

CHARM: Cassini-Huygens Mission to Saturn 12th Anniversary!!

Titan Highlights

Zibi Turtle, JHU/APL

Cassini Mission Overview

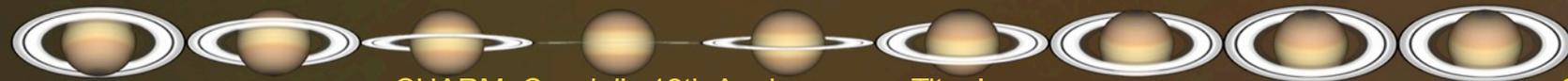
Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), May 2004 - September 2017



Proximal Orbits

EOM
Sep 15, 2017

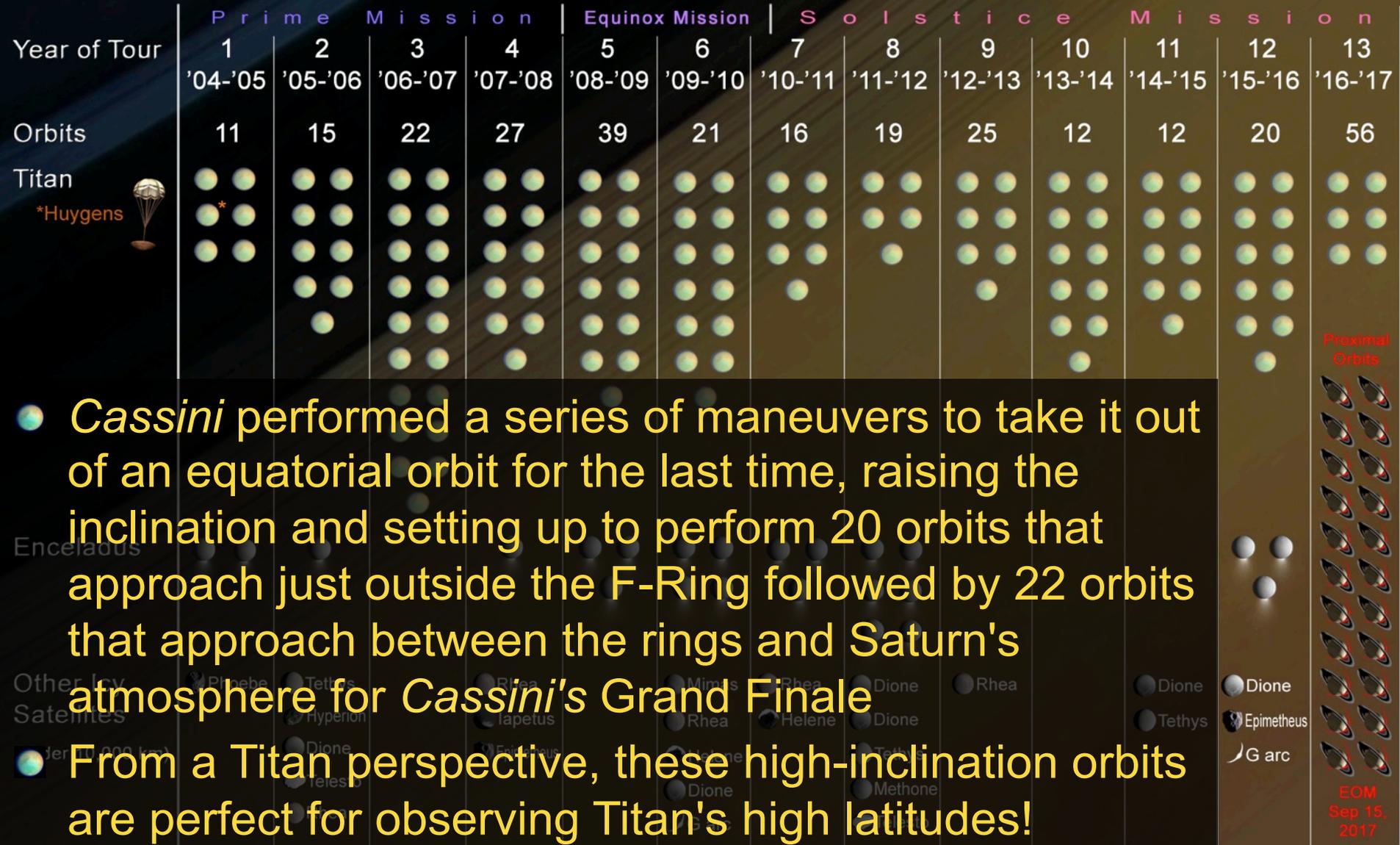
Saturn
(seen from Sun)
26 July 2016



CHARM: Cassini's 12th Anniversary -- Titan!

Cassini Mission Overview

Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), May 2004 - September 2017

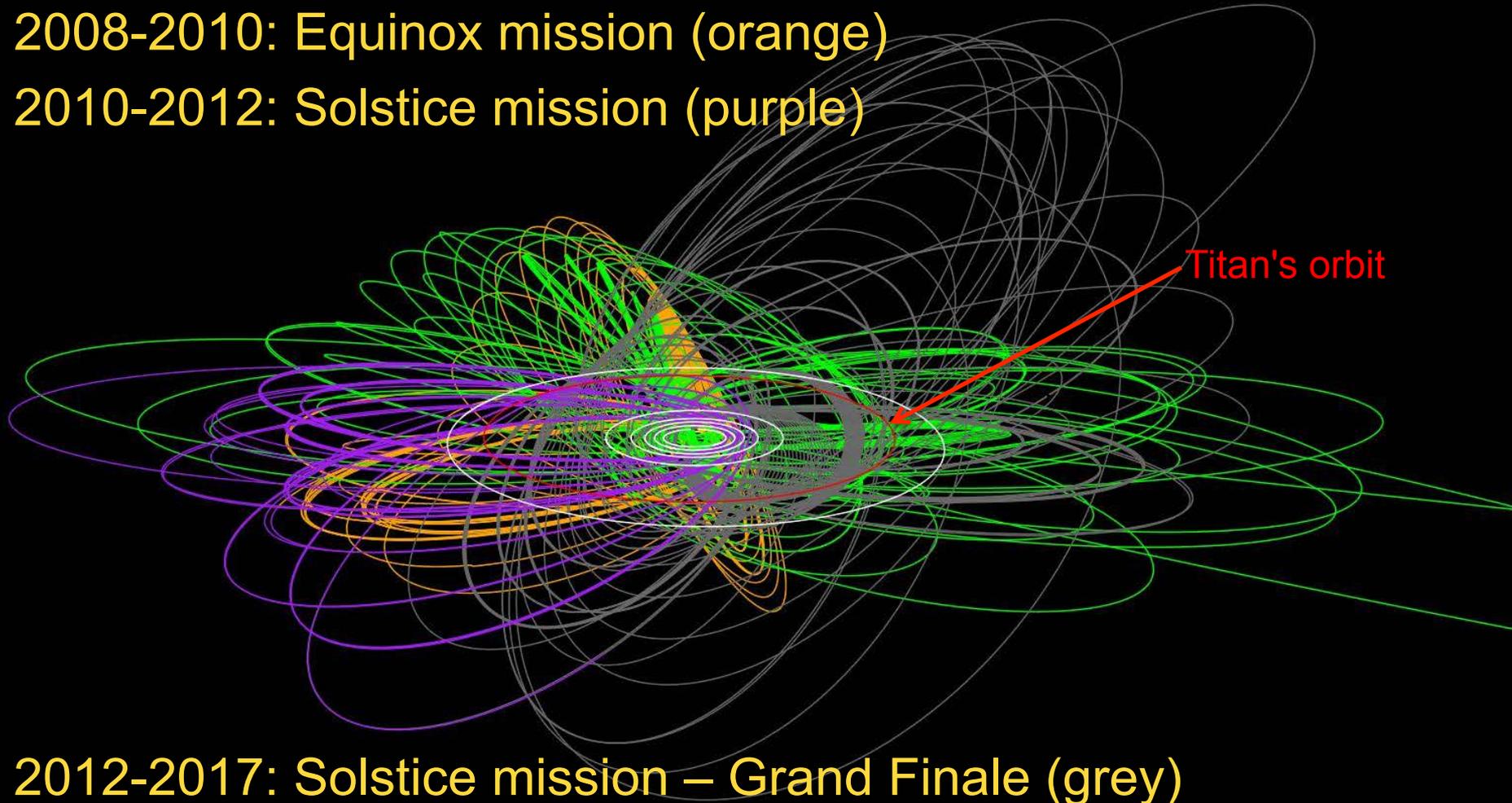


Cassini performed a series of maneuvers to take it out of an equatorial orbit for the last time, raising the inclination and setting up to perform 20 orbits that approach just outside the F-Ring followed by 22 orbits that approach between the rings and Saturn's atmosphere for *Cassini's* Grand Finale. From a Titan perspective, these high-inclination orbits are perfect for observing Titan's high latitudes!



Cassini's orbits of Saturn: 30 June 2004 – 15 Sept 2017

- 2004-2008: Prime mission (green)
- 2008-2010: Equinox mission (orange)
- 2010-2012: Solstice mission (purple)



- 2012-2017: Solstice mission – Grand Finale (grey)
 - Starting April 2017, Cassini's orbits will pass between Saturn's atmosphere and its innermost ring

Titan Flybys: July 2015-July 2016

Titan 112 Flyby

Probing the Summer and Winter Poles with CIRS

July 7, 2015



Titan 113 Flyby

Sampling Titan's Atmospheric Outflow

Sept. 28, 2015



Titan 114 Flyby

Last Good Look at Xanadu

Nov. 13, 2015



Titan T-115

Last Close Comparison of Titan's North and South Hemispheres

Jan. 16, 2016



Titan 116 Flyby

Solar and stellar occultations provide detailed information about Titan's atmosphere

Feb. 1, 2016



T112, 7 July 2015

T113, 28 Sep 2015

T114, 13 Nov 2015

T115, 16 Jan 2016

T116, 1 Feb 2016

T117, 16 Feb 2016

T118, 4 April 2016

T119, 6 May 2016

T120, 7 June 2016

T121, 25 July 2016

Titan 117 Flyby

One Flyby, Two Radio Science Experiments

Feb. 16, 2016



April 4, 2016
Cassini's 'T-118' Titan Encounter

Fly By Once
Measure Twice



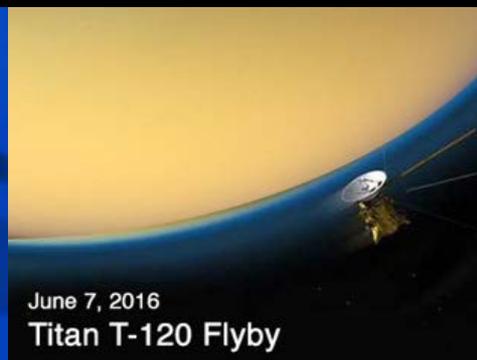
T-119 Titan Flyby, May 6, 2016

A Unique 'Double Midnight' Flyby



June 7, 2016

Titan T-120 Flyby



Radar: 'Switch Hitting' at Titan

Titan Flyby T-121
July 25, 2016



Prime Mission Titan Activity

Extended Mission Titan Activity

Voyager Birthdays

XXM

January

M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12 SOI	13	14	15	16	17 TA
18 TB	19 TC	20 T3	21	22 T4&T5	23	24
25	26	27	28 T6&T7	29	30 T8	31

