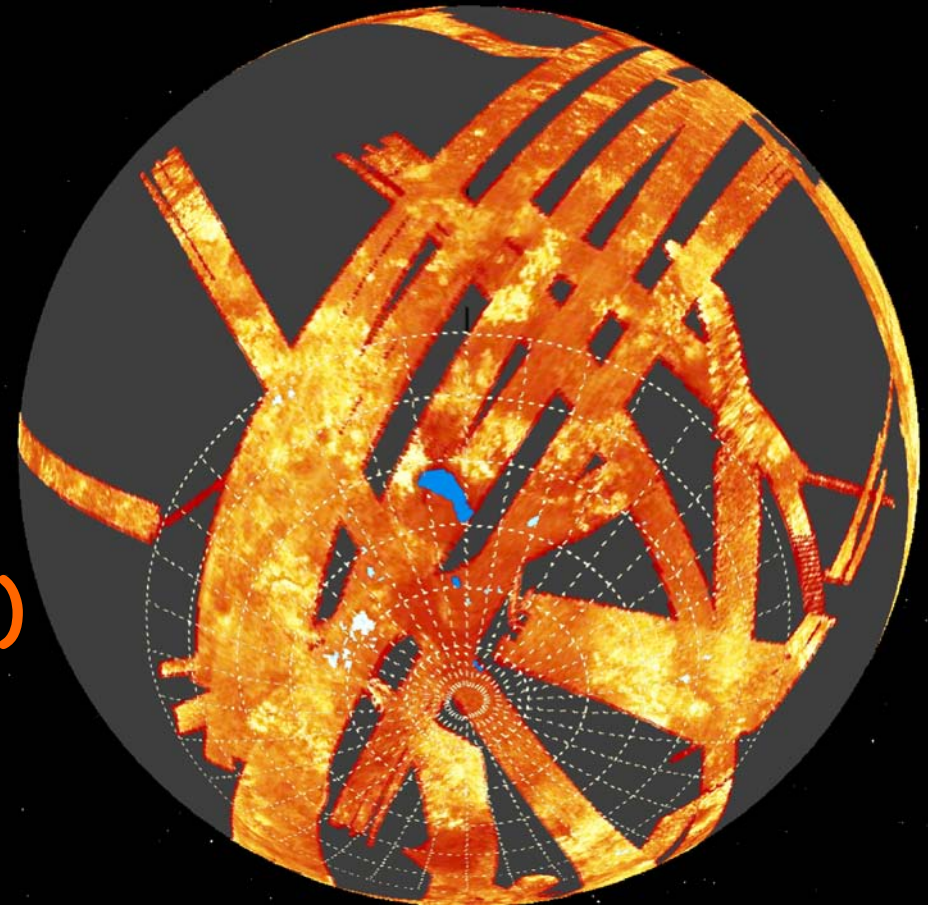
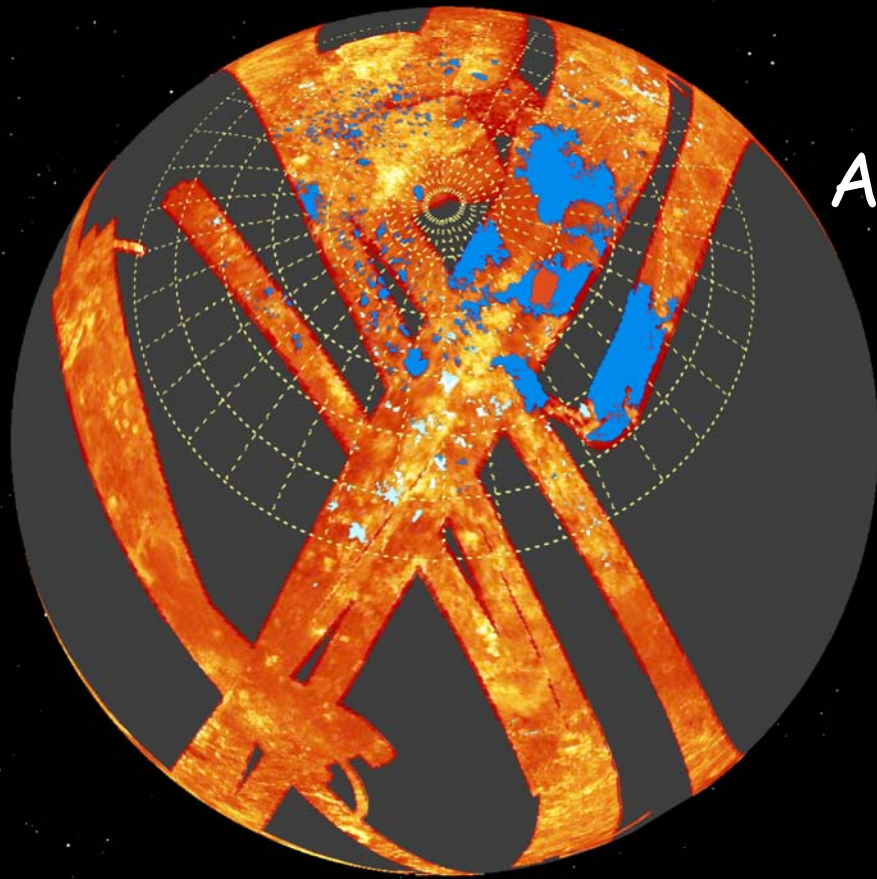


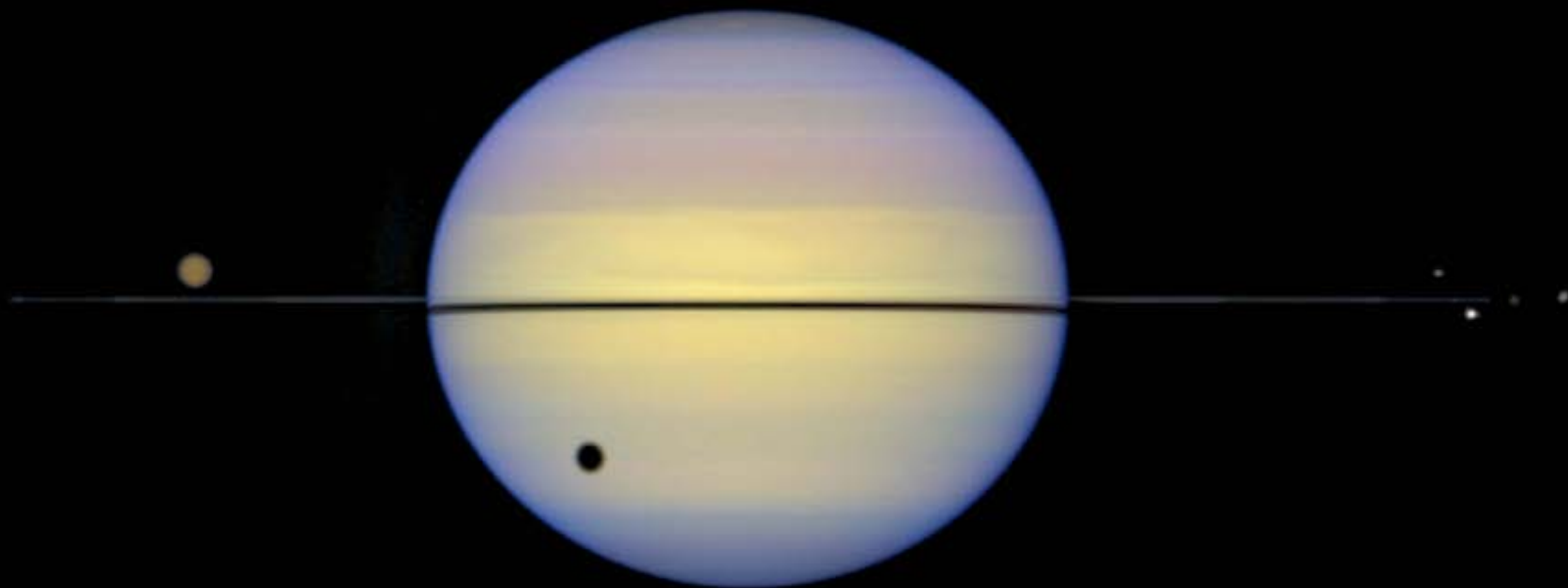
Unveiling Titan:

A World Strange and Familiar



Oded Aharonson (Caltech)

Alex Hayes, Jonathan Lunine,
Ralph Lorenz, Michael Allison,
Charles Elachi, Cassini Radar
Science Team



HST, Wide Field Camera 2

Voyager 1 - 1980

A Hazy world. Hemispheric Asymmetry,
Polar Collar/Hood

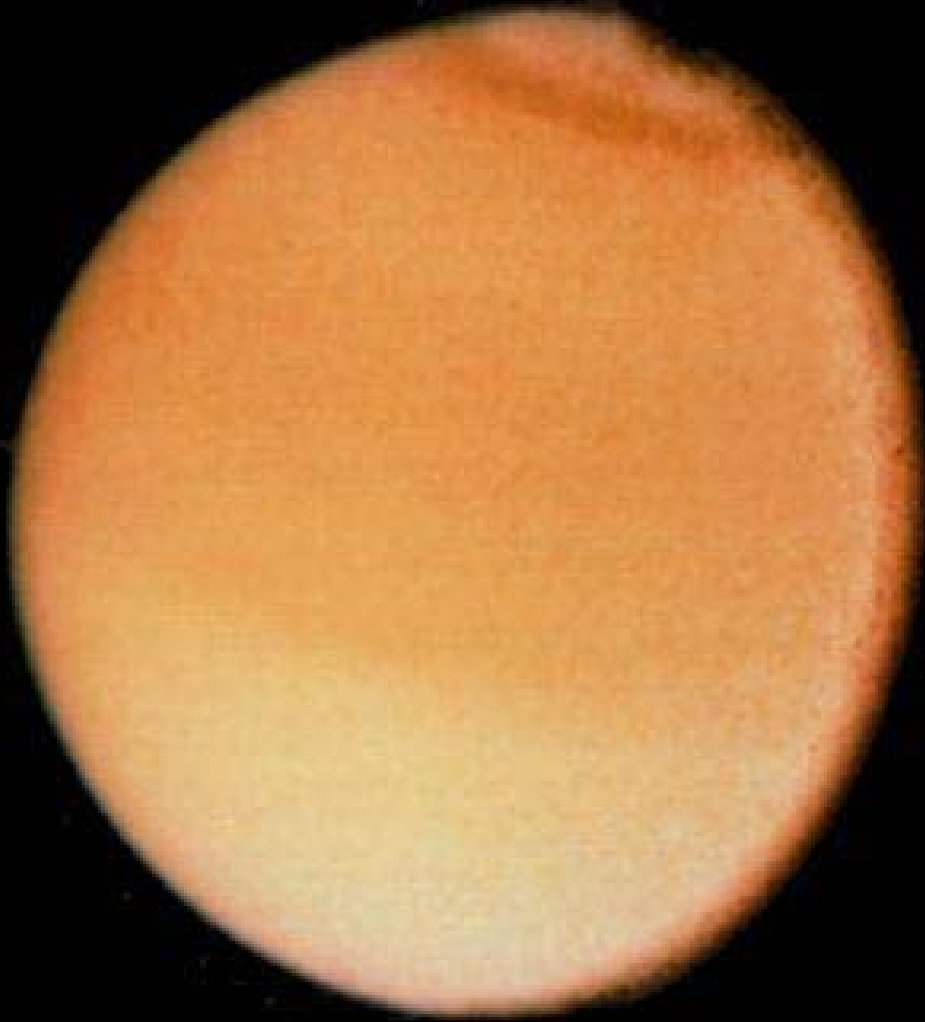


Image Credit: NASA/JPL/Caltech

UV radiation and corona
discharge of N_2/CH_4
mixtures

End product - '**tholin**'
(from Greek 'muddy', via
Carl Sagan)



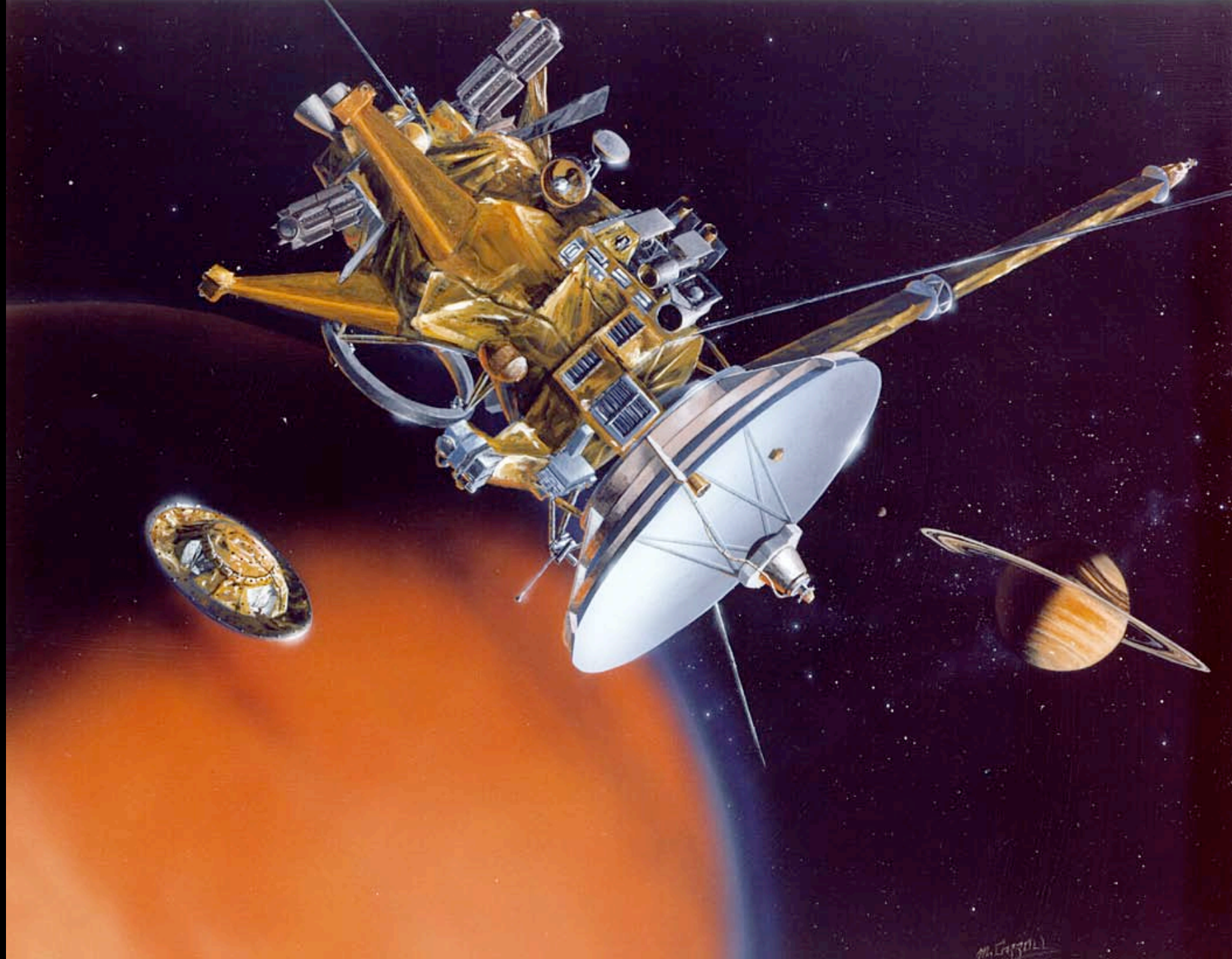
Titan: A New World



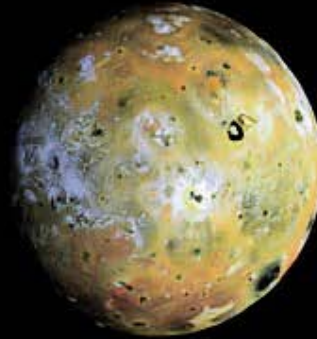


10 15 '97

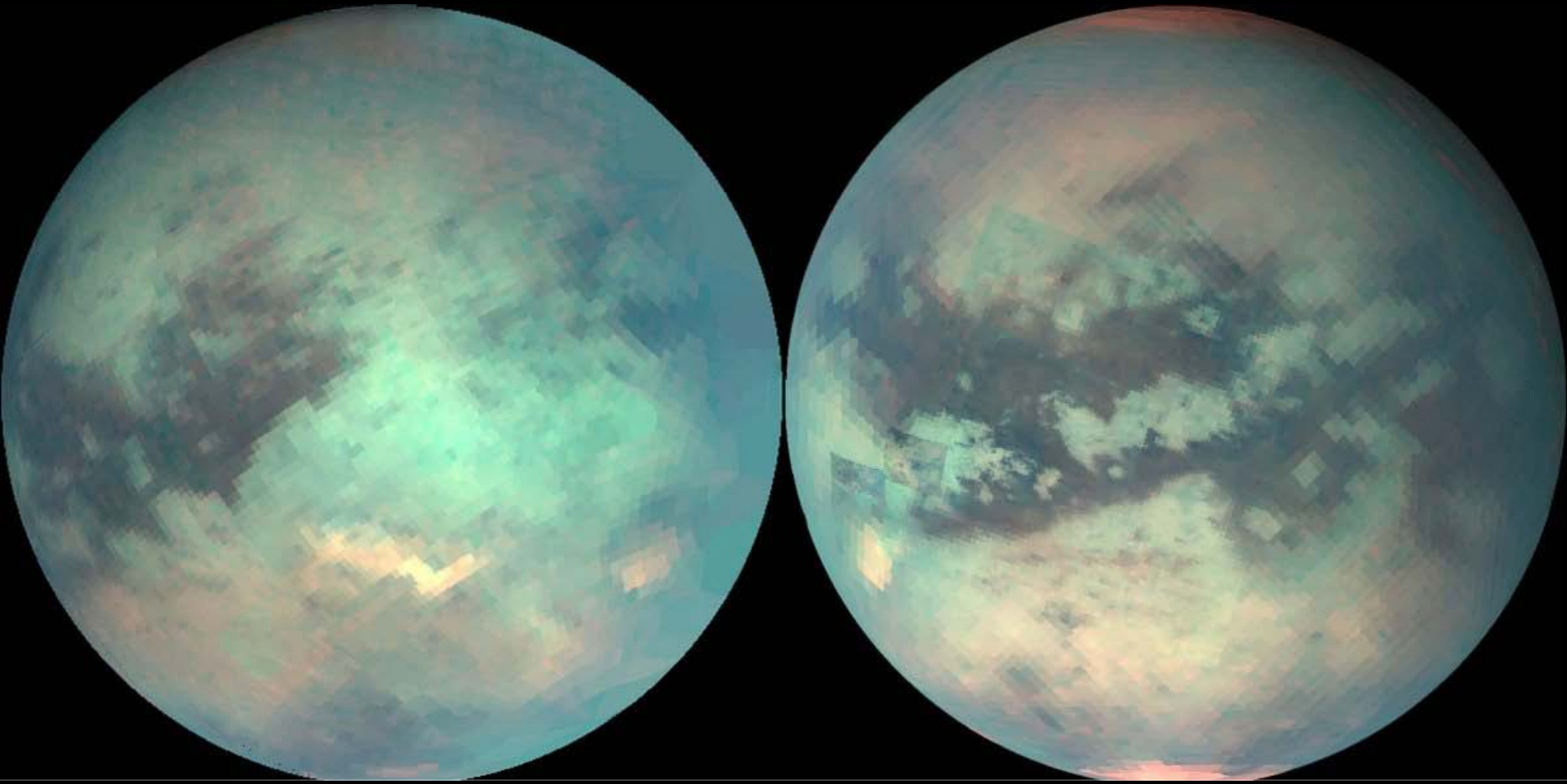
Photo by K. Sturgill, Marion, Virginia



The Magnificent Seven:



