nature geoscience

SUPPLEMENTARY INFORMATION

DOI: 10.1038/NGEO3033

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Methane bursts as a trigger for intermittent lake-forming climates on post-Noachian Mars

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Site	Delta volume (V_d, km^3)	Lake area (A_p, km^2)	Evaporation rate constraint (E, m/yr)	V_W/V_S assumed	Minimum lake lifetime (Kyr)
Eberswalde delta (1)	6	>410	<1 m/yr	10^3	15
SW Melas Fan "C" (2)	3.5	350	<1 m/yr	10^3	10
SW Melas Fan "F" (2)	1.3	350	<1 m/yr	10^3	4
Dulce Vallis (3)	1.5	3008	<1 m/yr	10^3	0.5
Farah Vallis (4)	22.5	3617	<1 m/yr	10^3	6
Gale Pancake (3)	14	5832	<1 m/yr	10^3	3

Sources of measurements: 1. Irwin et al. 2015. 2. Williams & Weitz 2014. 3. Palucis et al. 2016.

Table S1. Minimum paleolake lifetimes. We used published delta volume and lake area data, and applied a uniform lake evaporation rate and sediment:water ratio.

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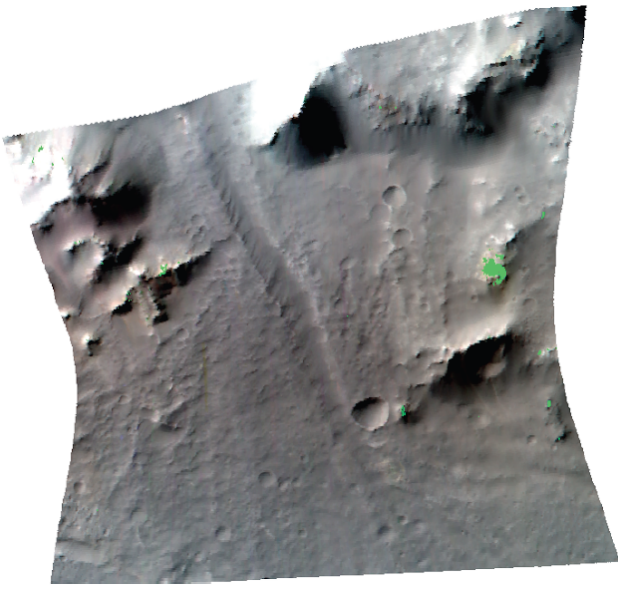

Fig. S1. An olivine outcrop in an alluvial fan source region (fan drains to bottom of image). Olivine detections highlighted in green. Spectra for individual pixels within these areas were checked manually in order to verify that absorptions diagnostic of olivine were present. CRISM FRT00016E79, Saheki crater. Work by David P. Mayer.