March

M	T	W	T	F	S	S
1	2 T41	3 T42	4	5	6 T43&T44	7 EOM
8 T45	9	10	11 T46	12 T47	13 T48&T49	14
15 T50	16 T51	17 T52	18 T53	19 T54&T55	20 T56&T57	21 Equinox T58&T59
22 T60&T61	23	24 T62	25	26 T63	27 T64&T65	28 T66
29 V1	30 T67	31 T68&T69				

May

M	T	W	T	F	S	S
					1	2
3 T89 & 90	4	5 T91	6	7 T92&T93	8	9 T94
10 T95	11 T96	12 T97	13	14 T98	15 T99	16 T100
17 T101	18 T102	19 T103	20 T104	21 105 & 106	22	23 T107
24 T108	25 T109	26 T110	27	28 T111	29	30 T112
31						

February

M	T	W	T	F	S	S
1 T9	2 T10	3 T11	4 T12	5	6 T13	7 T14
8 T15	9 T16	10	11 T17&T18	12 T19	13 T20	14 T21
15 T22&T23	16 T24	17 T25&T26	18 T27&T28	19	20 T29&T30	21 T31&T32
22 T33	23 T34	24 T35	25 T36	26	27 T37&T38	28 T39&T40

April

M	T	W	T	F	S	S
			1 T70 & 71	2	3	4 T72
5	6 T73	7	8 V2	9 T74	10	11 T75 & 76
12 T77	13	14	15 T78	16	17	18 T79
19 T80	20 T81&T82	21	22	23 T83	24 T84	25
26 T85	27	28 T86	29 T87	30 T88		

June

M	T	W	T	F	S	S
	1	2 T113	3	4 T114	5	6 T115&116
7 T117 & 118	8	9 T119	10 T120	11 T121	12 T122	13 T123
14	15 T124	16 T125, nT253	17 nT255	18 nT259,261	19 nT264	20 T126
21 Solstice nT273,275	22 nT278	23 nT283,285	24 nT288	25 EOM nT292	26	27
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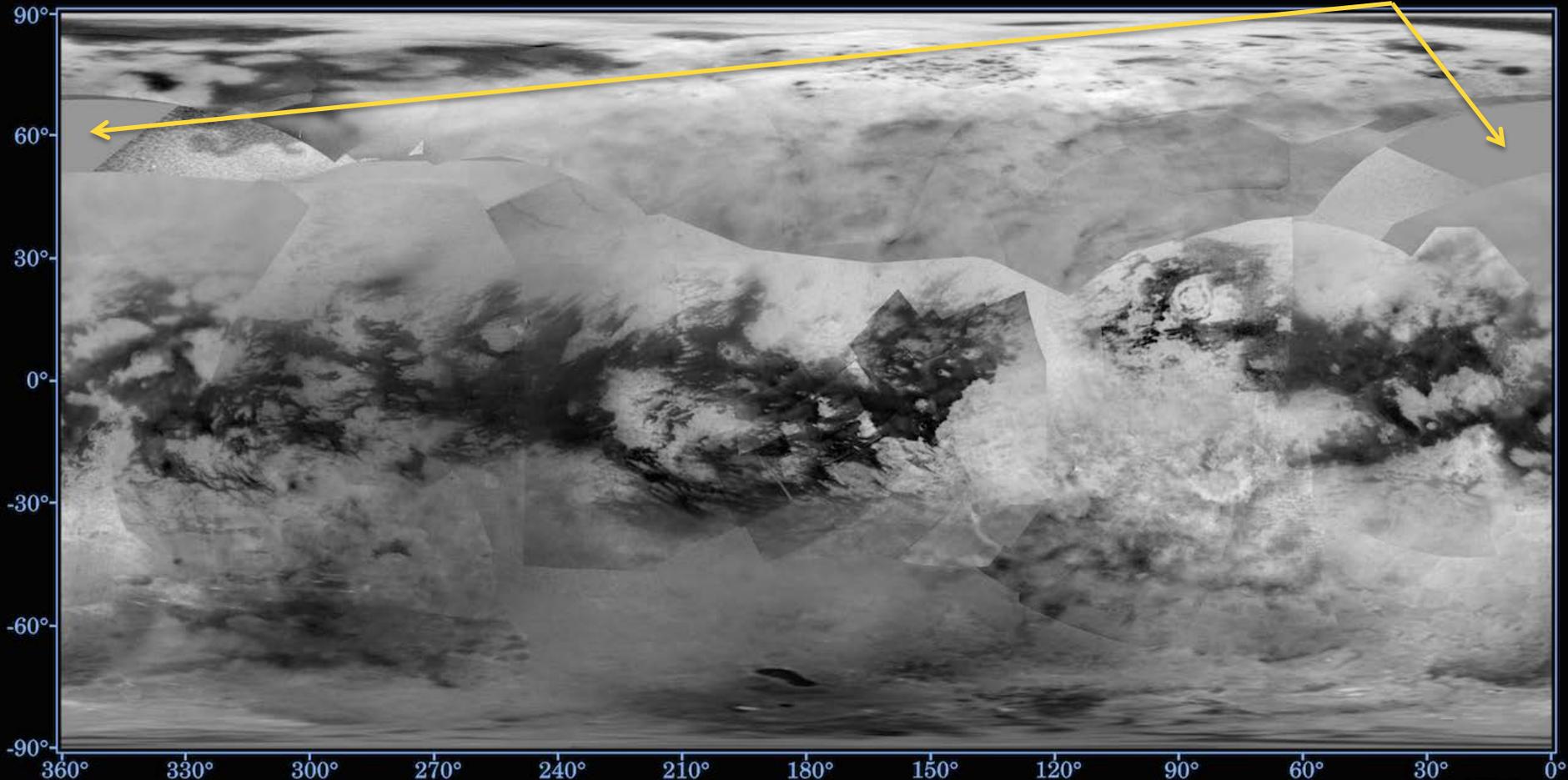
Updated map of Titan's surface (938 nm)

- Equidistant projection at 4 km pixel scale

- Data through T100 (7 April 2014)

- <http://photojournal.jpl.nasa.gov/catalog/PIA19658>

Distant flybys in
Revs 253 & 264
have geometry to
fill remaining gap



26 July 2016

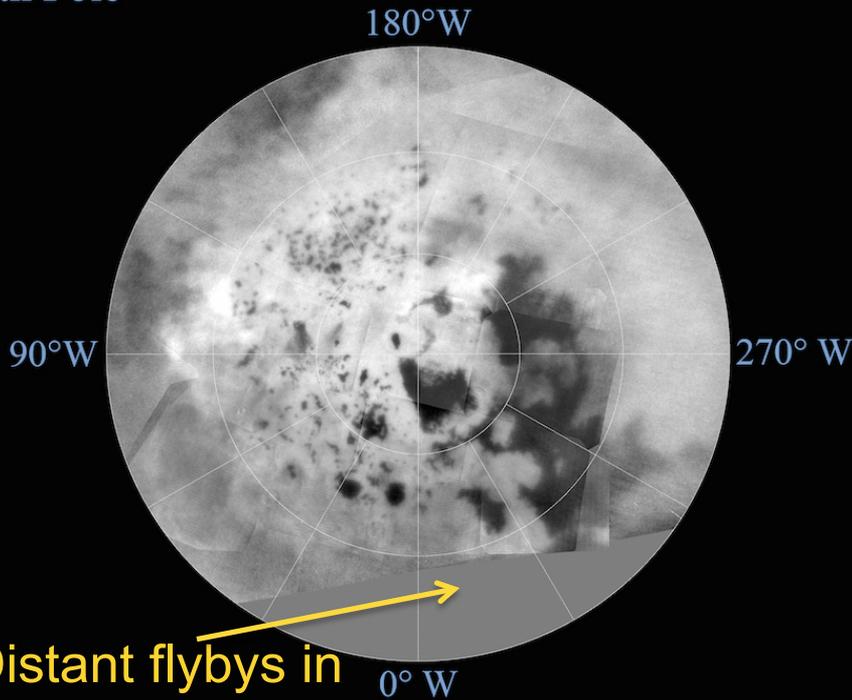
CHARM: Cassini's 12th Anniversary -- Titan!

4000 km 7

Updated map of Titan's surface (938 nm)

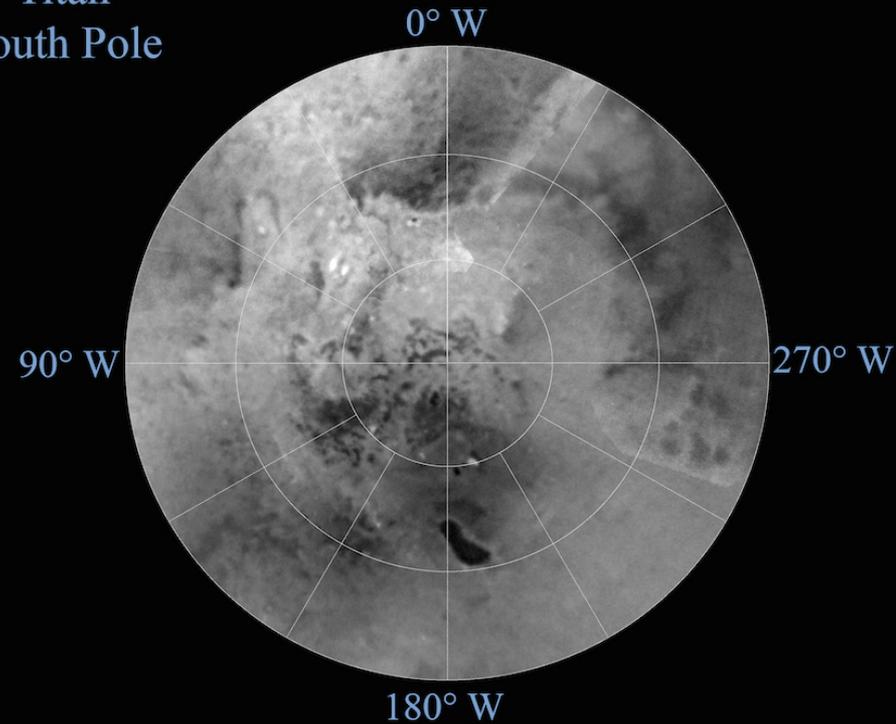
- Polar projections at 1.4 km pixel scale
- Data through T100 (7 April 2014)
- <http://photojournal.jpl.nasa.gov/catalog/PIA19657>