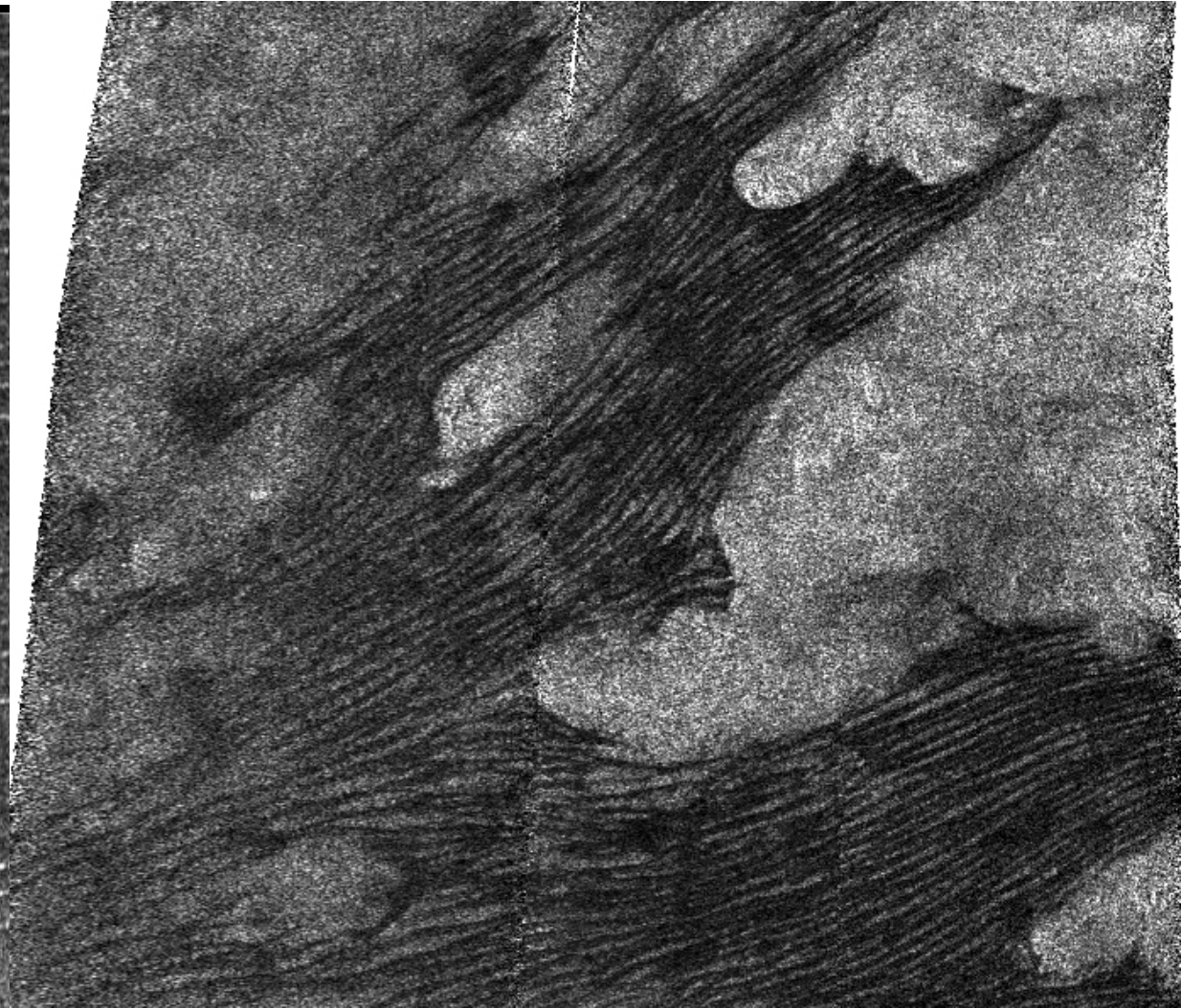
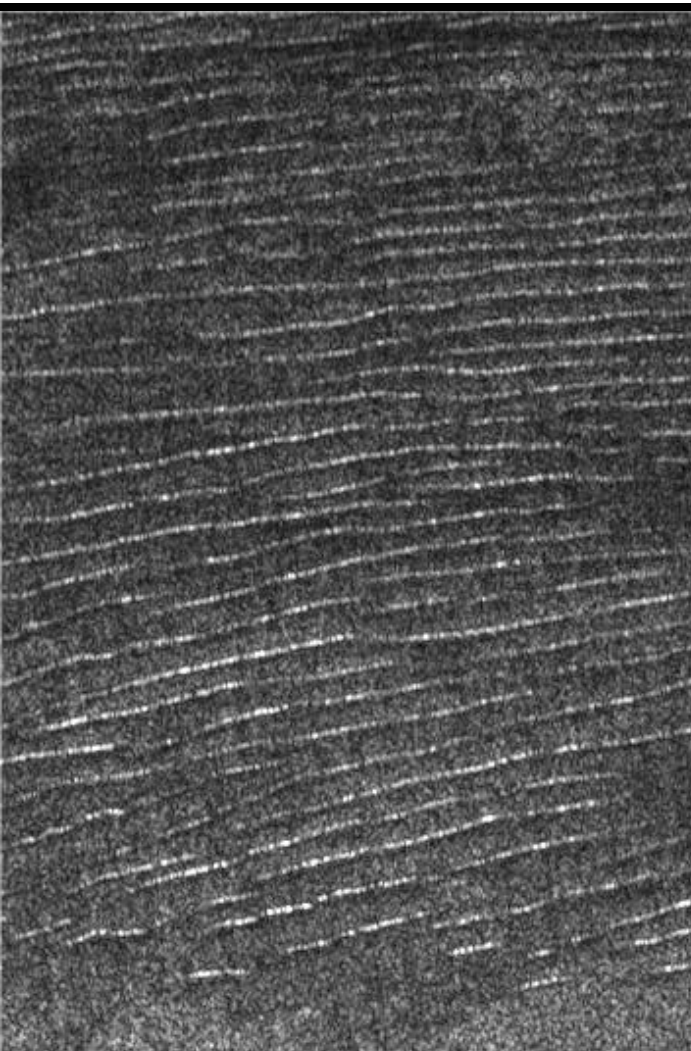
Cassini VIMS: Titan's spectral diversity



Based on Barnes et al., 2007

Titan's Dune

1-2 km spacing
150 m characteristic heights

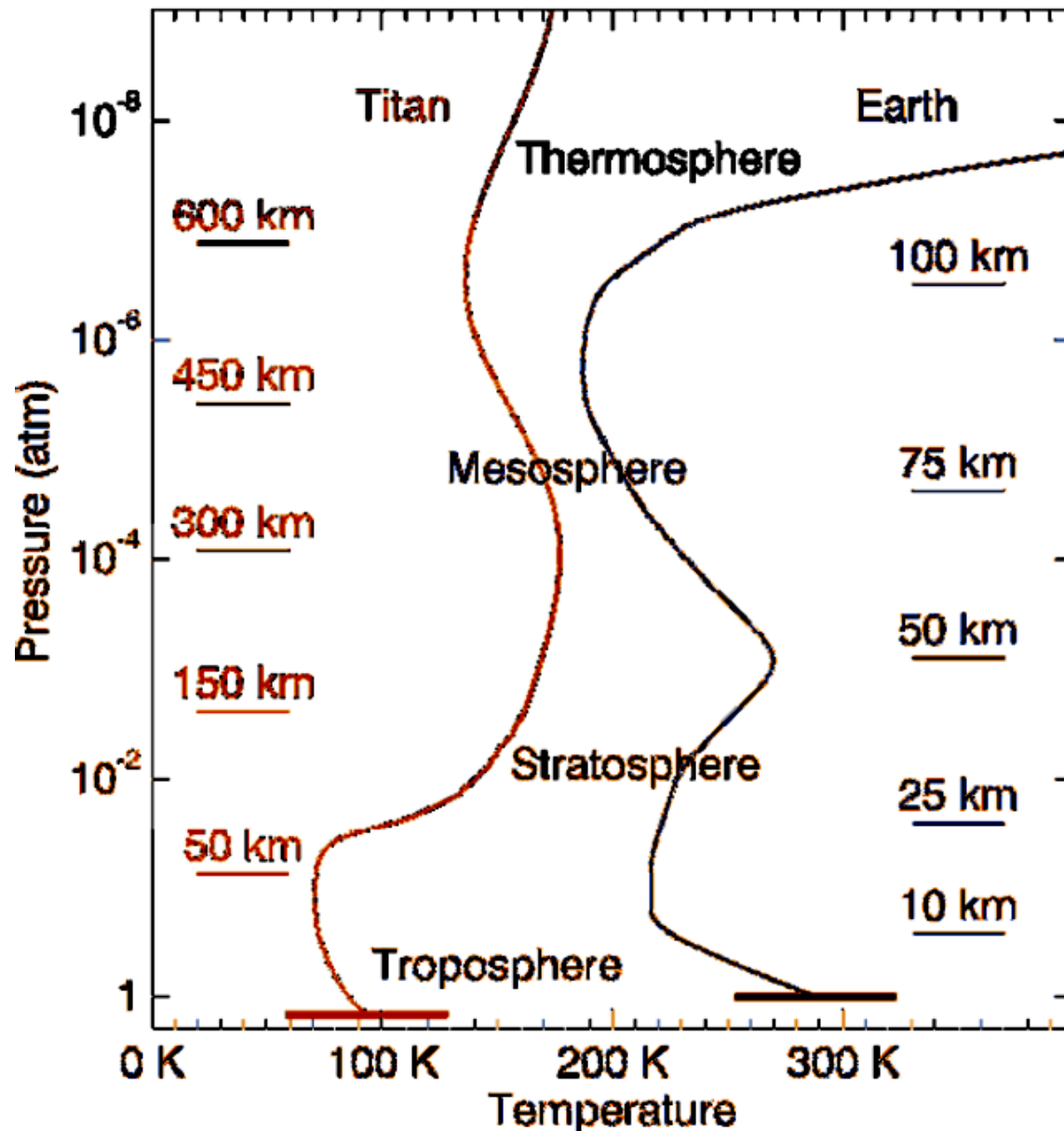


Linear Dunes in the Namib Desert

Shuttle handheld digital camera
STS107

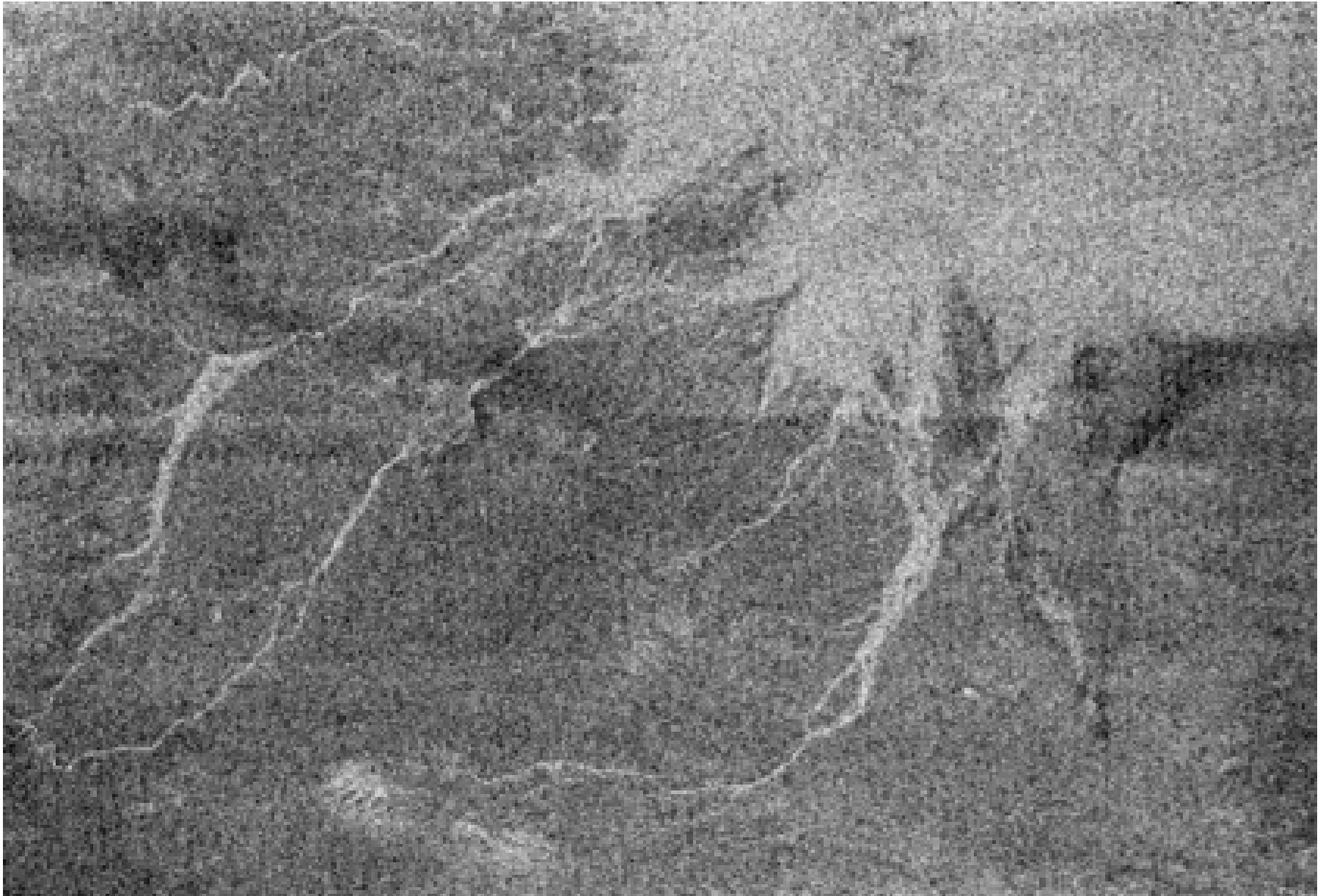


Titan's Hydrologic Cycle



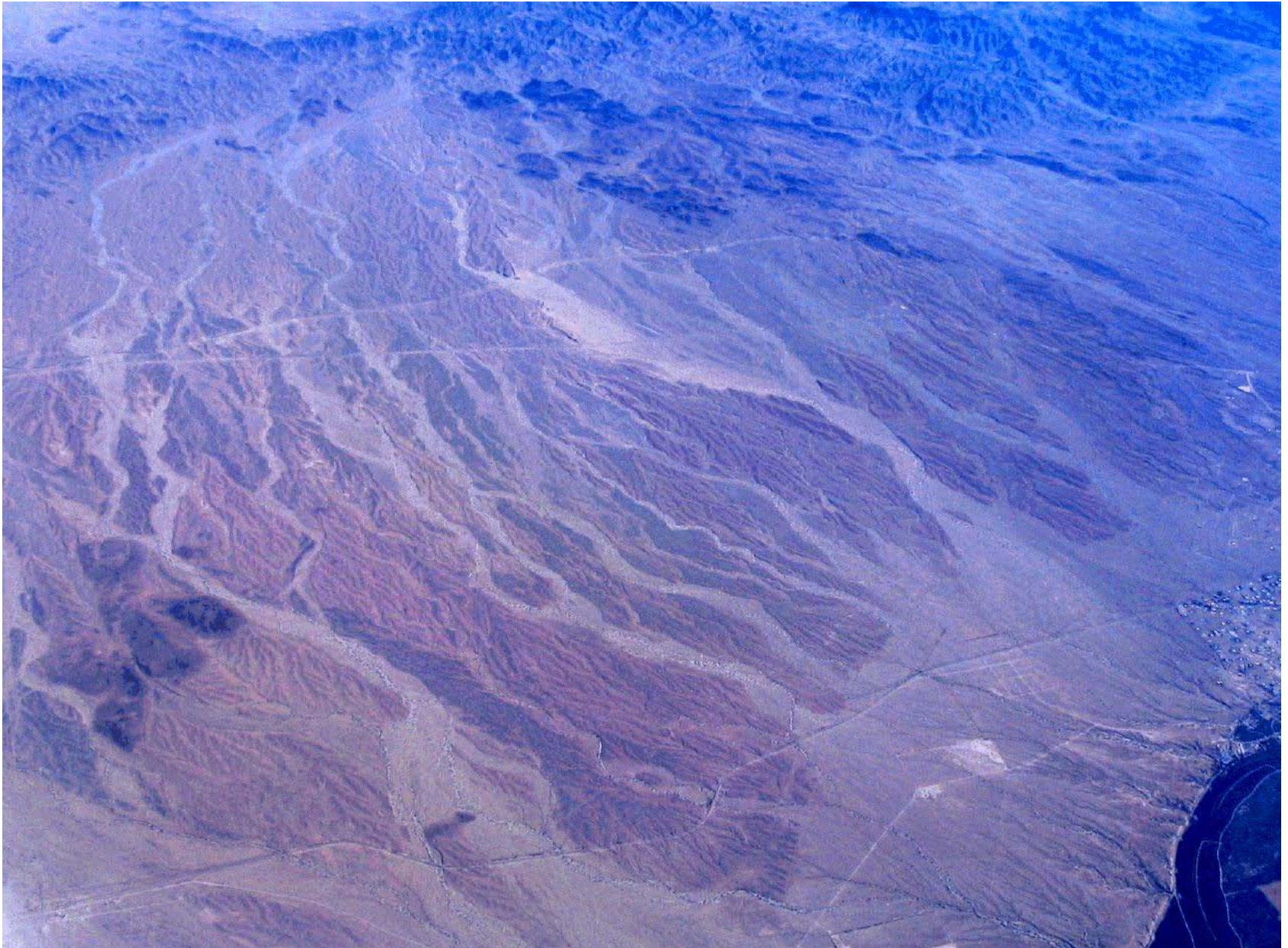
Elivagar Flumina

Braided, sinuous channels



Analog Site - near Parker AZ

(identified from airplane window, TUS-LAX circa 730am)





Titan's Odds @ Caltech

Titan betting pool


What will the Huygens probe land in/on?

Place your bets now,
for bragging rights later!

