[4,5] (K_u-band wavelength 2.17 cm instrument had its sixth radar pass of Titan (T_{16}) on 22 July 200 (UTC). The synthetic aperture radar (SAR) arc-shaped imagin swath extends from mid-northern latitudes to near the north pol and back, and is 6,130 km long with spatial resolutions of 300 1,200 m (Fig. 1, and Supplementary Fig. 1). Incidence angles acros the swath vary from 15° to 35°. The portion of the swath tha extended from about 70° to 83° north contained more than 75 rada dark patches, from 3 km to more than 70 km across.

The dark patches contrast with the surrounding terrain, which ha a mottled appearance similar to that of other 'plains' regions o Titan[4,5,16]. The backscatter of some of the dark patches is extremel low. Several appear at the noise floor of the data (about −25 dB σ_0 with much lower reflectivity than previously imaged areas on Titar including the radar-dark (about −13 dB σ_0) sand dunes observe near Titan's equator. For the darkest patch we have observed s far, the normalized radar cross-section (σ_0) value is less than abou −26 dB and could be zero, because the measured signal is at th system noise level (Fig. 2). We are unable to ascertain that any signa at all has been reflected from this feature.

The radar backscatter of the dark patches at Cassini SAR imagin incidence angles is consistent with that expected from a very smoot surface of any kind (for example liquid, rock, ice or organics) or eve simply a non-reflecting, absorbing surface (for example a low-densit surface smoothly matched into a non-scattering absorber such a fluffy soot or dirty snow overlying a uniform and electrically absorb ing substrate). Radiometric brightness temperatures are obtaine along with the SAR swaths, although the spatial resolution is limite to the footprints of the respective radar beams (that is, more tha

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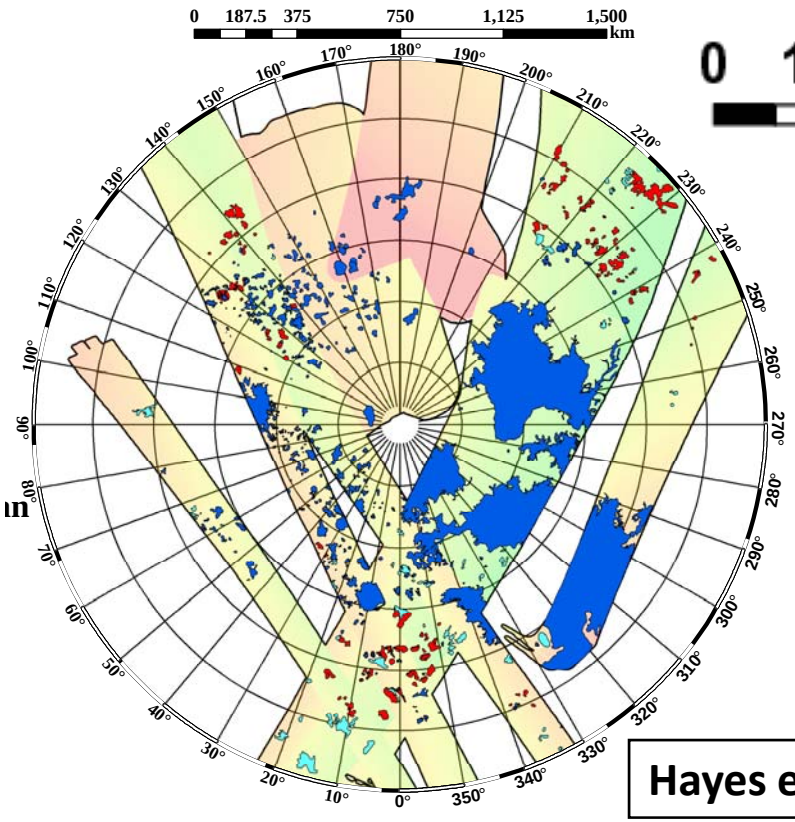
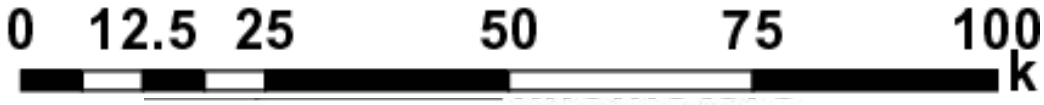
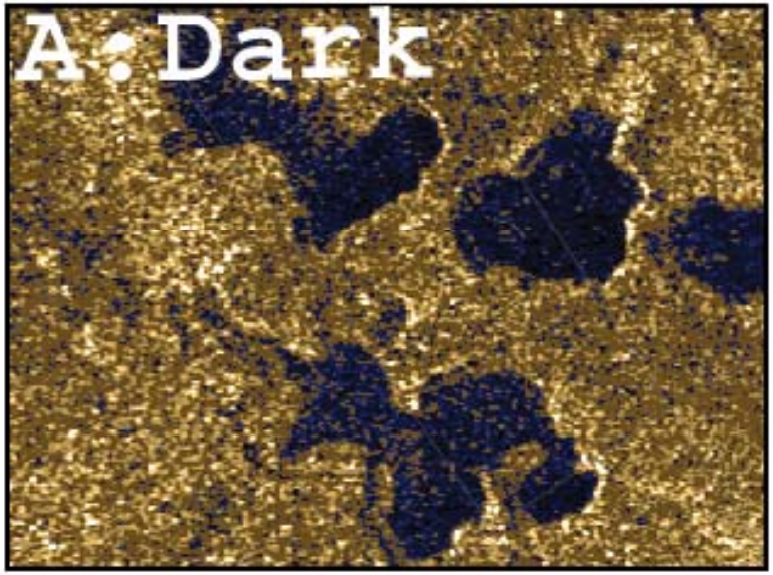
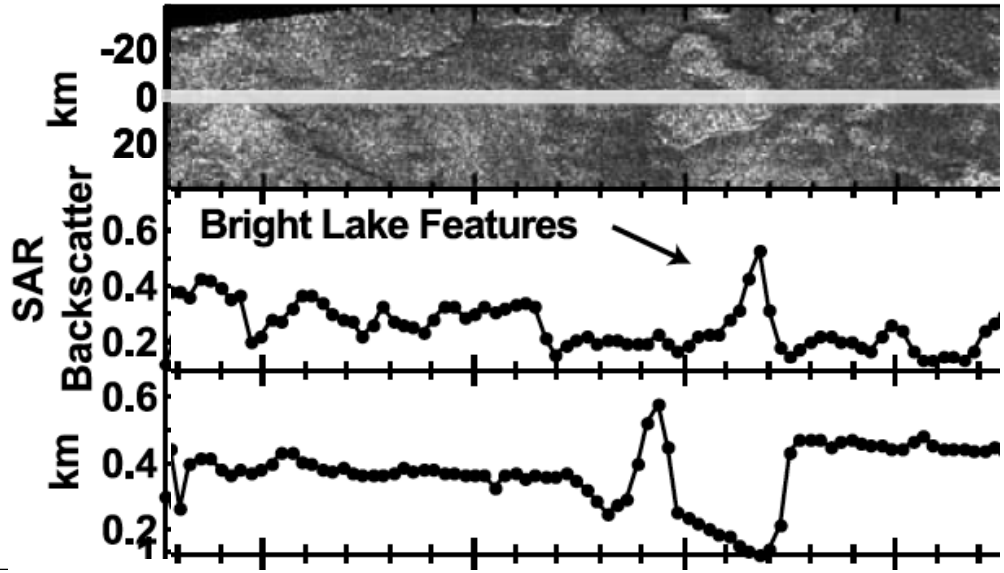
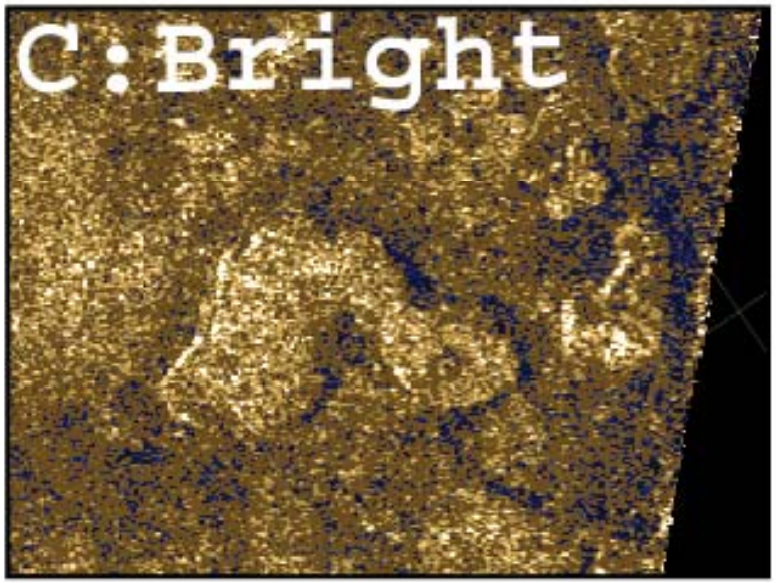


