Supplement 3

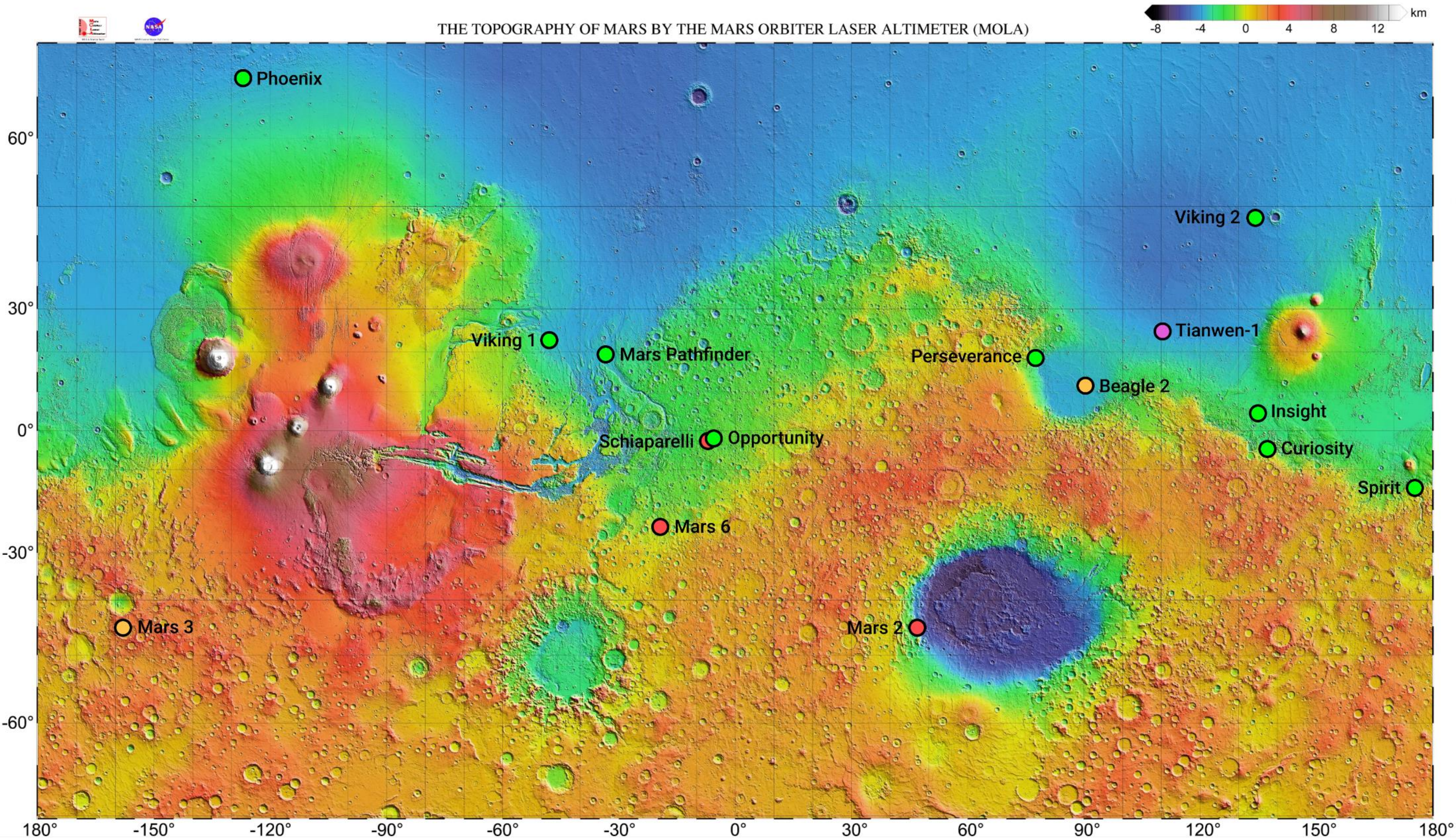
Combed strike angles

Application for Mars

for theory see Suppl. 1

for tutorial part and truncation error tests see Suppl. 2

Landing sites



[Mars map with landing sites - Wikimedia Commons, 2022]