GOING TO
LAND ON
TITAN
LADY
TITAN
YES

Ice
Emma
Greg
Kauah

Tar
Emily
Geoff
Soto
Bruce

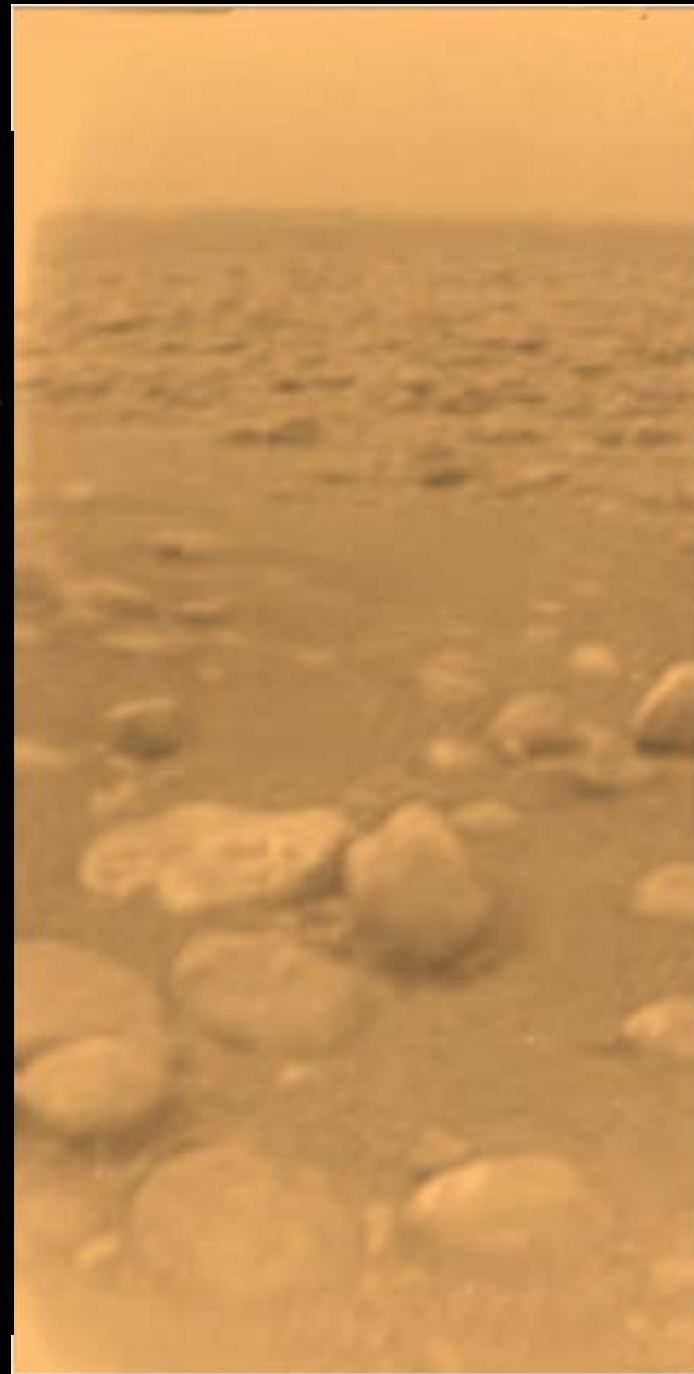
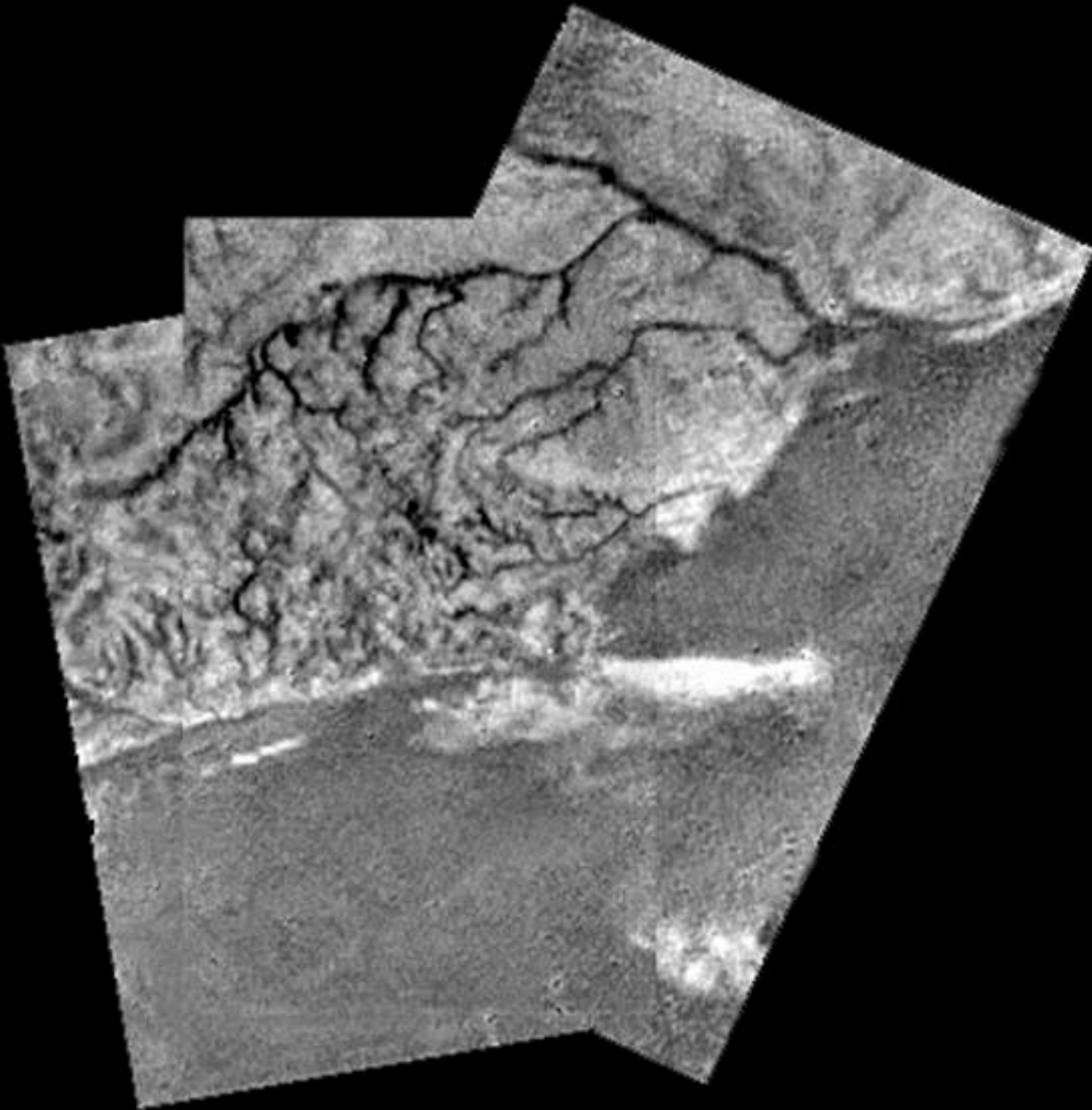
Liquid
x DARIN 
Sign here

Undeterminable
Sloane
Colette
Ben
Margarita
MEB (it'll be tar, but we can't tell)

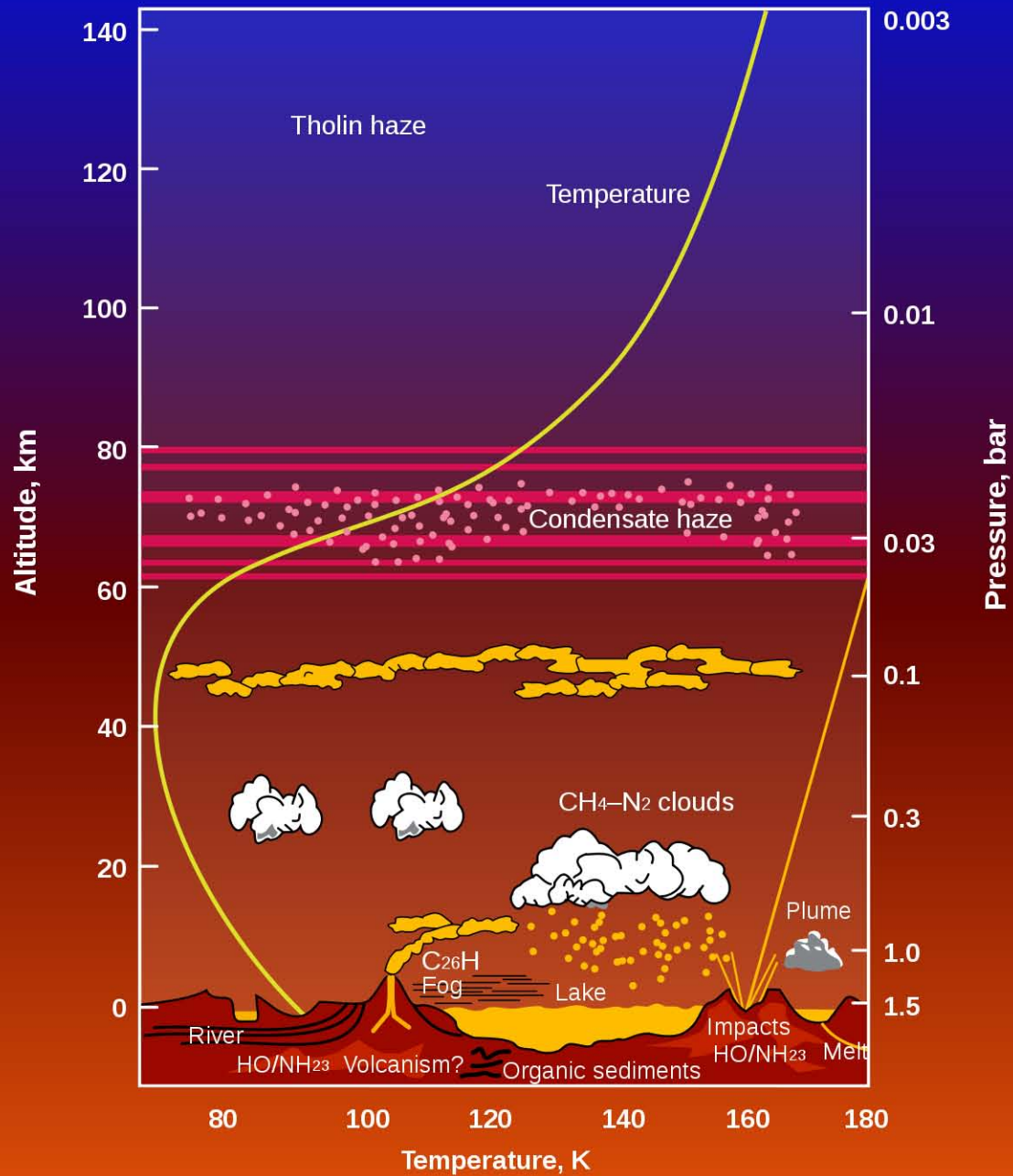
DOA
Kevin
Can.

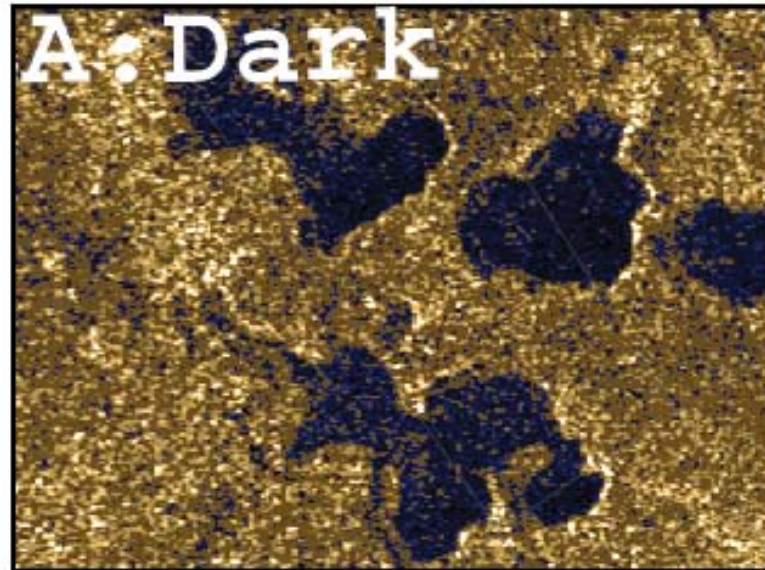
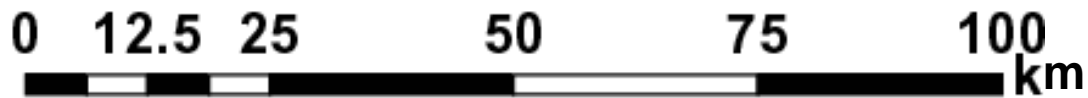
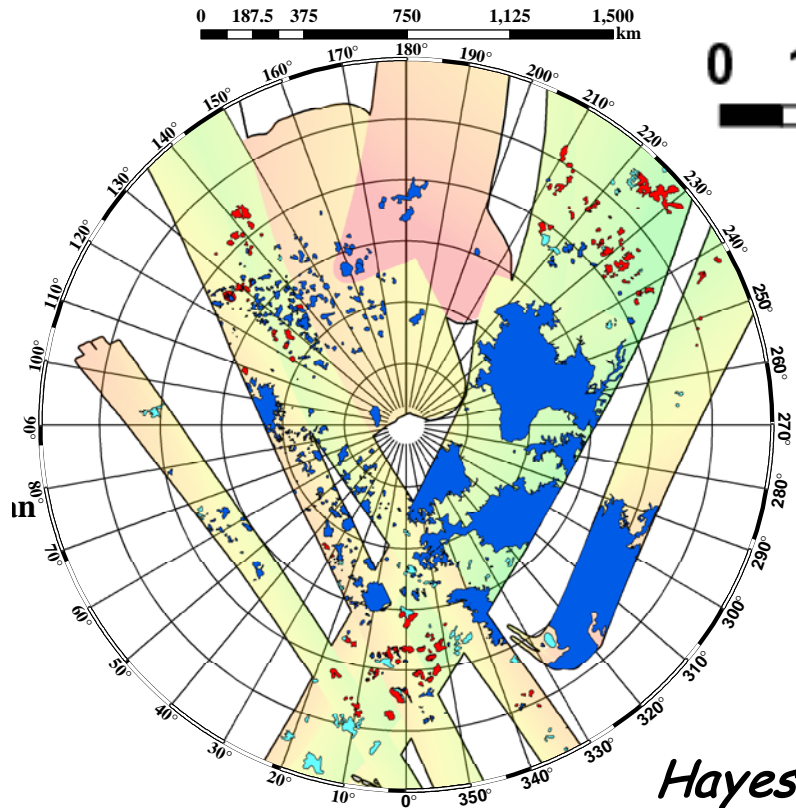
EATEN
Dave

The View from Huygens

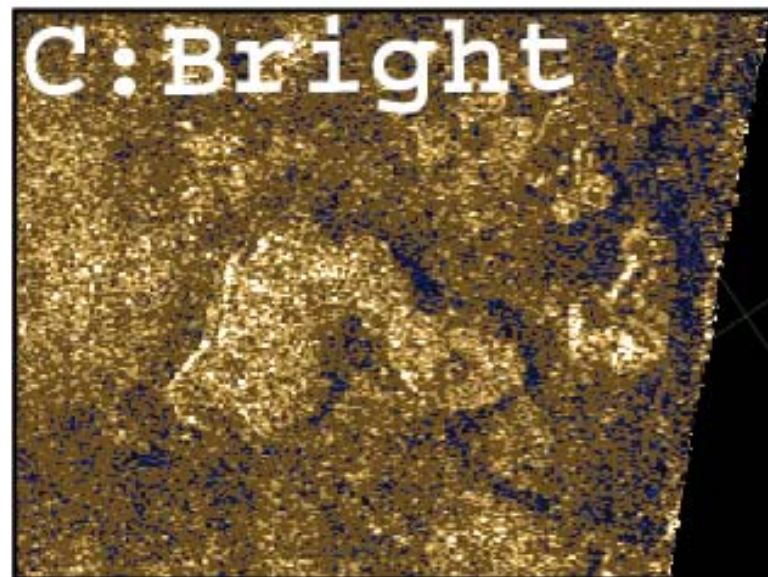
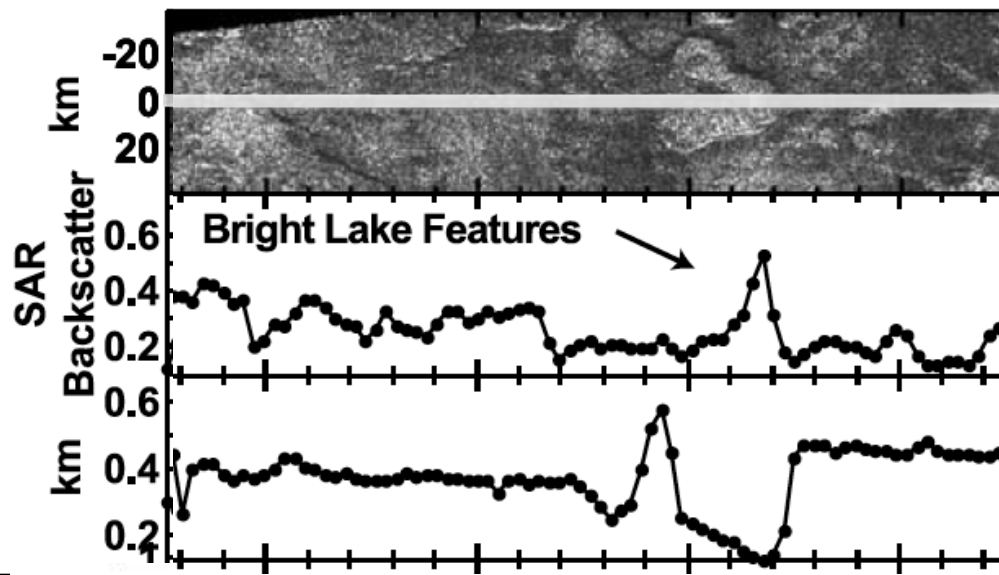


Credit: ESA, NASA, Descent Imager/Spectral Radiometer Team (LPL)





Hayes et al., 2008





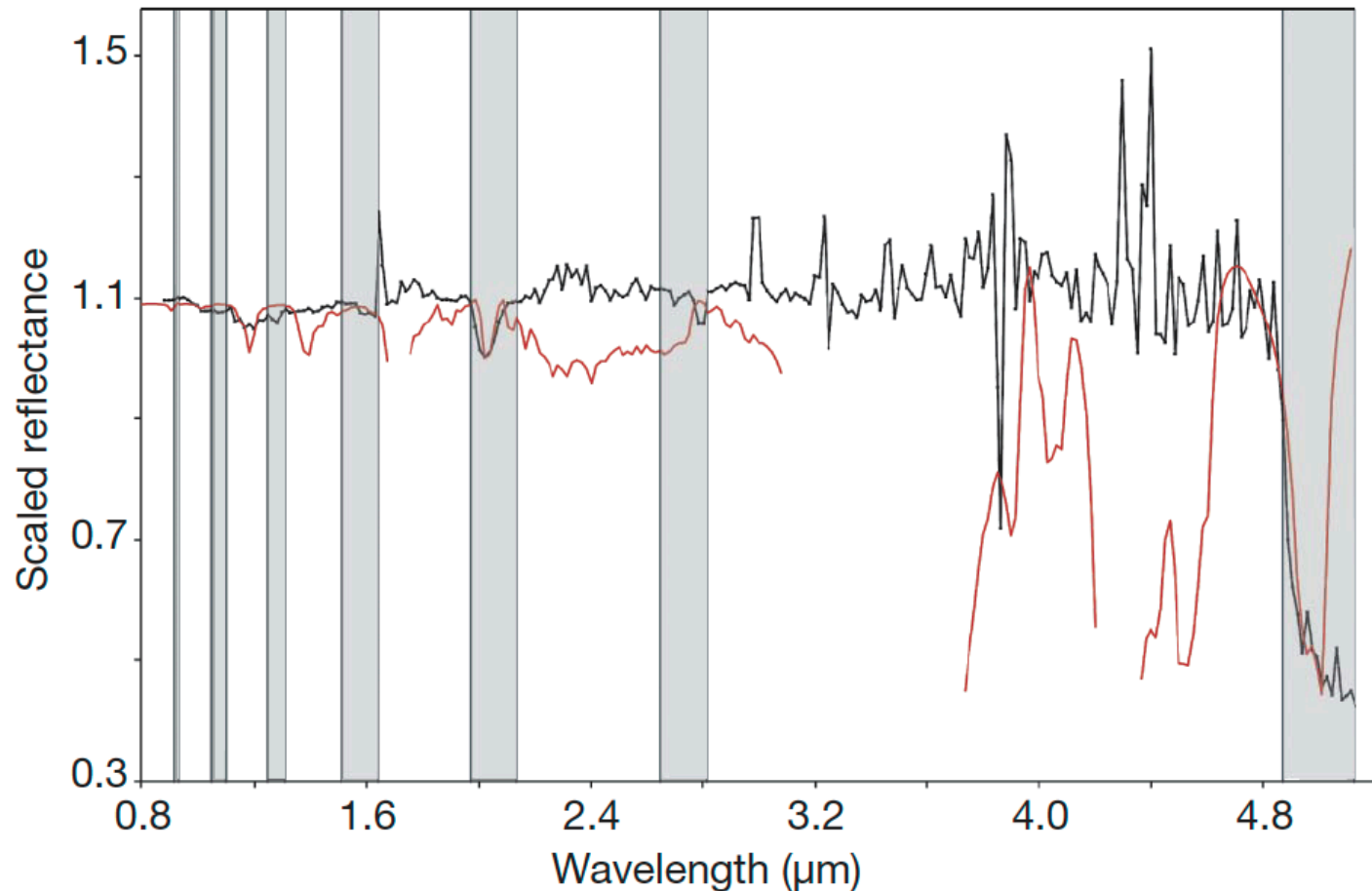
Courtesy NASA/JPL-Caltech



Image Credit: NASA / JPL / University of Arizona / DLR

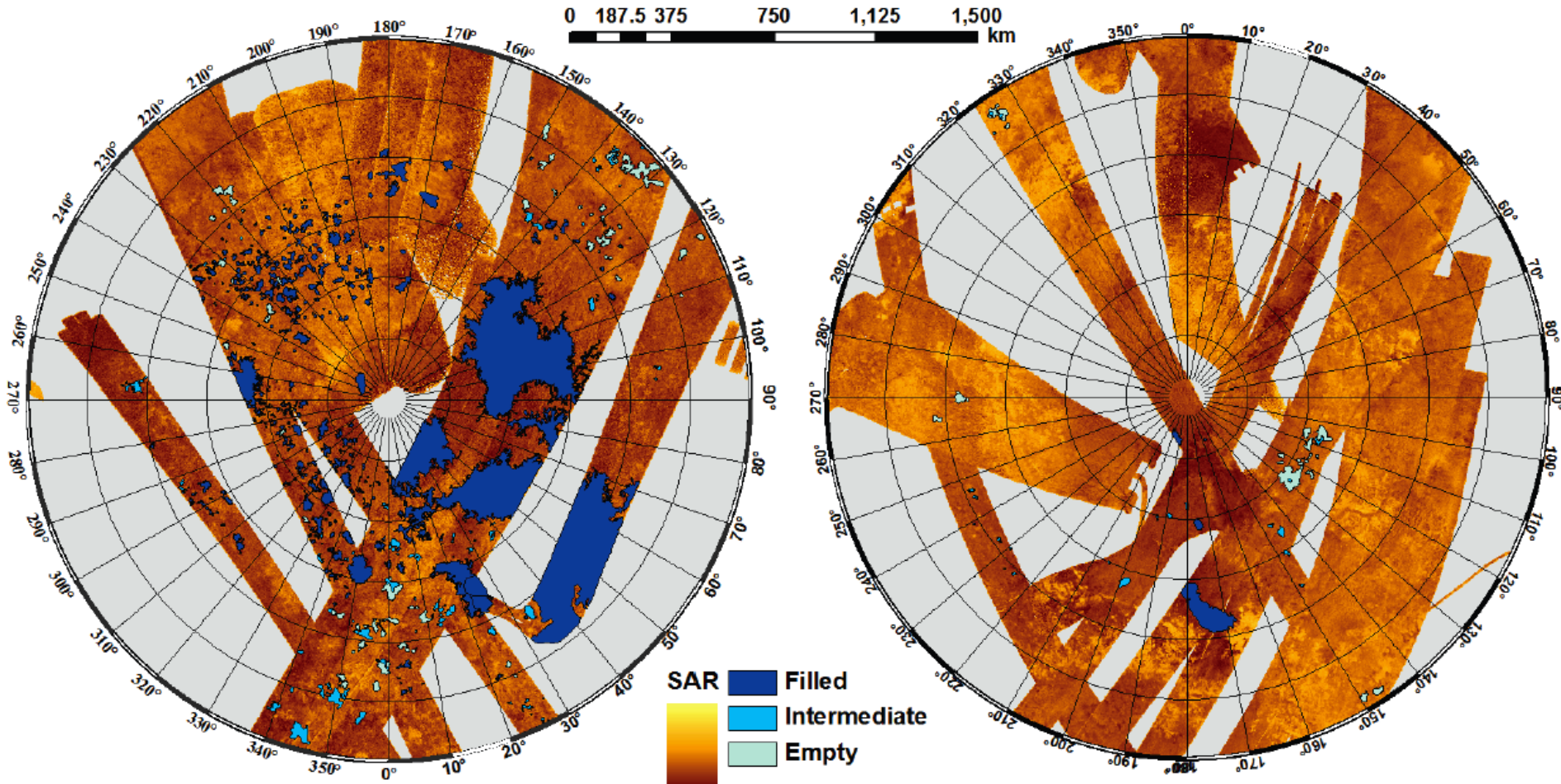
The identification of liquid ethane in Titan's Ontario Lacus