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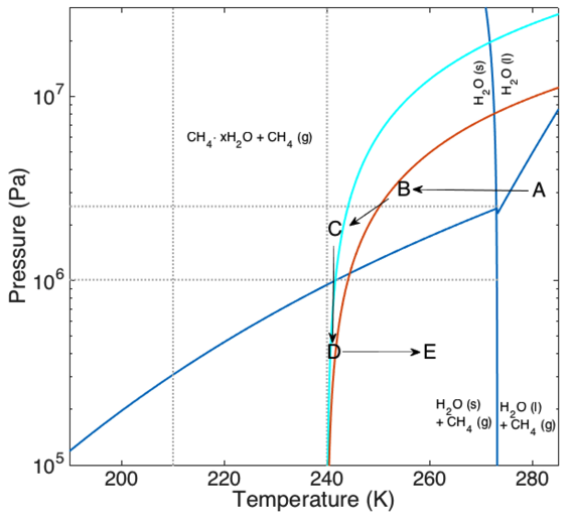
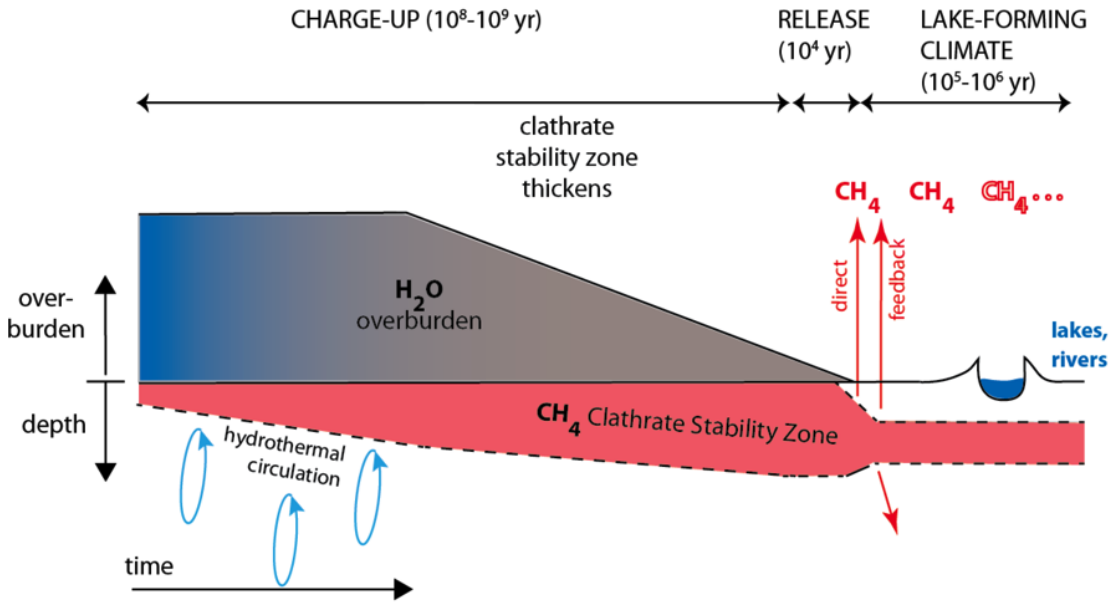


(a)



(b)

Fig. S2. Clathrate charge-up and release scenario. **(a)** Methane clathrate phase diagram, showing pathways to charge-up and release. Phase boundaries shown in dark blue. Mars geotherms shown in red (early, steep geotherm) and cyan (later, shallow geotherm). Early in Mars history, cooling of the geotherm locks-in CH_4 as clathrate in regolith, e.g. beneath early seas or ice sheets (A→B). Further geotherm