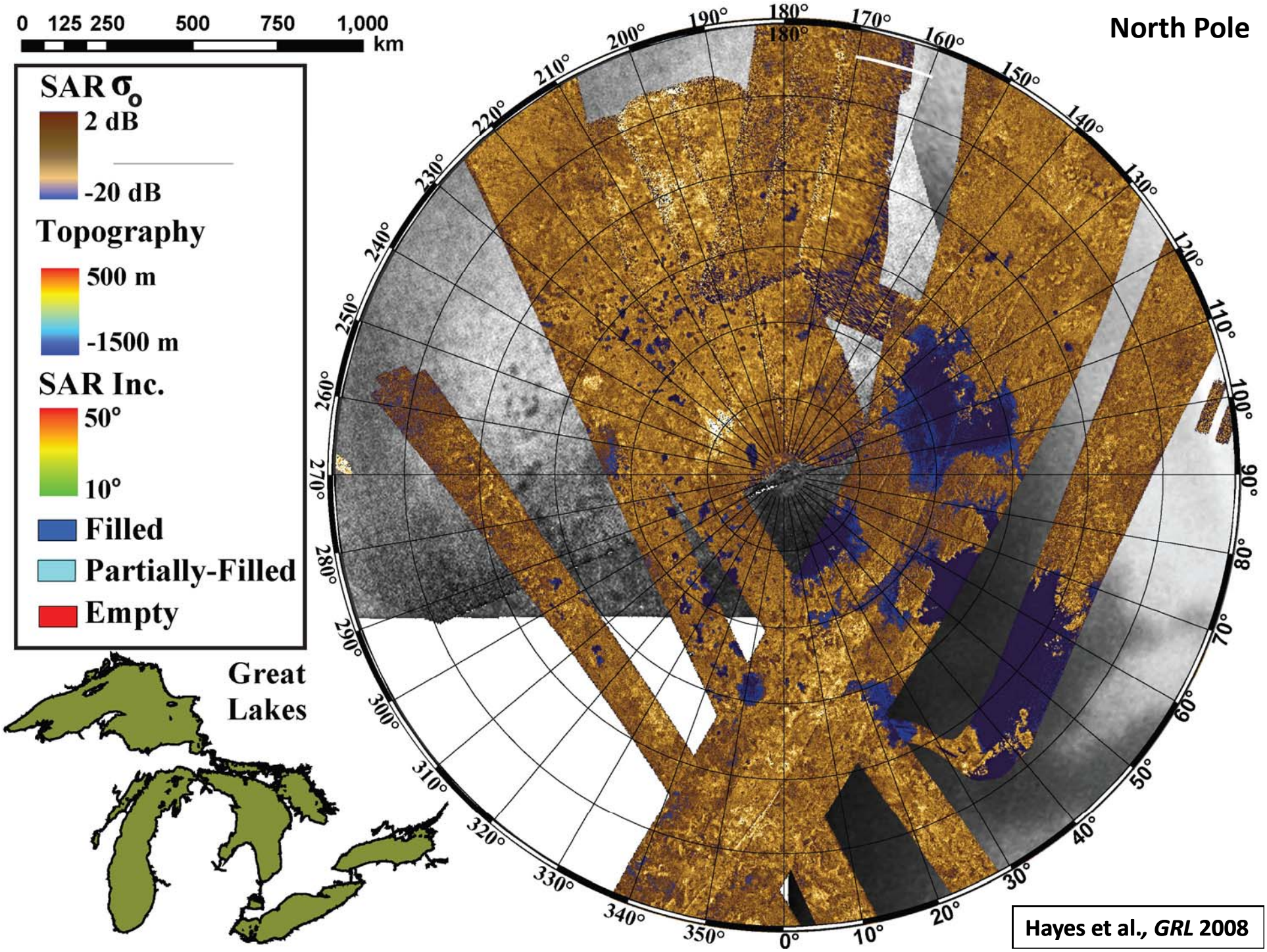




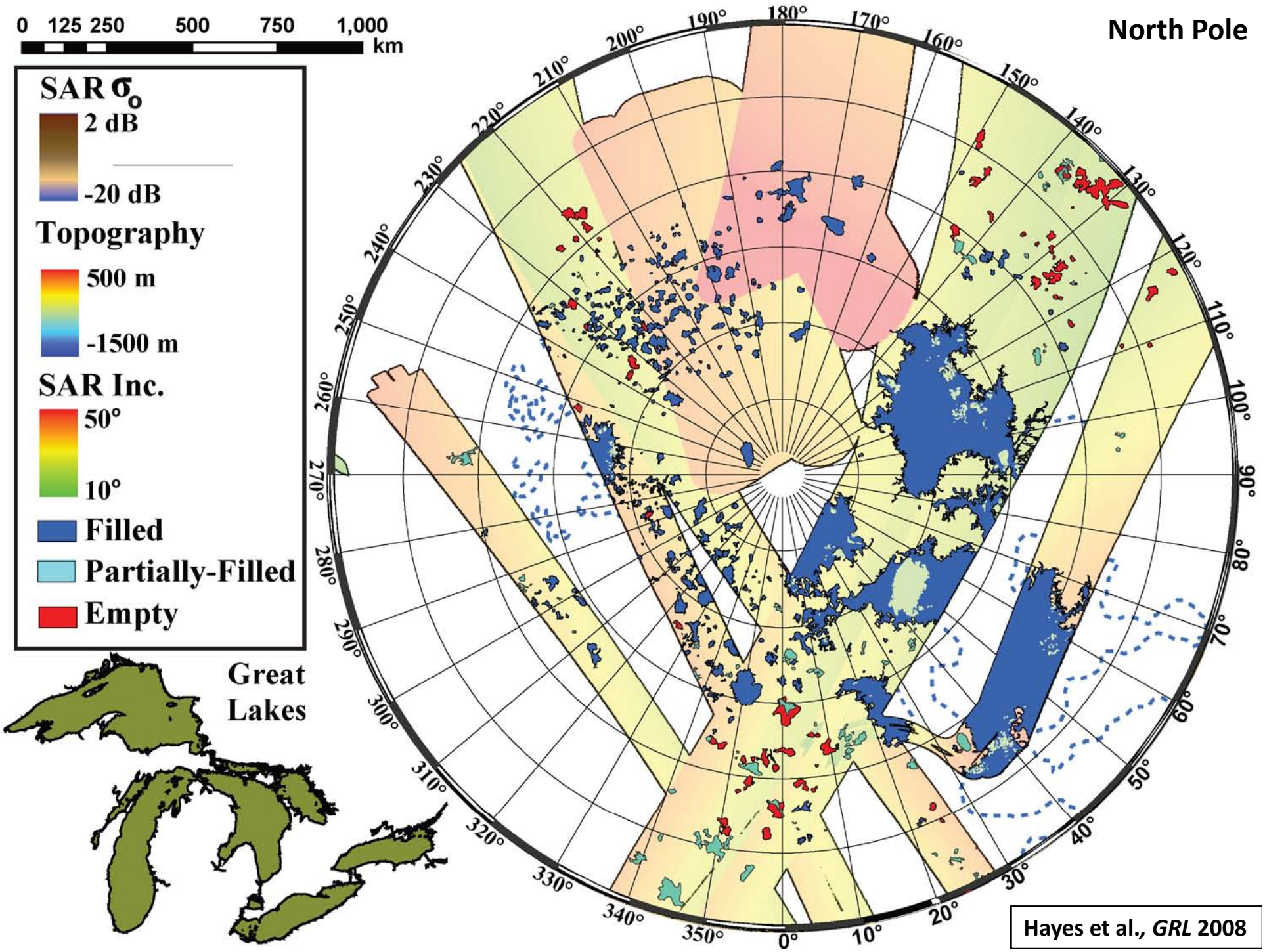
Hayes et al., *GRL* 2008



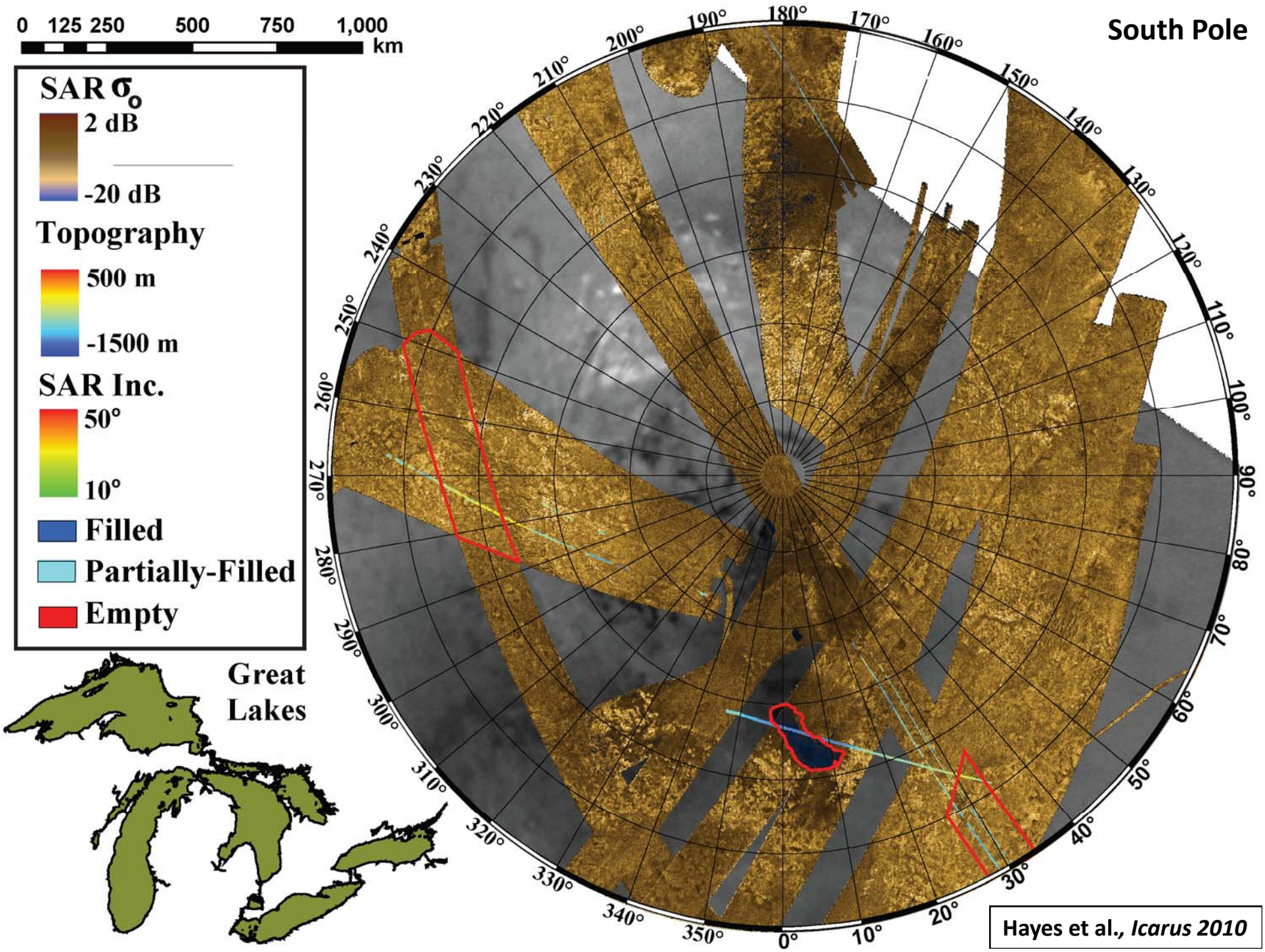




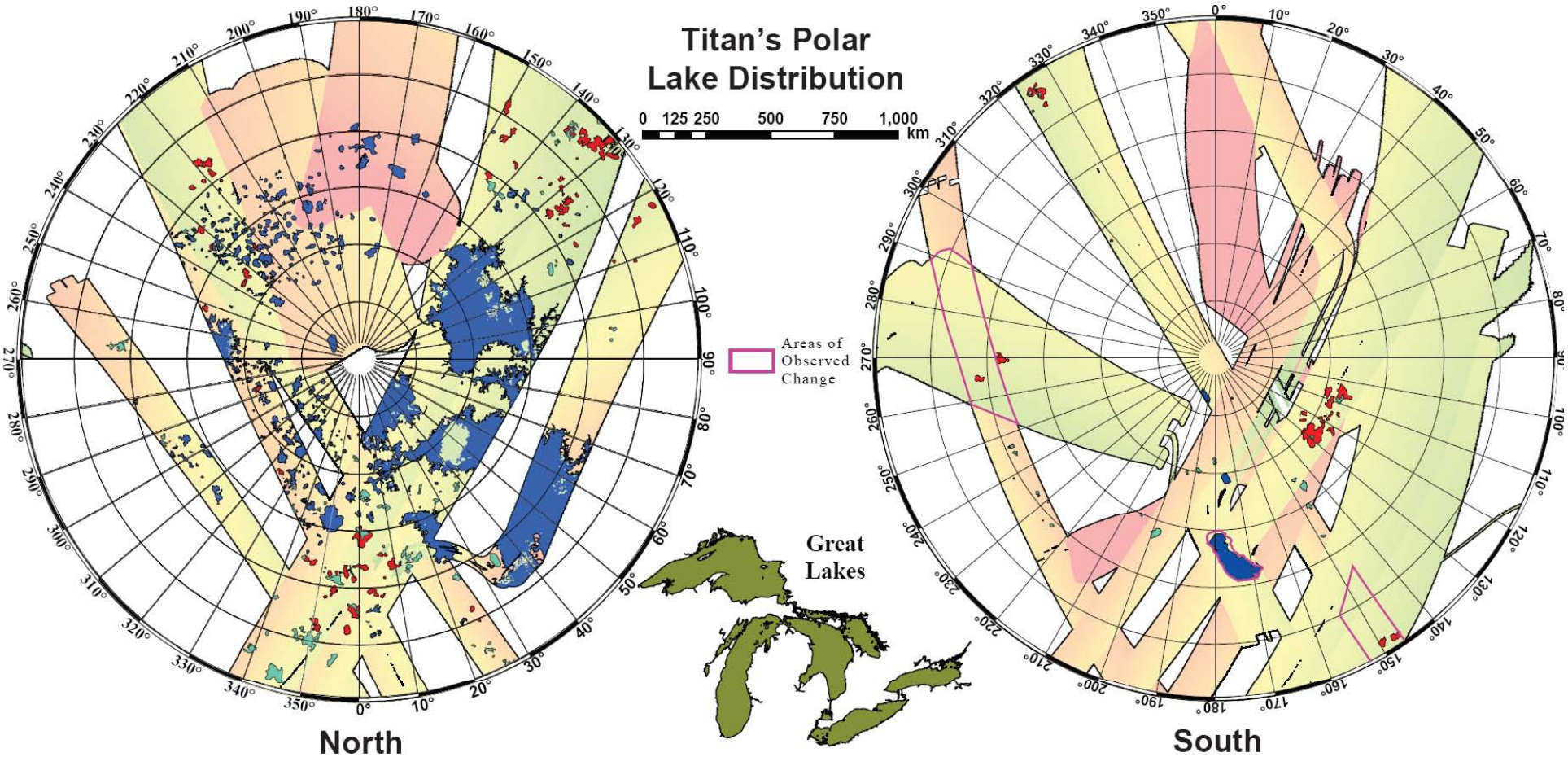
Hayes et al., *GRL* 2008



Hayes et al., *GRL* 2008

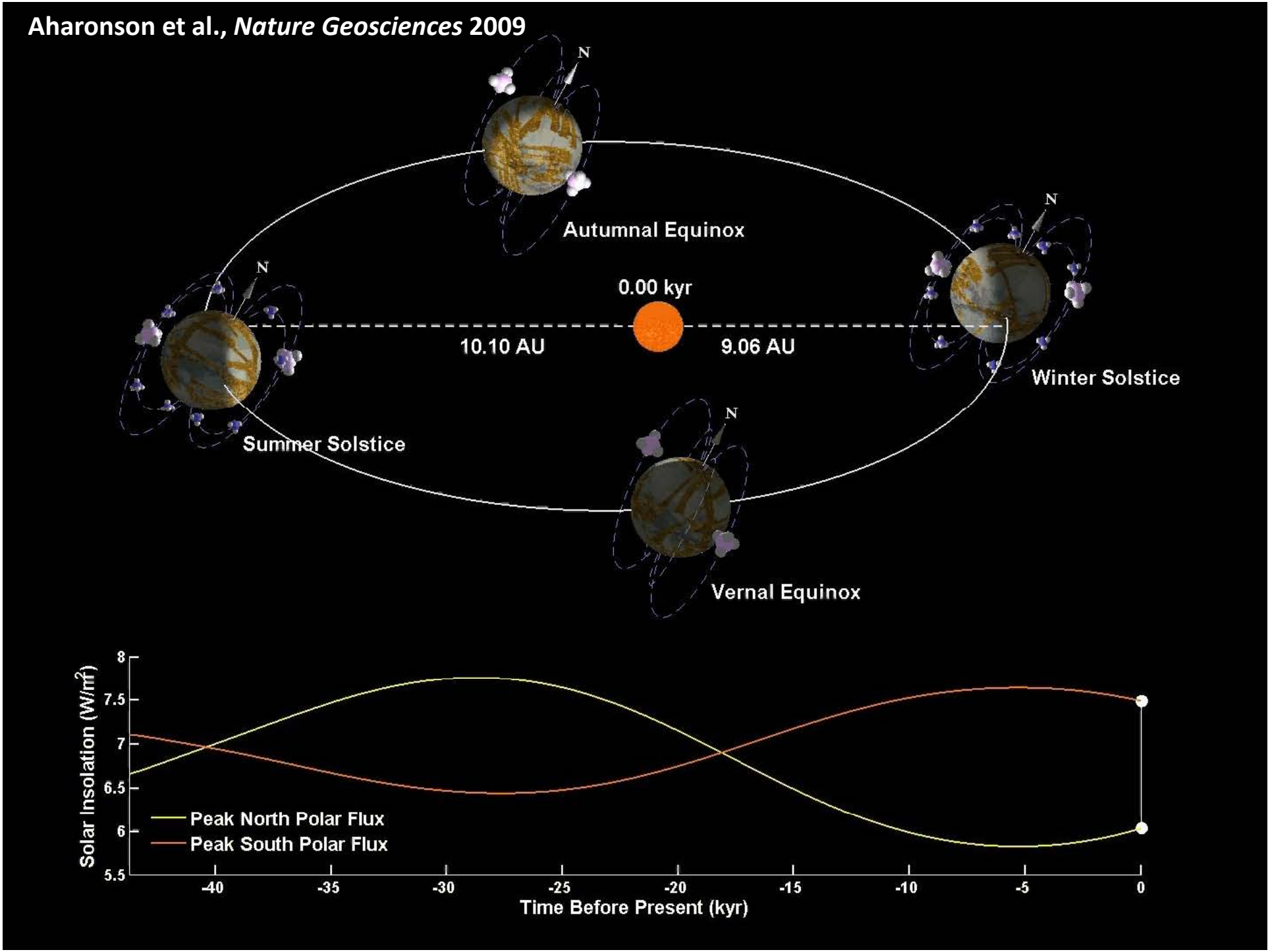


Hayes et al., *Icarus 2010*

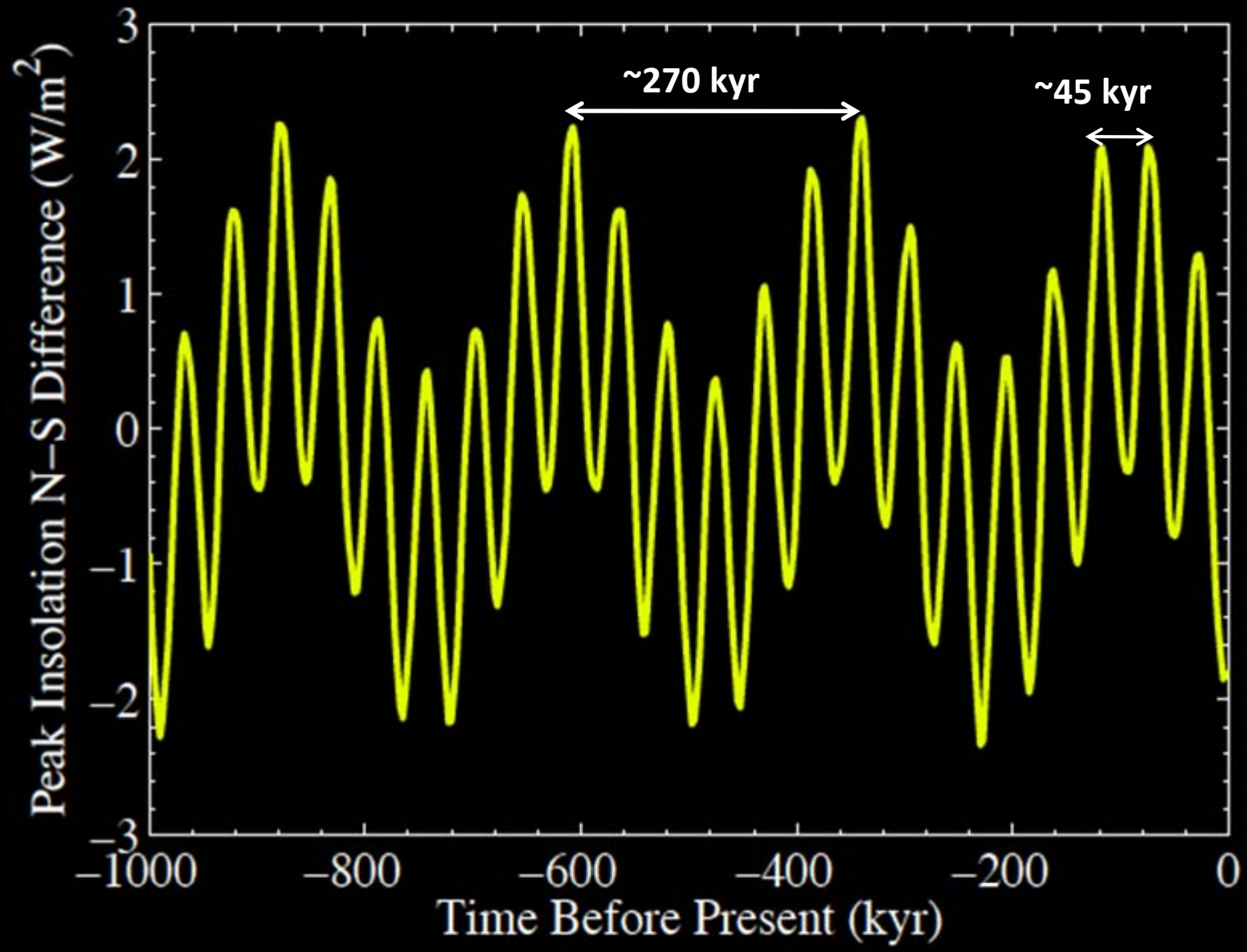


Lake Feature	Global	North (55°N-90°N)	South (55°S-90°S)
Swath Coverage	45.1%	56.5%	62.3%
Filled / Partially Filled / Empty	1.2% / 0.1% / 0.2%	10.5% / 0.7% / 1.2%	0.4% / 0.1% / 0.4%