Fig. S3: 2

General global views on Mars

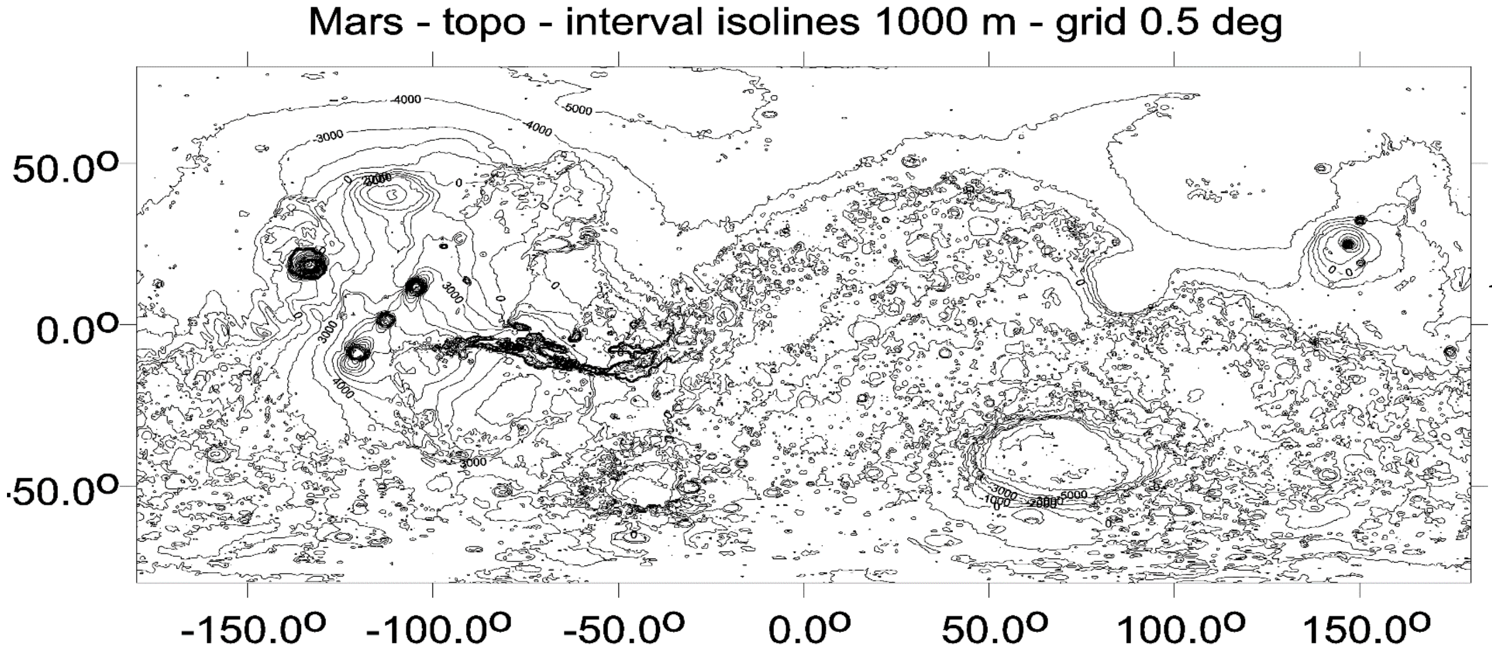