cooling and escape of ice-sheet water to space (B→C) has little effect on CH_4-clathrate stability. Orbital change drives ice shift which leads to CH_4 breakdown (C→D). Orbitally-induced warming of the surface, plus warming induced by earlier release of CH_4 , move the regolith deeper into the CH_4-clathrate destabilization region (D→E). (In practice, steps C→D and D→E overlap). **(b)** Schematic of the long-term evolution of a column of the Mars uppermost crust.

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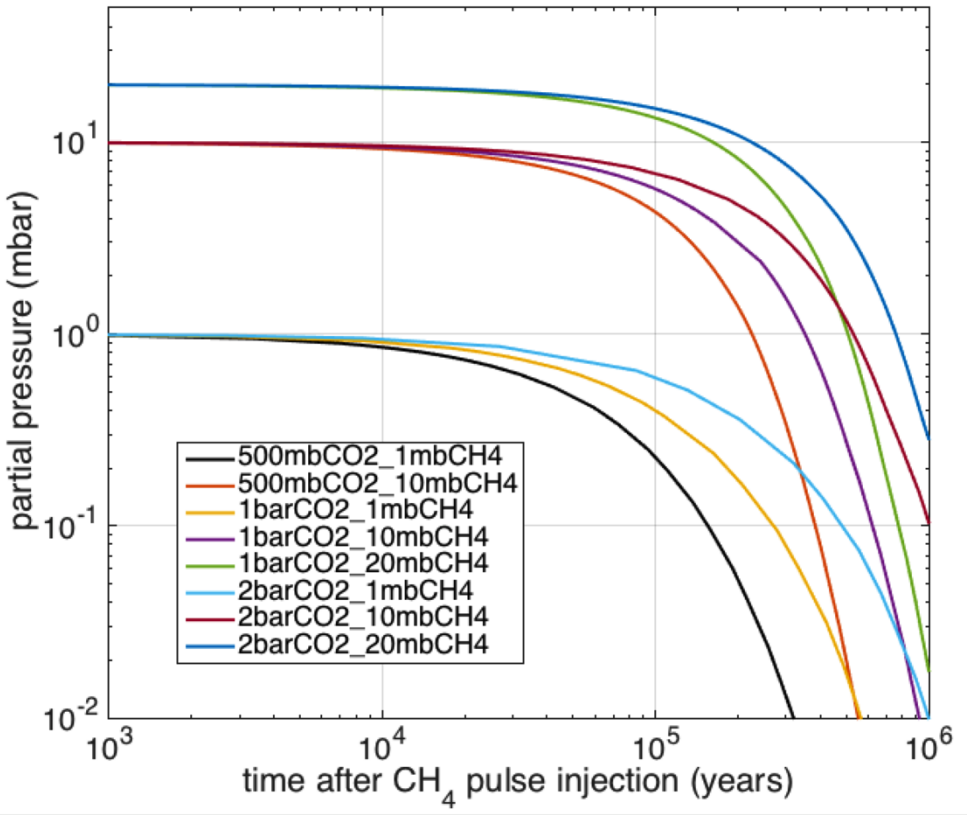