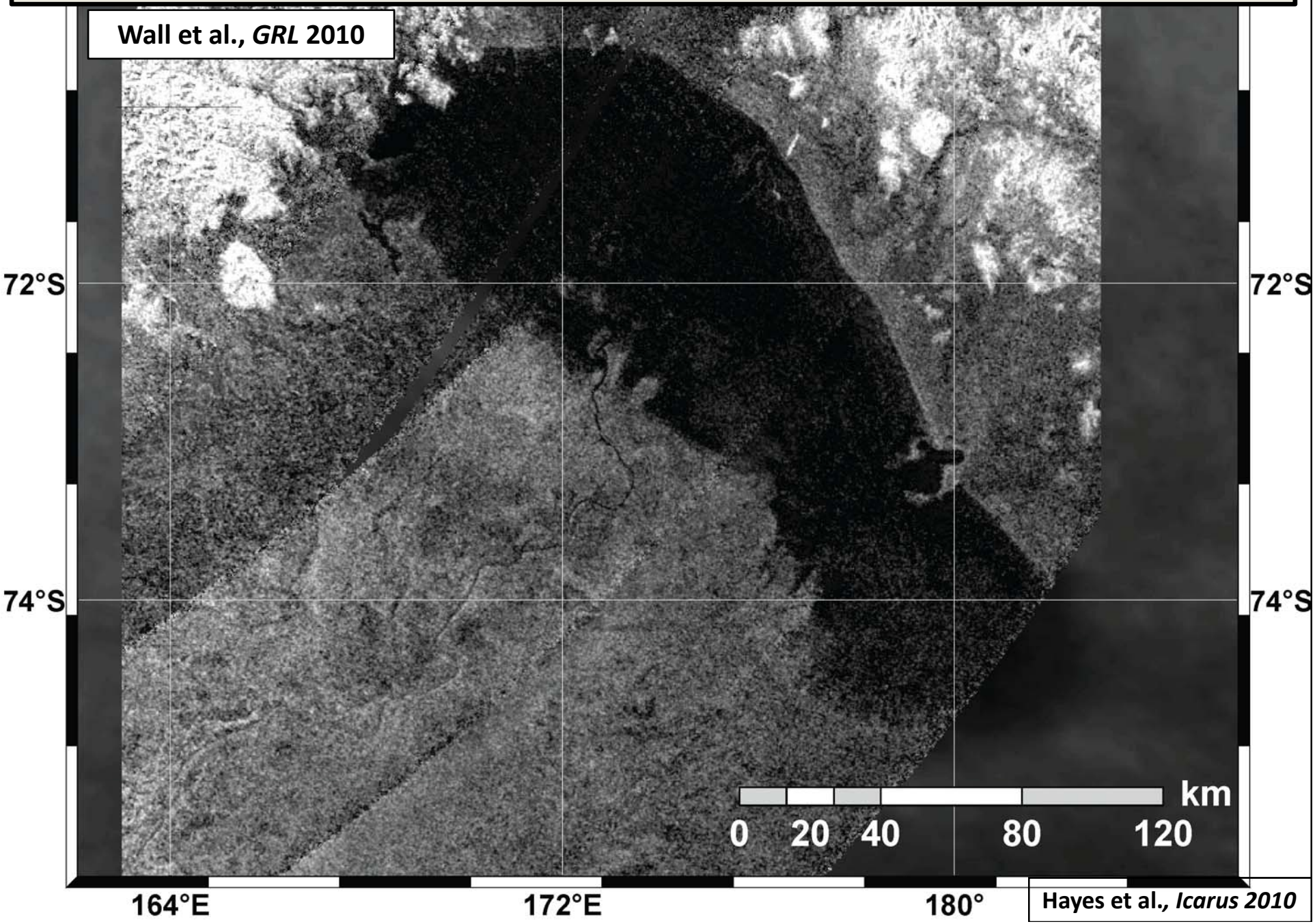
Aharonson et al., *Nature Geosciences* 2009