R. H. Brown¹, L. A. Soderblom², J. M. Soderblom¹, R. N. Clark³, R. Jaumann⁴, J. W. Barnes⁵, C. Sotin⁶, B. Buratti⁶, K. H. Baines⁶ & P. D. Nicholson⁷



Brown et al., Nature, 2008

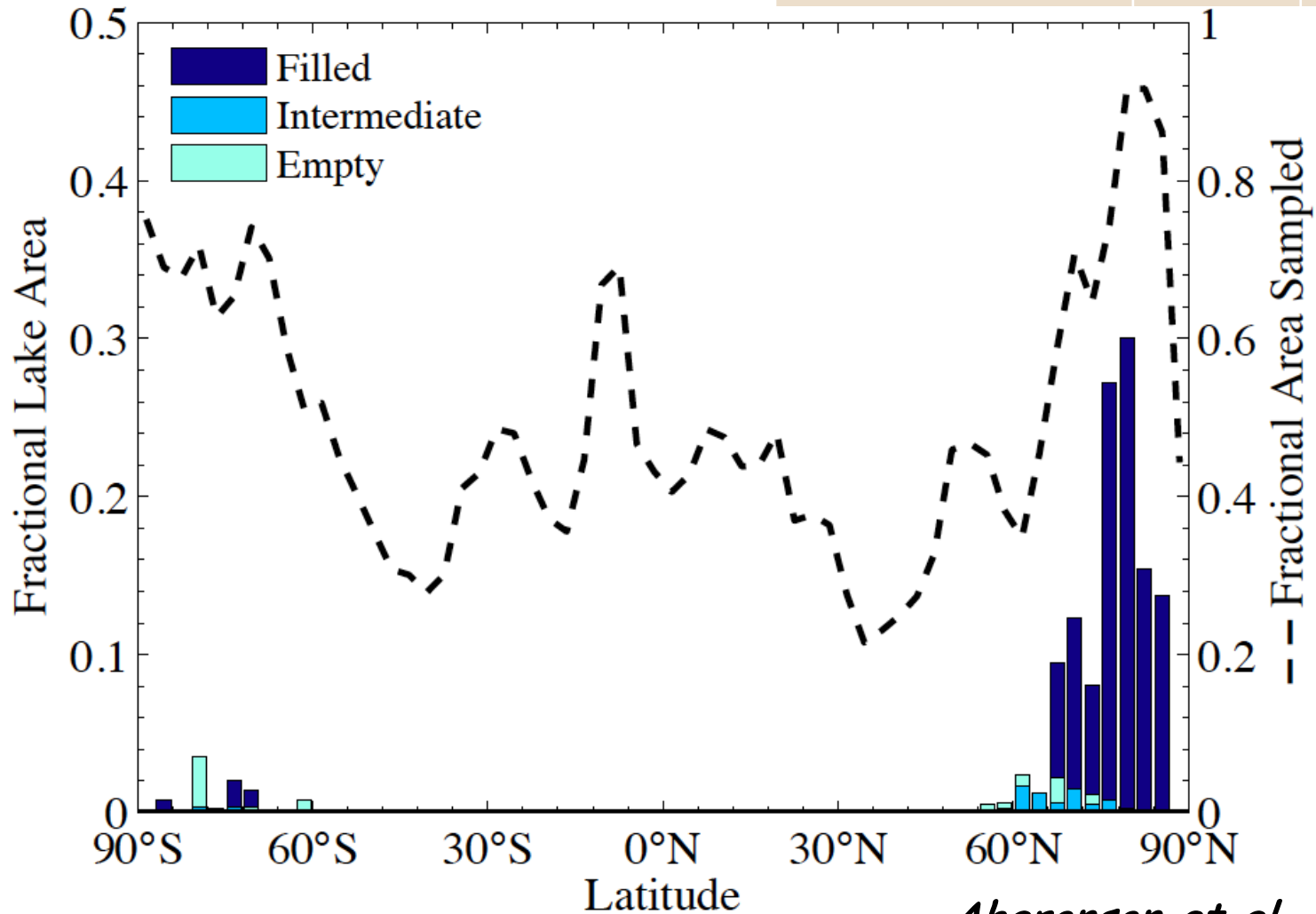
Current Radar Mapping



Aharonson et al., 2009

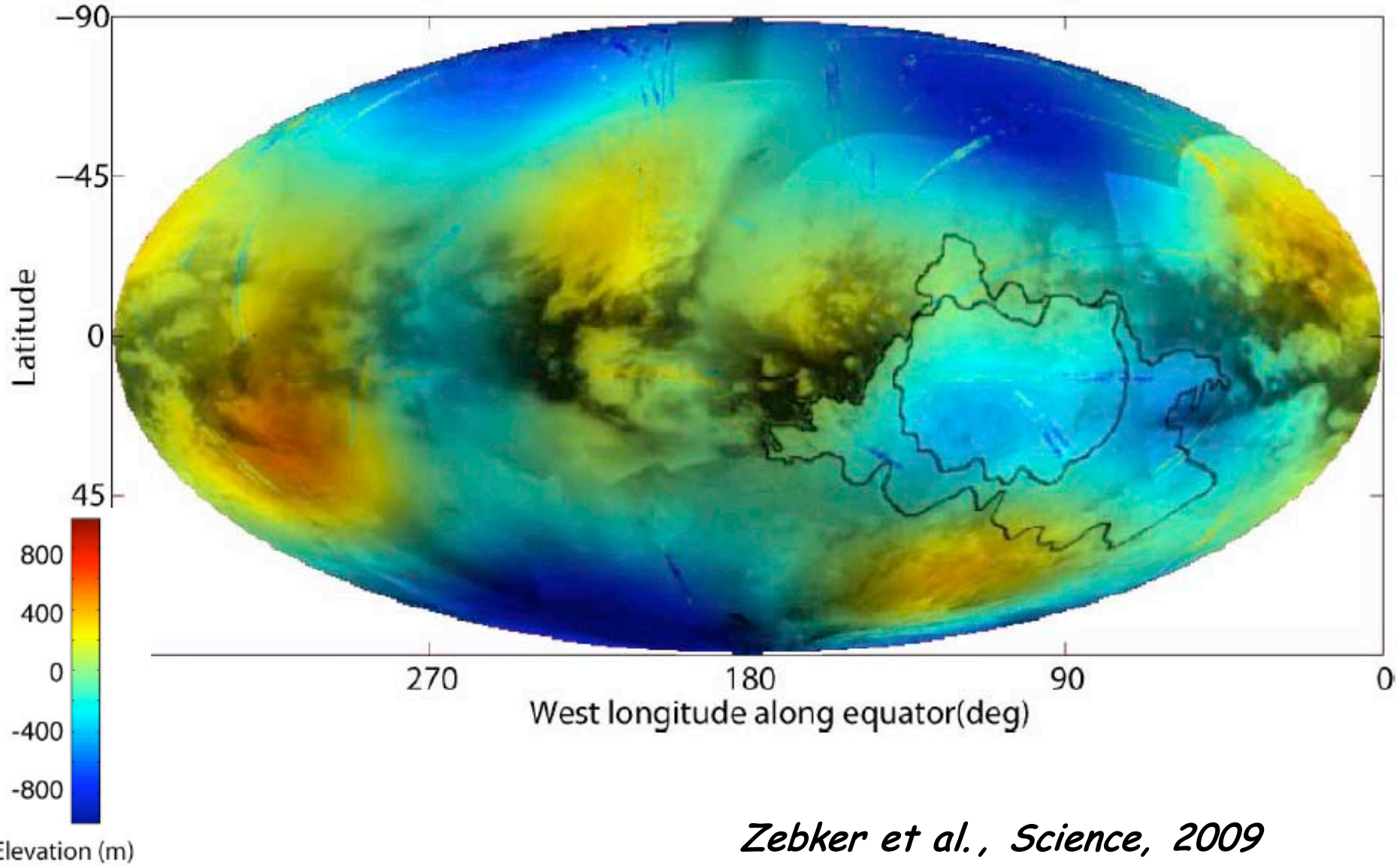
- Polewards of 55° , now >50% coverage in both hemispheres

	North	South
Filled	10%	<0.1%
Partially Filled	0.7%	0.1%
Empty	1.0%	0.2%

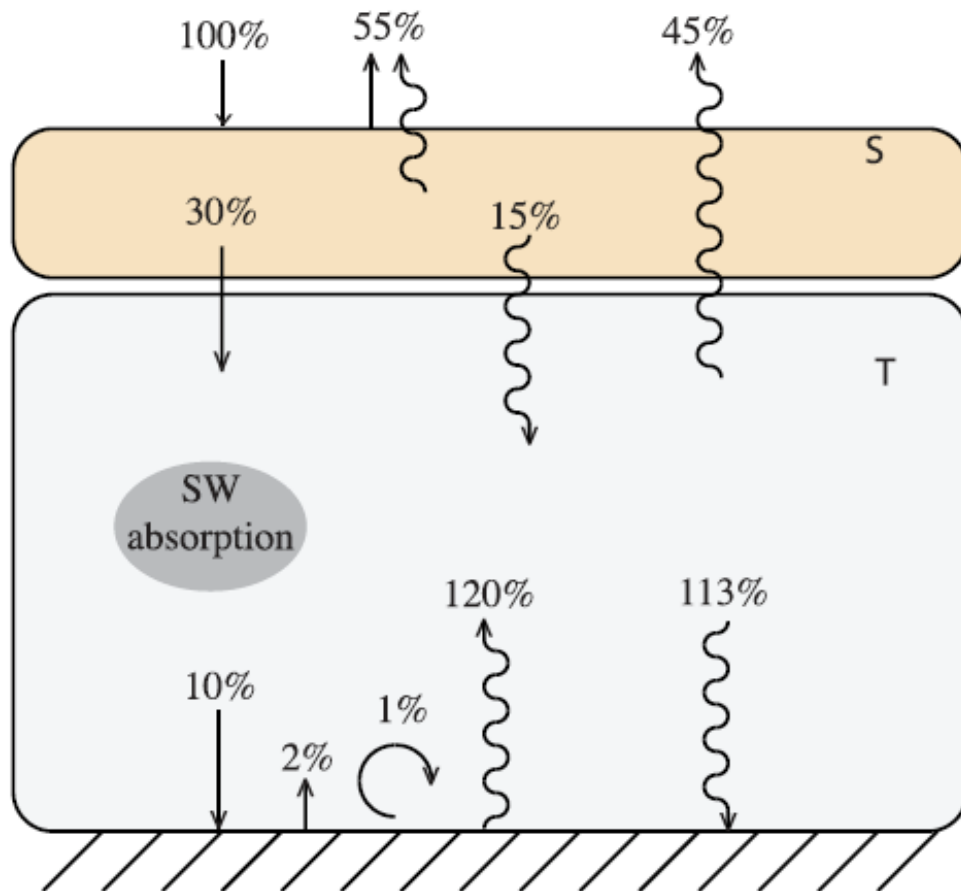


Aharonson et al., 2009

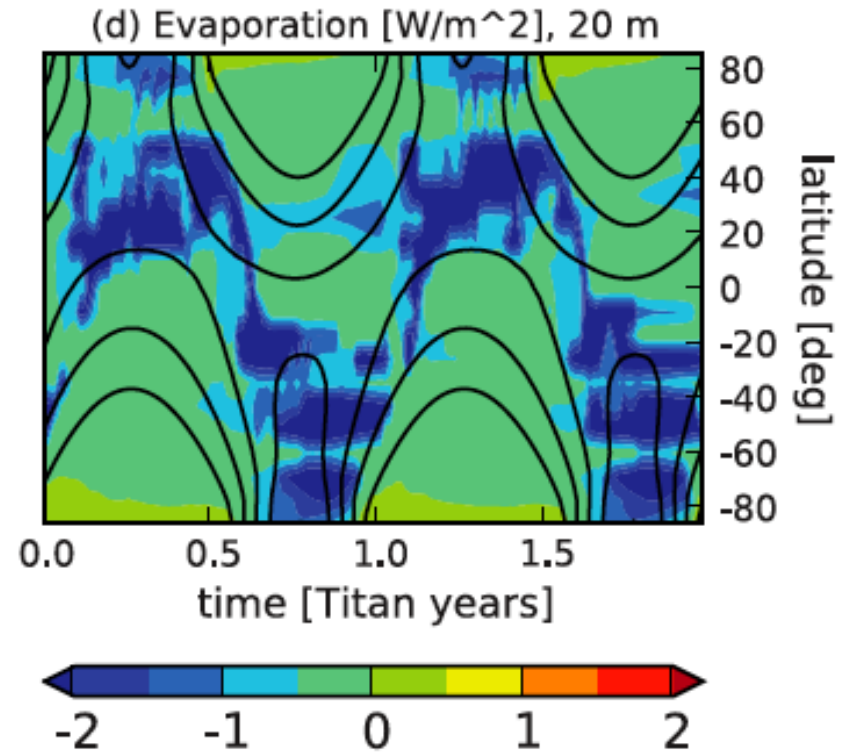
Global Shape



Numerical Predictions



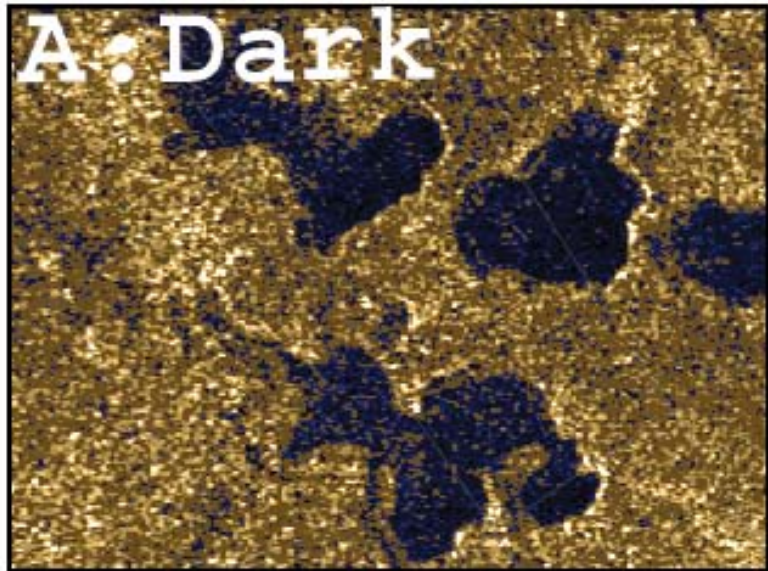
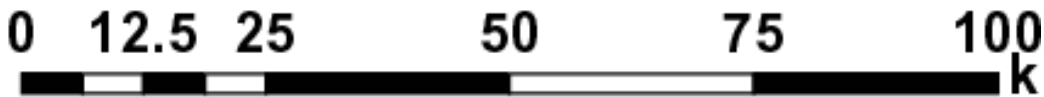
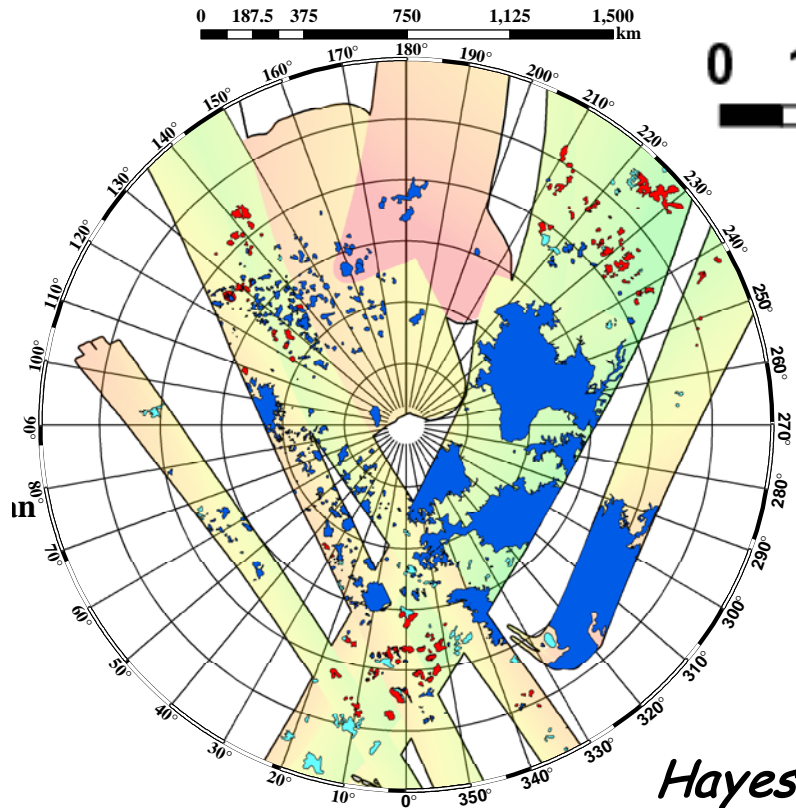
Mitchell et al., 2008