Fig. S3. Methane drawdown for initial methane concentrations of 1mb, 10mb, and 20mb, in CO_2 atmospheres of varying thickness. The 500 mb CO_2, 20 mb CH_4 case is not shown due to numerical instability.

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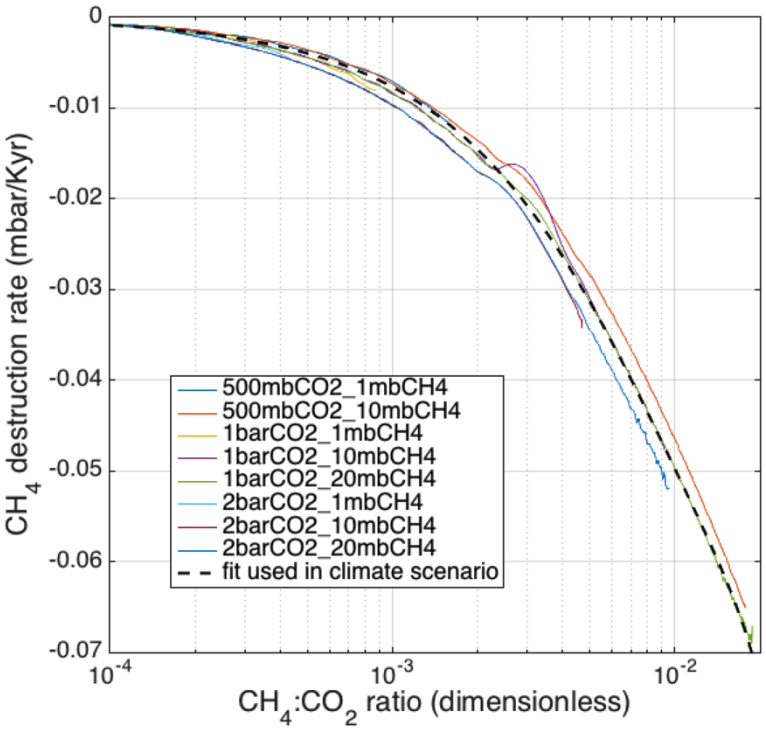

Fig. S4. Methane destruction rate. The first 15 Kyr of each run are excluded due to numerical artifacts associated with model startup. The dashed black line is a fit to the 1 bar CO_2, 20 mbar CH_4 run.