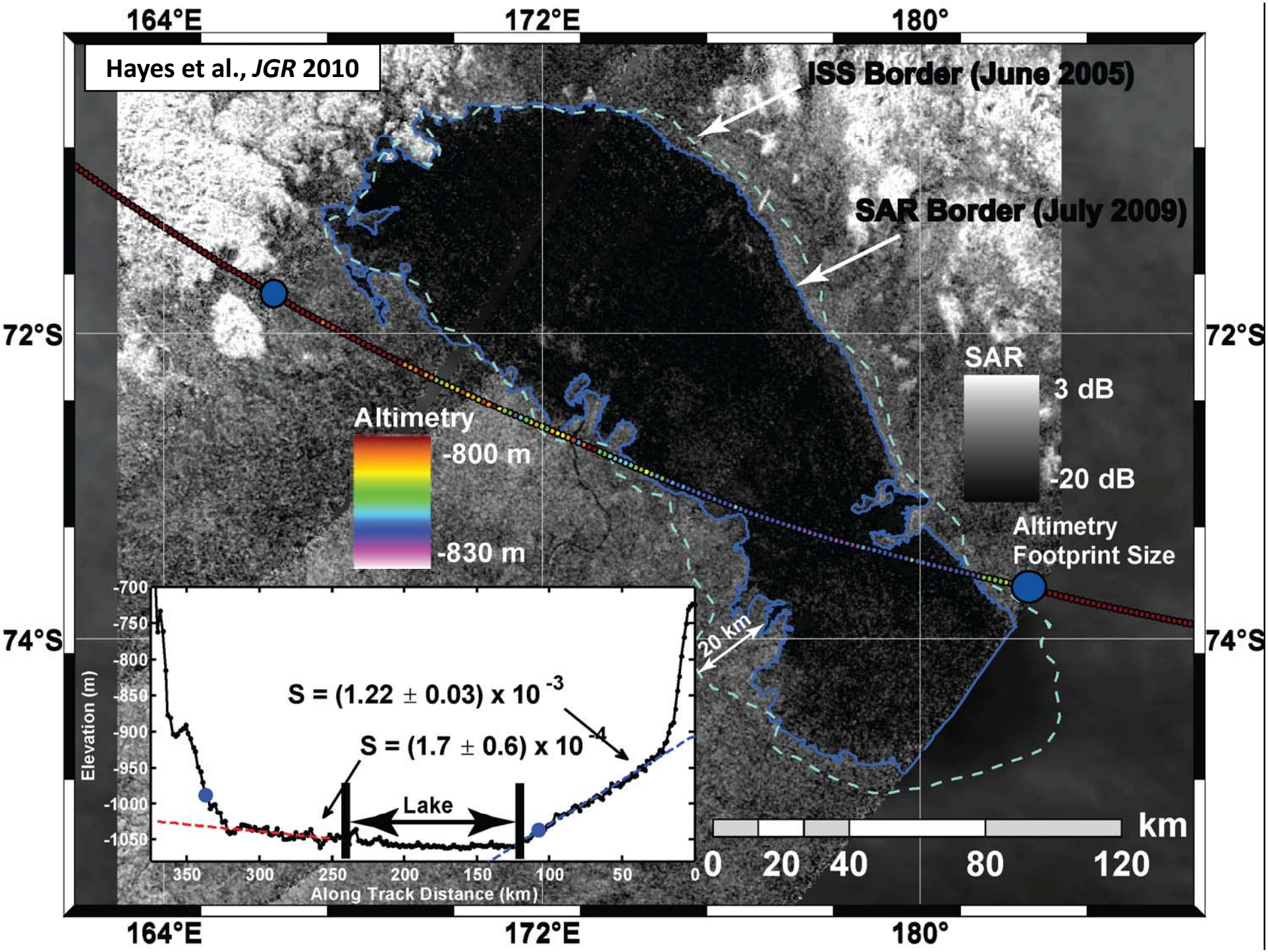


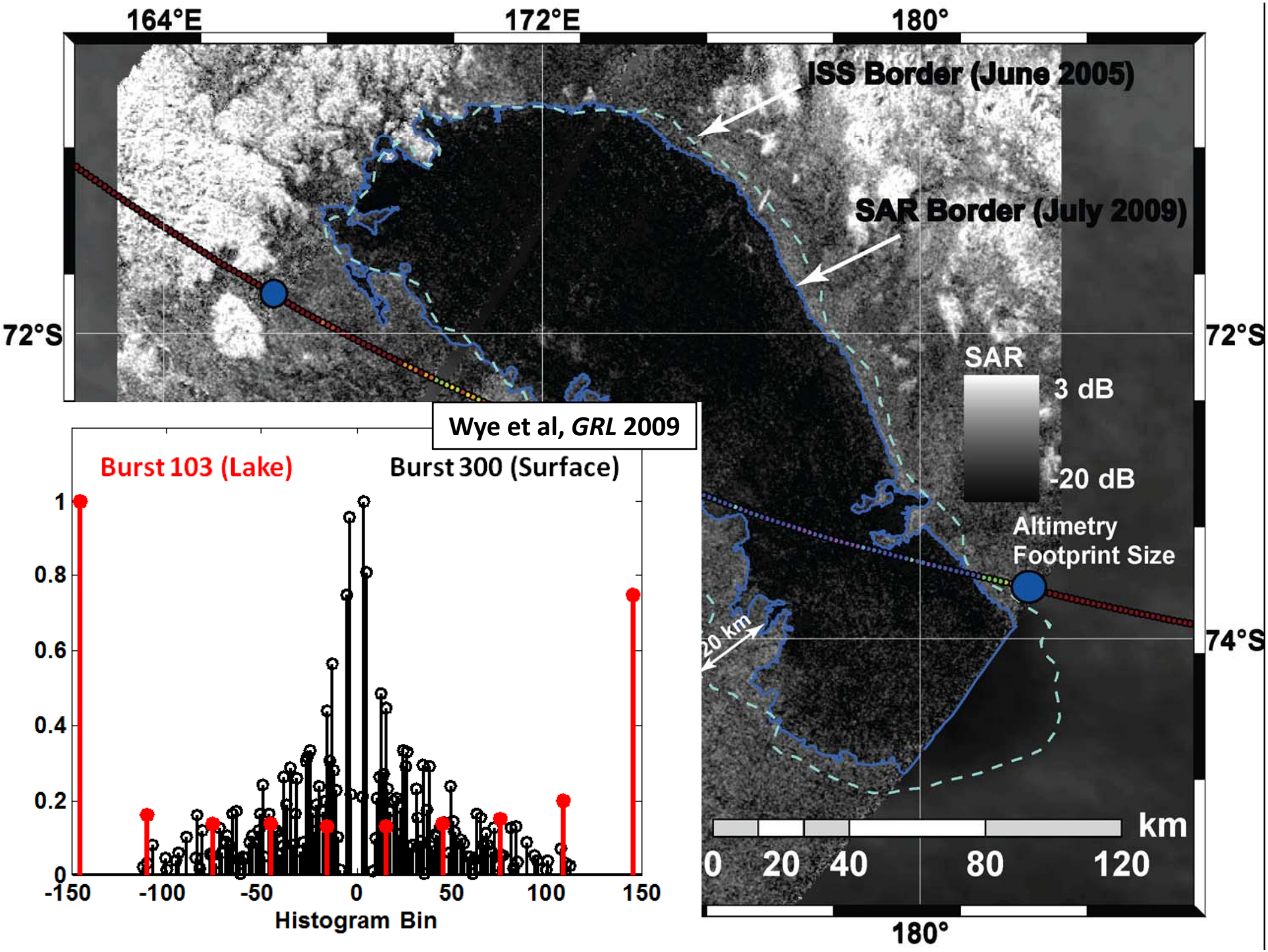
Titan's Milankovitch Periods

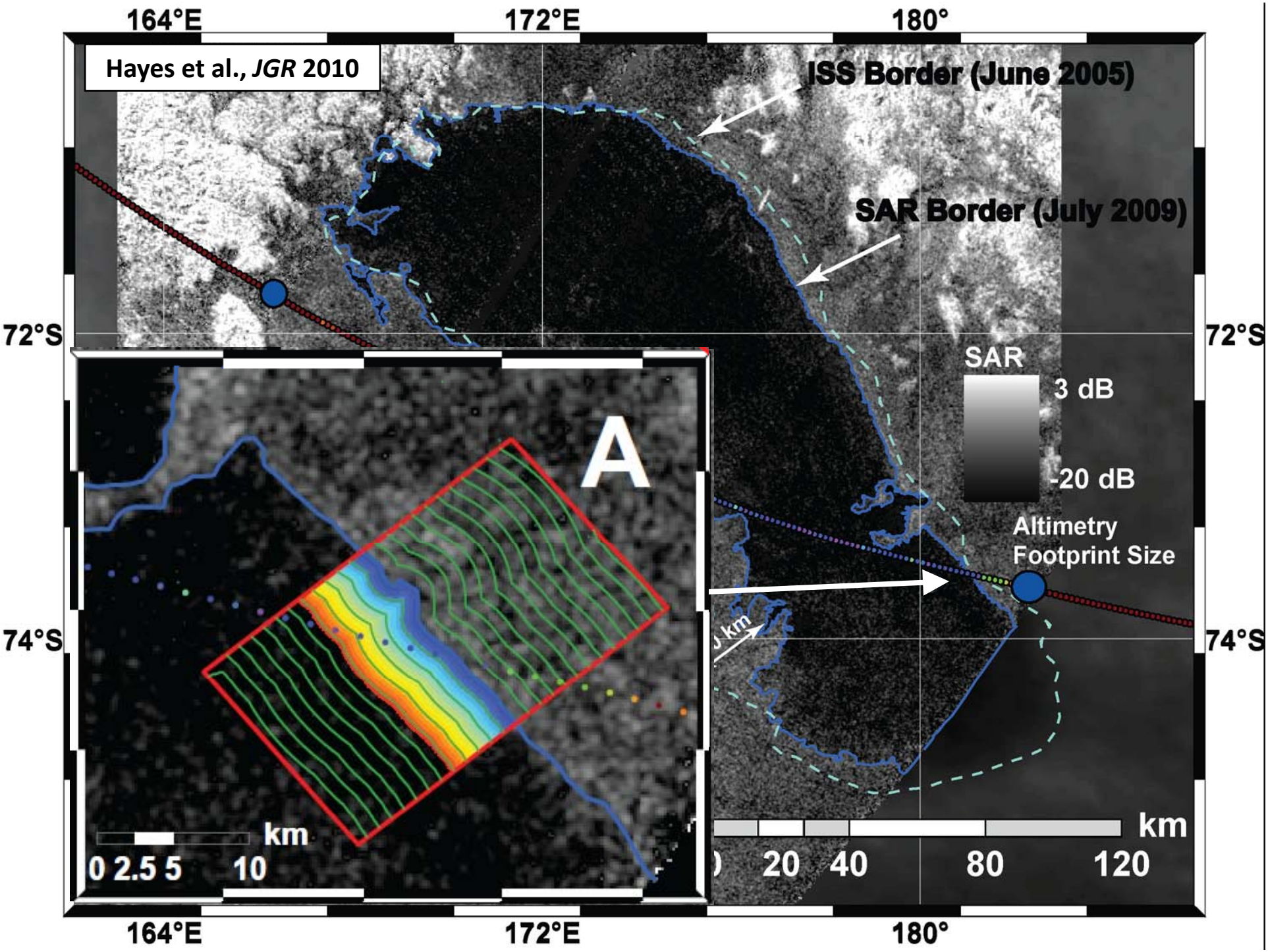


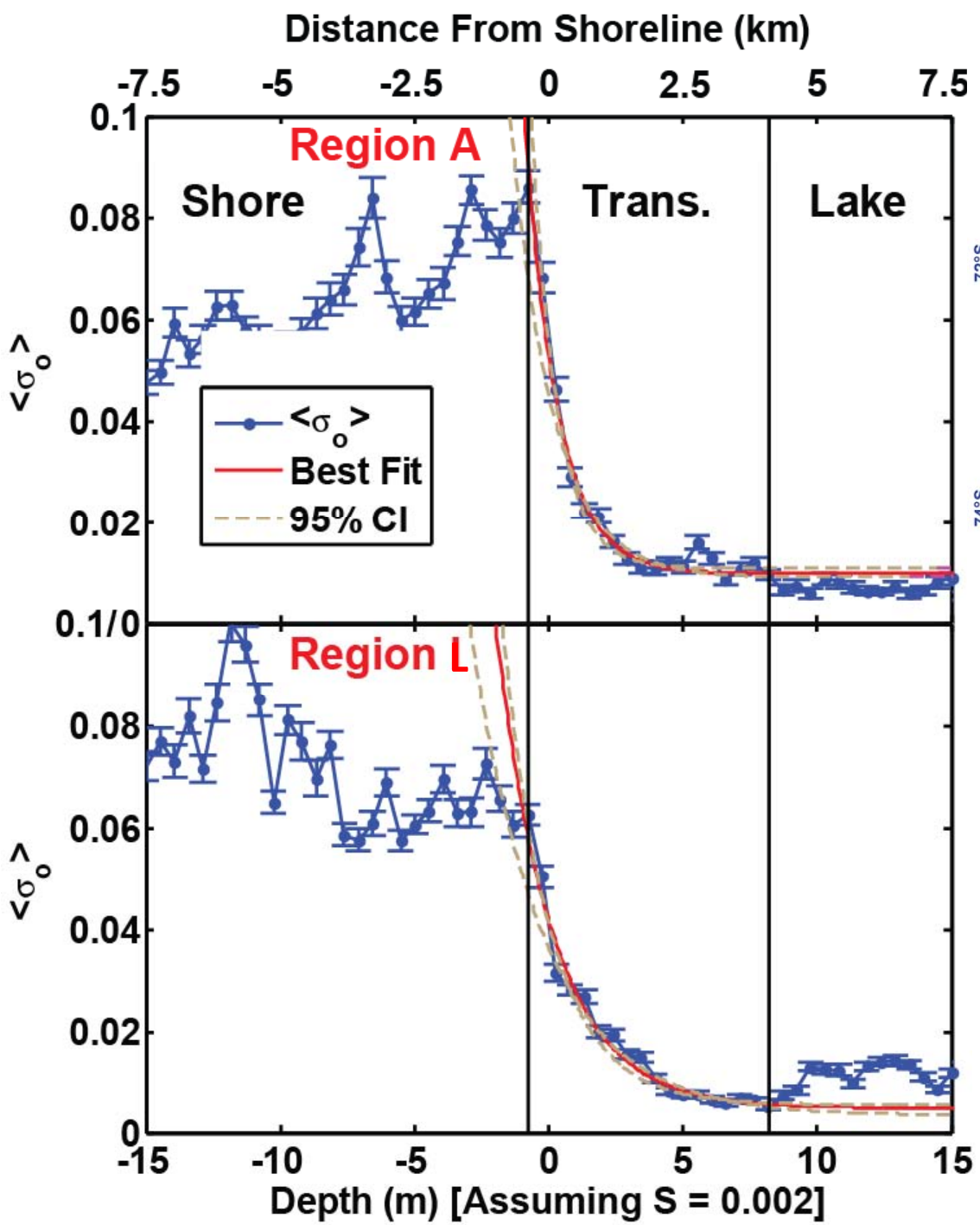
Aharonson et al., *Nature Geosciences* 2009

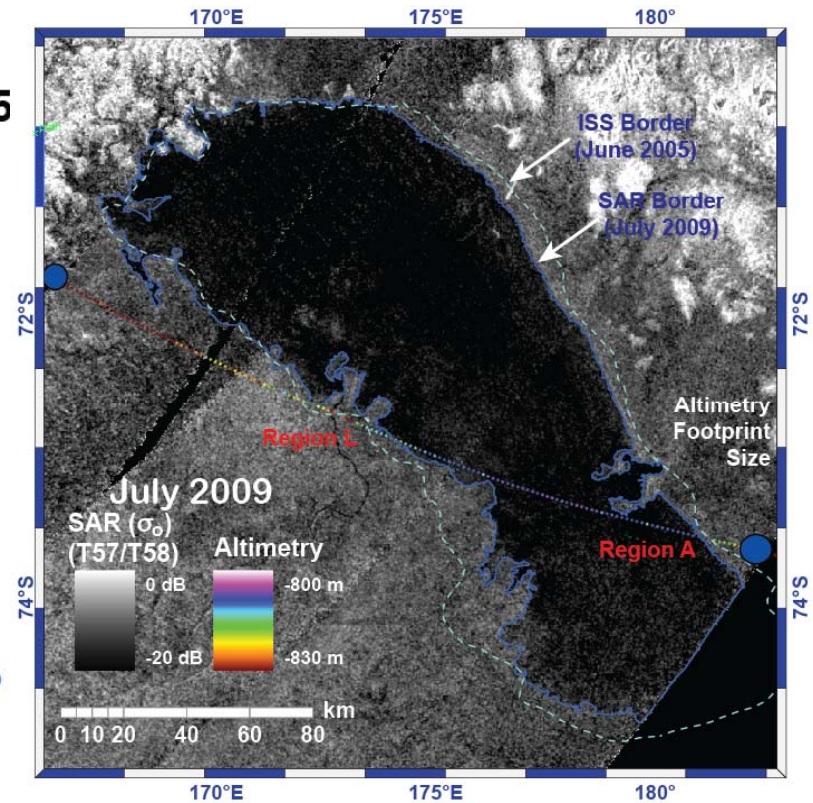

Wall et al., *GRL* 2010
72°S
74°S
72°S
74°S
km
0 20 40 80 120
164°E
172°E
180°
Hayes et al., *Icarus 2010*


Hayes et al., *JGR* 2010
164°E
172°E
180°
72°S
74°S
ISS Border (June 2005)
SAR Border (July 2009)
SAR
3 dB
-20 dB
Altimetry
-800 m
-830 m
Altimetry
Footprint Size
20 km
km
0
20
40
80
120
S = (1.22 ± 0.03) x 10 -3
S = (1.7 ± 0.6) x 10 -4
Lake
Elevation (m)
-700
-750
-800
-850
-900
-950
-1000
-1050
350
300
250
200
150
100
50
0
Along Track Distance (km)


164°E
172°E
180°
ISS Border (June 2005)
SAR Border (July 2009)
72°S
72°S
SAR
3 dB
-20 dB
Altimetry
Footprint Size
74°S
20 km
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


Hayes et al., *JGR* 2010
164°E
172°E
180°
72°S
74°S
ISS Border (June 2005)
SAR Border (July 2009)
SAR
3 dB
-20 dB
Altimetry
Footprint Size
A
km
0 2.5 5 10
20 40 80 120



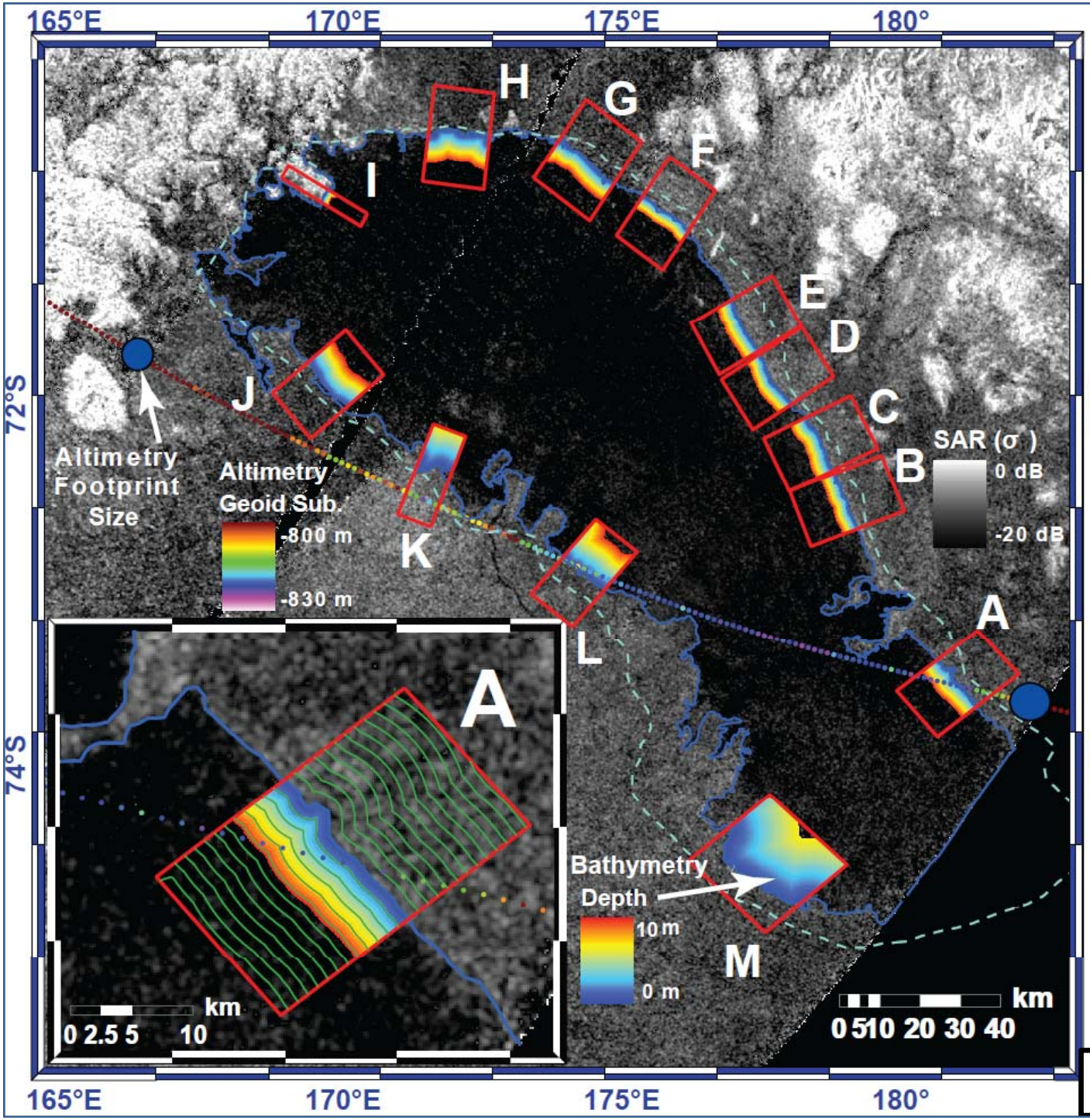


$$\sigma_o = \sigma_1 + \sigma_2 e^{\left(\frac{-8\pi\ \kappa\ d}{\lambda\ \cos\theta_{liq}}\right)}$$

$$\kappa = (6.1 \pm 1.6)\times 10^{-4}$$

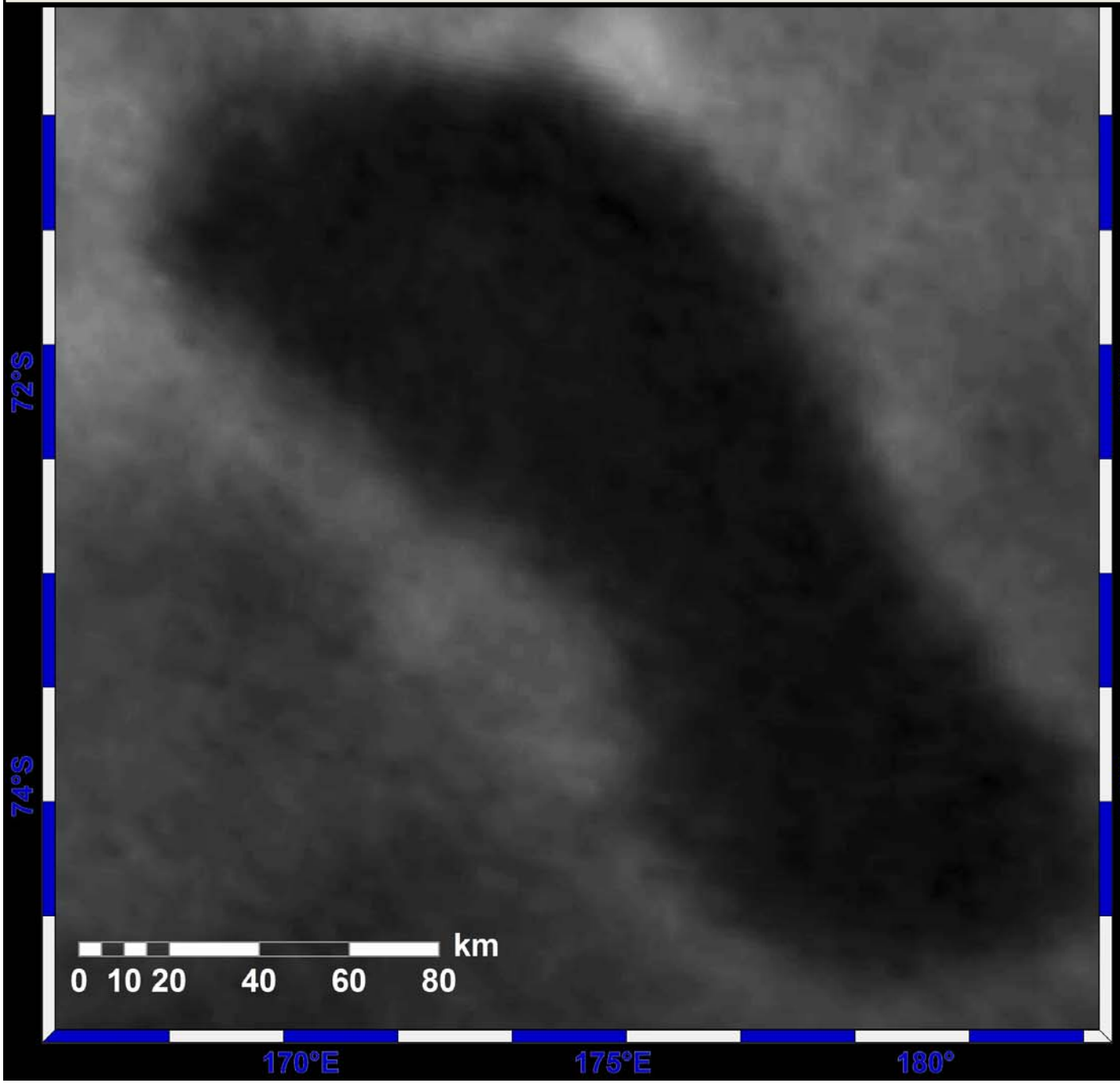
$$\tan\Delta = (9.2 \pm 2.4)\times 10^{-4}$$