North Pole

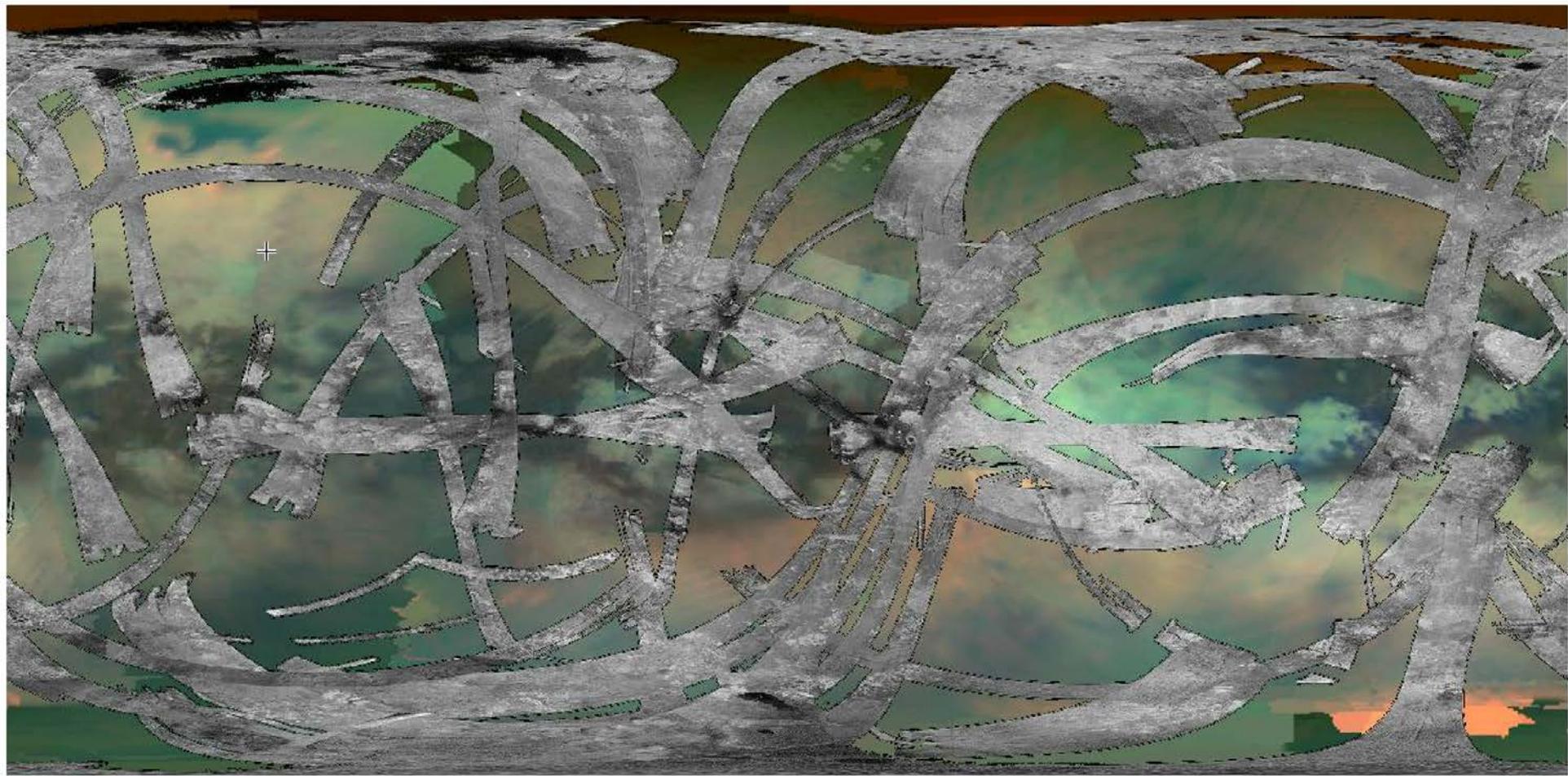


Distant flybys in
Revs 253 & 264
have geometry to
fill remaining gap

Titan
South Pole

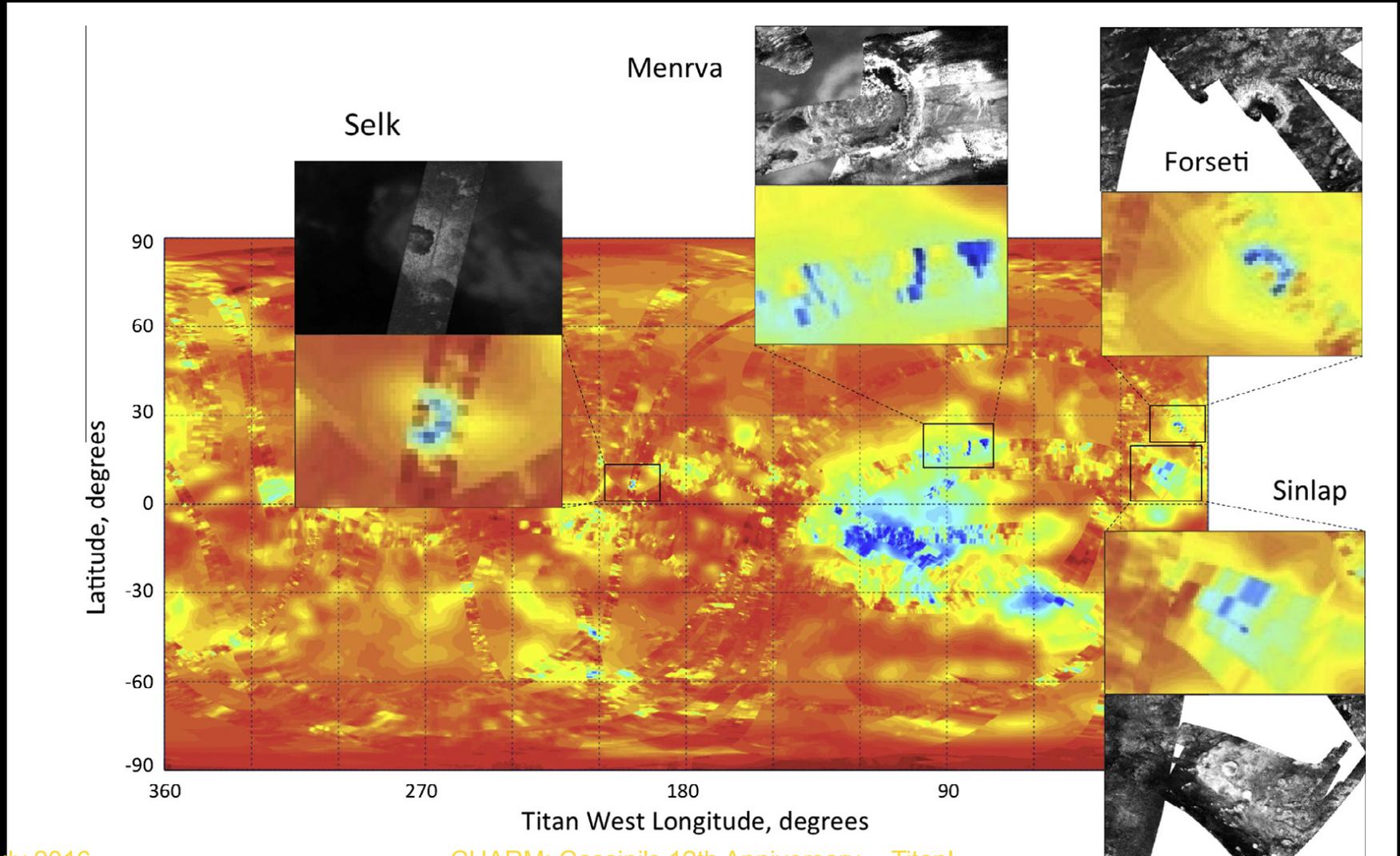


Cassini RADAR (TA-T104=Aug 2014; 2.2 cm) and VIMS (2011; red = 4.8-5.2 μ m, green = 2.0 μ m, blue = 1.28 μ m)