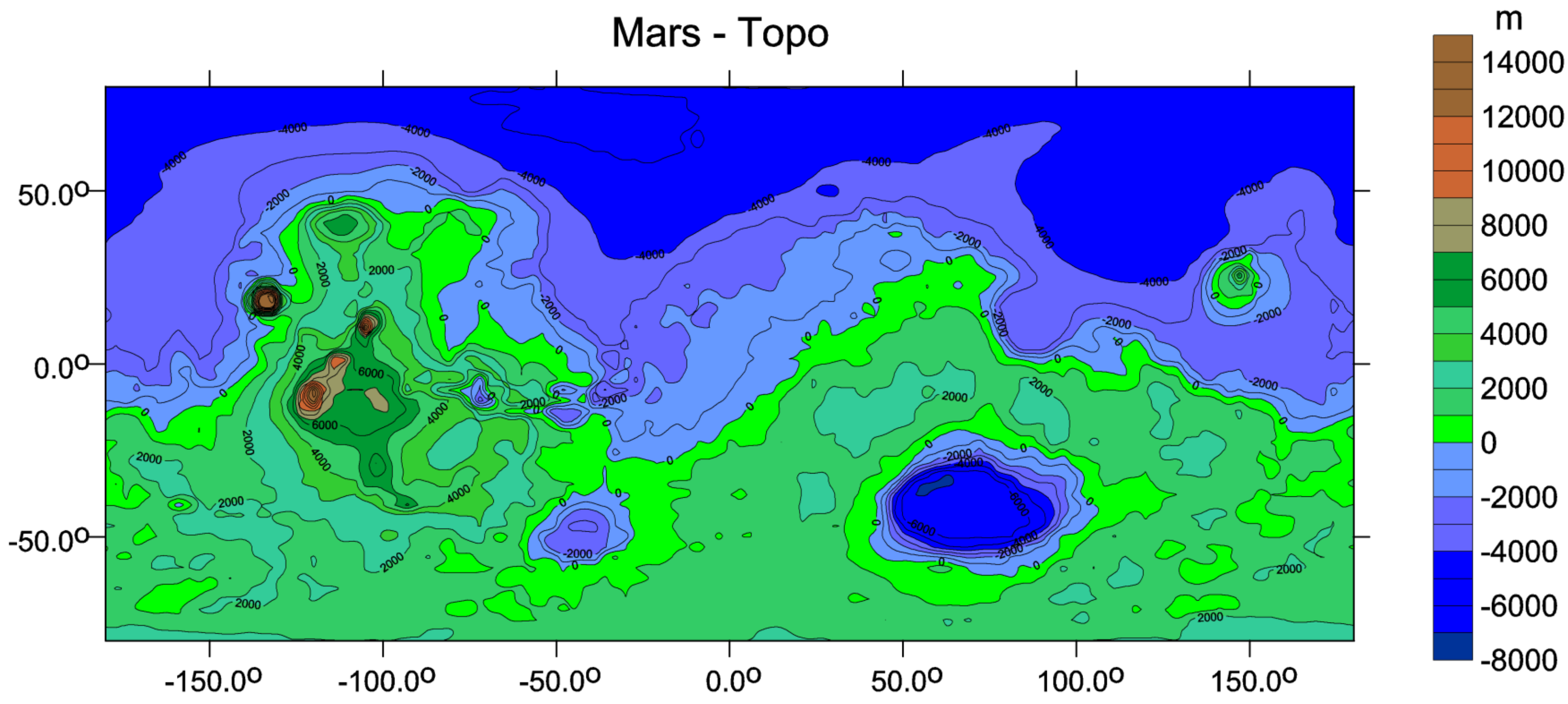
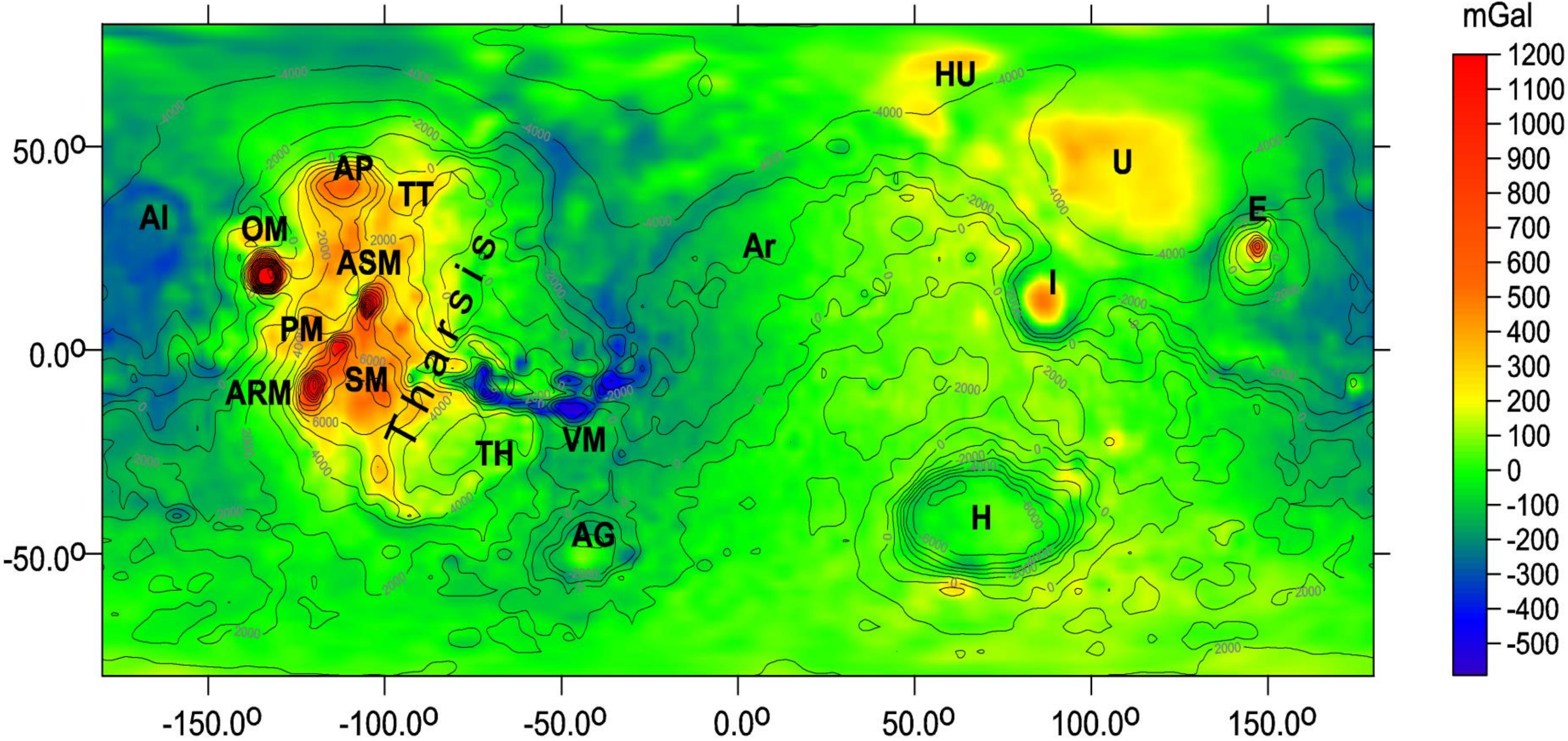