Hayes et al., *JGR* 2010



Region	Slope ($\times 10^{-3}$)
A	2.0±0.1
B	2.5±1.6
C	2.3±1.4
D	2.3±1.7
E	2.2±2.4
F	2.7±0.8
G	1.9±0.7
H	1.4±0.6
I	4.9±2.0
J	1.2±0.9
K	0.74±0.14
L	1.0±0.5
M	0.46±0.15

Hayes et al., *JGR* 2010



Turtle et al., *GRL* 2009

June 2005

Δt = 3.8 yrs

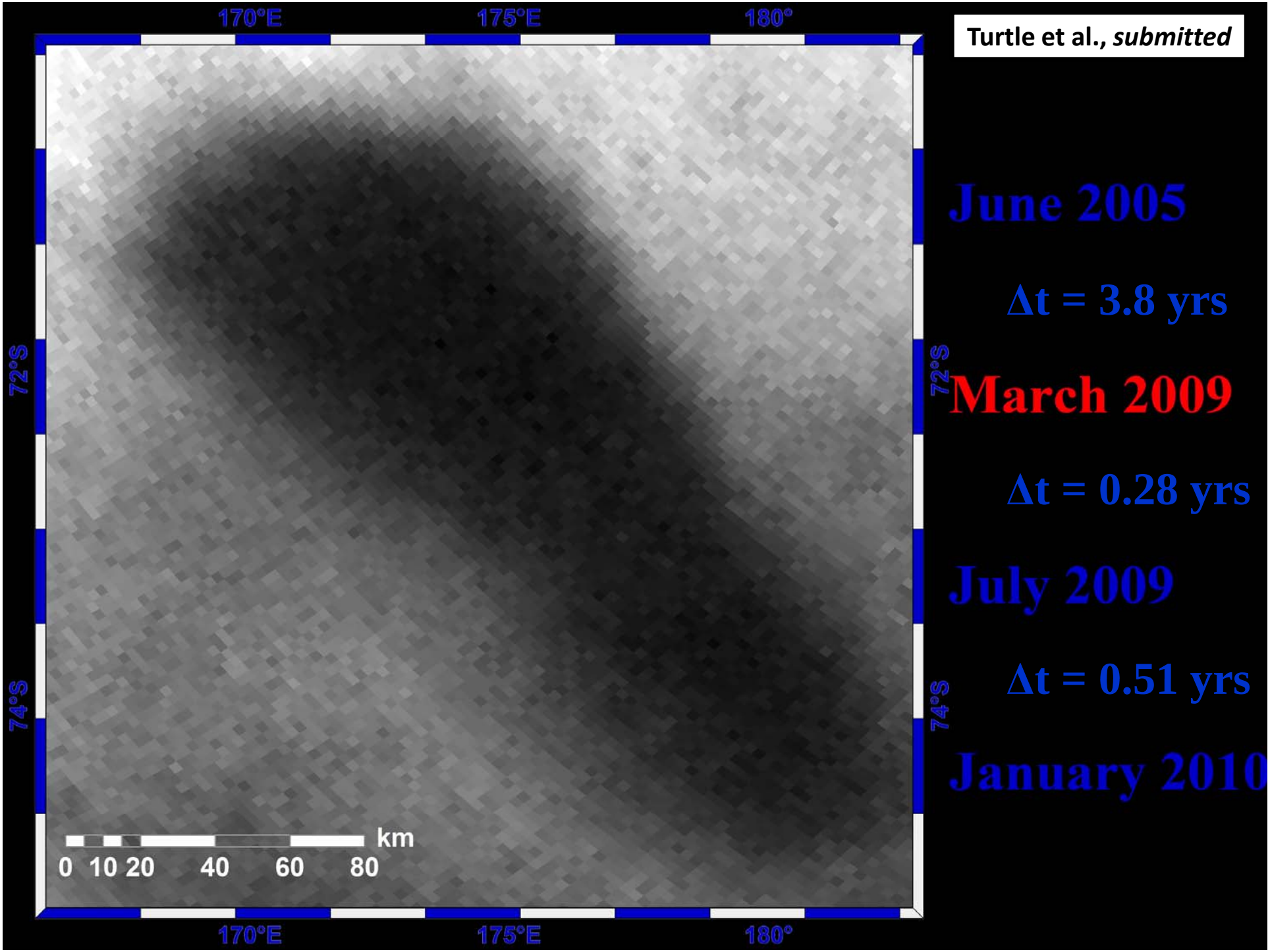
March 2009

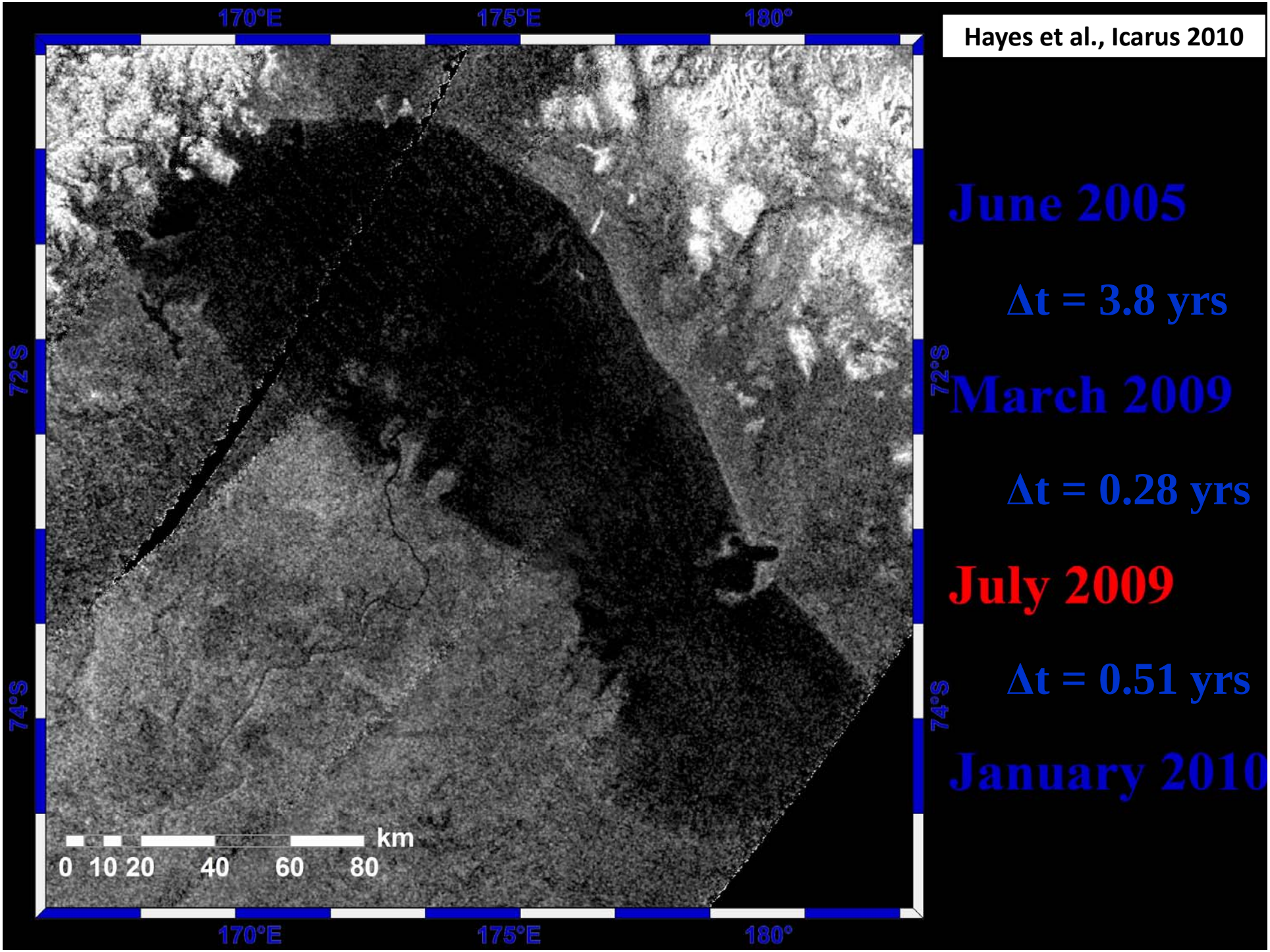
Δt = 0.28 yrs

July 2009

Δt = 0.51 yrs

January 2010


Turtle et al., *submitted*
170°E
175°E
180°
72°S
74°S
June 2005
Δt = 3.8 yrs
March 2009
Δt = 0.28 yrs
July 2009
Δt = 0.51 yrs
January 2010
km
0 10 20 40 60 80


Hayes et al., Icarus 2010
170°E
175°E
180°
72°S
74°S
km
0 10 20 40 60 80
June 2005
Δt = 3.8 yrs
March 2009
Δt = 0.28 yrs
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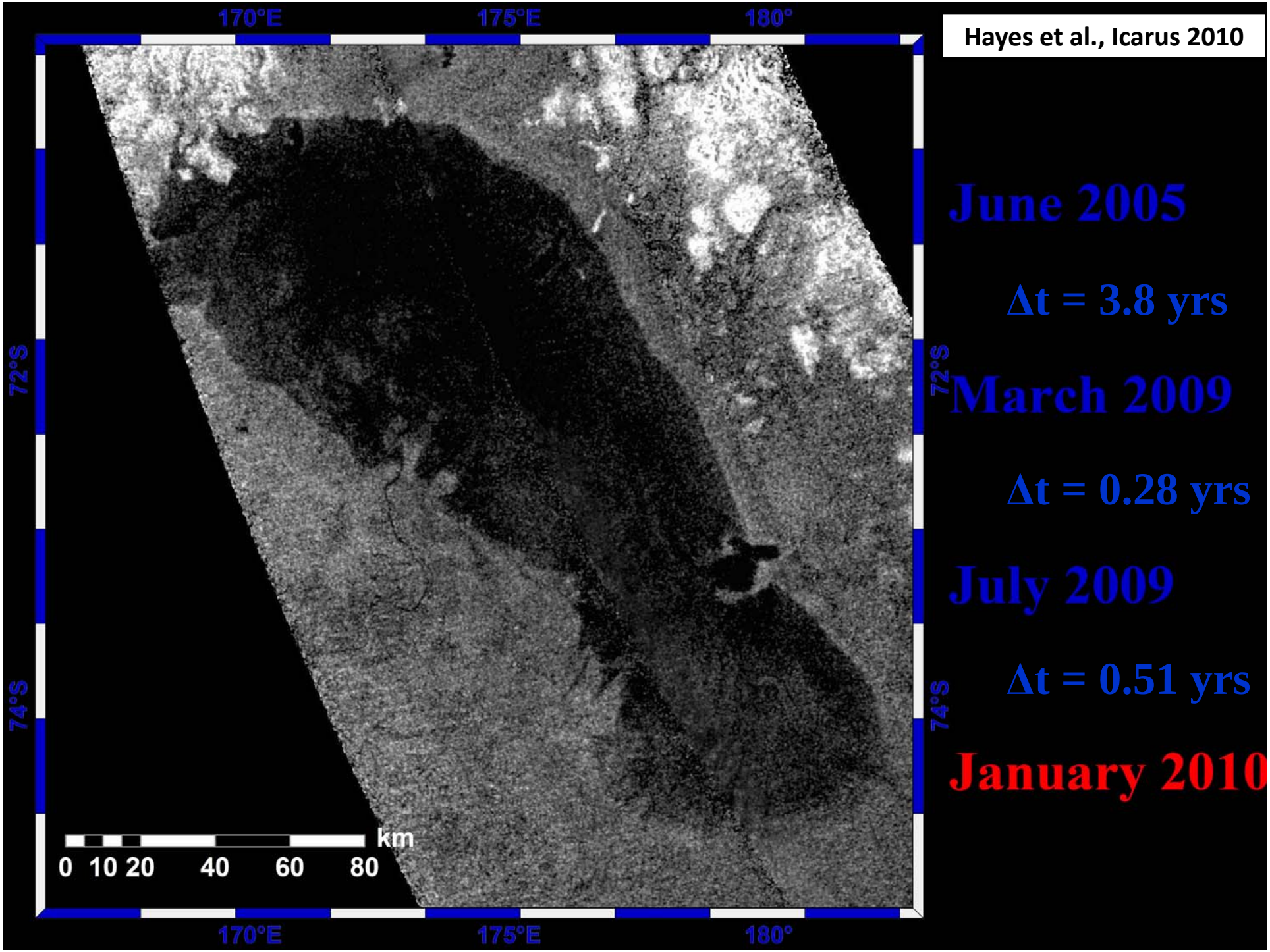
January 2010