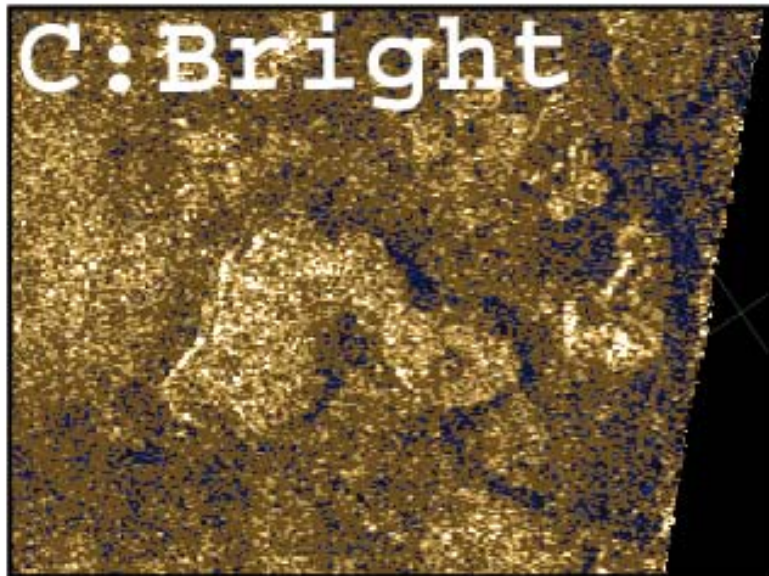
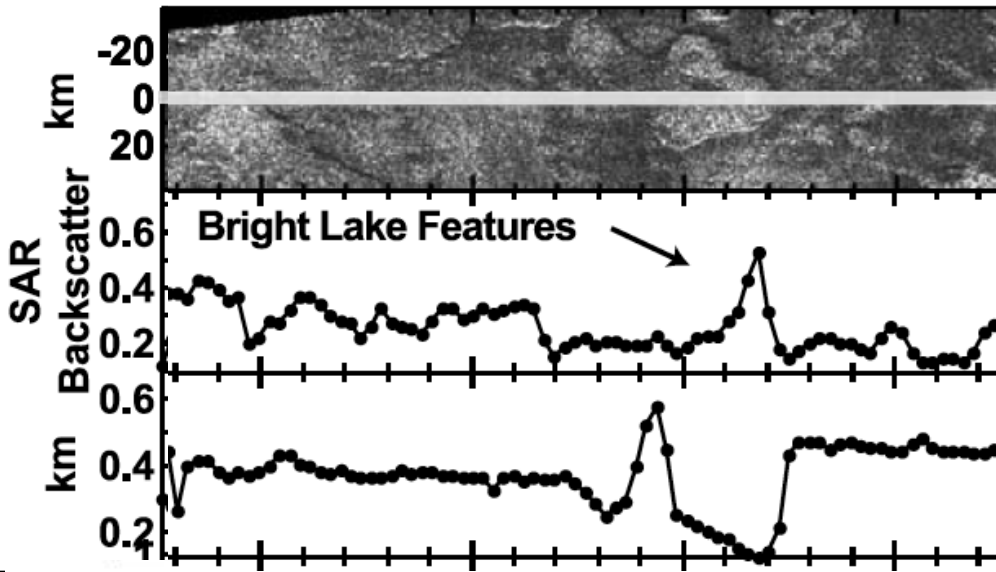
2D GCM predicts:

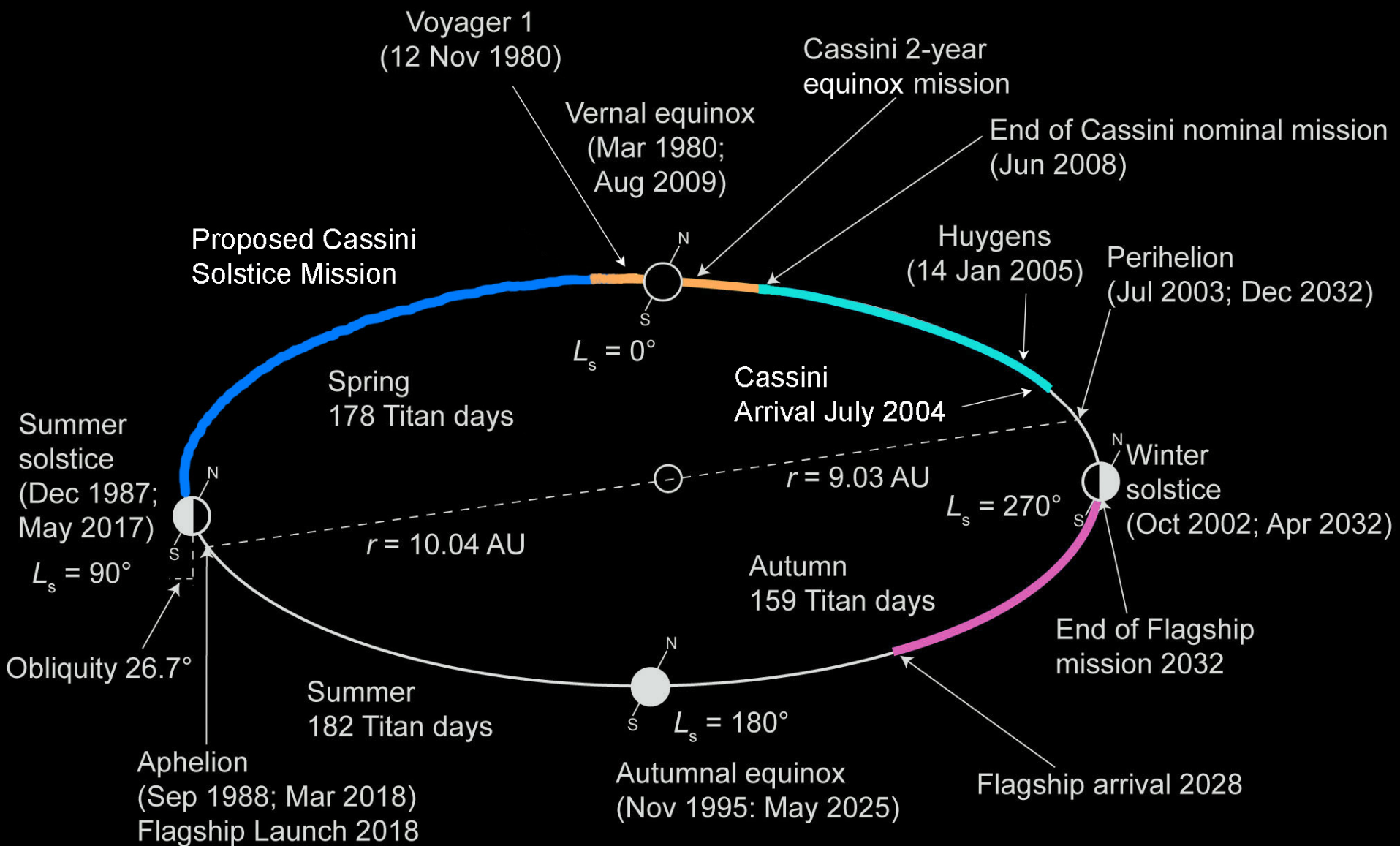
$$E_{\text{evap.}} \sim 2 \text{ W/m}^2$$

i.e. 0.3 m/yr



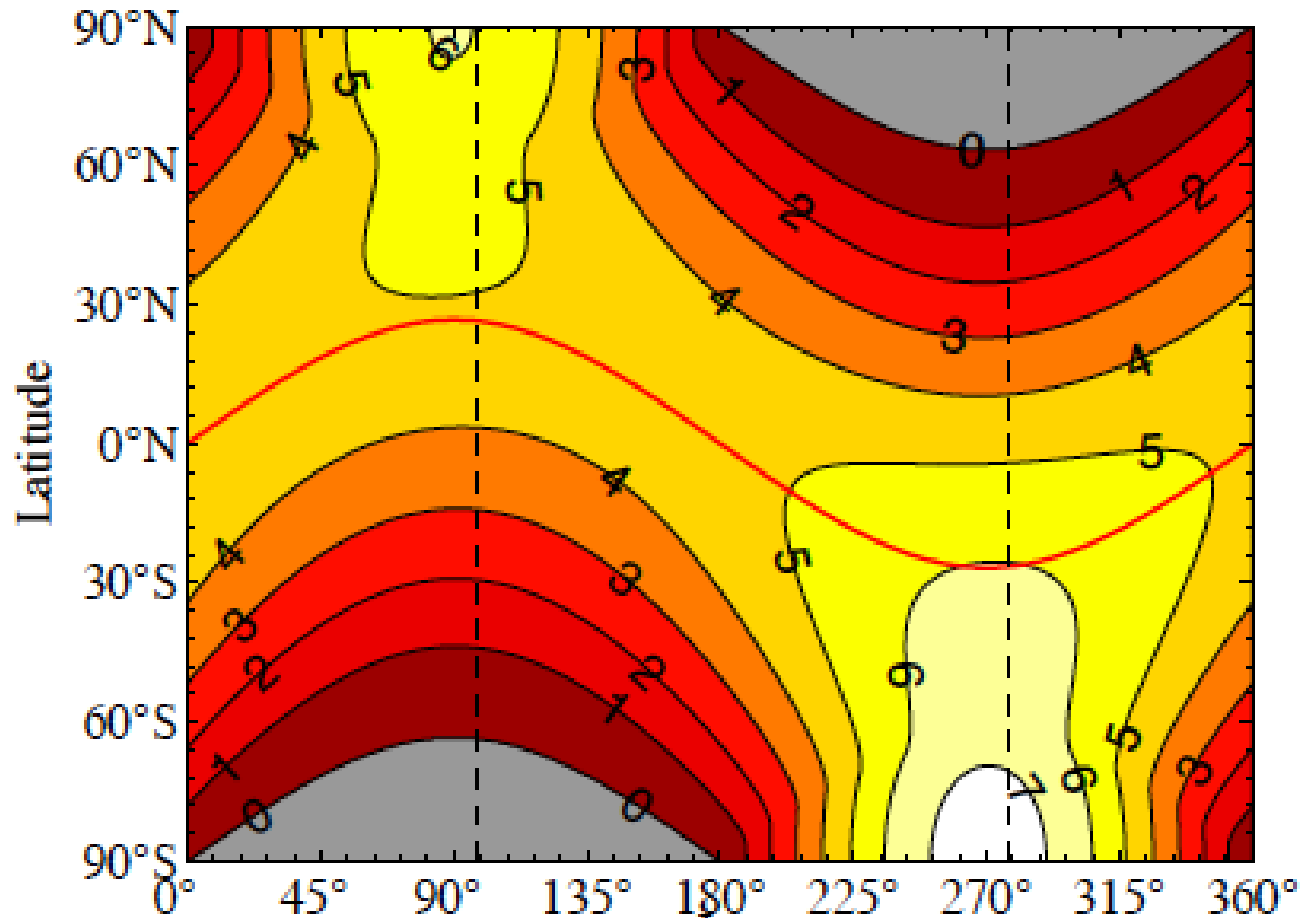
Hayes et al., 2008





R. Lorenz (Pers. Comm.)

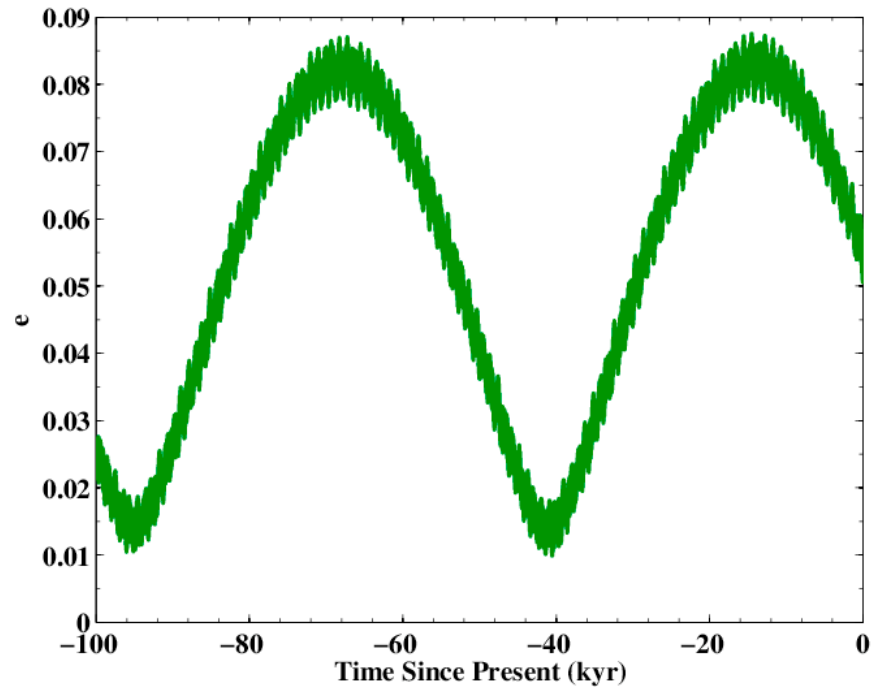
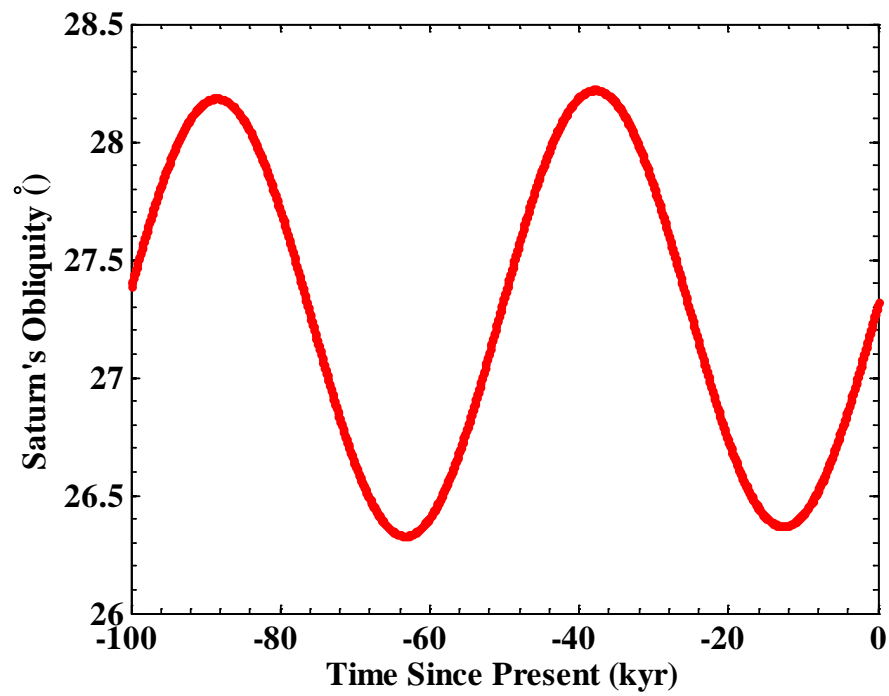
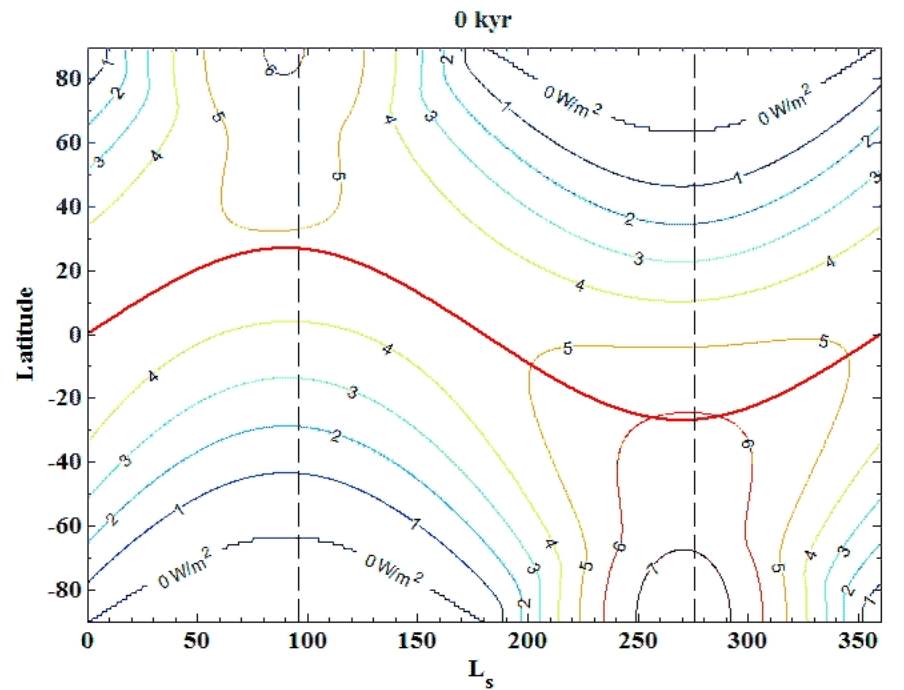
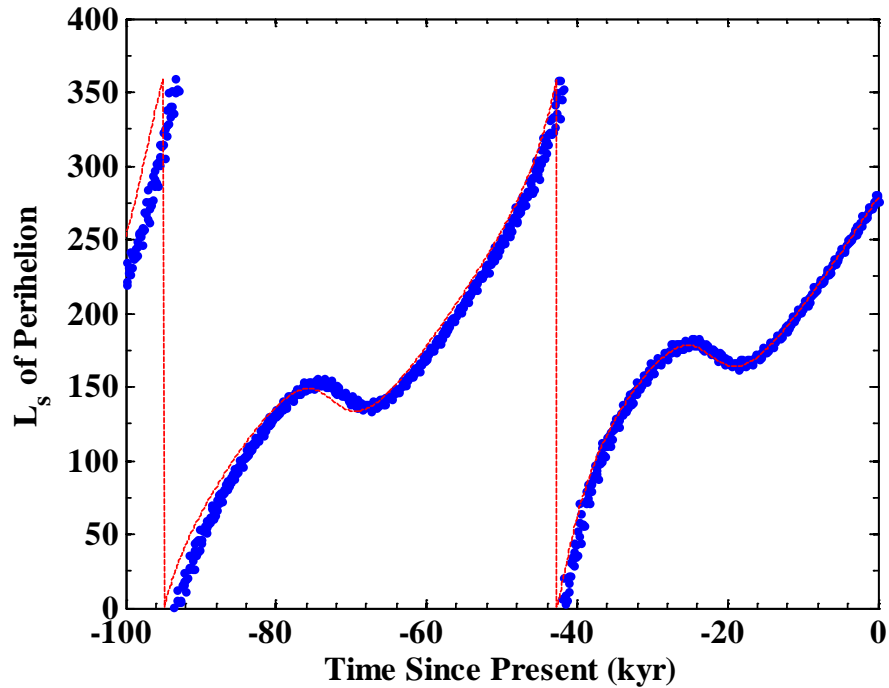
Solar Insolation