Fig. S3: 4 MOLA topography





Gravity disturbances Δ*g* [mGal] on Mars

according to the gravity field model JGMRO_120 F (Konopliv et al. 2020), used here everywhere to plot the gravity aspects, cut always at maximum degree and order d/o = 80, as recommended by the authors of the model, together with contour lines derived from the MOLA topography [m] (metres above the reference ellipsoid).

Valles Marineris (VM). Hellas (H), area at the Crater Lake (Syrtis Major/Isidis) I, Utopia (U), Hustak (HU), Elysium (E), Tharsis area (T), Olympus Mt (OM) and other volcanoes in T, Ascraeus Mons (ASM), Pavonis and Arsia Mons (PM and ARM), Alba Patera and Syria Mons (AP and SM), Tempe Terra (TT), Thaumasia Highlands (TH), one of ancient structures (AI).

Fig. S3: 5

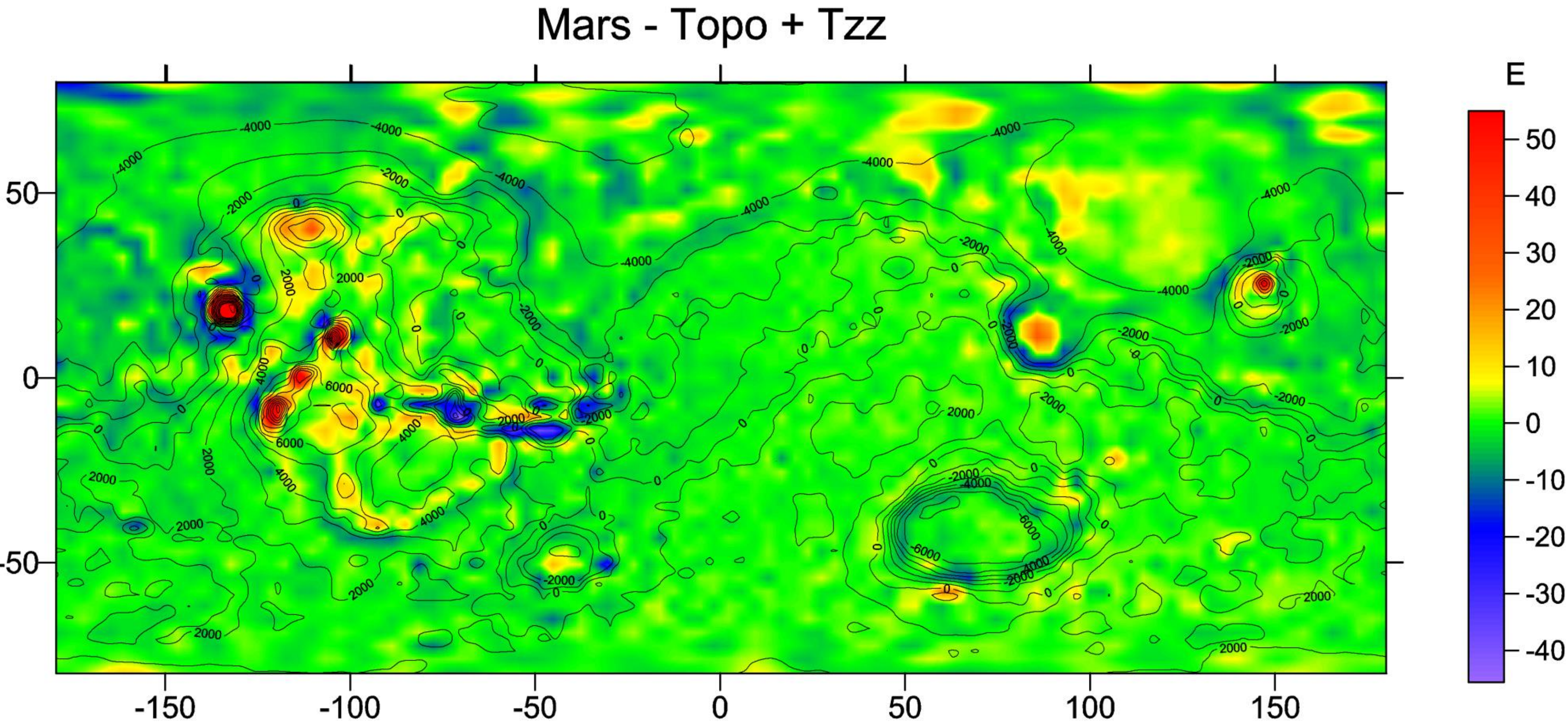


Fig. S3: 6

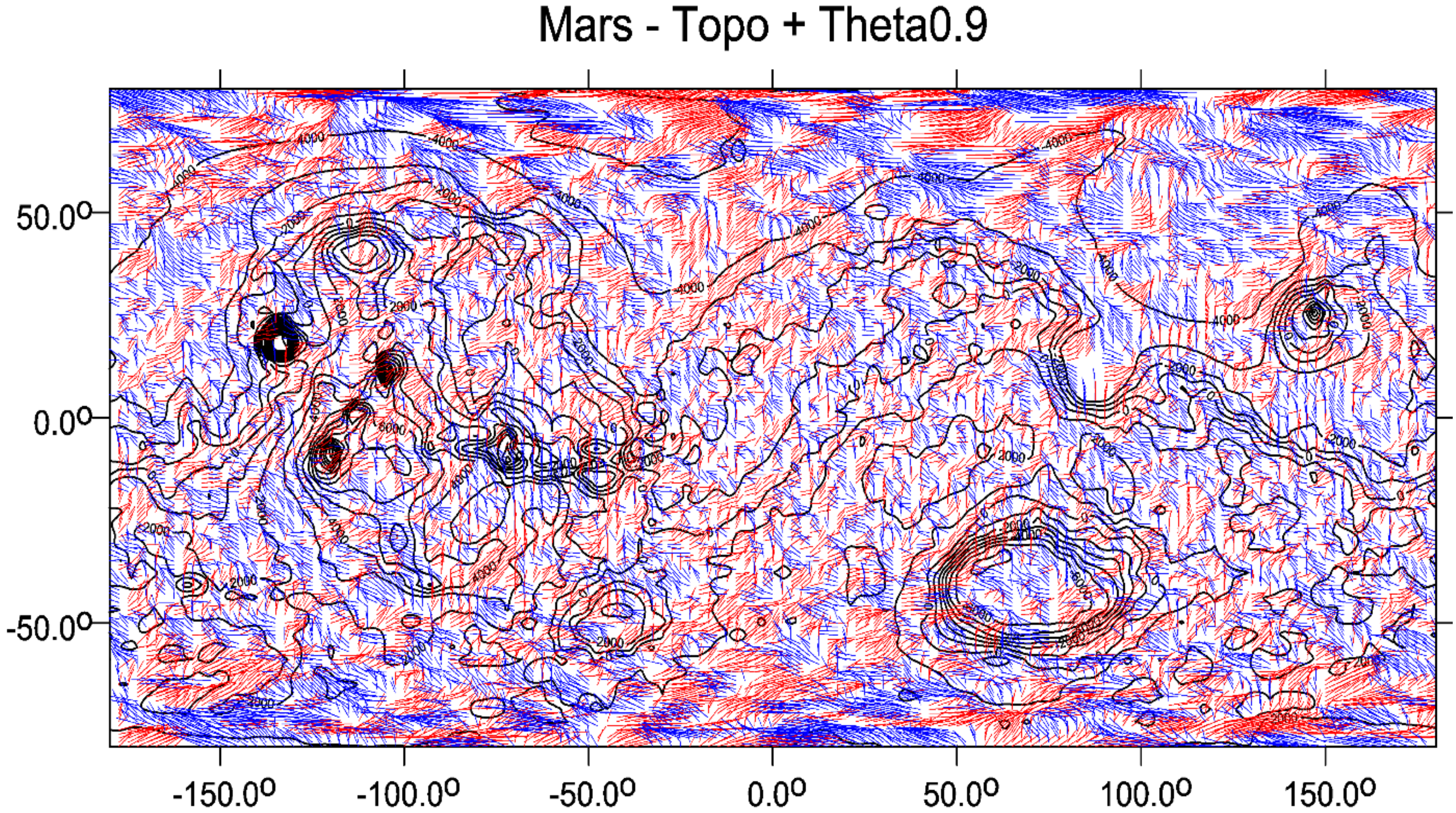


Fig. S3: 7. Strike angles [deg]