Hayes et al., Icarus 2010
170°E
175°E
180°
72°S
74°S
km
0 10 20 40 60 80
June 2005
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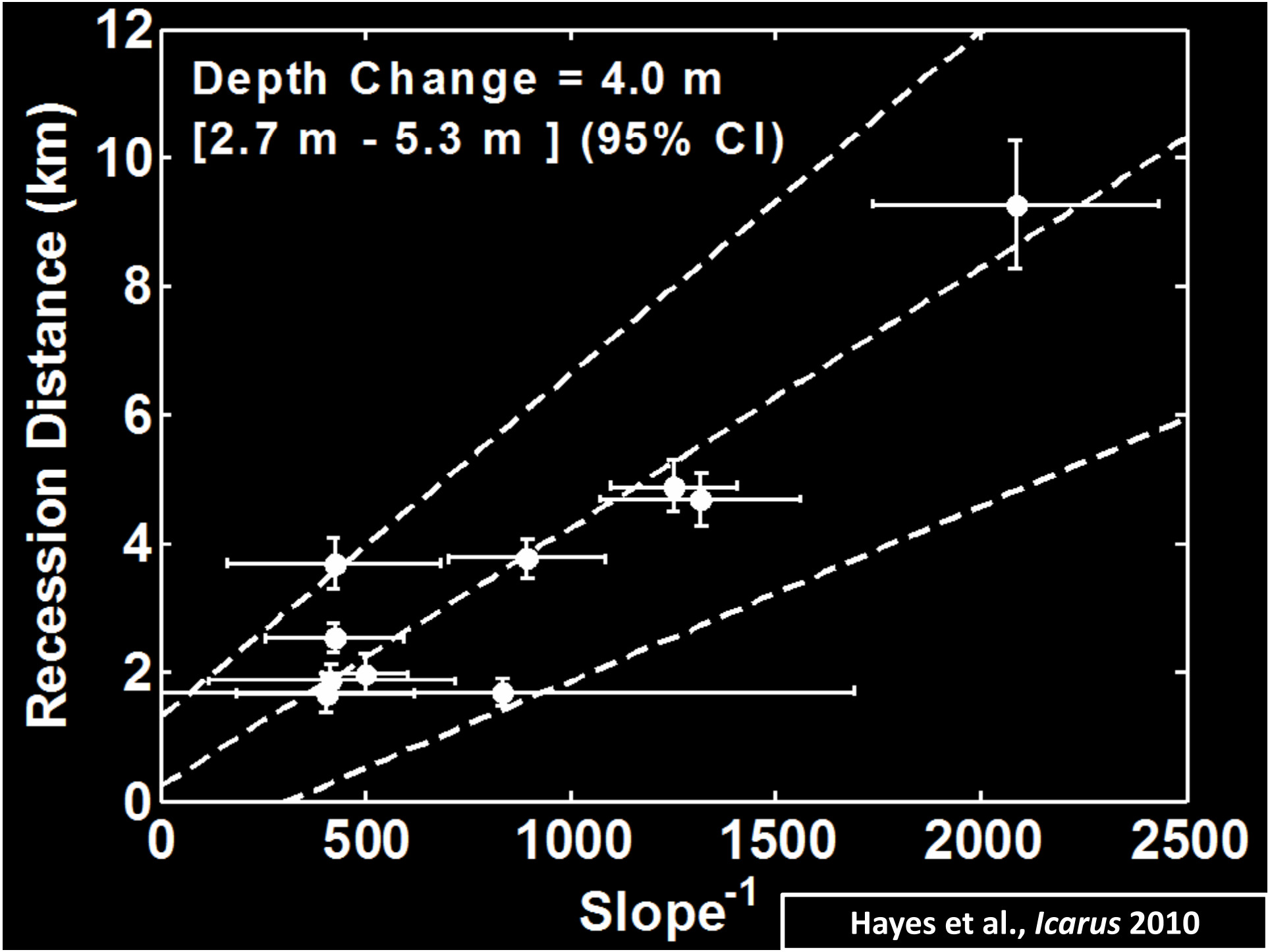
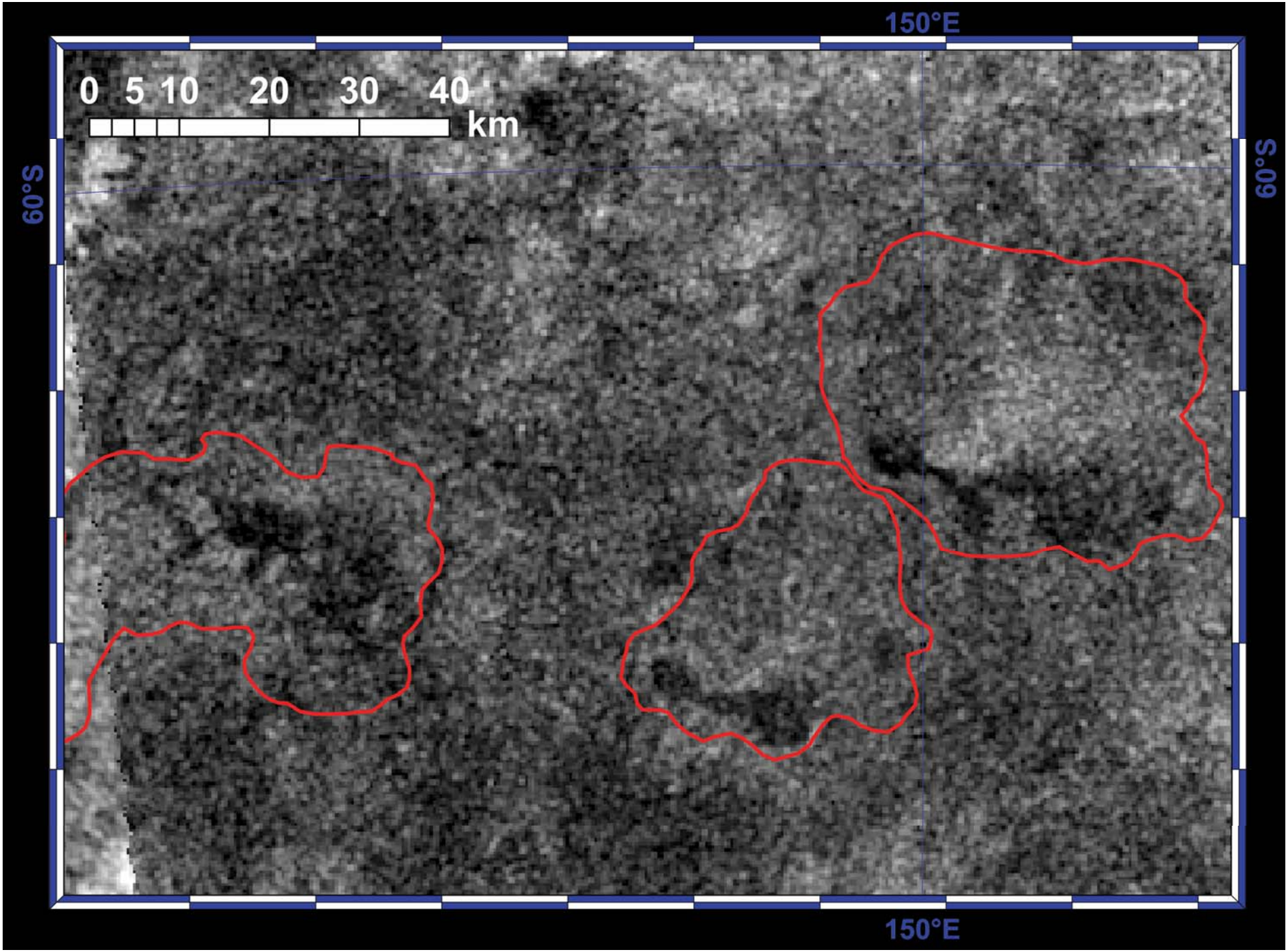
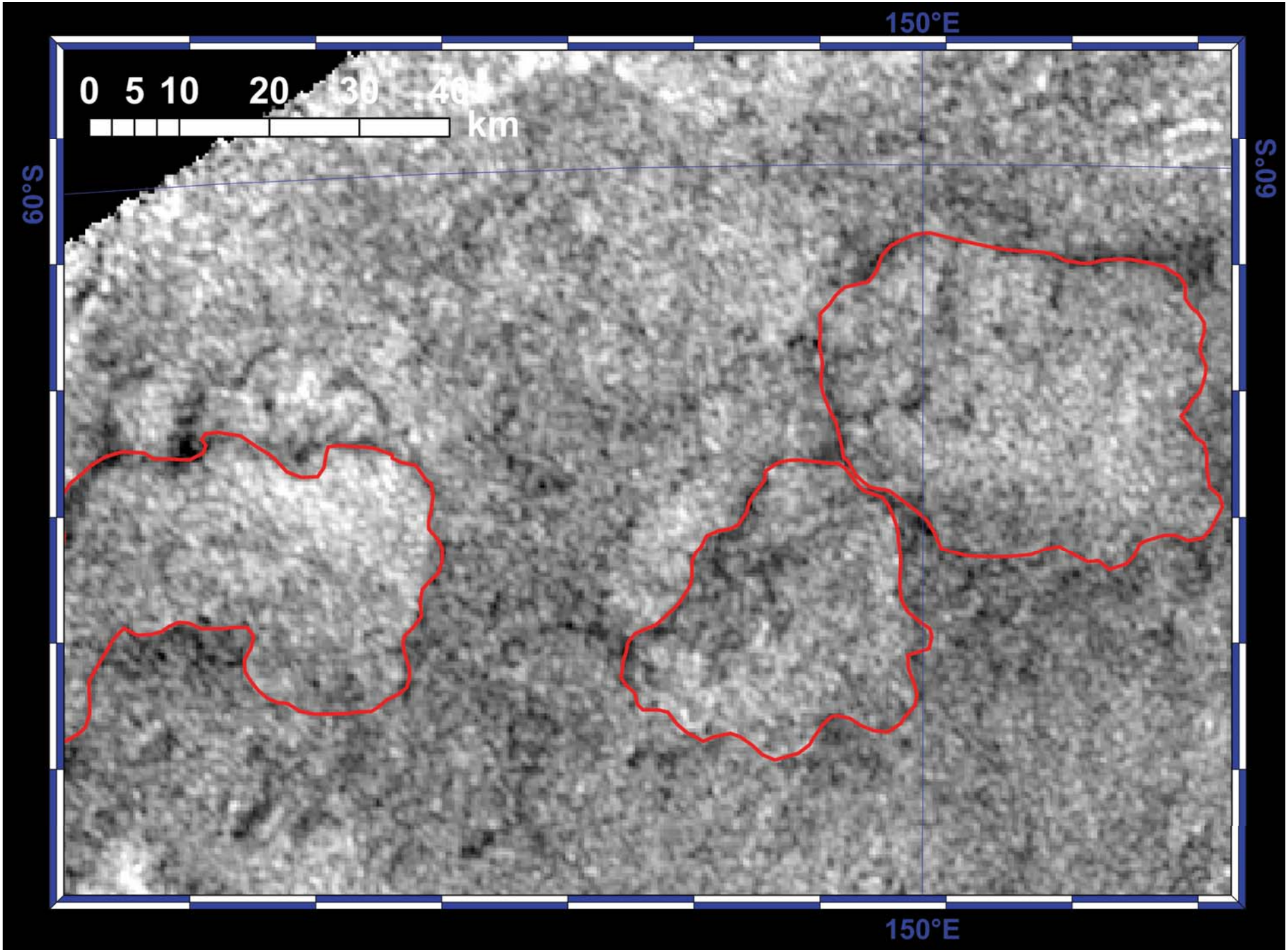
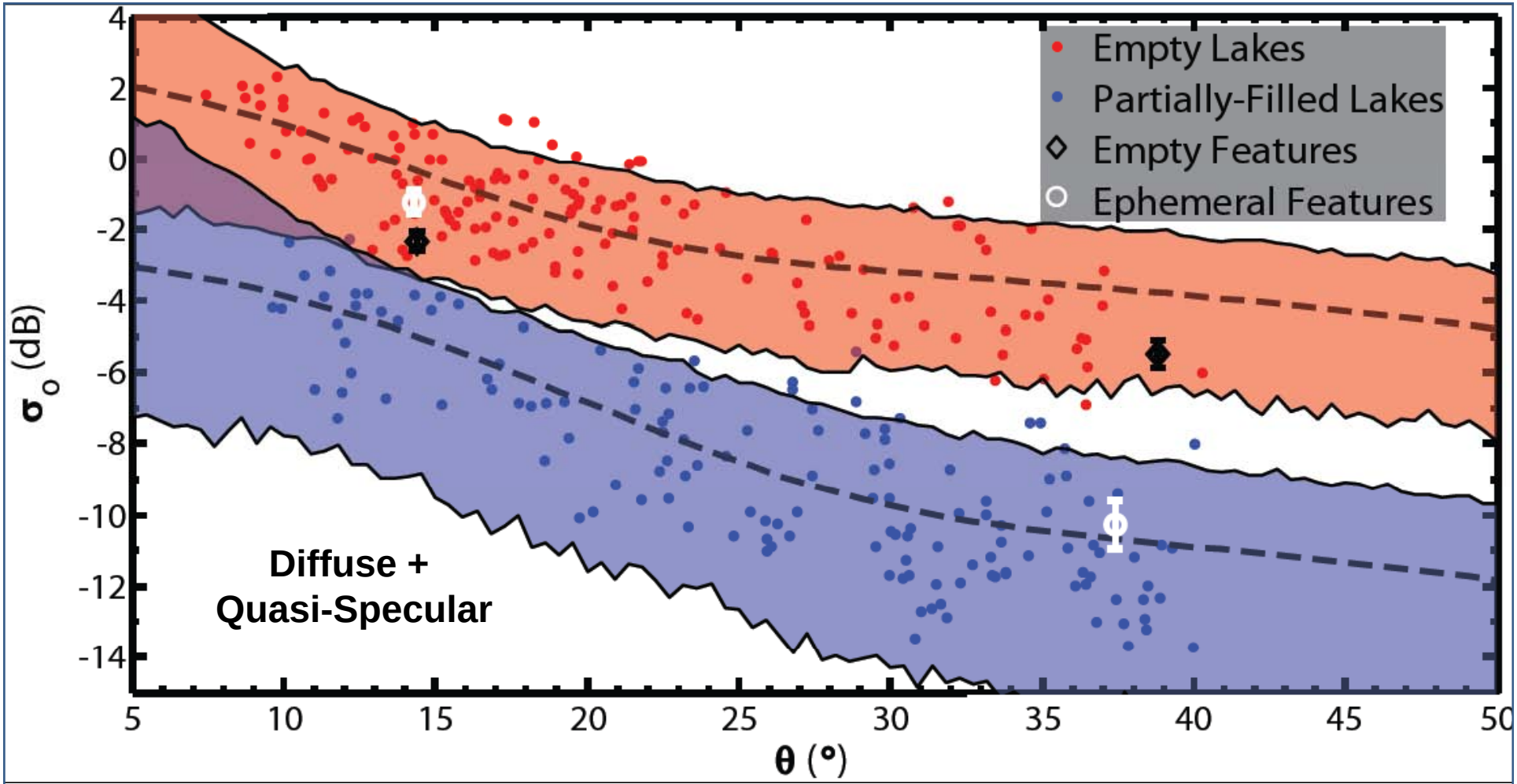