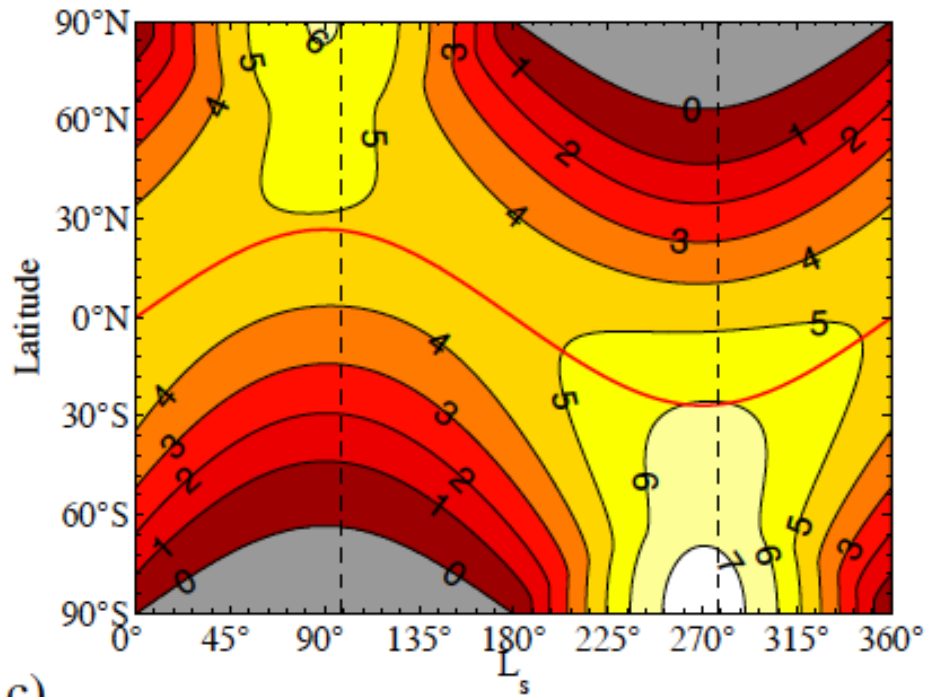
c) $t=0, L_{s,p}=277.7, e=0.054$

Peak South Polar Insolation:
 $7.48 W/m^2$

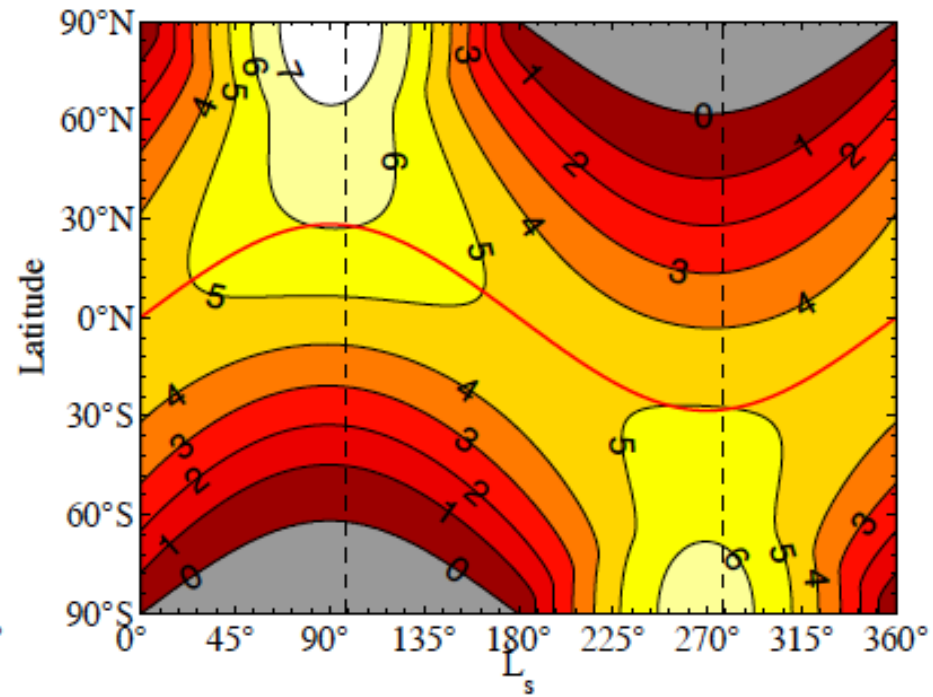
Peak North Polar Insolation:
 $6.04 W/m^2$



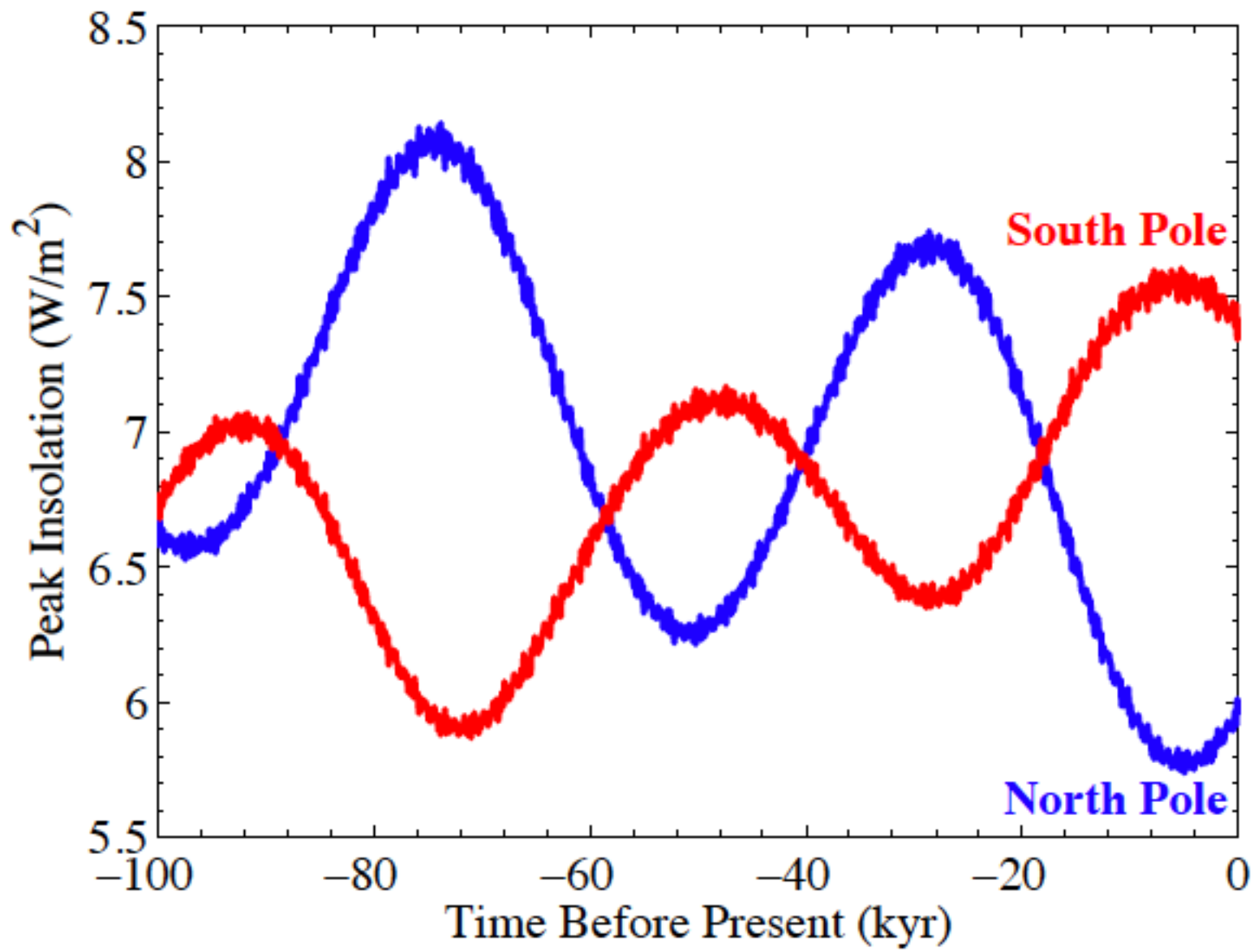
Solar Insolation

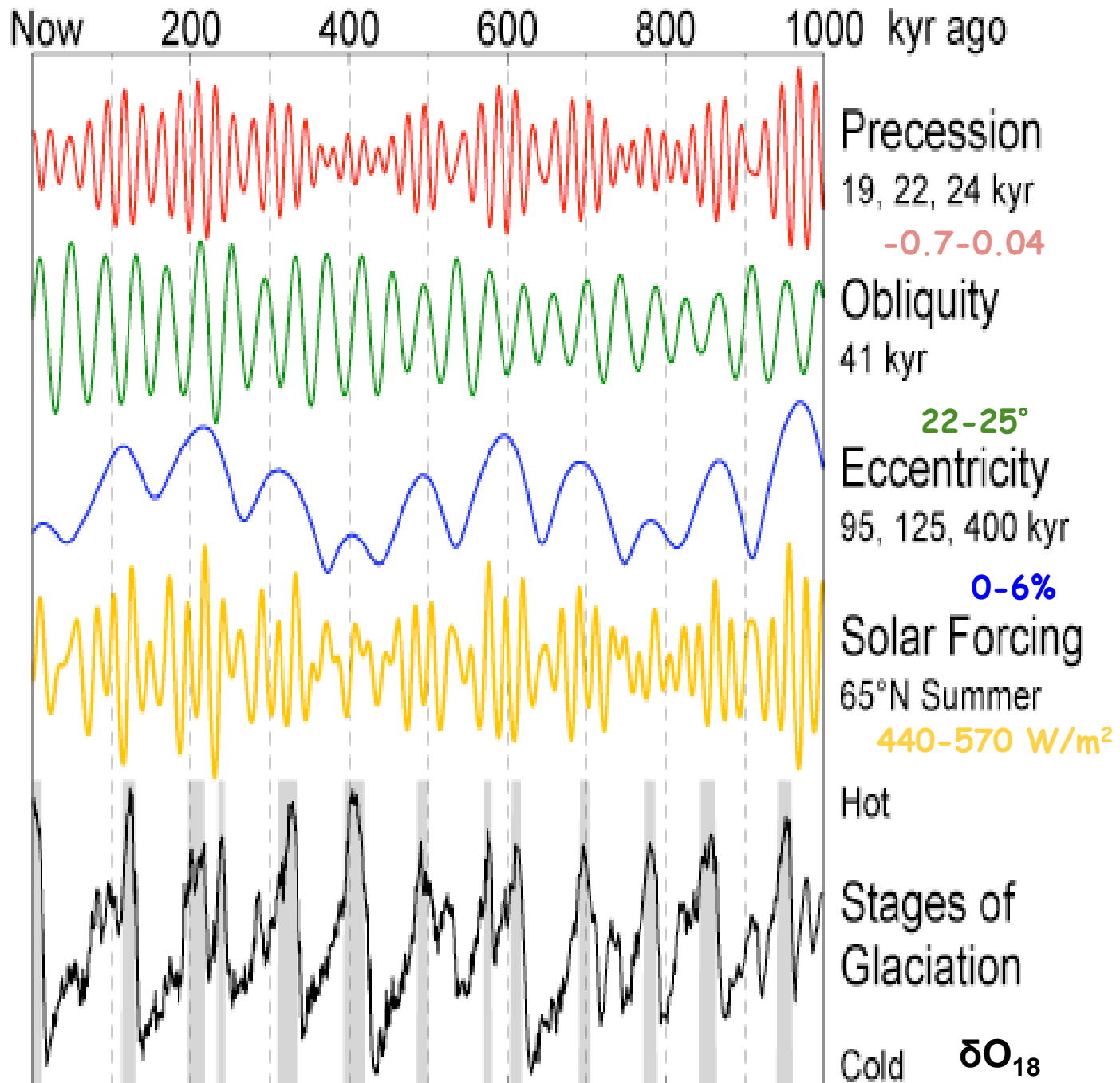
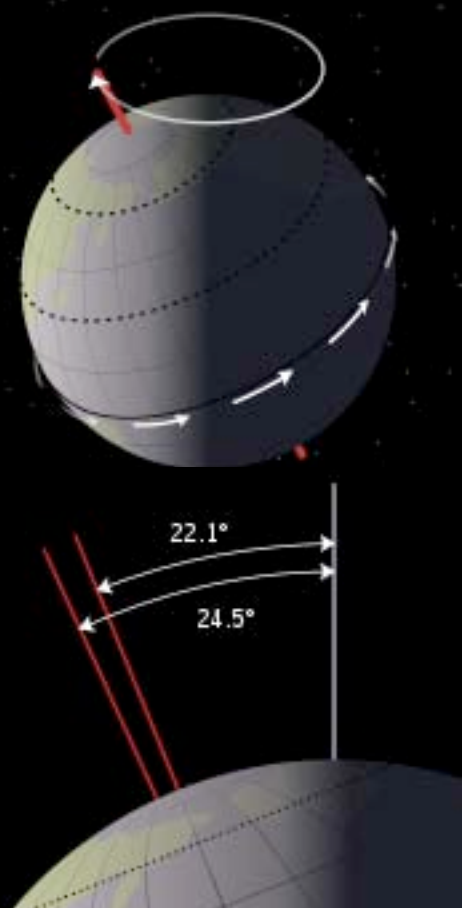


$t=0, L_{s,p}=277.7, e=0.054$

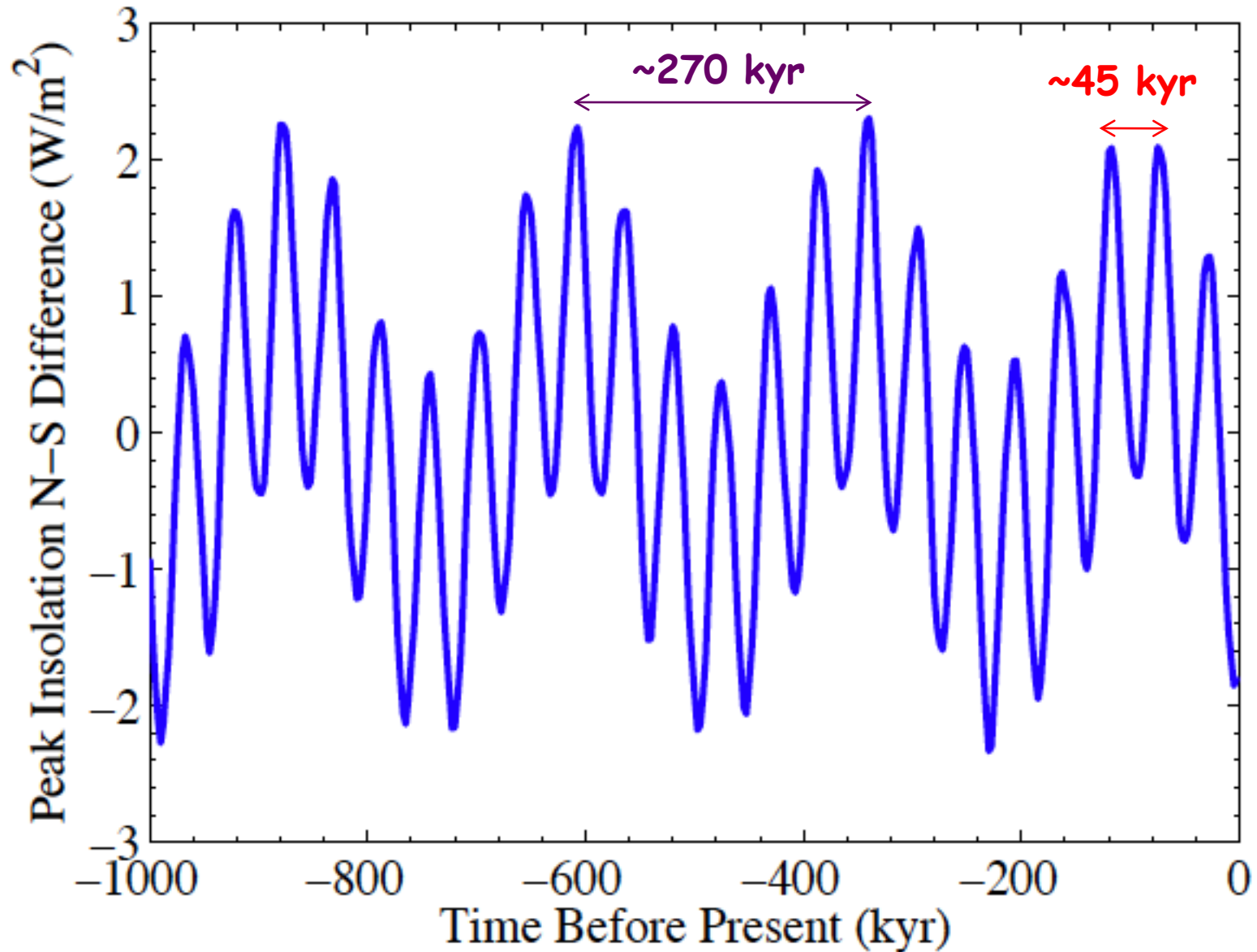


$t=-31.5 \text{ kyr}, L_{s,p}=97.7, e=0.046$

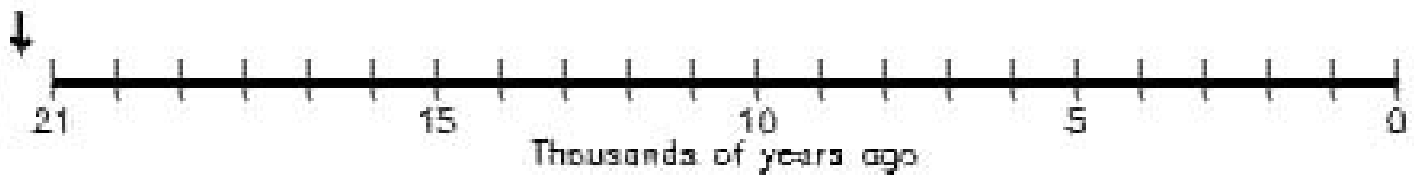
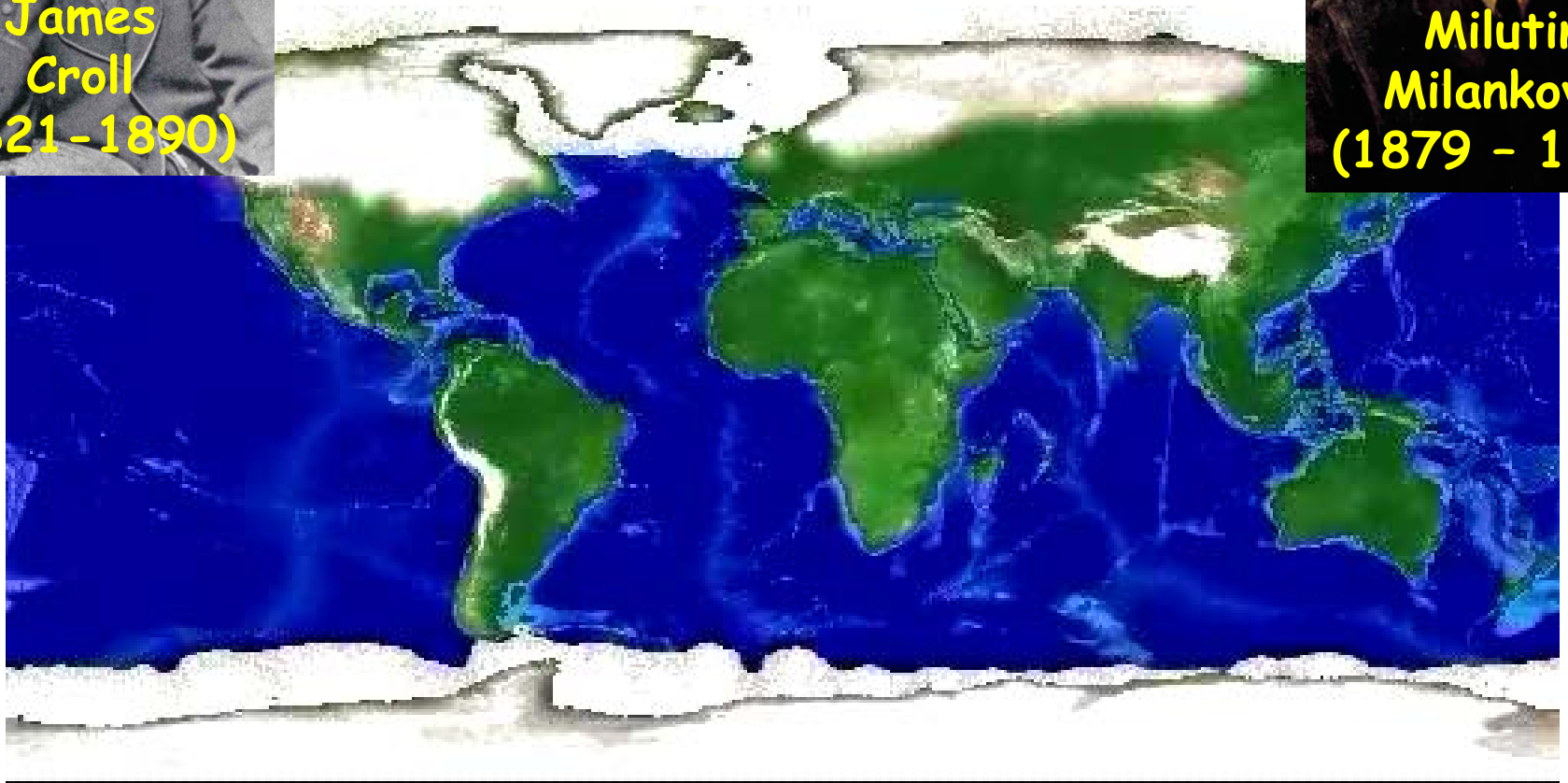
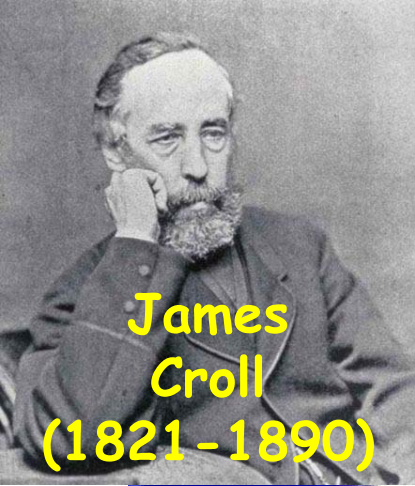