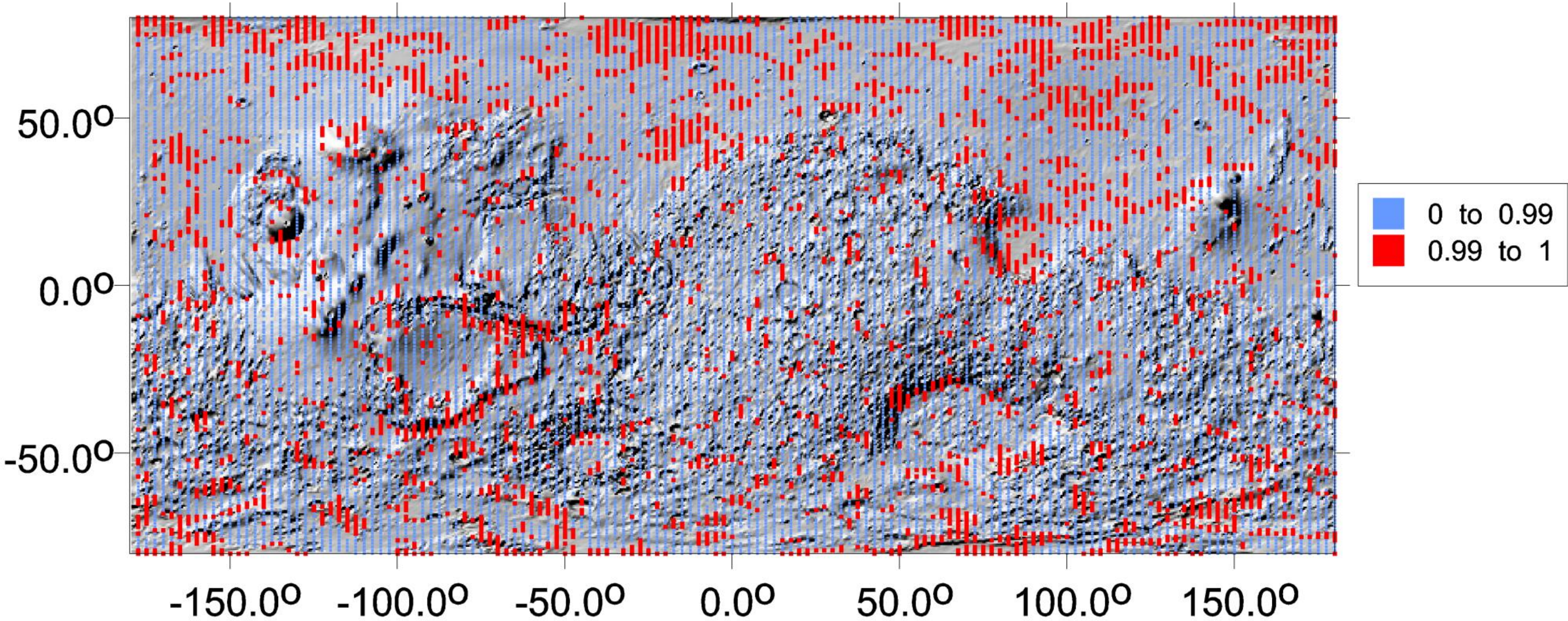


Fig. S3: 8. Strike angles, *Comb* factor, and MOLA topography

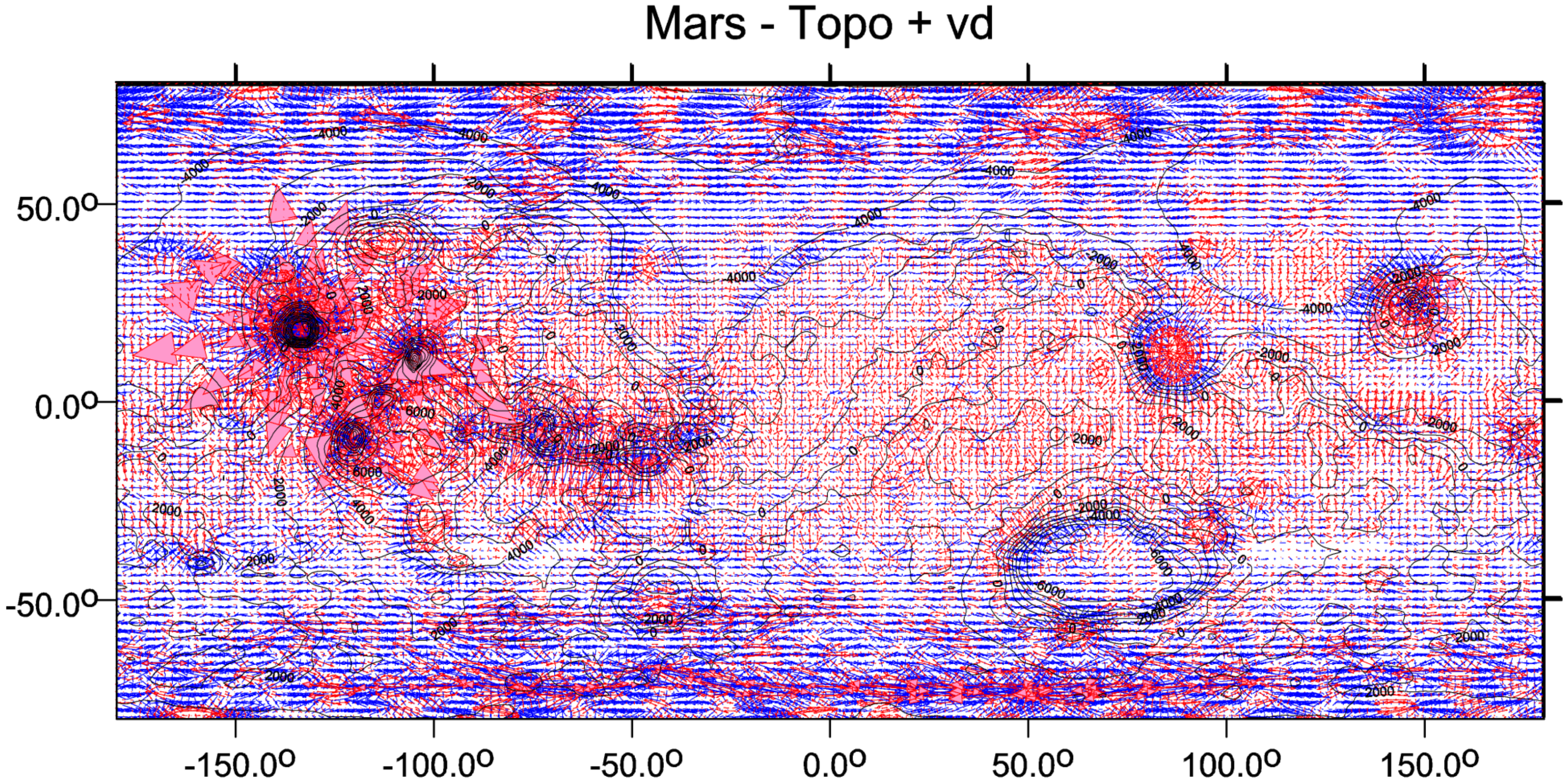


Fig. S3: 9. Virtual deformations [-] and topography [m]