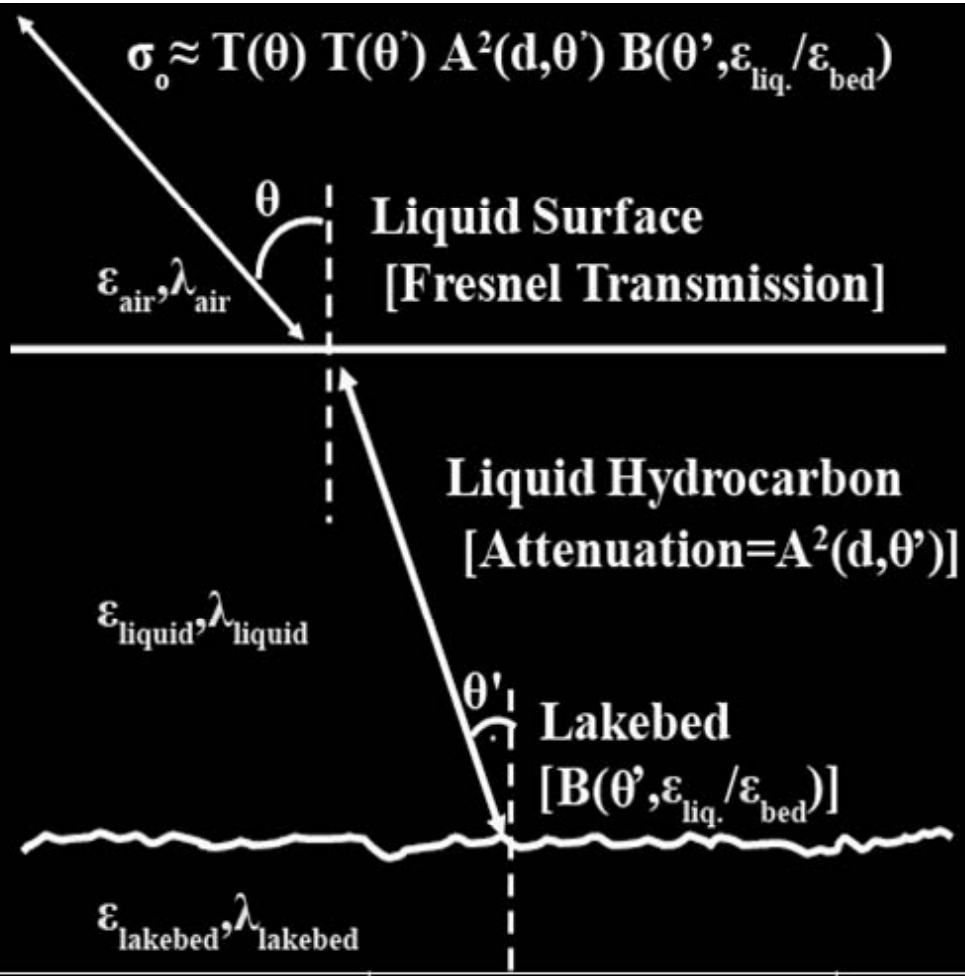
Hayes et al., *Icarus* 2010


150°E
0 5 10 20 30 40
km
60°S
60°S
150°E

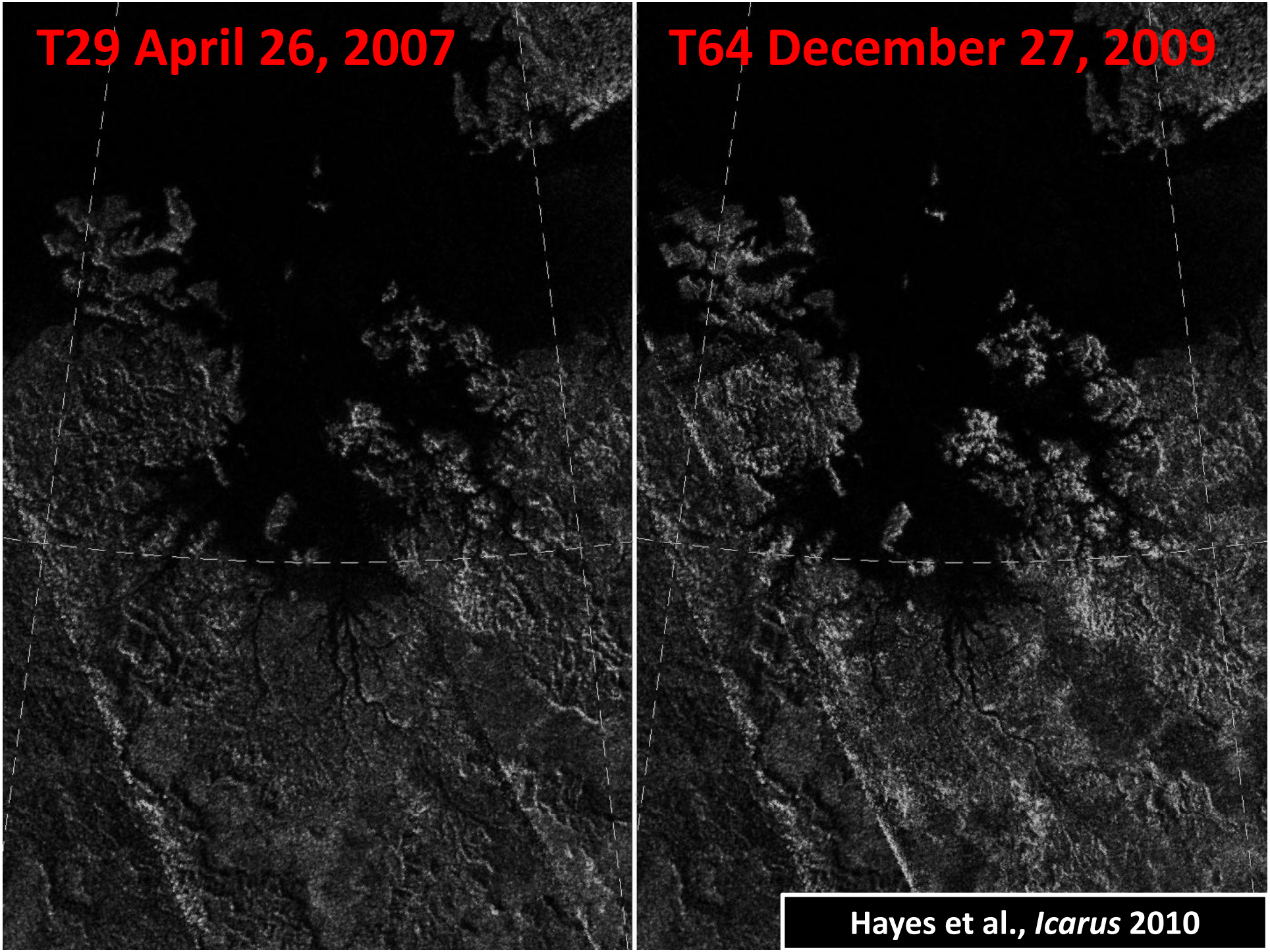

150°E
0 5 10 20 30 40
km
60°S
60°S
150°E

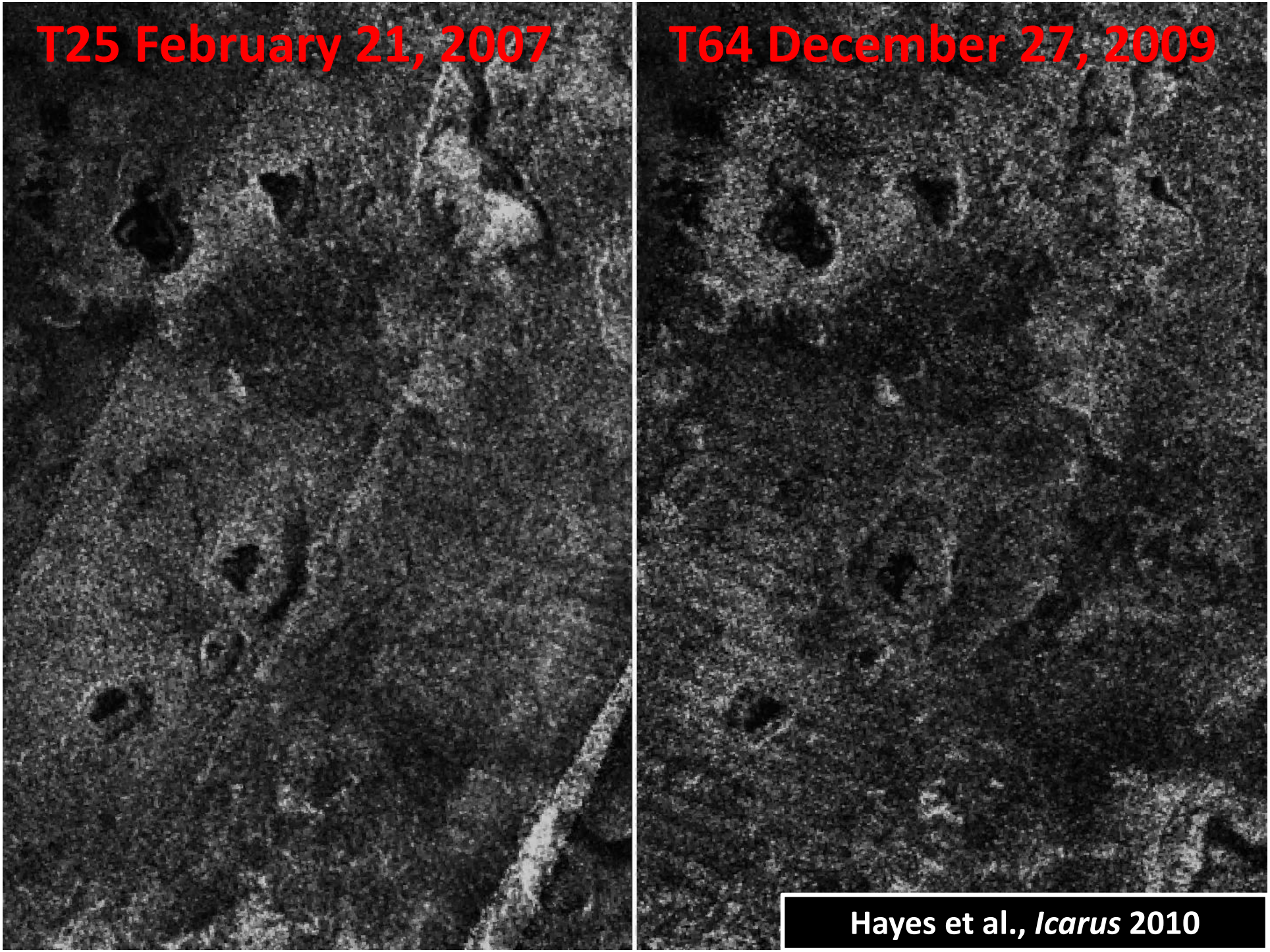


Feature	Best Model	Parameters			
		e	θ_{rms}	A	n*
Empty Lakes	Gaussian	2.74±0.3	12.88±1.6	0.57±0.07	1.22
Partially-Filled	Gaussian	2.09±0.16	15.84±2.0	0.11±0.02	1.22
Background	Hagfors	2.57±0.2	8.88±0.8	0.33±0.04	1.22

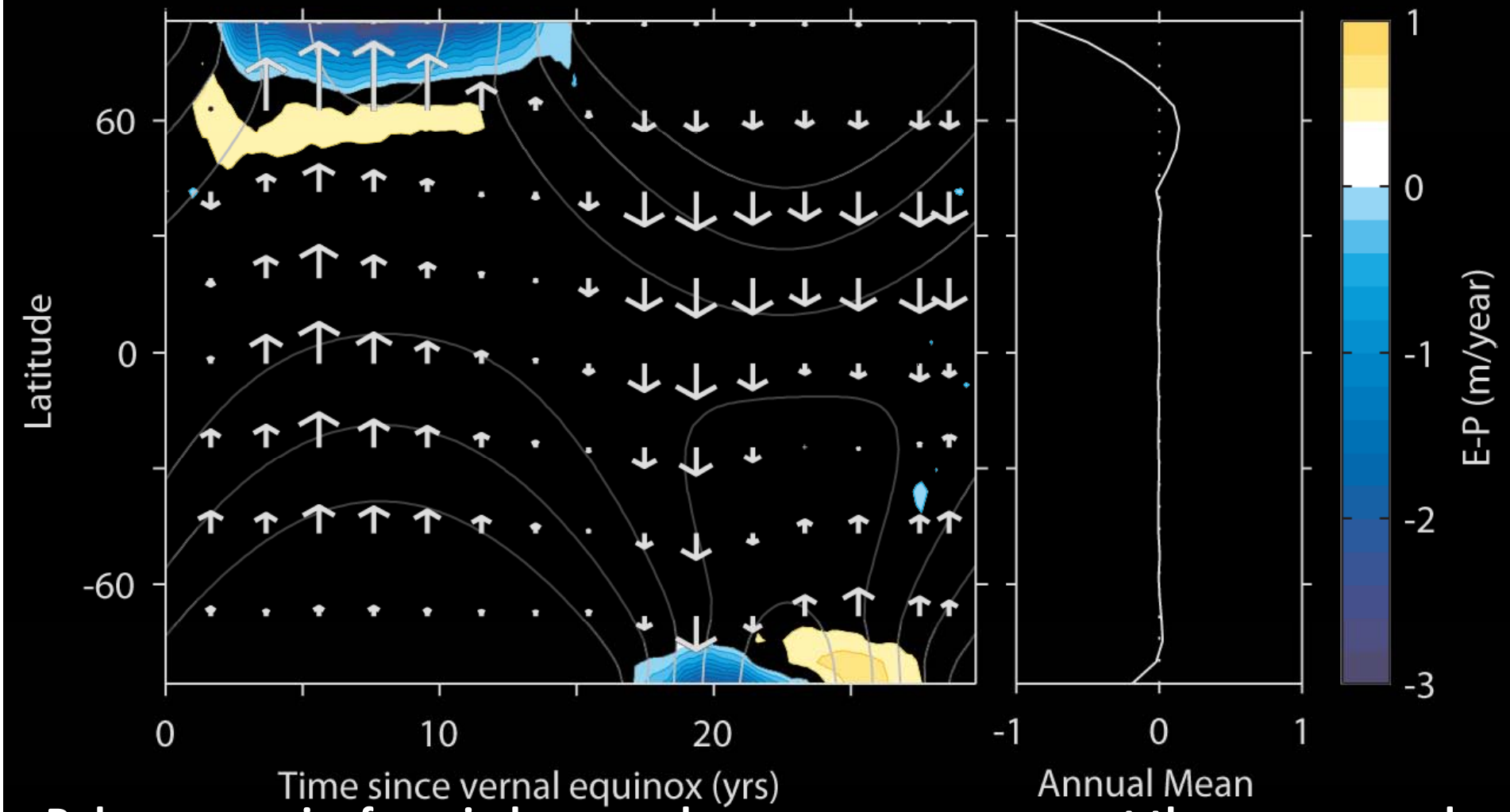


Swaths		Transition	Depth	Flux
T39	T55	Par.-filled to Empty	1.11±0.26 m	0.74±0.17 m/yr
T39	T55	Par.-filled to Par.-filled	1.14±0.28 m	0.74±0.19 m/yr
T36	T49	Par.-filled to Empty	0.85±0.20 m	0.68±0.16 m/yr
T36	T49	Par.-filled to Par.-filled	1.32±0.38 m	1.0±0.30 m/yr


T29 April 26, 2007
T64 December 27, 2009
Hayes et al., *Icarus* 2010



Hayes et al., *Icarus* 2010

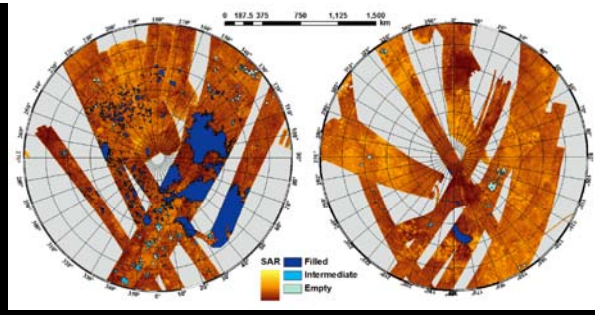


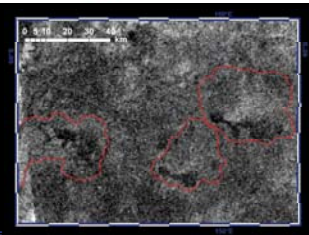
- **Polar reservoirs form in large-scale convergence zones at the summer poles.**
- **Methane is transported toward the summer pole by the mean meridional circulation and subsequently cold-trapped there.**
- **Moist static energy, or moist enthalpy, is maximum at the summer pole.**

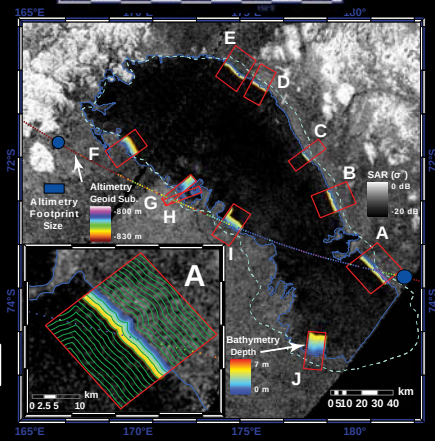
Graves et al., *Nat. Geo.* Sub.