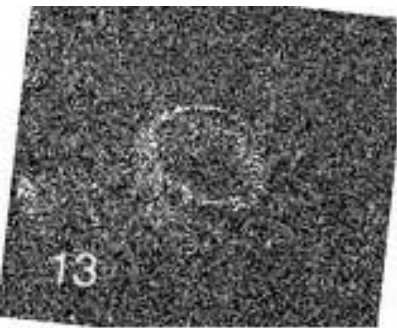
Titan's Milankovitch Periods



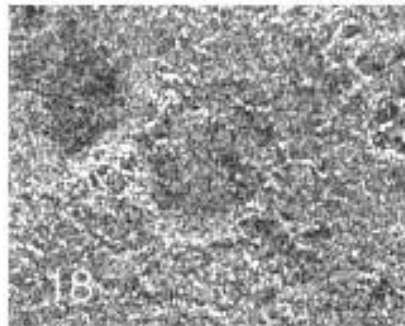
Ice Ages



http://earth.rice.edu/mtpe/cryo/cryosphere/topics/ice_age.html



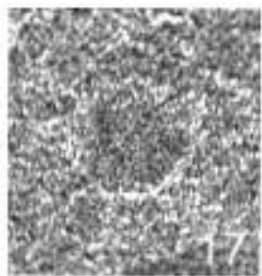
T21-13



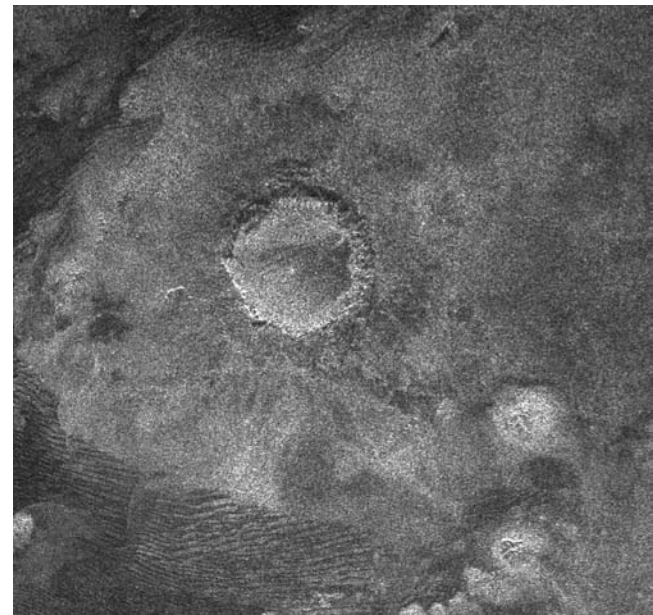
T13-18



T13-15



T13-17

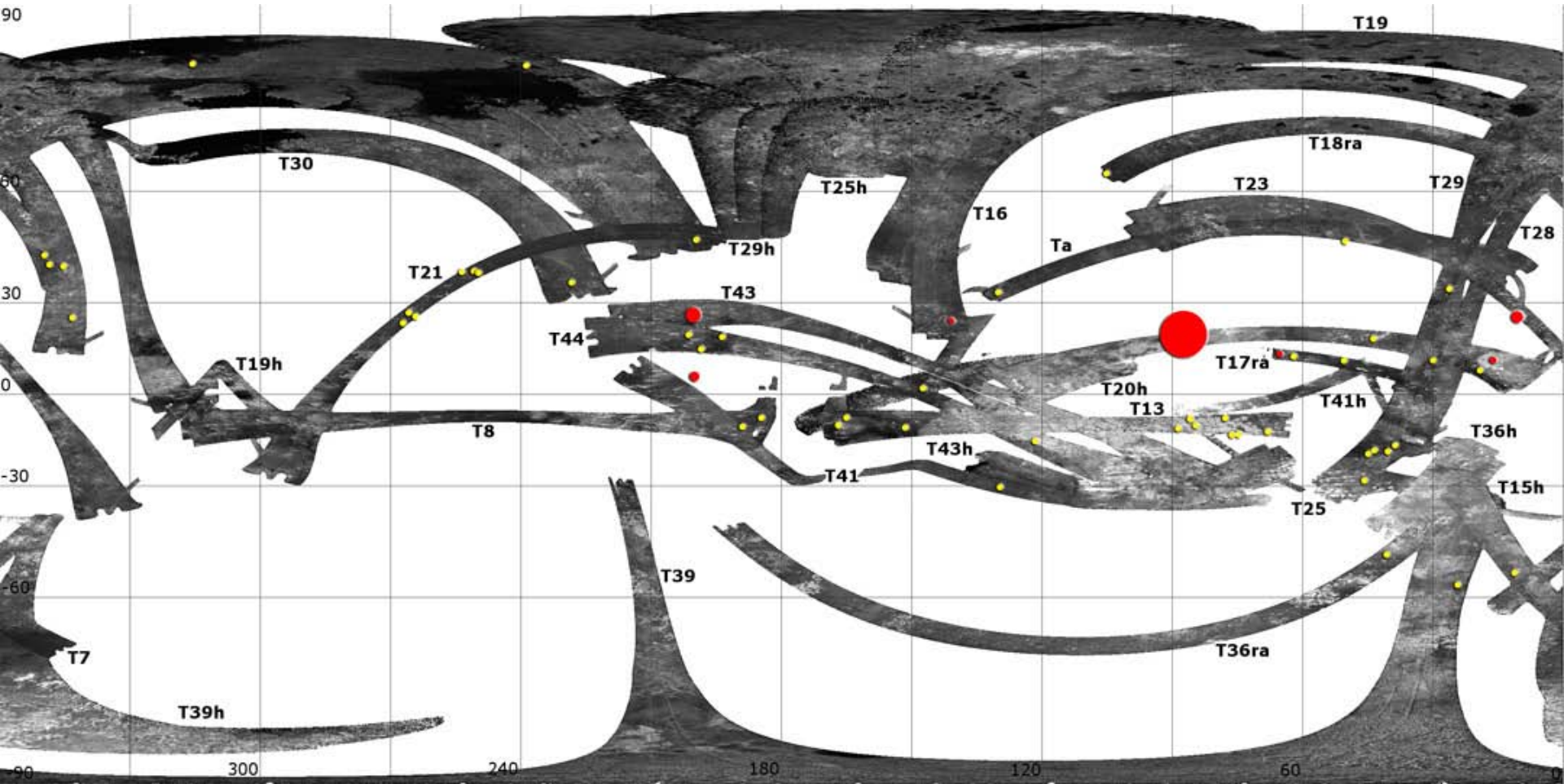


- 11-20 km Putative Craters

- Crater retention age:
200 Myr (*Wood et al., 2009*) up to
1 Gyr crater retention age

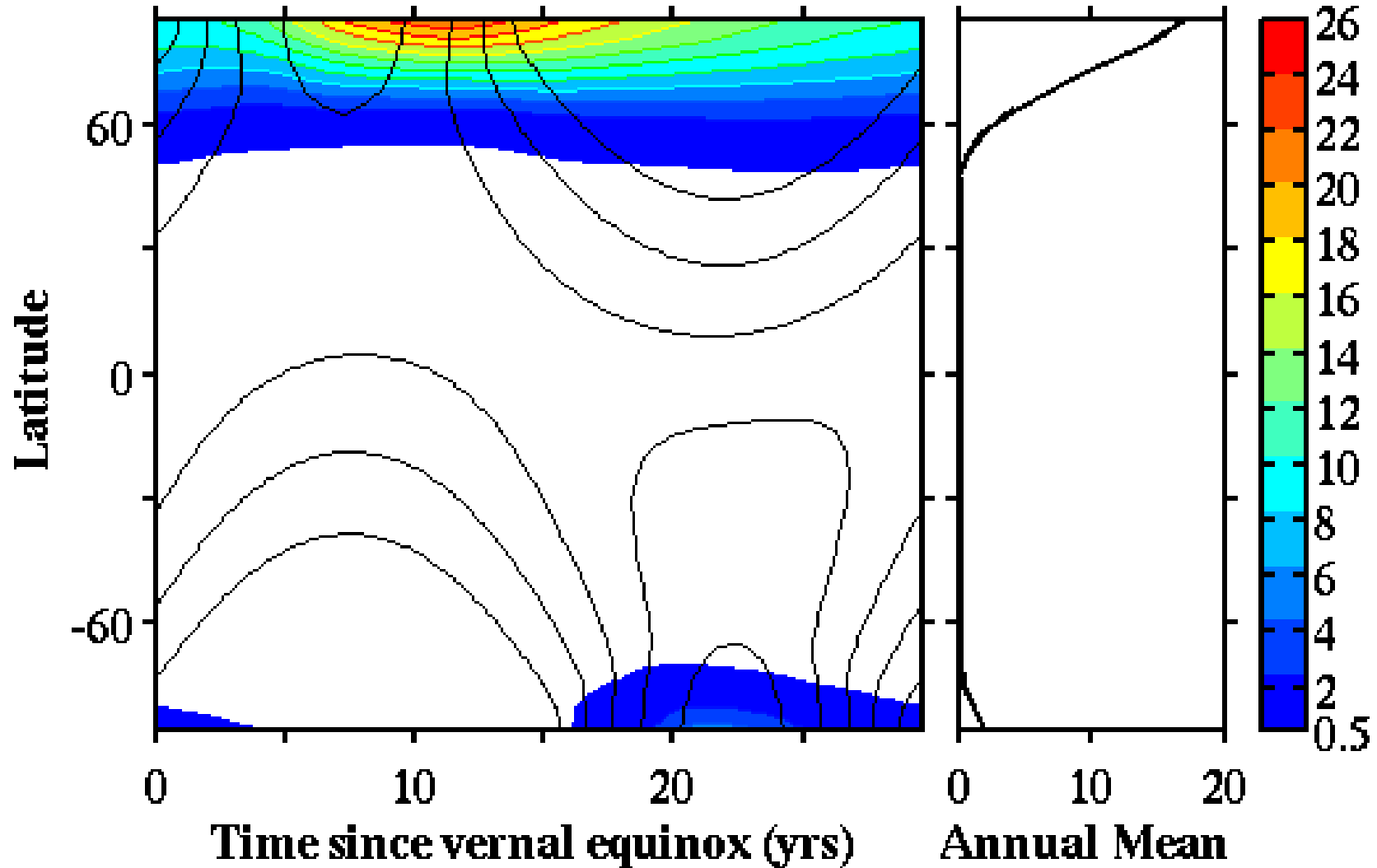
- Sinlap, 80 km

Putative Crater Distribution



Wood et al., 2009

GCM Results



Graves, Schneider, et al.

Some Numbers

- The differential heat flux can evaporate:

$$\delta F \sim 1.5 \text{ W/m}^2$$

$$L = 510 \text{ kJ/kg}$$

$$\rho = 422 \text{ kg/m}^3$$

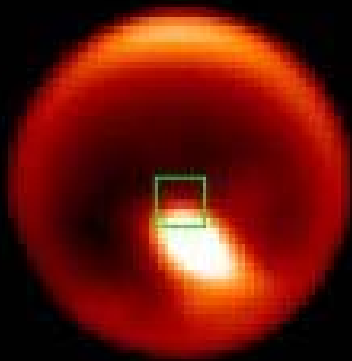
$$\frac{\delta F}{L\rho} \sim 0.22 \text{ m/yr}$$

- Ethane is significantly ($\times 10,000$) less volatile so is likely to remain, and can retain residual methane in solution

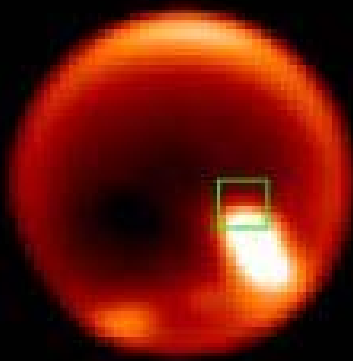
Hypothesis consistent with...

- Hemispheric asymmetry in lakes
- Ontario Lake Ethane detection by VIMS
- Insolation function energetics
- Crater distribution latitudinal gradients

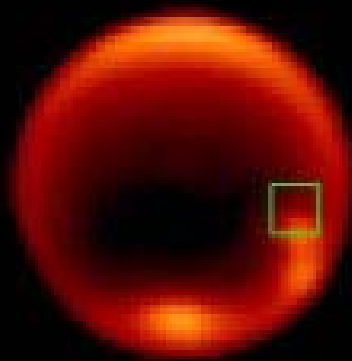
2008-04-14 (251°)



2008-04-15 (273°)



2008-04-16 (296°)



2008-04-18 (341°)



2008-04-20 (27°)



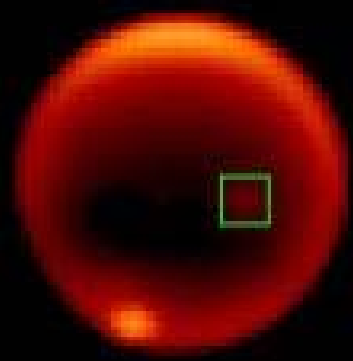
2008-04-25 (140°)



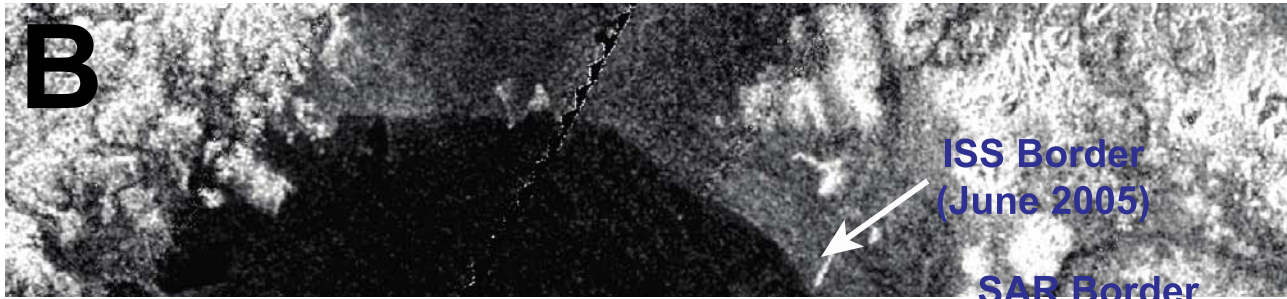
2008-04-28 (210°)



2008-05-01 (275°)

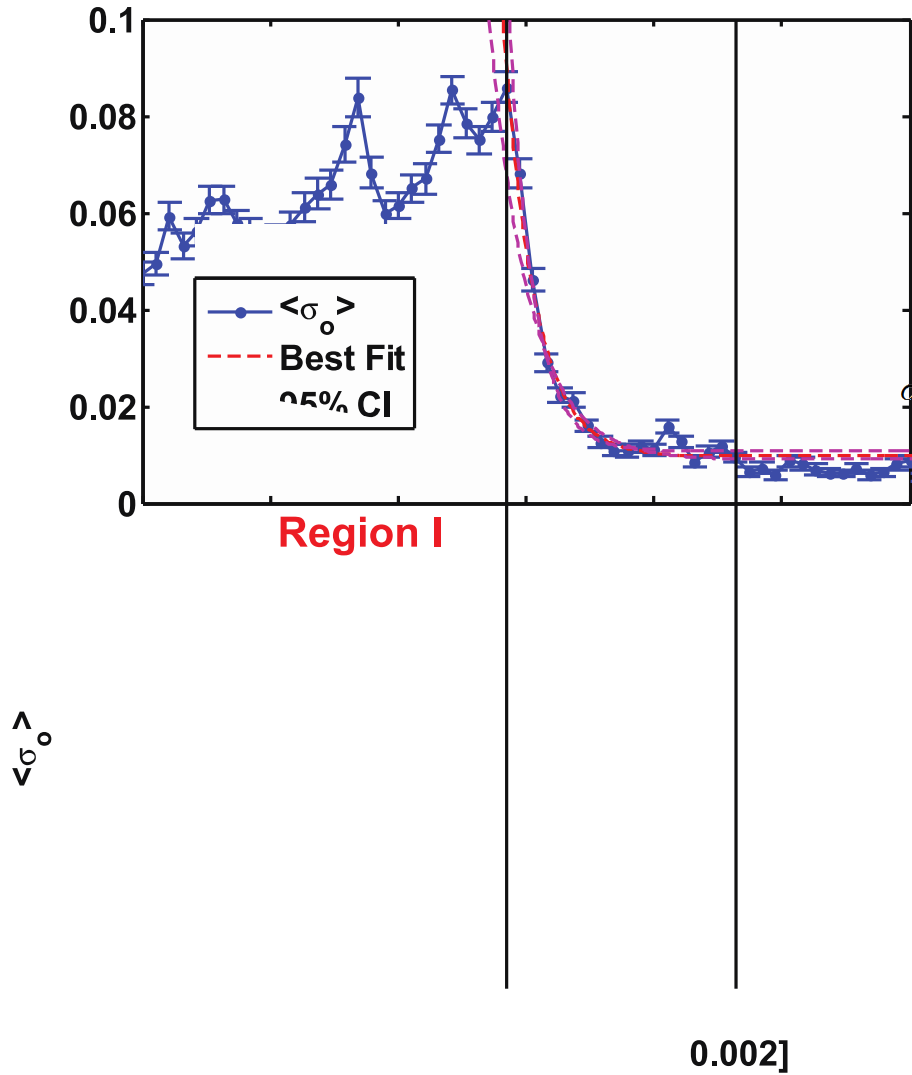


Schaller et al., 2009



Hayes et al., 2010a (in press)