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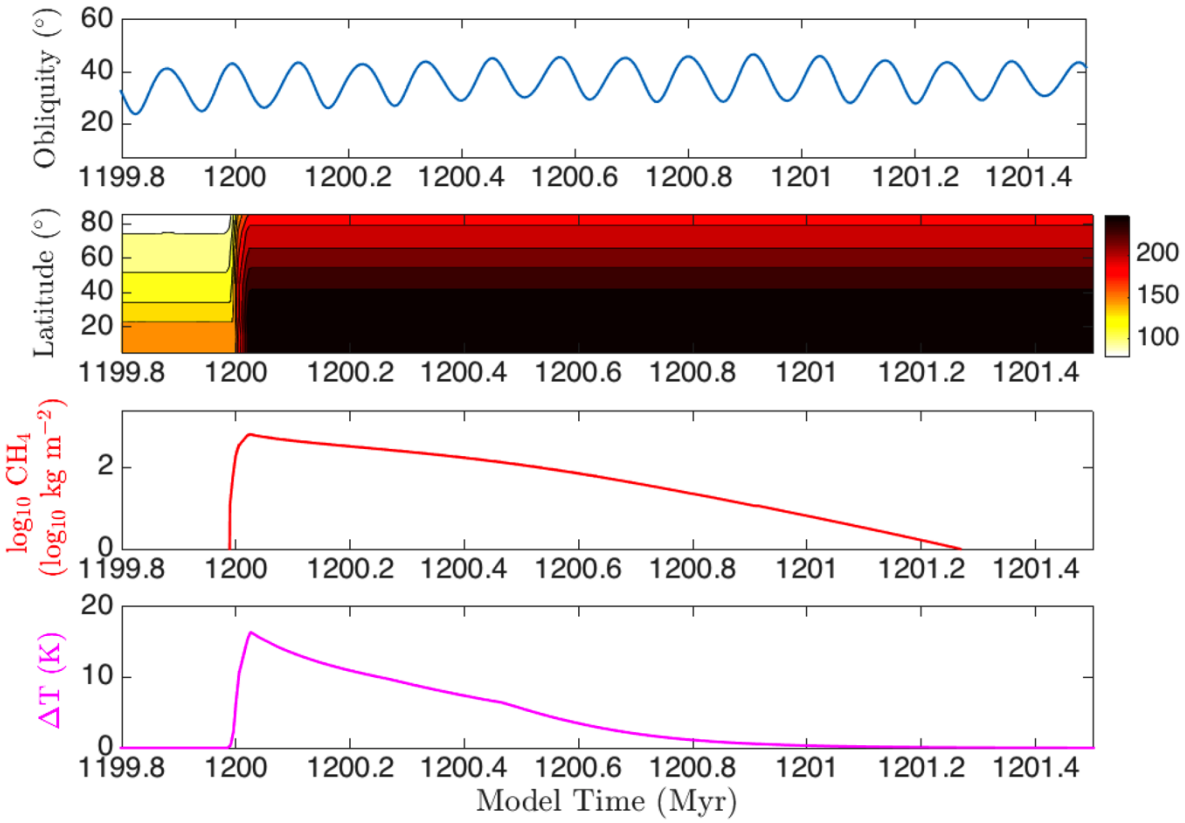
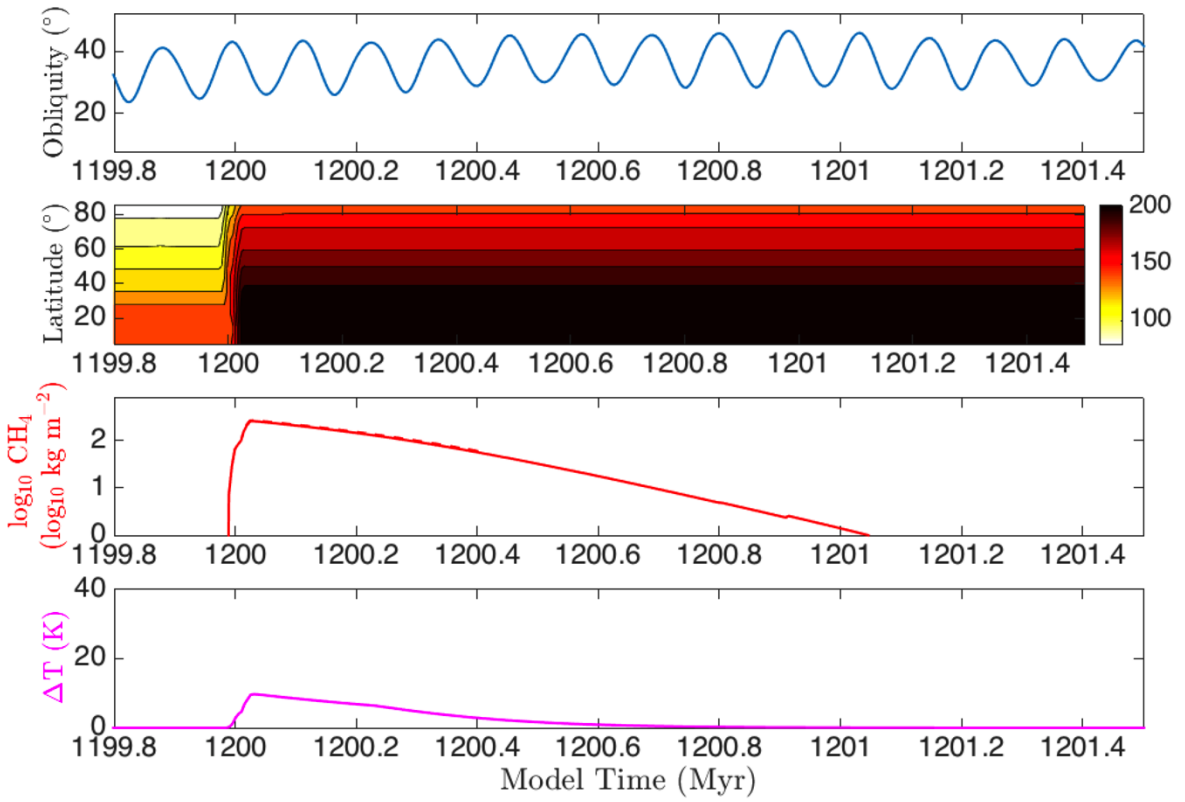
(a)