What We Know

- **SAR observations of Titan's surface show a complex and active hydrologic cycle**
  - Lake size and morphology similar to terrestrial analogs [Hayes et al, GRL, 2008]
  - Statistically significant asymmetry [Aharonson, et al., Nat. Geo 2009]
  - Ephemeral Lakes suggest ~1 m/yr loss rates [Hayes, et al. Icarus 2010]







- **Near-shore backscatter at Ontario Lacus imply $\tan\Delta=(9.2\pm2.4)\times10^{-4}$ and loss rate of 1±0.3 m/yr**

  -Consistency between:
  - Interpreted geology/morphology [Wall, et al. GRL 2010]
  - Measured slopes from backscatter atten. [Hayes, et al. JGR 2010]
  - Recession rate [Hayes, et al. Icarus, 2010]

- **Asymmetric lake distribution can be a result of orbital asymmetry in Titan's seasons**
  - **Orbital parameters vary on 10 kyr timescales**
  - **Consistent with lake coverage, crater distribution, and insolation energetics [Aharonson, et al., Nat. Geo 2009]**

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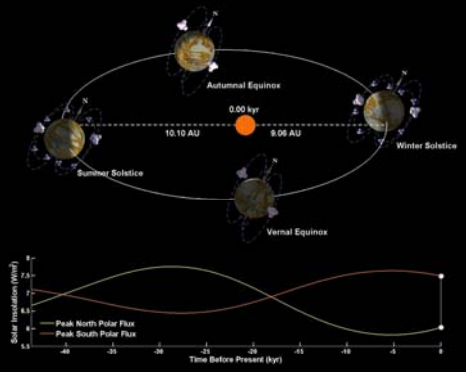
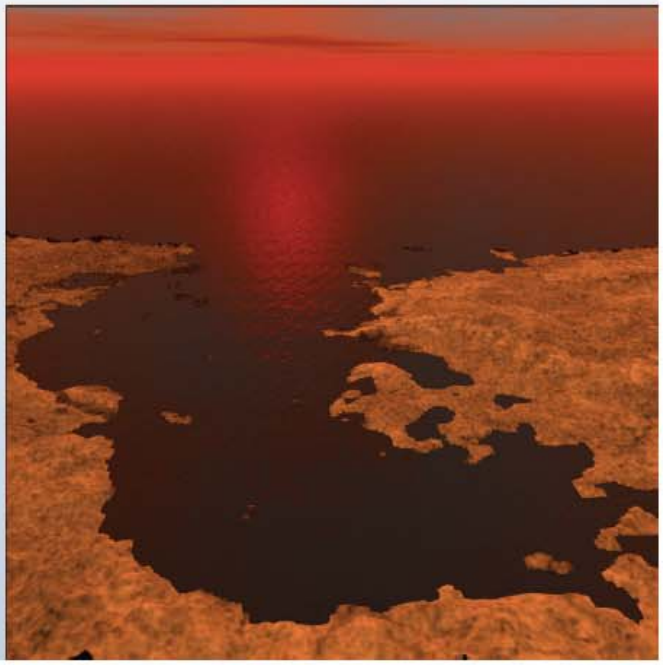
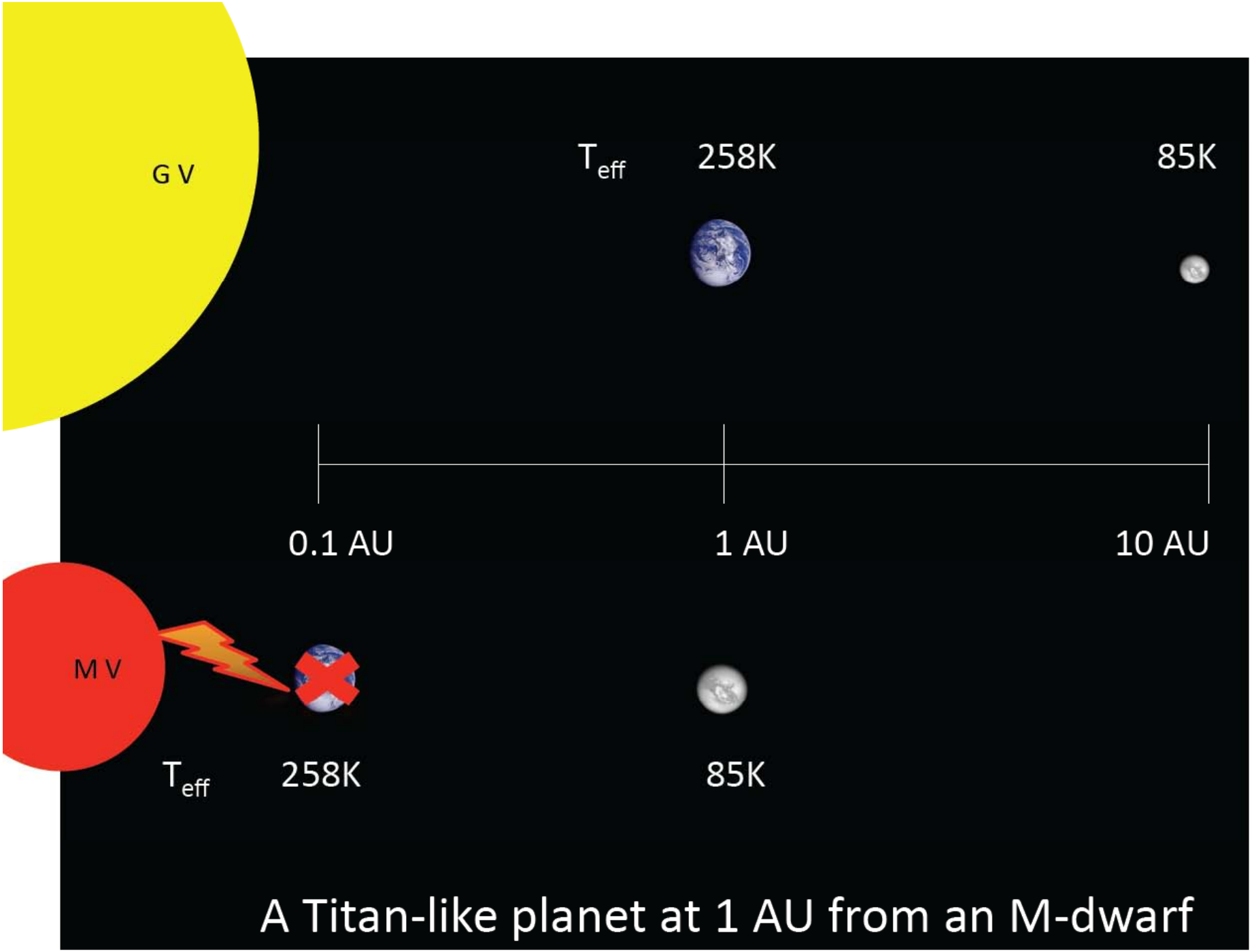


Could methane and ethane act as a liquid medium for life?

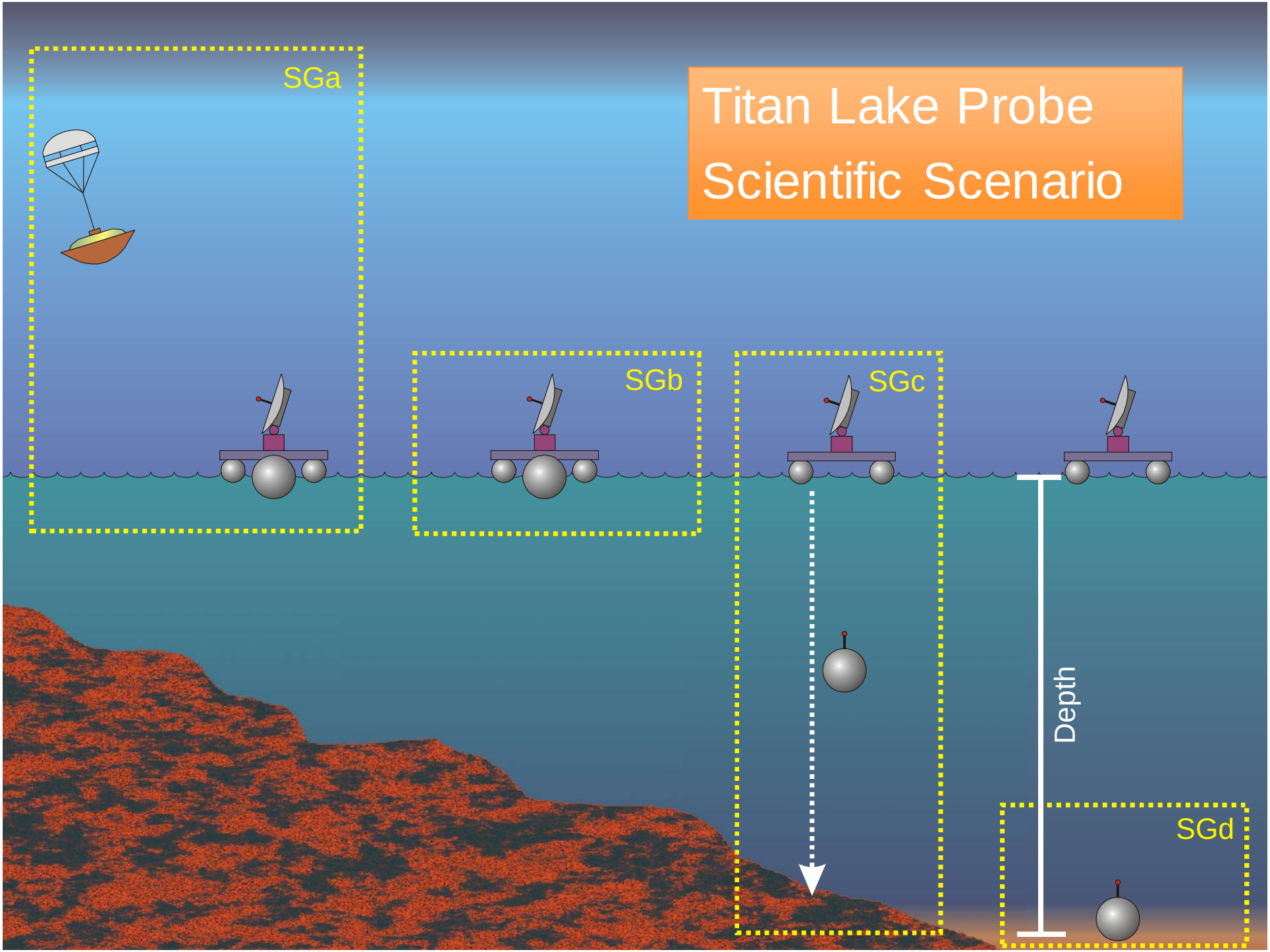
- Allows organic molecules to hydrogen-bond
- Suitable for low temperatures
- Polar hydrocarbons might create "insides" and "outsides" in liquid ethane/methane
- "Biological" molecules would be dominated by C-N bonds rather than C-O as on Earth. No DNA, or RNA, or proteins…



Steve Benner and colleagues



Jonathan Lunine: Titan Short Course


Titan Lake Probe
Scientific Scenario
SGa
SGb
SGc
SGd
Depth

Fundamental Challenges in Liquid Sample Acquisition on Titan

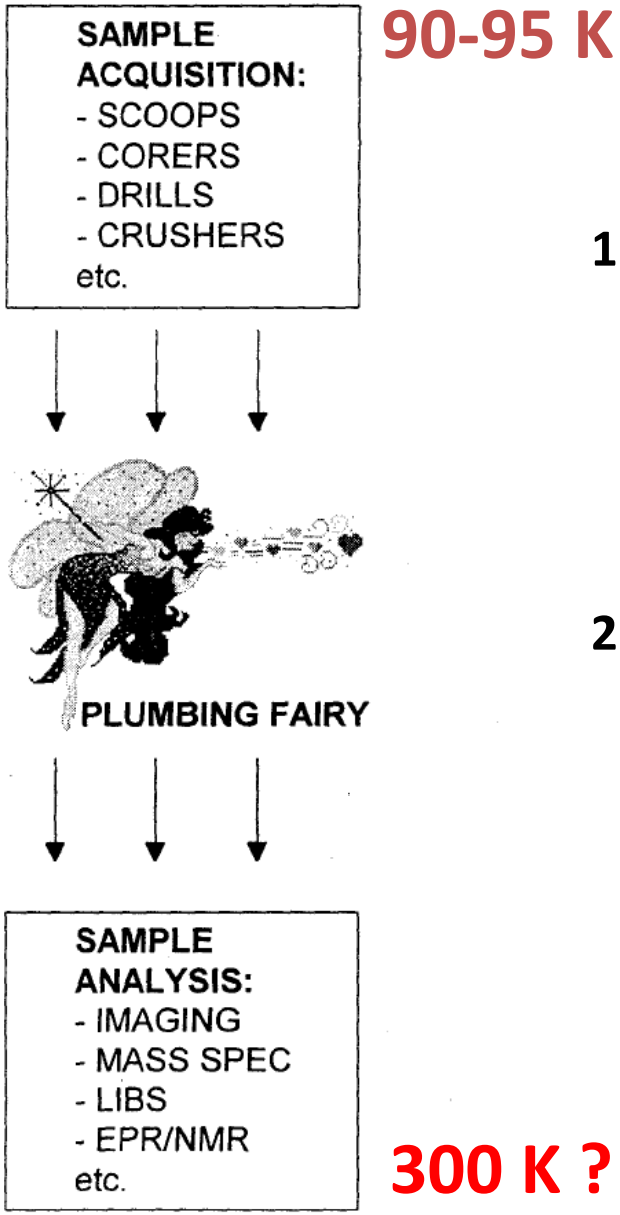


Figure 1. A technology gap exists today between sample acquisition and sample analysis tools. Integrated science payload packages need an

Bearman and Kossakovski, IEEE 2001

1. Low temperature (90-95 K) environment

   - Must inject sample into analysis system without alteration
     (acquisition system also at 90-95K)

2. Thermal gradient between sample tube inlet and sample collection chamber

   - Thermal Volatilization of sample
     - Particulates and high order hydrocarbons may not volatilize
     - Potential for real-time TV analysis (complex thermal model)
   - Volume (pressure) increase

3. Contamination of sample handling system (Condensation in plumbing)

Stephan et al., submitted
North Pole
For more information visit:
http://www.gps.caltech.edu/~hayes/
Hayes et al., GRL 2008