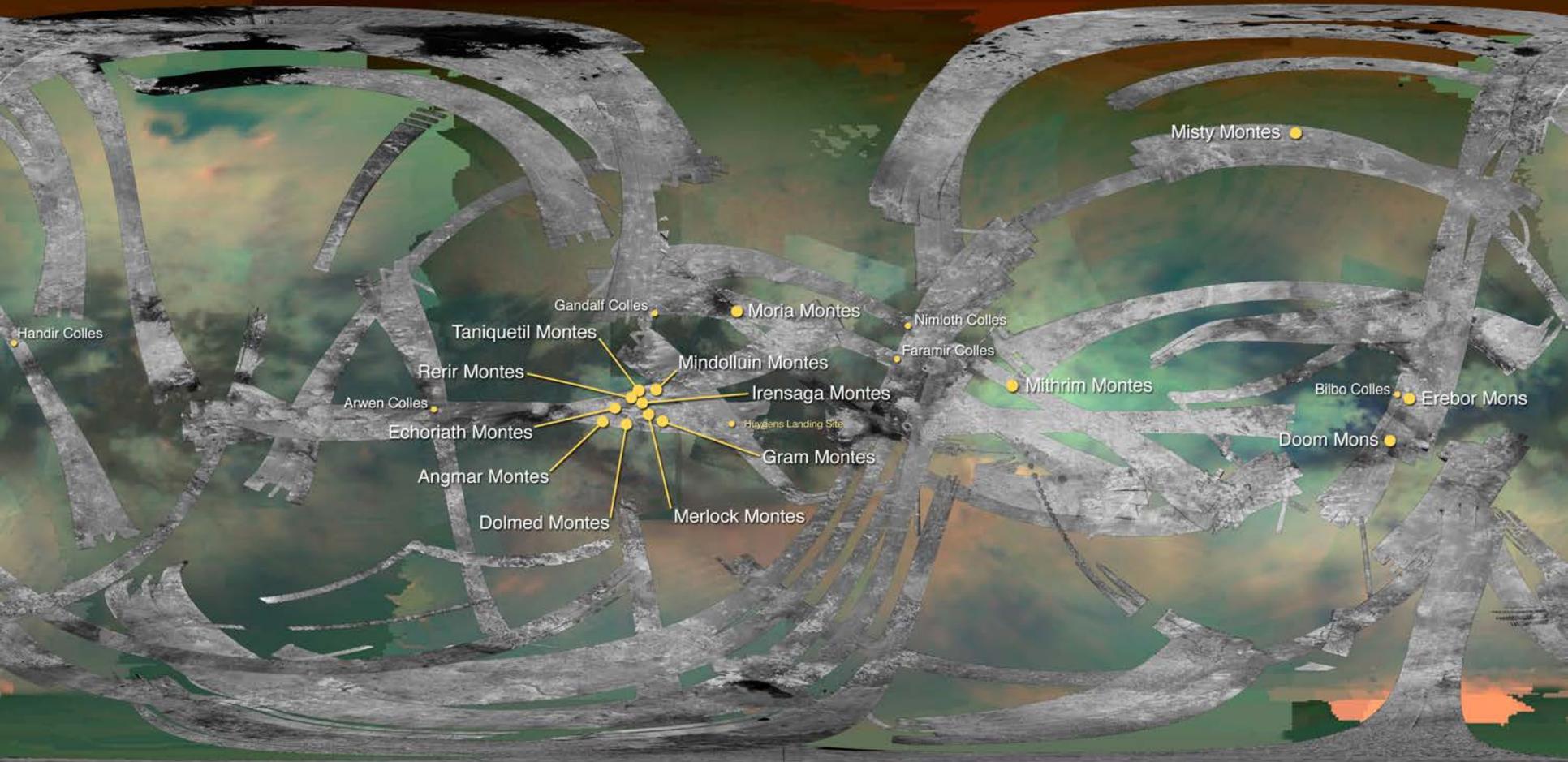


Cassini RADAR emissivity map

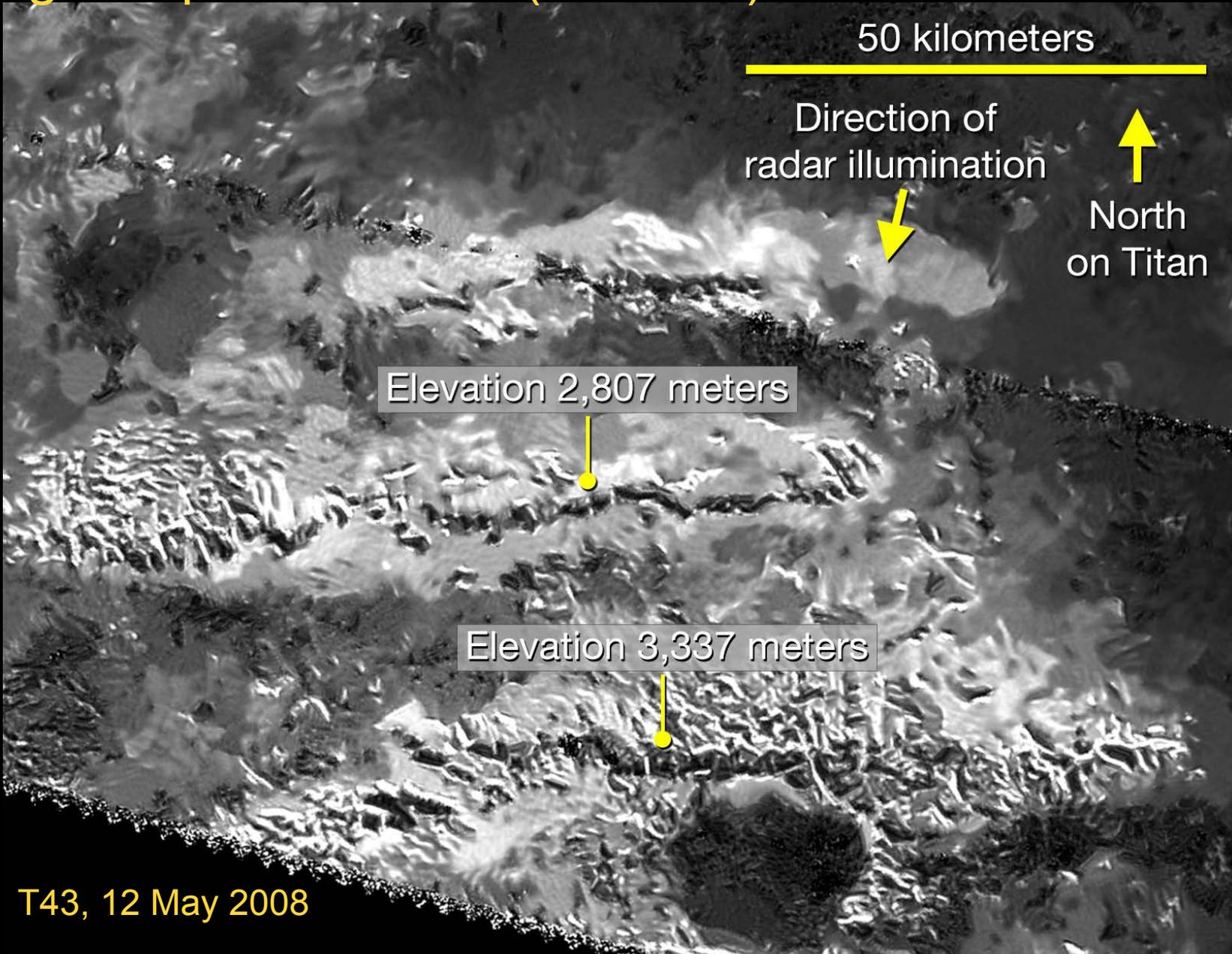
Small regions of low emissivity near impact craters attributed to presence of near-surface (\sim m) water ice (Janssen *et al.* 2016)



Updated map of Titanian mountains (named for mountains & peaks in Tolkien's Middle Earth)

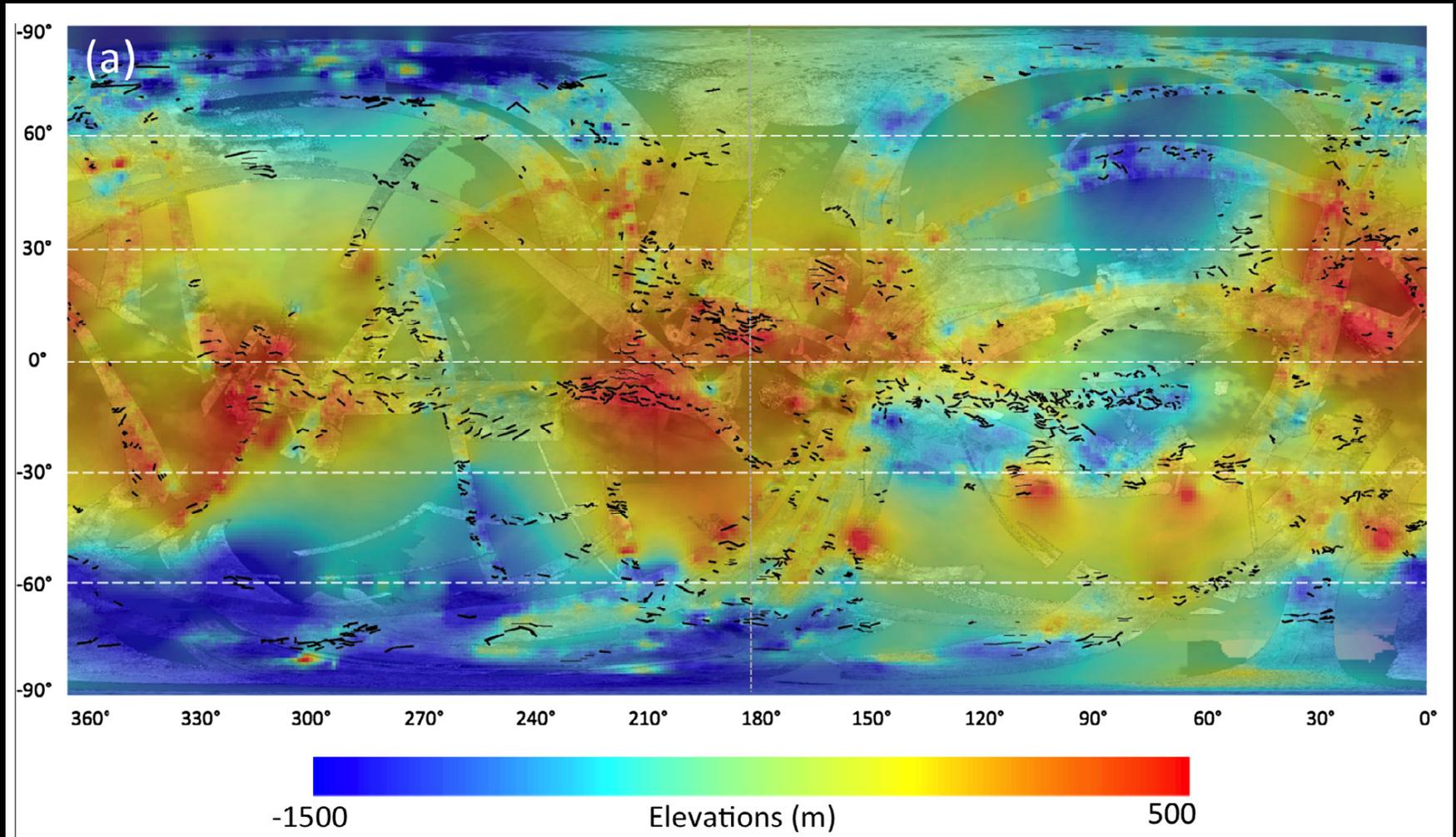


Titan's highest peak 3337 m (10948 ft) in Mithrim Montes



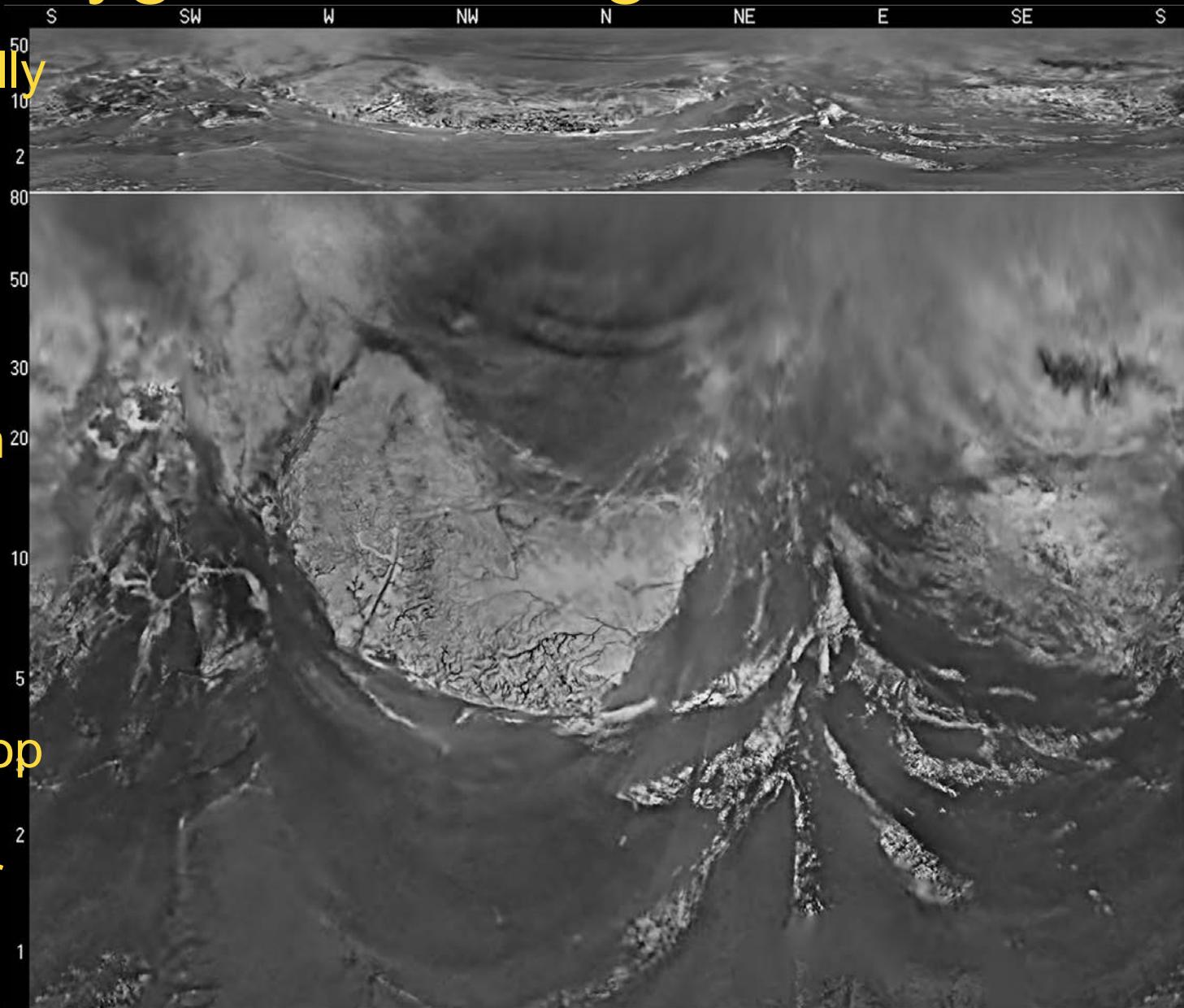
Tectonics

Map of mountain ridges (Liu *et al.* 2016) overlain on interpolated RADAR topography data (Lorenz *et al.* 2013)