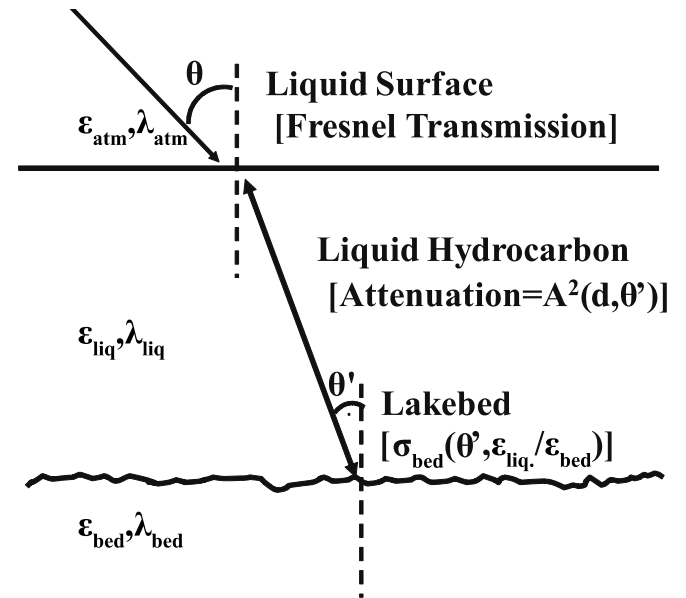
Data



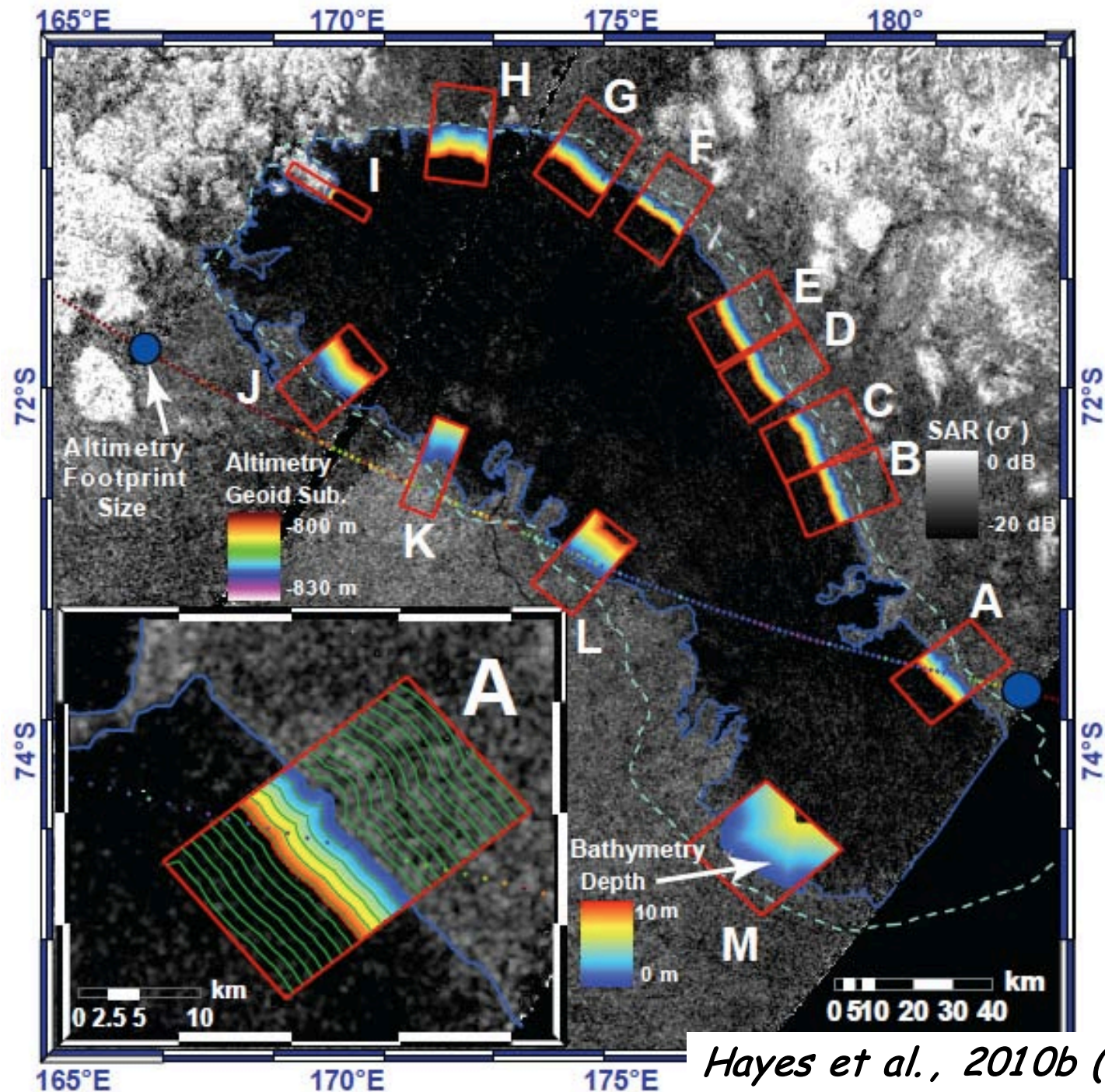
A Model

$$\sigma_o = \sigma_o^l + \sigma_o^s e^{-8\pi k d \sec \theta_{liq} / \lambda}$$

$$n_{air} \sin \theta_{air} = n_{liq} \sin \theta_{liq}$$



Hayes et al., 2010a (in press)



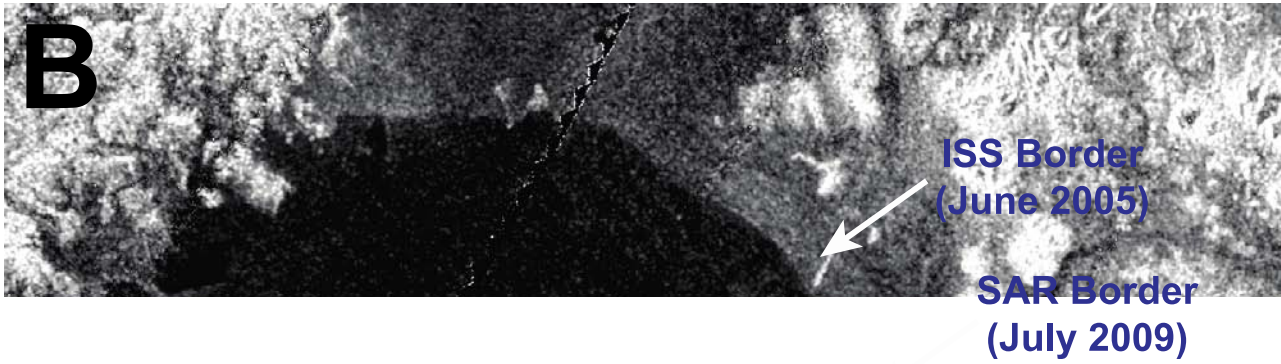
Hayes et al., 2010b (in press)

A

or
(June 2005)

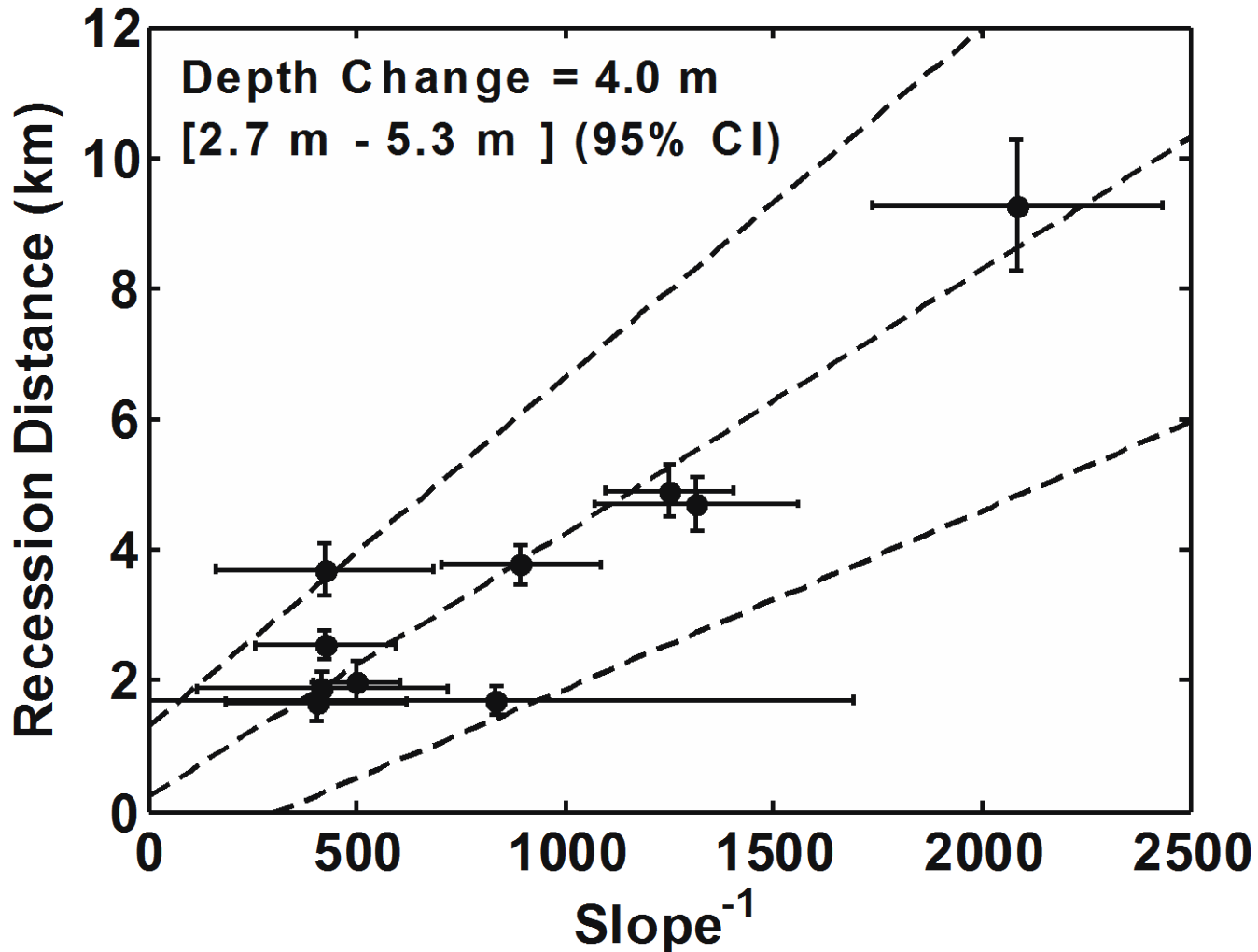
20 km

Altimetry
Footprint
Size



Hayes et al., 2010b (in press)

Ontario Reduction

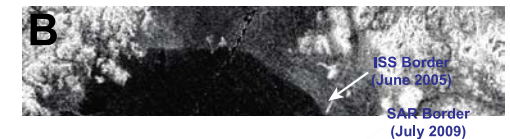
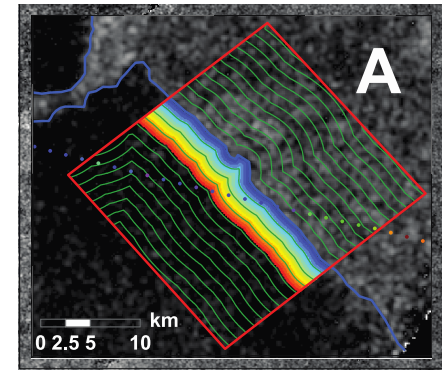
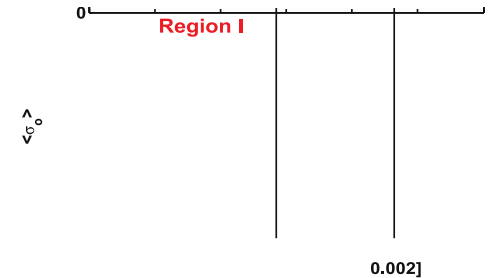


Flux: 1.0 ± 0.2 m/yr

Hayes et al., 2010b, (in press)

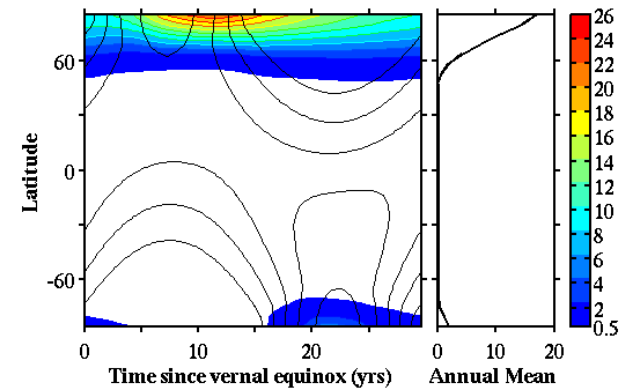
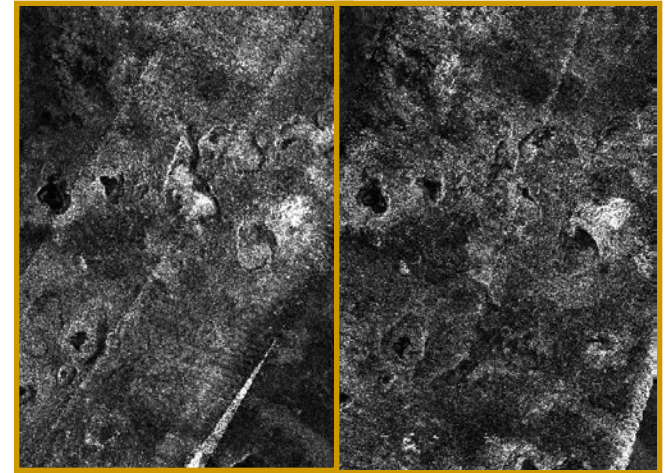
Summary

- $\tan \Delta = (9.1^{+2.5}_{-2.0}) \times 10^{-4}$
- Possible to obtain **first extra-terrestrial bathymetry** of near-shore lake regions, correlate with geology
- Seasonal methane loss rate from southern lakes
 - Ontario: 1.0 ± 0.2 m/yr
 - Smaller lakes: 1.07 ± 0.23 , 1.10 ± 0.23 , 1.03 ± 0.25 , 1.09 ± 0.34 m/yr



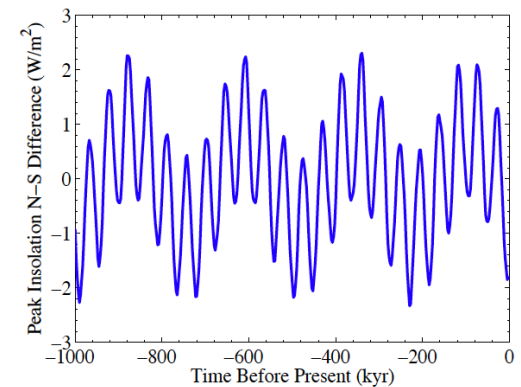
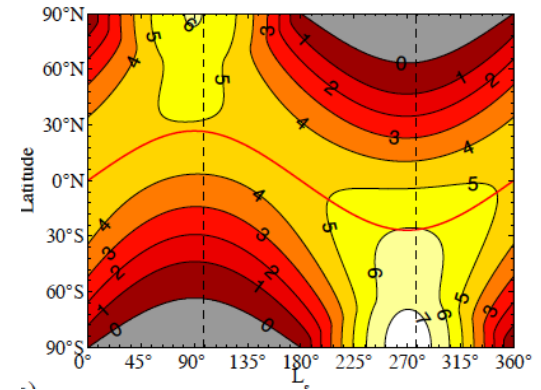
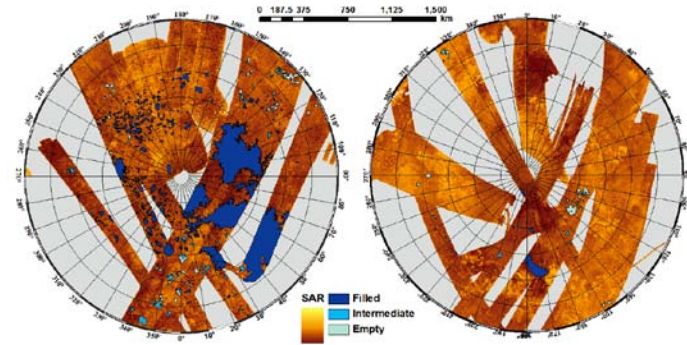
Summary

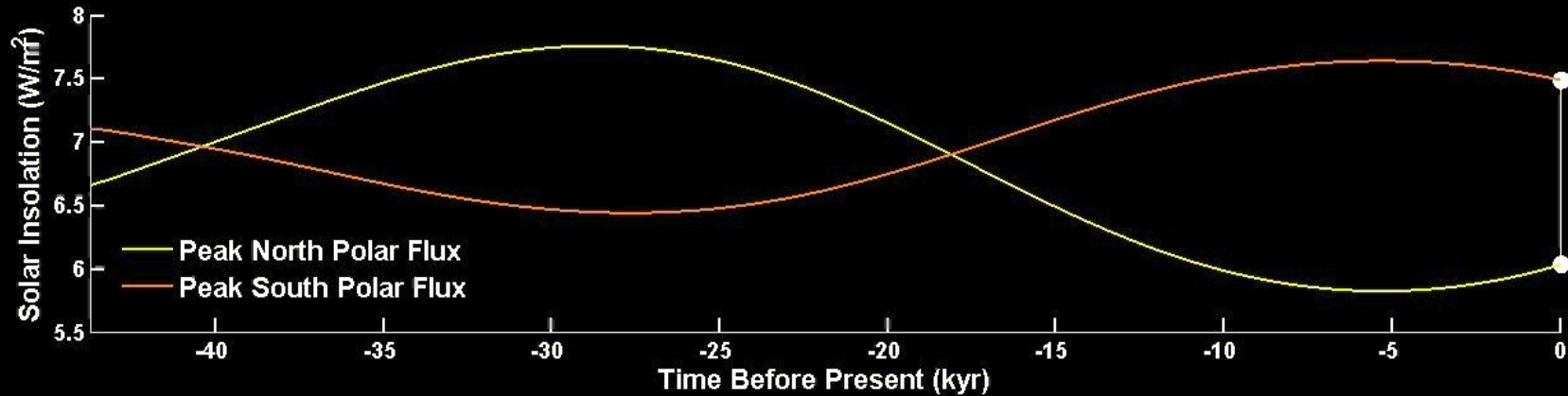
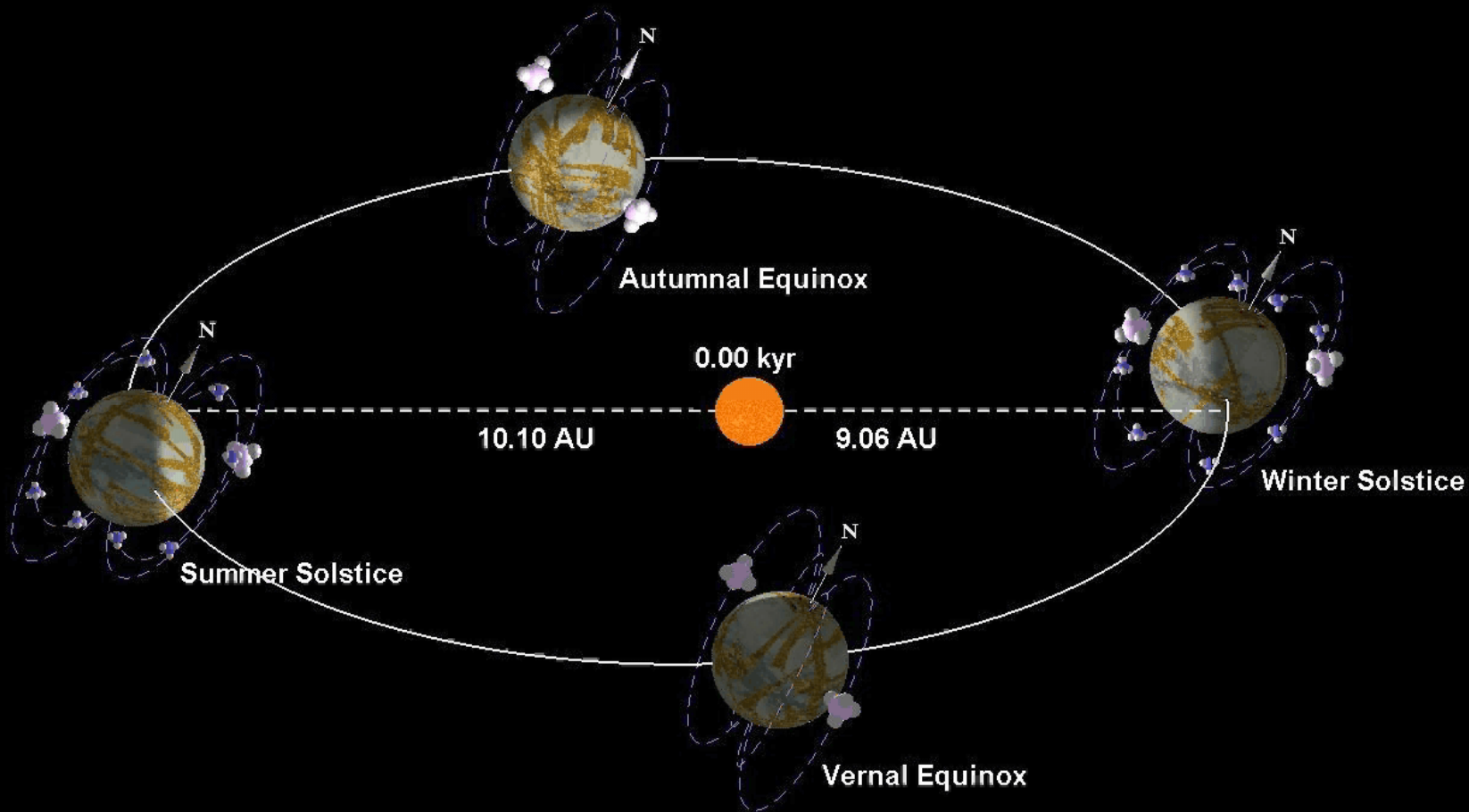
- So far, **no demonstrable lake height** changes have been identified in the **North** (Although several putative changes are seen, in part may be due to incidence angle variations)
- **Climate models vary** in their predictions, e.g. **Newman et al.**, **Graves et al.**, predict peak summer evaporation, **Tokano et al.** predict peak in the winter



Summary

- Cassini revealed a statistically significant **asymmetry in lake distribution**
- If the asymmetry is not inherent to the crust, we propose it is **due to an asymmetry in Titan's seasons forced by the orbit**
- The orbital parameters vary with **10's kyr periods**, suggesting a **dynamic hydrologic methane cycle**







Thanks...

Titan Mare Explorer