Northern Paleoocean

selected areas 1-5

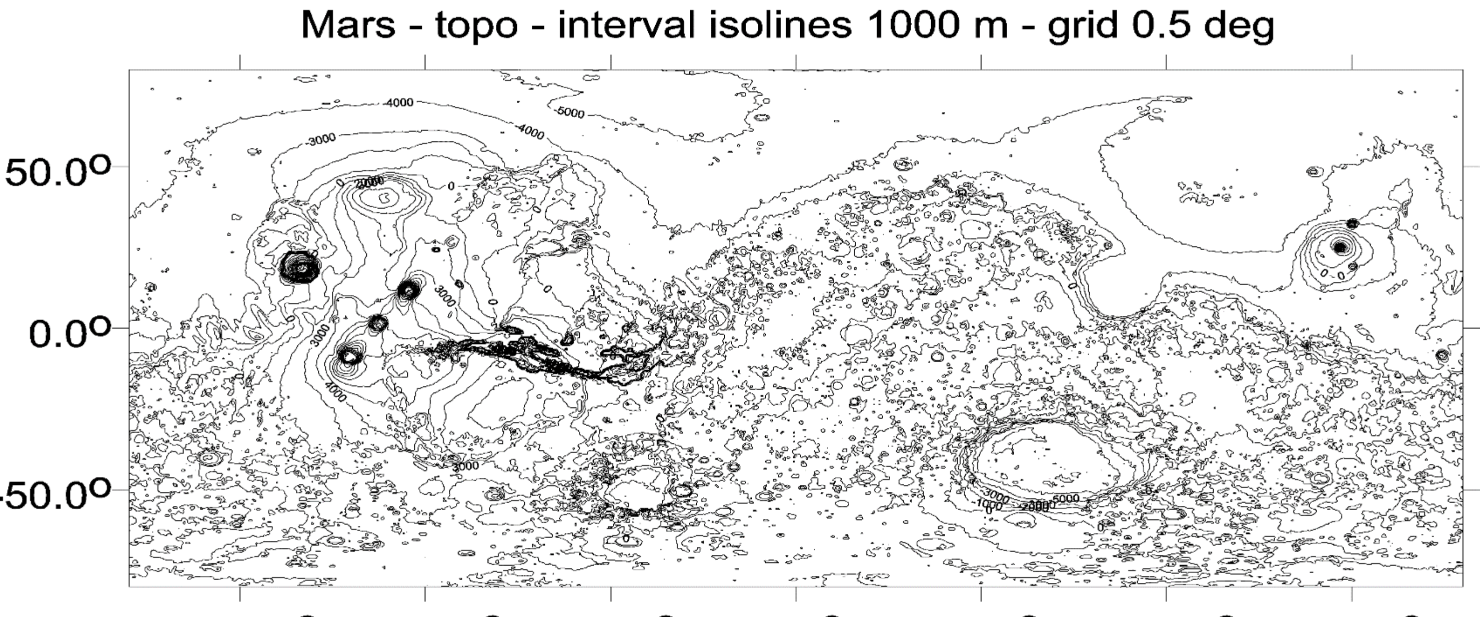
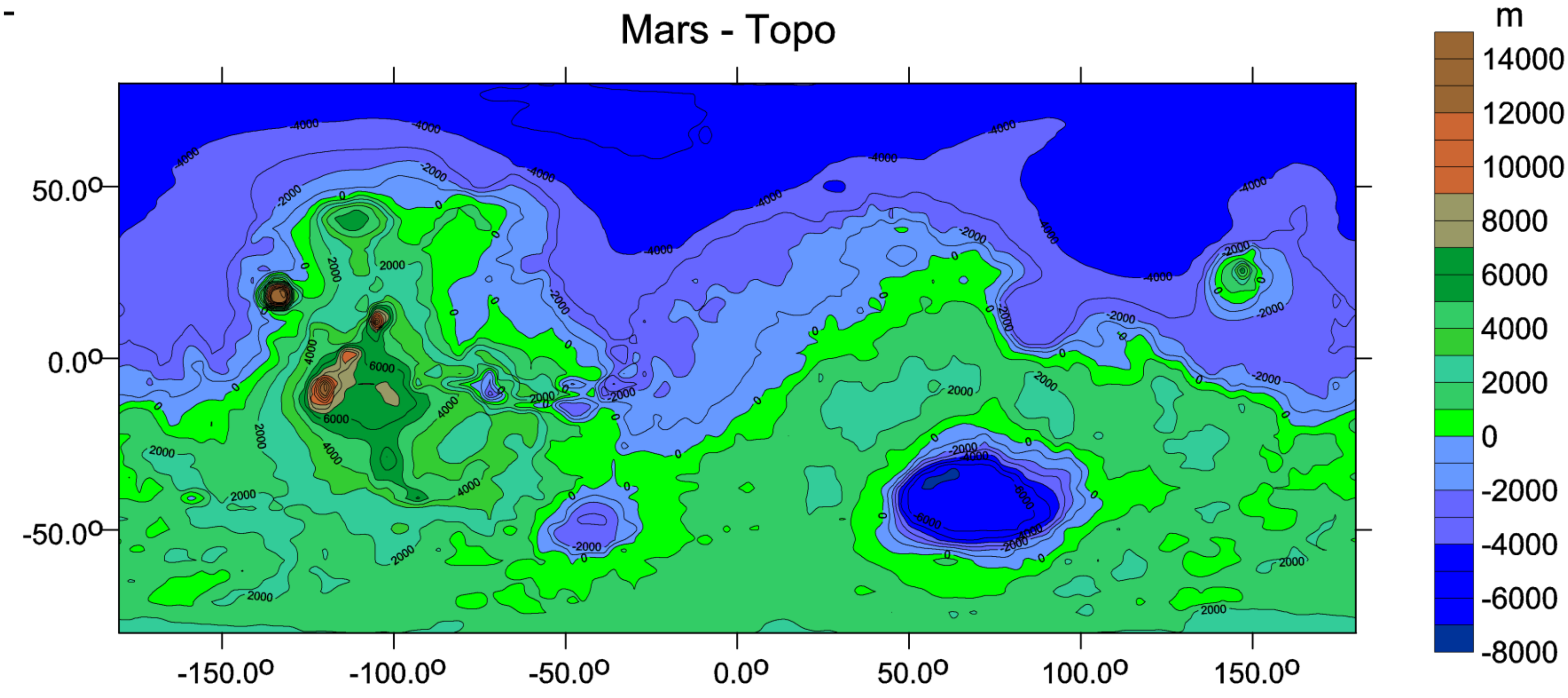