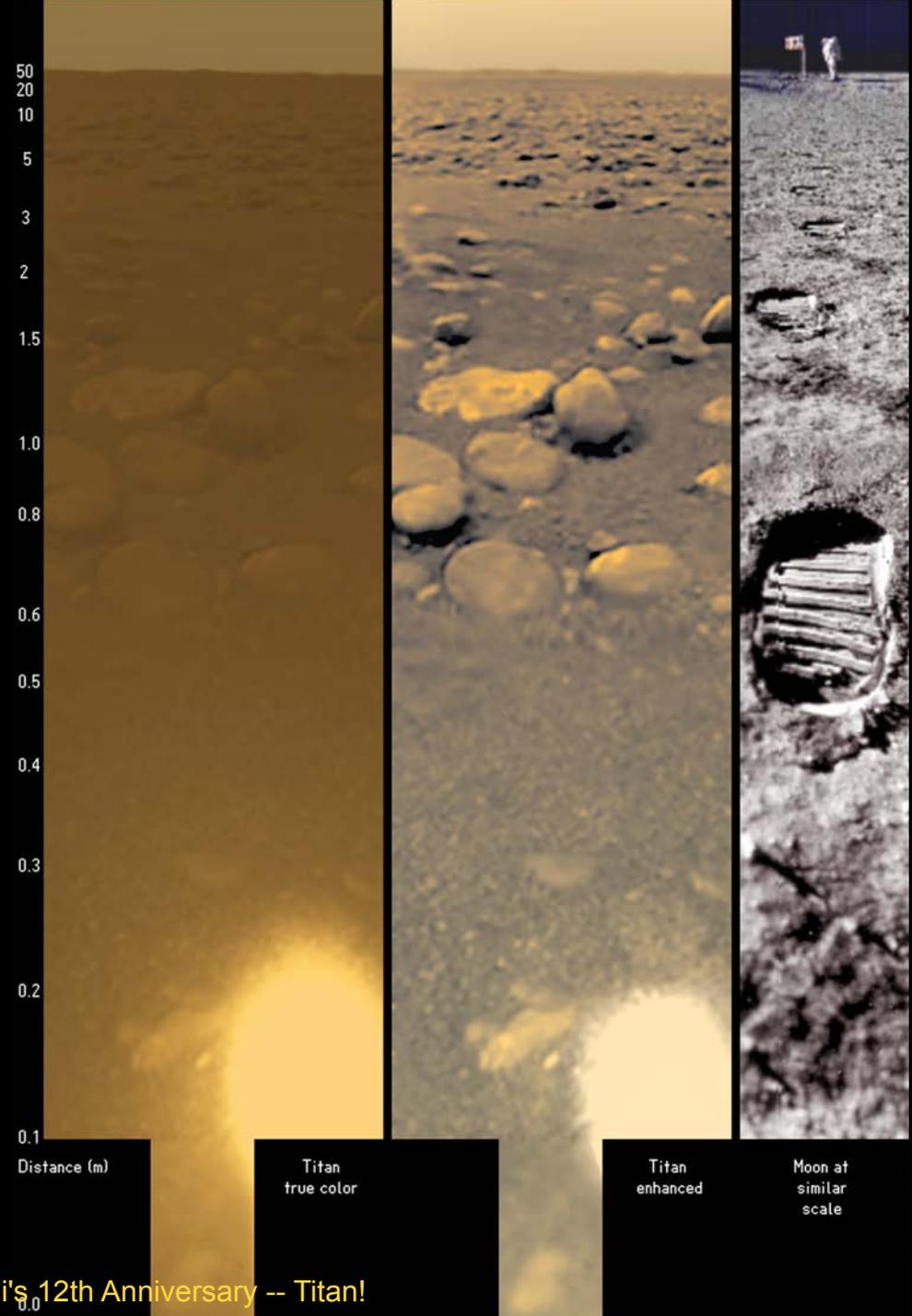
Huygens Landing Site

● Photometrically calibrated mosaic; side-looking (top) and down-looking (bottom), with range from landing site indicated at left, direction indicated at top (Karkoschka and Schröder 2016)



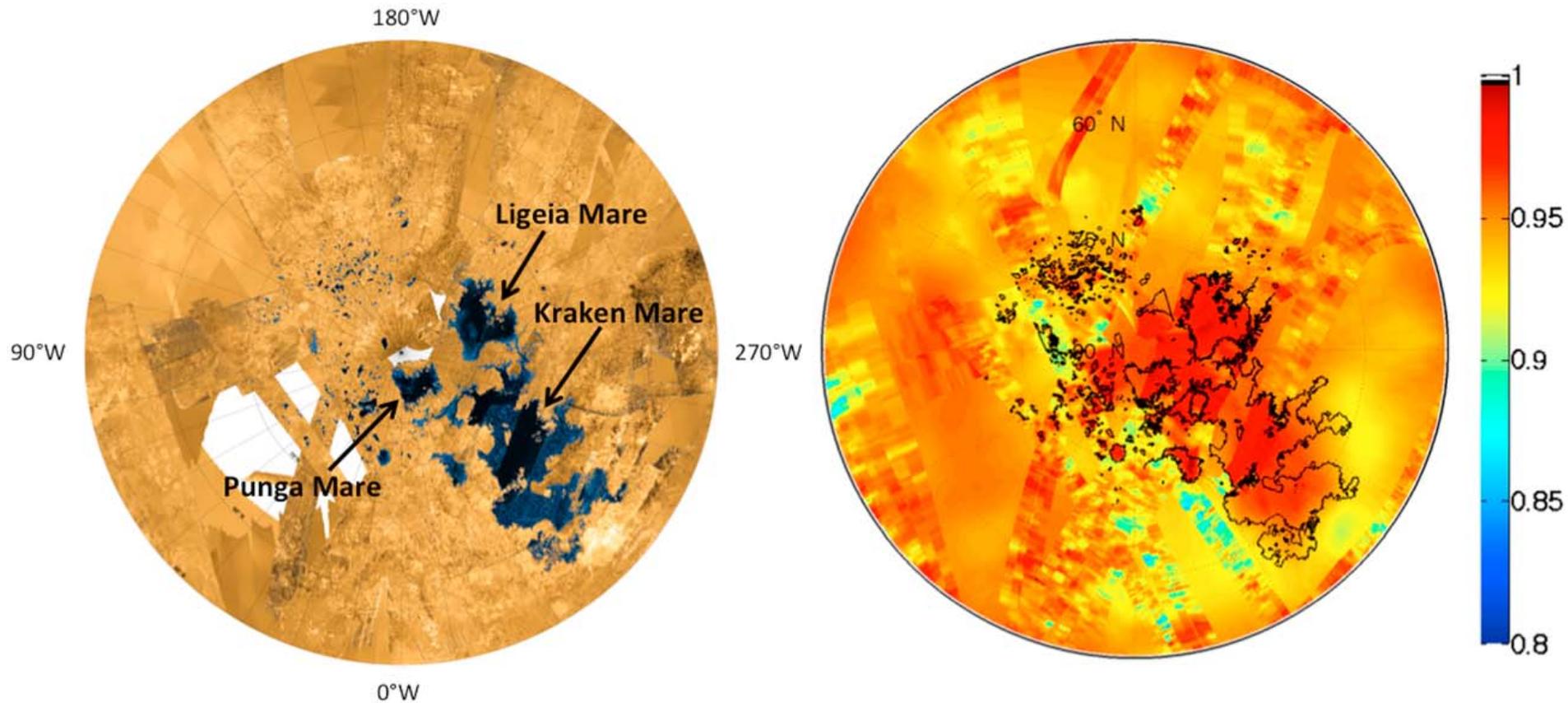
Huygens Landing Site

- True color (left), enhanced (middle), Moon to scale (right) Side-looking (top) and down-looking (bottom), with range indicated at left (Karkoschka and Schröder 2016)



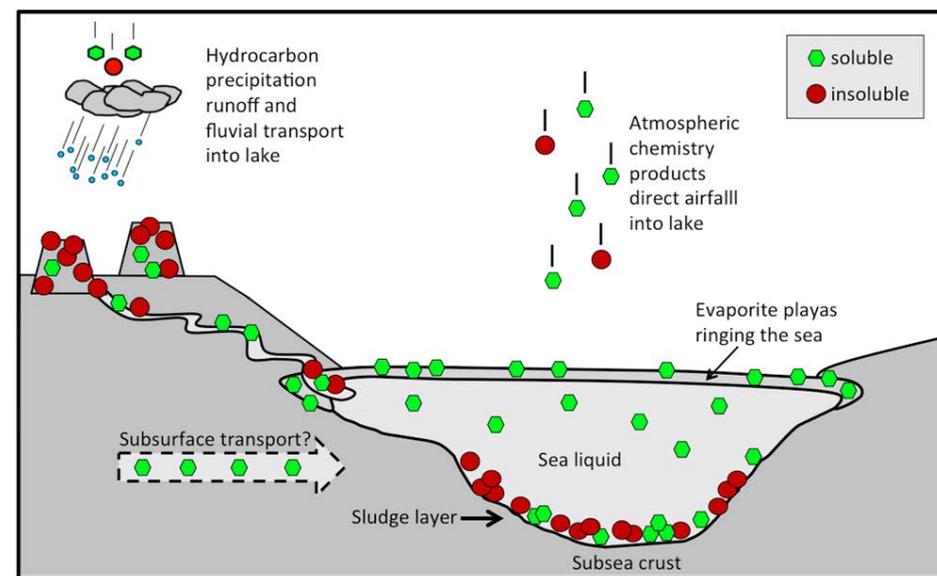
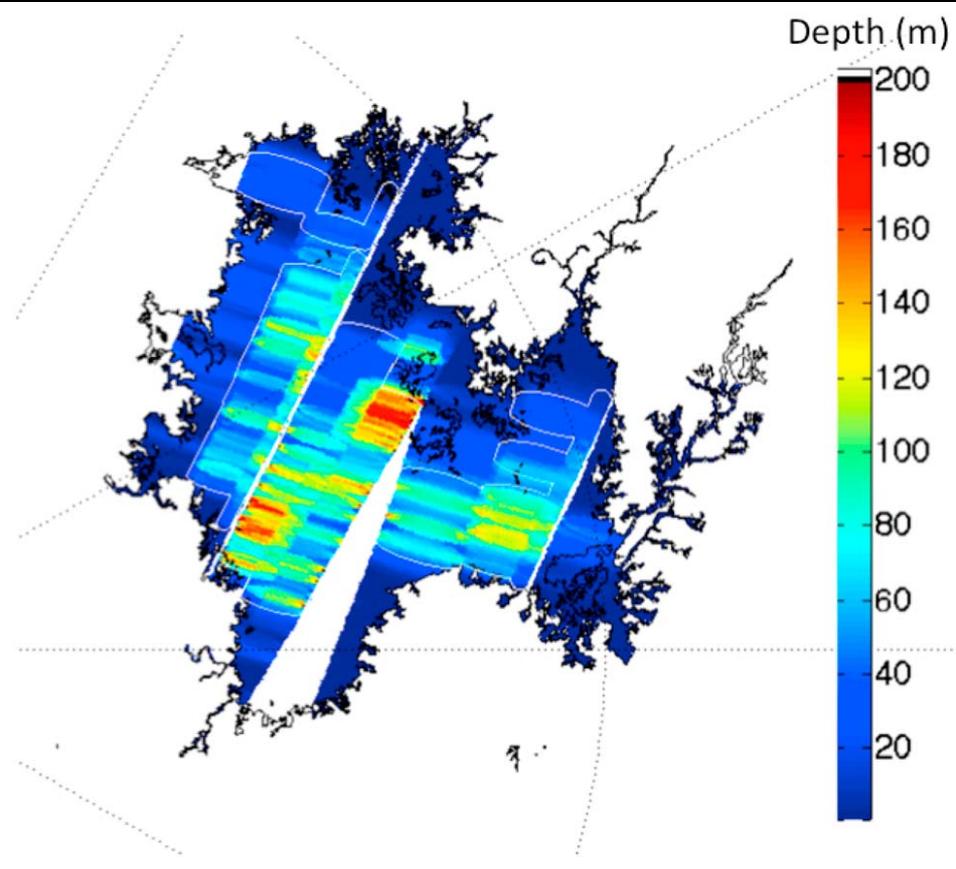
Ligeia Mare: composition, bathymetry, and nature of the seafloor (Le Gall *et al.* 2016)

- False color SAR (left) and surface emissivity (right)