(b)



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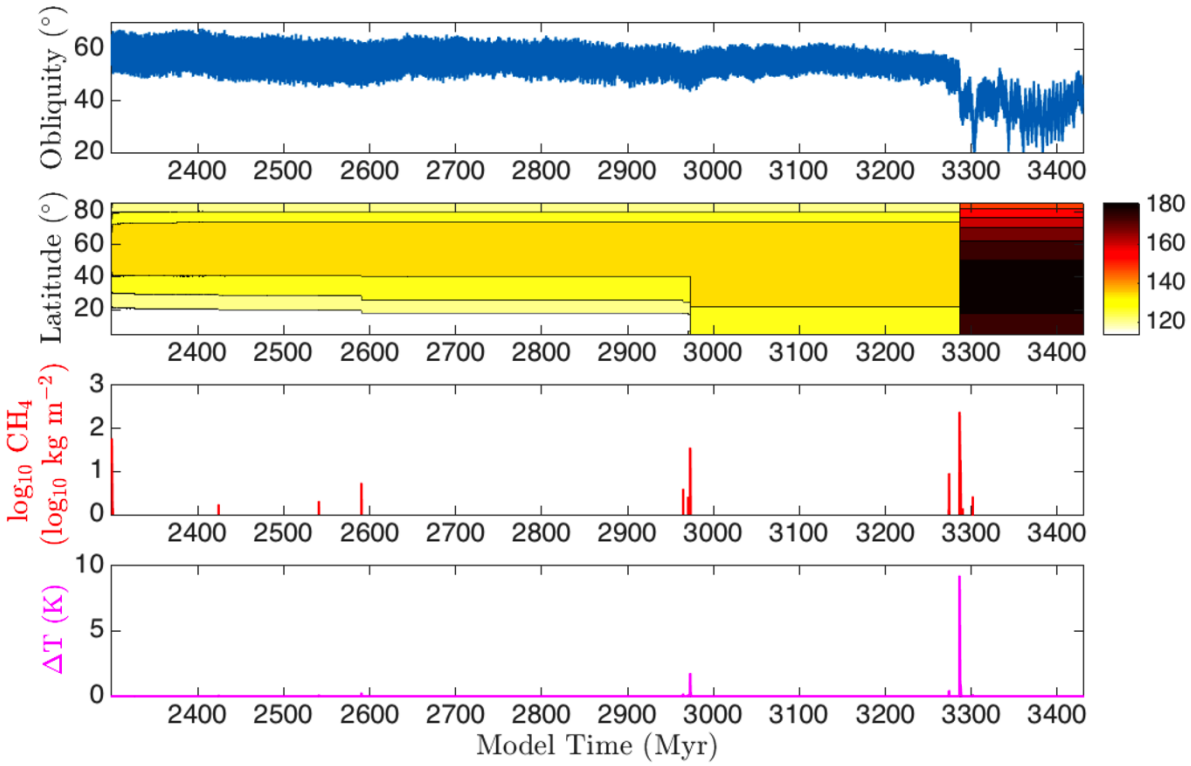
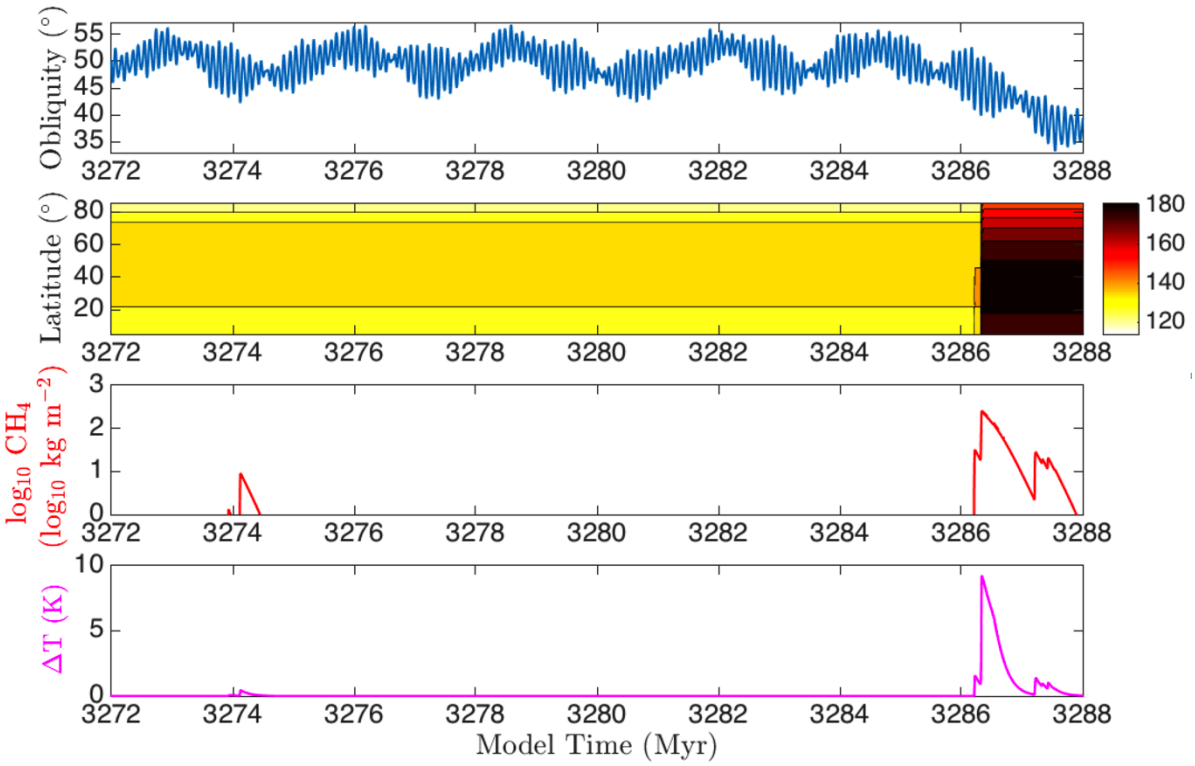
(c)



(d)