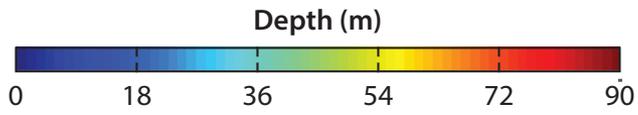
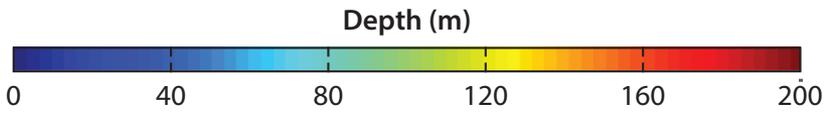
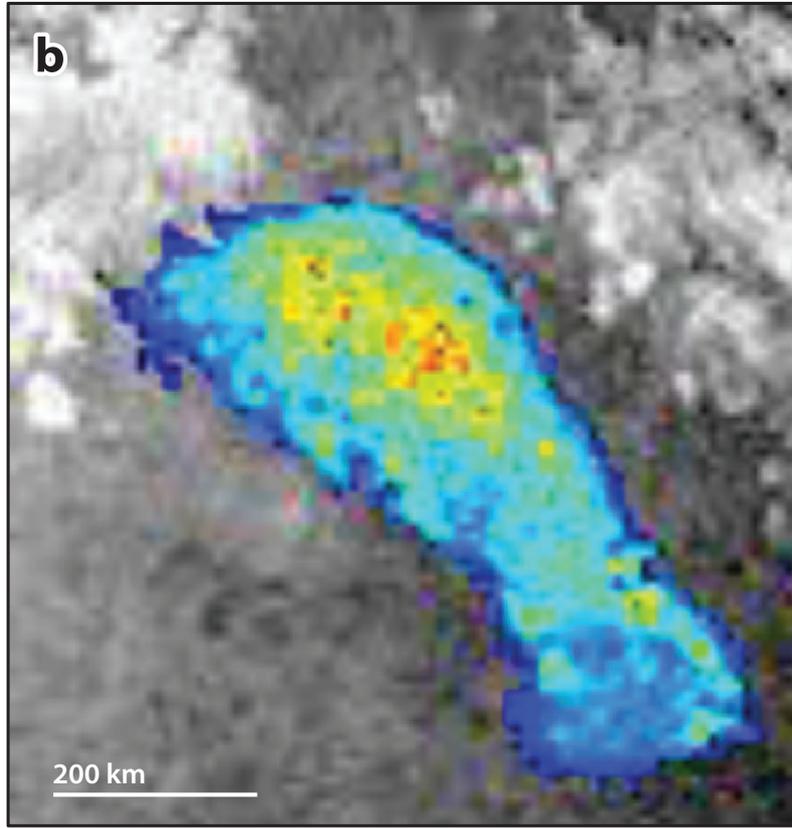
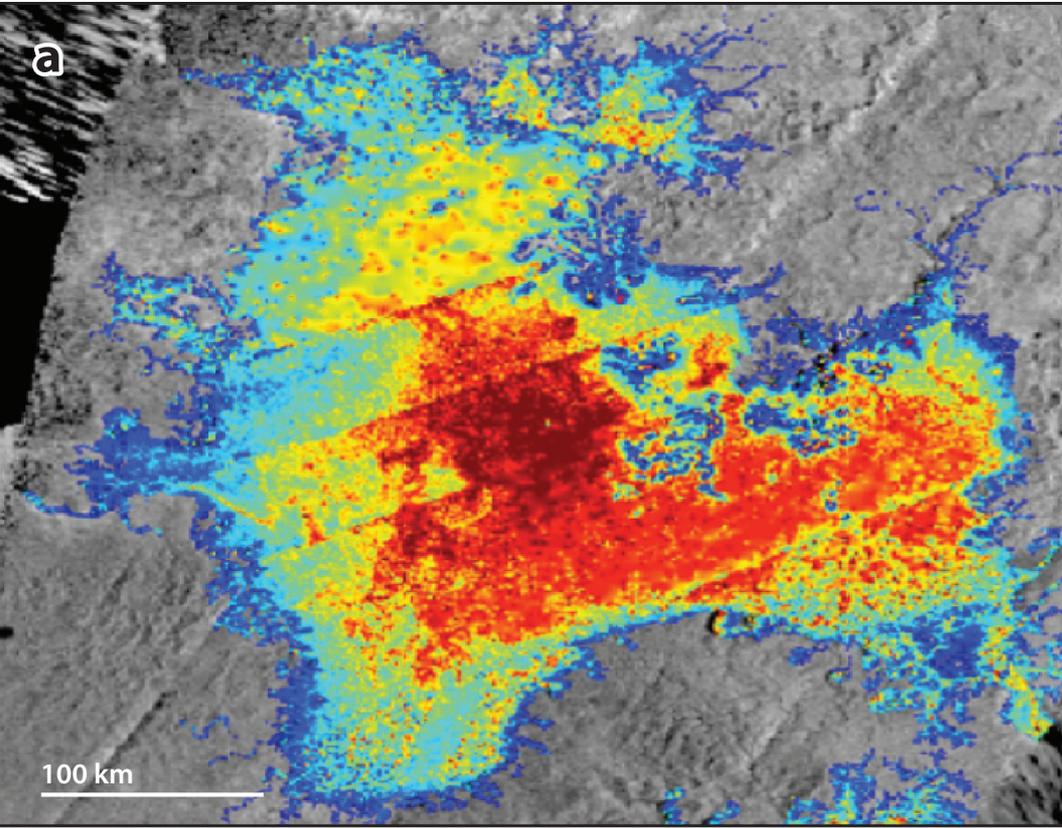
Ligeia Mare: composition, bathymetry, and nature of the seafloor (Le Gall *et al.* 2016)

- Bathymetry inferred from radiometry observations (left) and schematic overview of delivery of material to the seafloor (right)



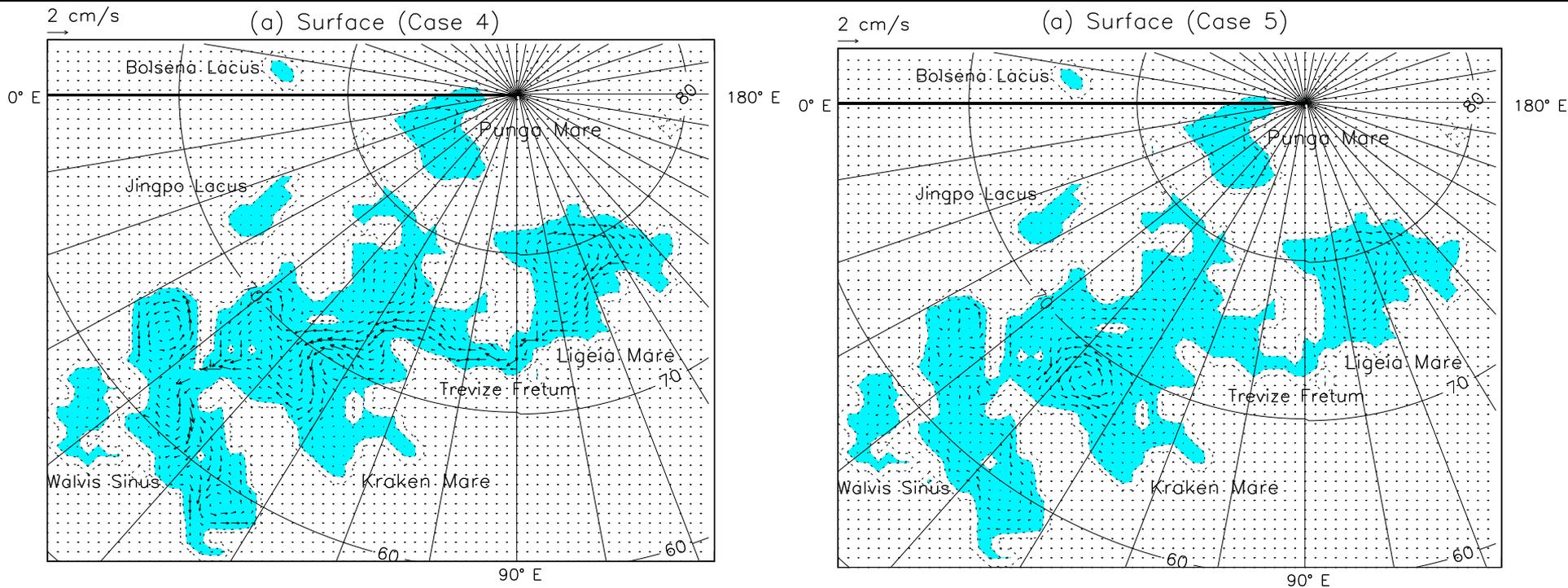
Hydrocarbon inventory in lakes and seas $\sim 70,000 \text{ km}^3 = 35\text{x}$ all terrestrial fossil fuel reserves (Hayes 2016)

- Ligeia Mare & Ontario Lacus bathymetry derived from SAR data



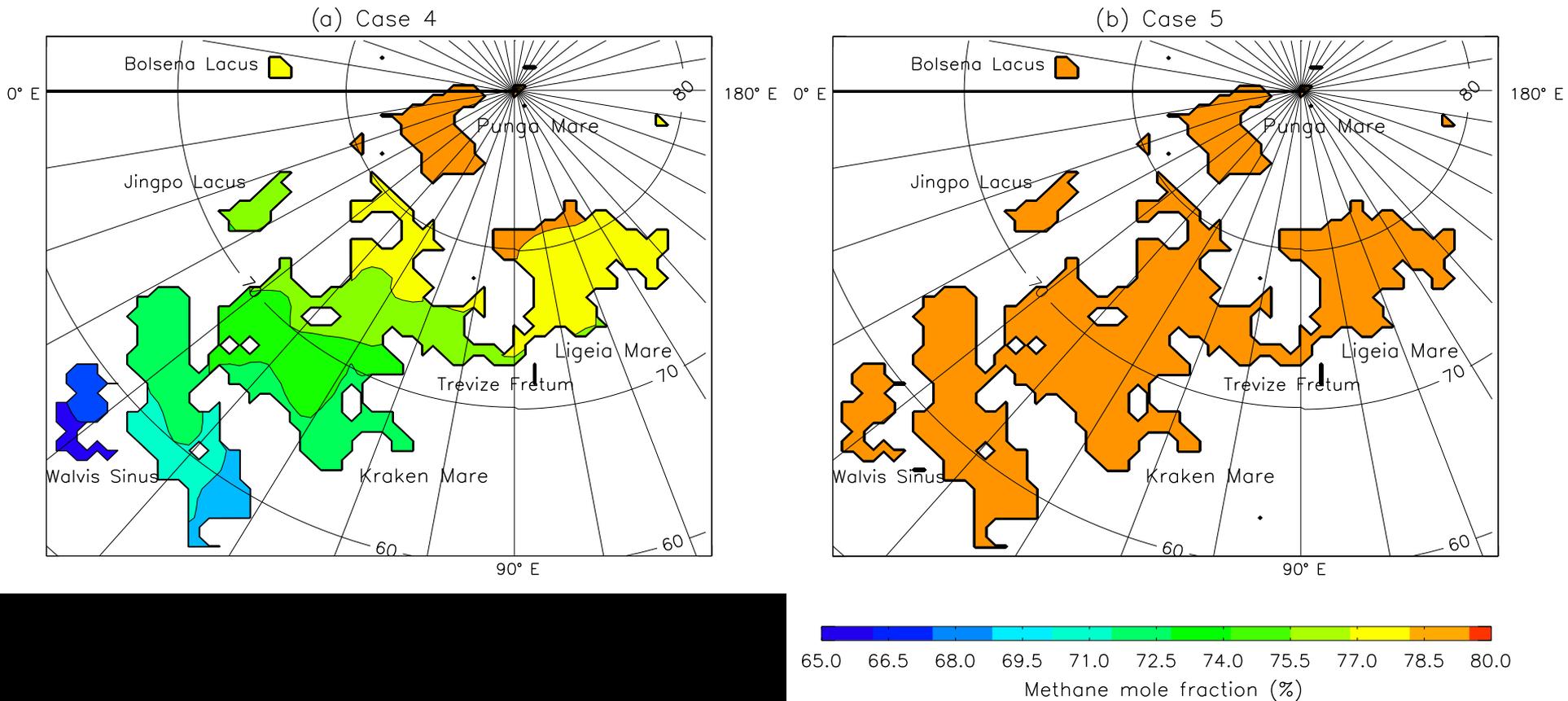
Modeling circulation of Titan's seas (Tokano and Lorenz 2016)

- Sea surface currents with low (left) and high (right) precipitation rates



Modeling circulation of Titan's seas (Tokano and Lorenz 2016)

- Sea surface CH₄ mole fraction with low (left) and high (right) precipitation rates



Seasonal changes – still waiting for N summer storms...

<u>Event, Date</u>	<u>Time in Titan's year</u>
Voyager 1 flyby, Nov. 1980	29 March
Voyager 2 Flyby, Aug. 1981	8 April
Cassini SOI, 2 July 2004	Mid-January
Dissipation of high-alt N.P. ethane cloud (VIMS), 2008-9	Late N. winter
11 Aug 2009	N. vernal equinox
Decrease in altitude of detached haze (ISS), 2009-2010	Early N. spring
Low-latitude rainstorm (ISS), Sept.-Oct. 2010	Early April
Rapid changes in south polar upper atmospheric temperatures and composition (CIRS), 2010-2011	N. spring
South polar vortex, ~300 km (ISS, VIMS) 2011/2012... S.P. stratospheric nitrile ice cloud, ~200 km alt (CIRS)	Onset in late April
Development of northern clouds (model predictions)	Spring...?
Development of northern clouds (observations), 2016	Mid-June?
May 2017	N. summer solstice

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Extended Mission Titan Activity						
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Voyager Birthdays						
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19 T80	20 T81&T82	21	22	23 T83	24 T84	25
26 T85	27	28 T86	29 T87	30 T88		

XXM						
June						
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31						

26 July 2016						
CHARM: Cassini's 12th Anniversary -- Titan!						

Cloud highlights
(dark=S, light=N)

Prime Mission Titan Activity

Extended Mission Titan Activity

Voyager Birthdays

XXM

January

M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

S. Pole clouds

Arrakis storm

February

M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

1st N clouds

March

M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

N clouds

Equinox

N clouds

April

M	T	W	T	F	S	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

"arrow" storm

Development of S polar vortex...

last S clouds

May

M	T	W	T	F	S	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

June

M	T	W	T	F	S	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

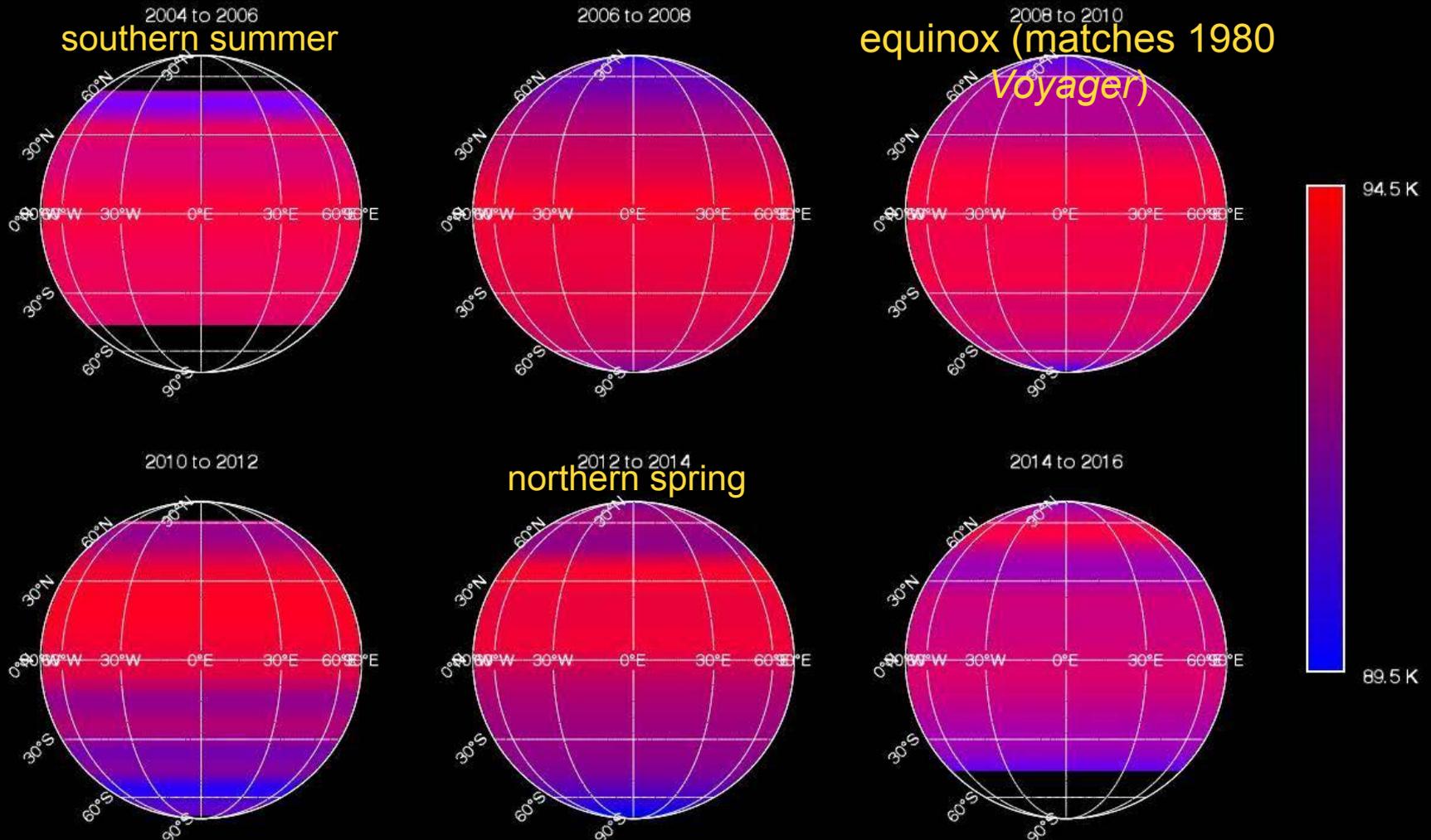
N clouds?

21 Solstice

25 EOM

Titan's surface temperatures, 2004-2016

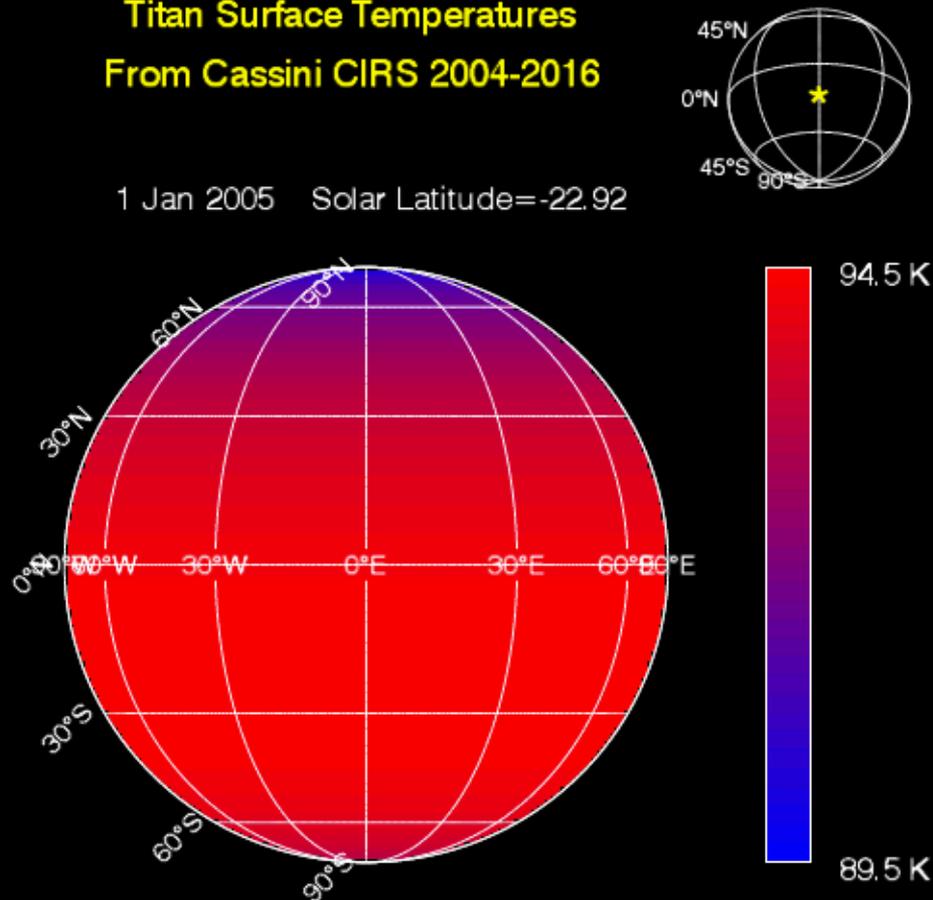
- *Cassini* CIRS measurements at 19 μm (Jennings *et al.* 2016) animation: <http://photojournal.jpl.nasa.gov/archive/PIA20020.gif>
- $T(\text{max}) = 93.6 \text{ K}$ (-179.6°C , -292°F), $T(\text{min}) = 90.1 \text{ K}$ (-183.1°C , -298°F)



Titan's surface temperatures, 2004-2016

- *Cassini* CIRS measurements at 19 μm (Jennings *et al.* 2016) animation: <http://photojournal.jpl.nasa.gov/archive/PIA20020.gif>
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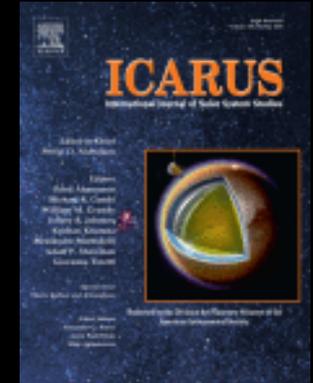
Titan Surface Temperatures
From Cassini CIRS 2004-2016



Recent results

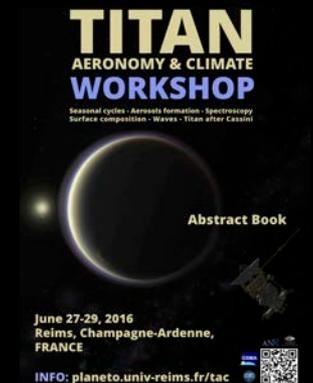
- Special issue of *Icarus* on Titan's Surface and Atmosphere, Vol. 270, published 15 May 2016:

<http://www.sciencedirect.com/science/journal/00191035/270>



- Titan Aeronomy and Climate Workshop, 27-29 June 2016

http://planeto.univ-reims.fr/tac/images/TAC_2016-Abstract_book.pdf



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Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), May 2004 - September 2017