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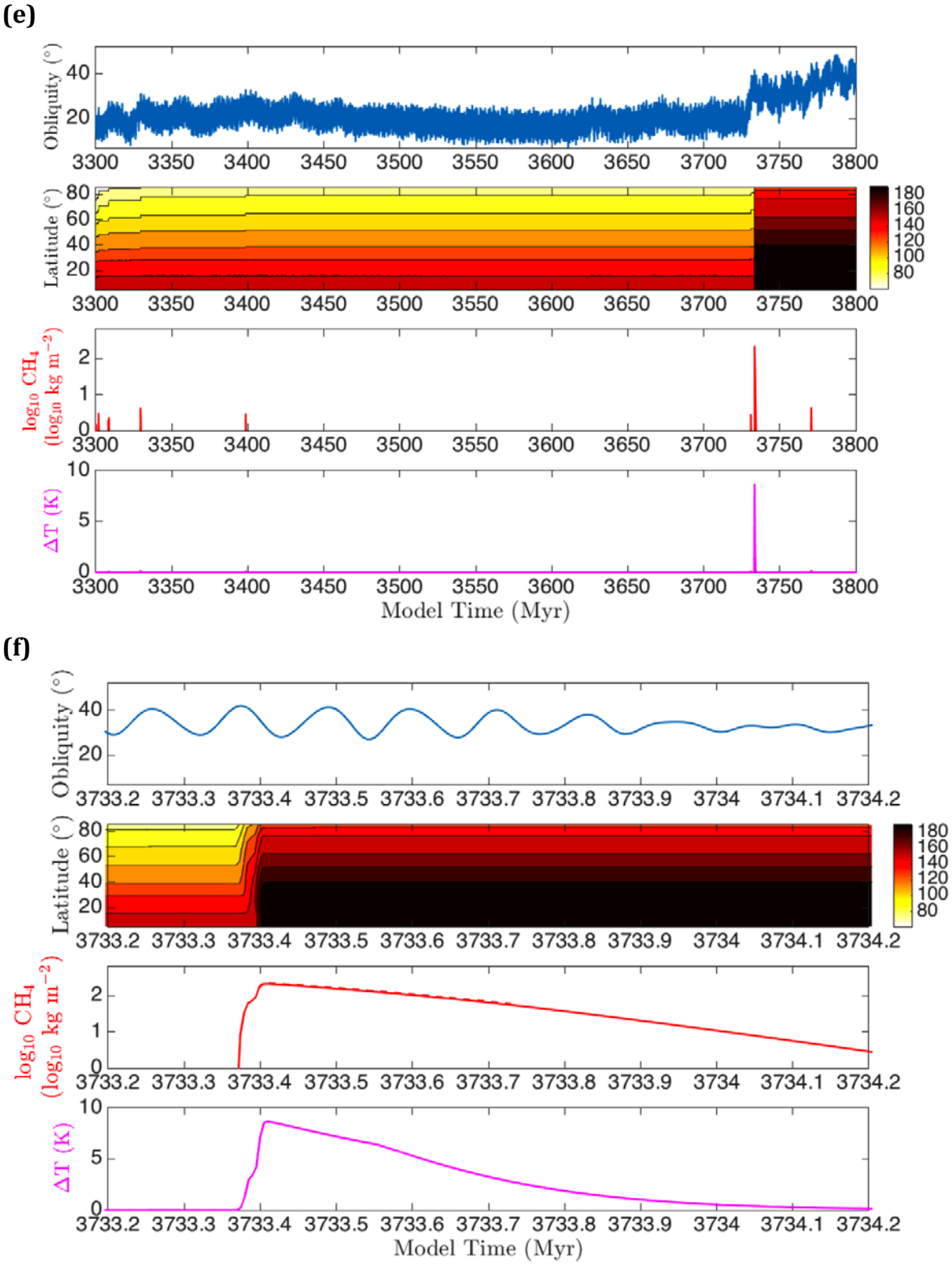

Fig. S5. Different CH_4-release scenarios. Model time is arbitrary. For each subfigure, the top panel shows example obliquity forcing. The colors in the second panel show the

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depth to the top of the clathrate-hydrate stability zone (depth in meters). Darkening of colors indicates clathrate destabilization. The third panel shows atmospheric CH_4 column mass. Dashed line includes talik feedback. The bottom panel shows temperature change. Solid line is for CH_4 alone; dashed line is for CH_4 +10%C_2H_6. (a) Zoom in on the biggest CH_4 burst from the f = 0.045 simulation shown in Fig. 4. (b) As for (a), but with f = 0.03, showing strong sensitivity to f. (c) CH_4 bursts for a simulation of long-term φ decline (temperature effects only, no decompression); f = 0.045. (d) Zoom in on part of (c). (e) Showing a different φ-rise scenario, with f = 0.03 (compare to Fig. 4). (f) Zoom in on the biggest CH_4 burst from the simulation shown in (e).