Proximal Orbits

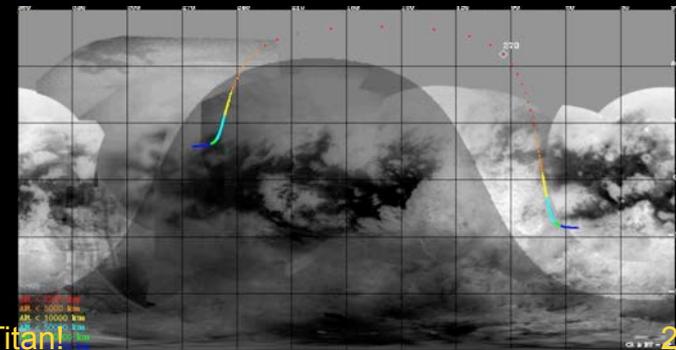
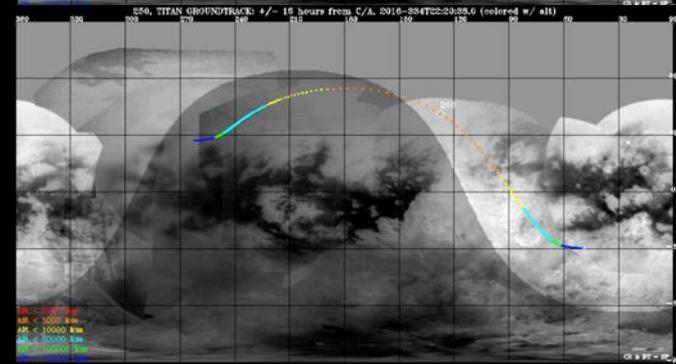
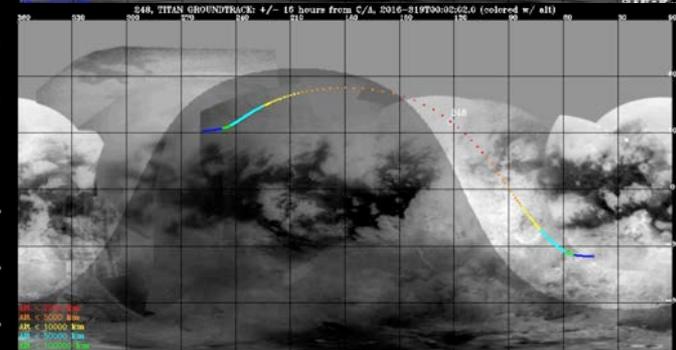
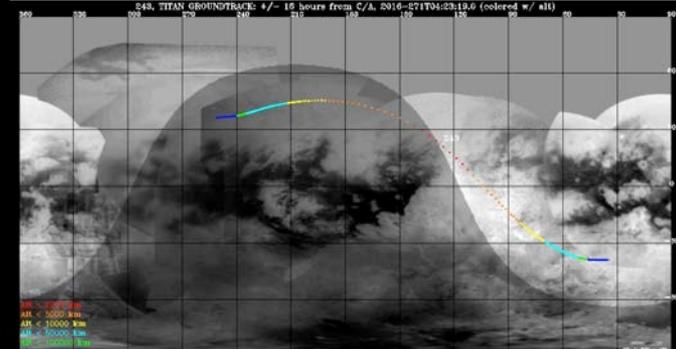
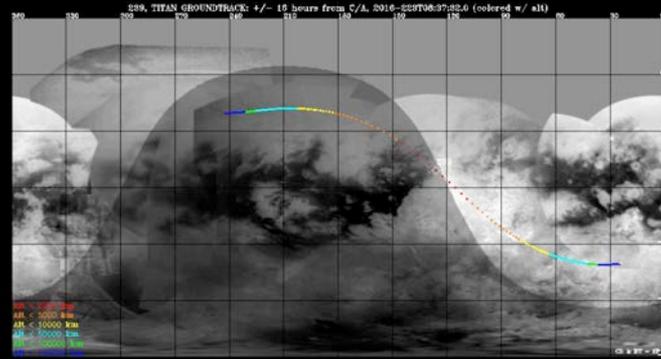
EOM
Sep 15, 2017

Saturn
(seen from Sun)
26 July 2016



CHARM: Cassini's 12th Anniversary -- Titan!

Upcoming Close Titan Flybys:

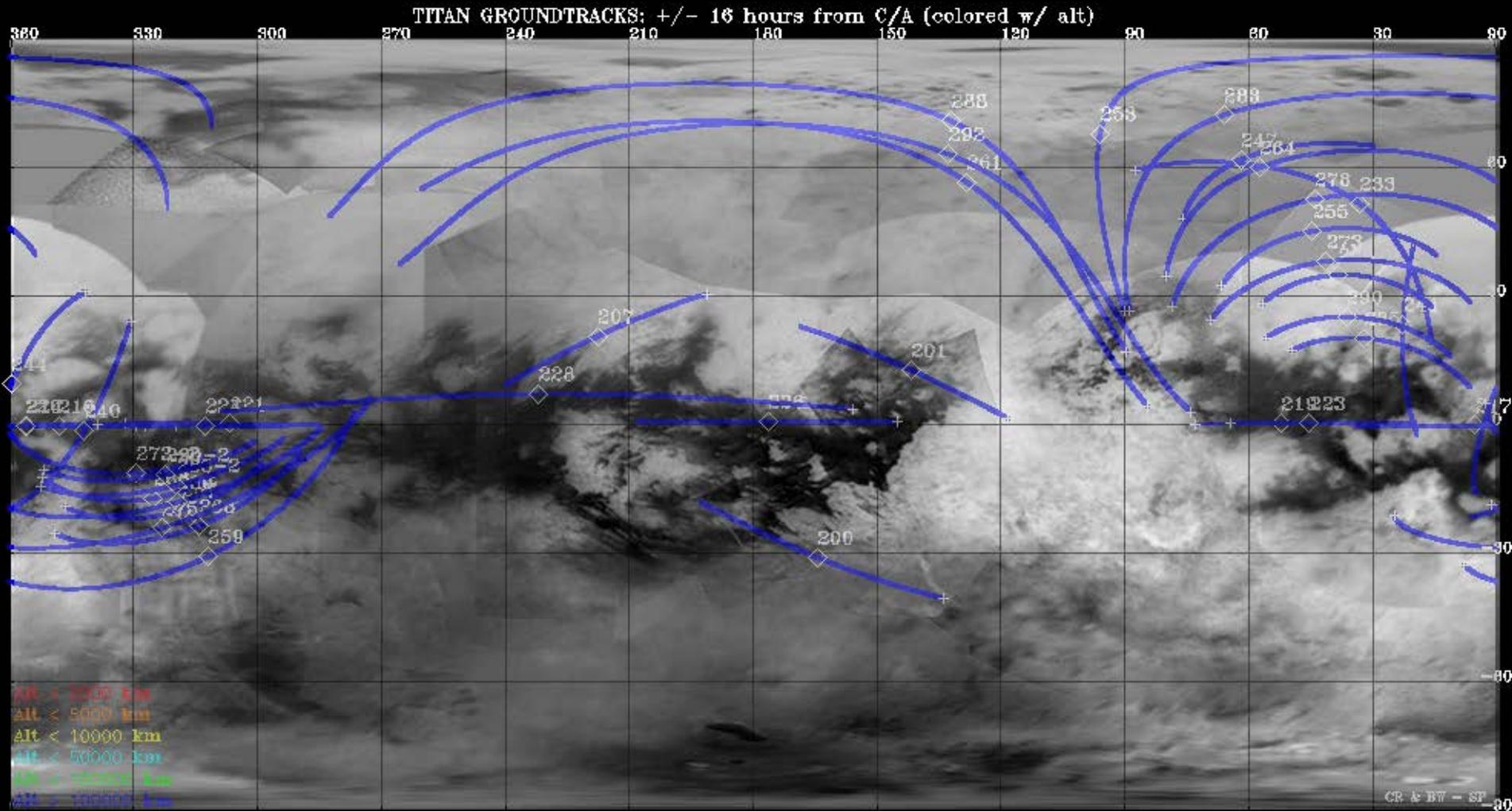


- T122, 10 Aug 2016
- T123, 27 Sep 2016
- T124, 14 Nov 2016
- T125, 29 Nov 2016
- T126, 22 Apr 2017

Upcoming Titan Encounters:

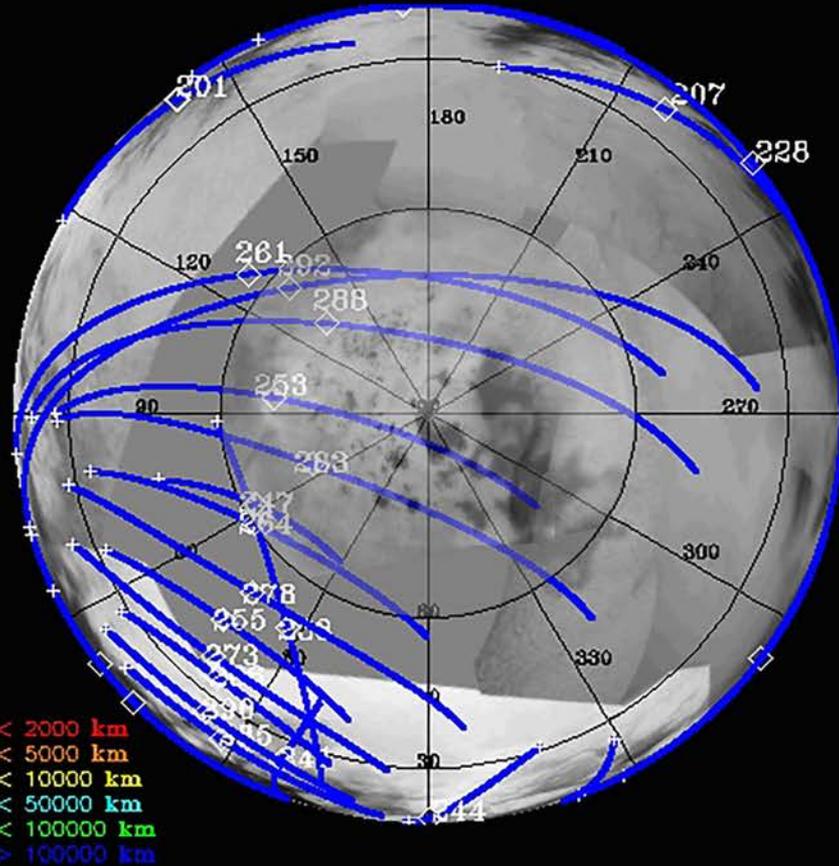
- Rev 250, 29 Nov 2016 =T125
- Rev 253, 5 Dec 2016
- Rev 255, 31 Dec 2016
- Rev 259, 1 Feb 2017
- Rev 261, 17 Feb 2017
- Rev 264, 5 Mar 2017
- Rev 266, 20 Mar 2017
- Rev 268, 6 Apr 2017
- Rev 270, 22 Apr 2017 = T126
- Rev 273, 7 May 2017
- Rev 275, 24 May 2017
- Rev 278 8 Jun 2017
- Rev 280, 25 Jun 2017
- Rev 283, 10 Jul 2017
- Rev 285, 26 Jul 2017
- Rev 288, 11 Aug 2017
- Rev 290, 28 Aug 2017
- Rev 292, 11 Sep 2017

Upcoming Distant Titan Encounters:



Upcoming Distant Titan Encounters:

TITAN GROUNDTRACKS: +/- 16 hrs from C/A (colored w/ alt)
NORTH



TITAN GROUNDTRACKS: +/- 16 hrs from C/A (colored w/ phase)
NORTH