Fig. S3: 4=11
MOLA
Topography
Paleoocean



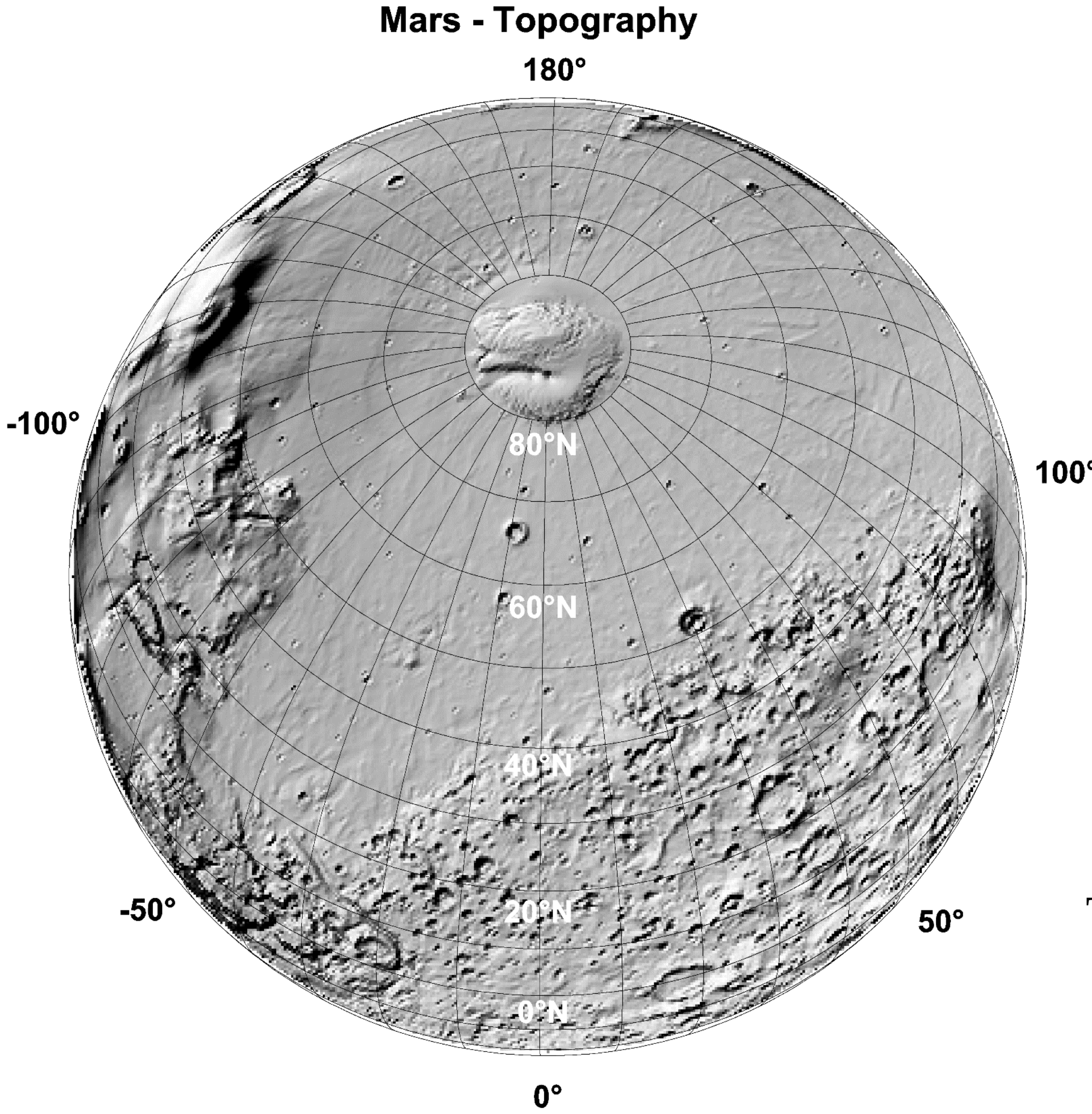


Fig. S3: 12
MOLA
Topography
Paleoocean

Mars - Topography

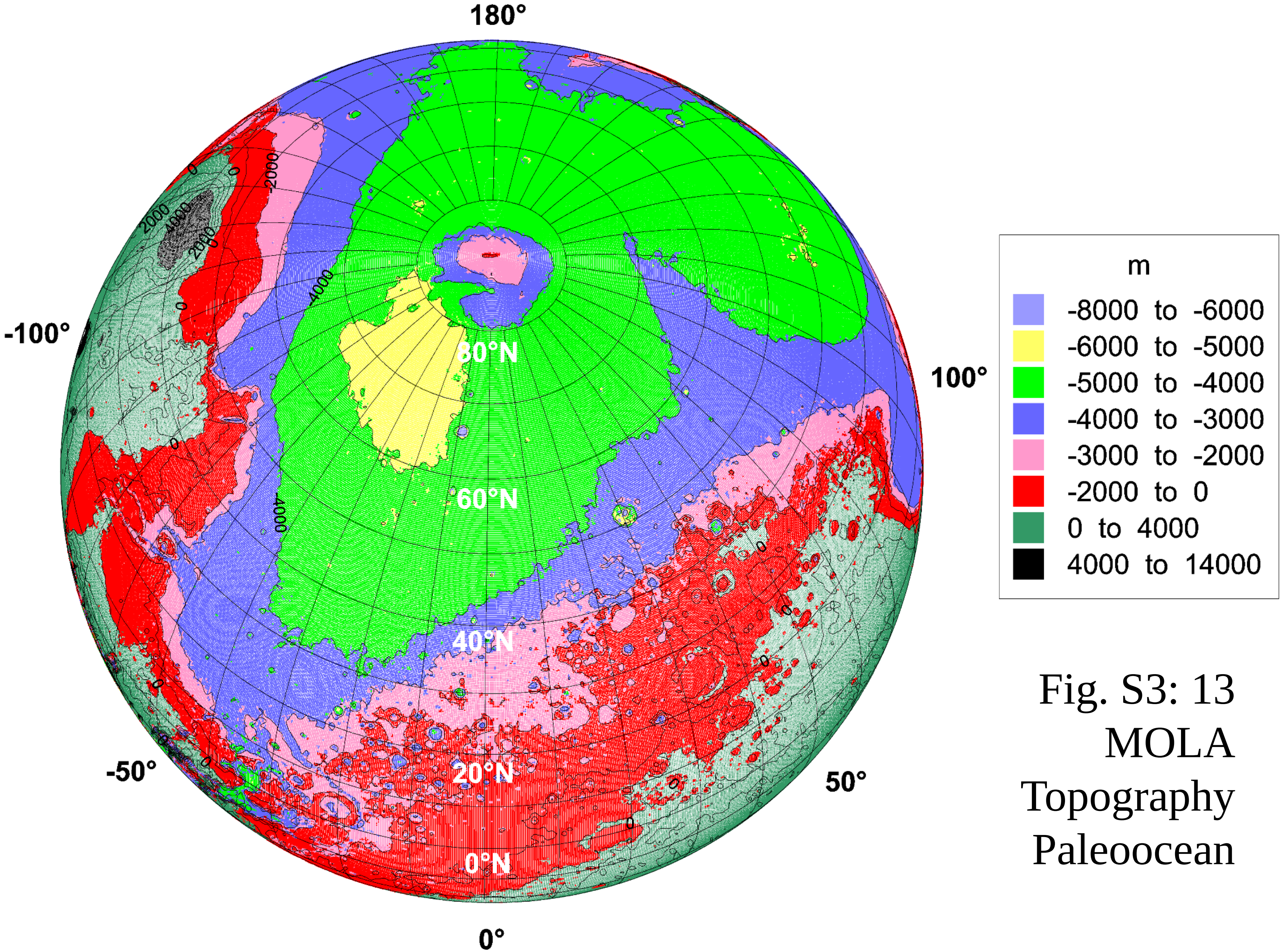
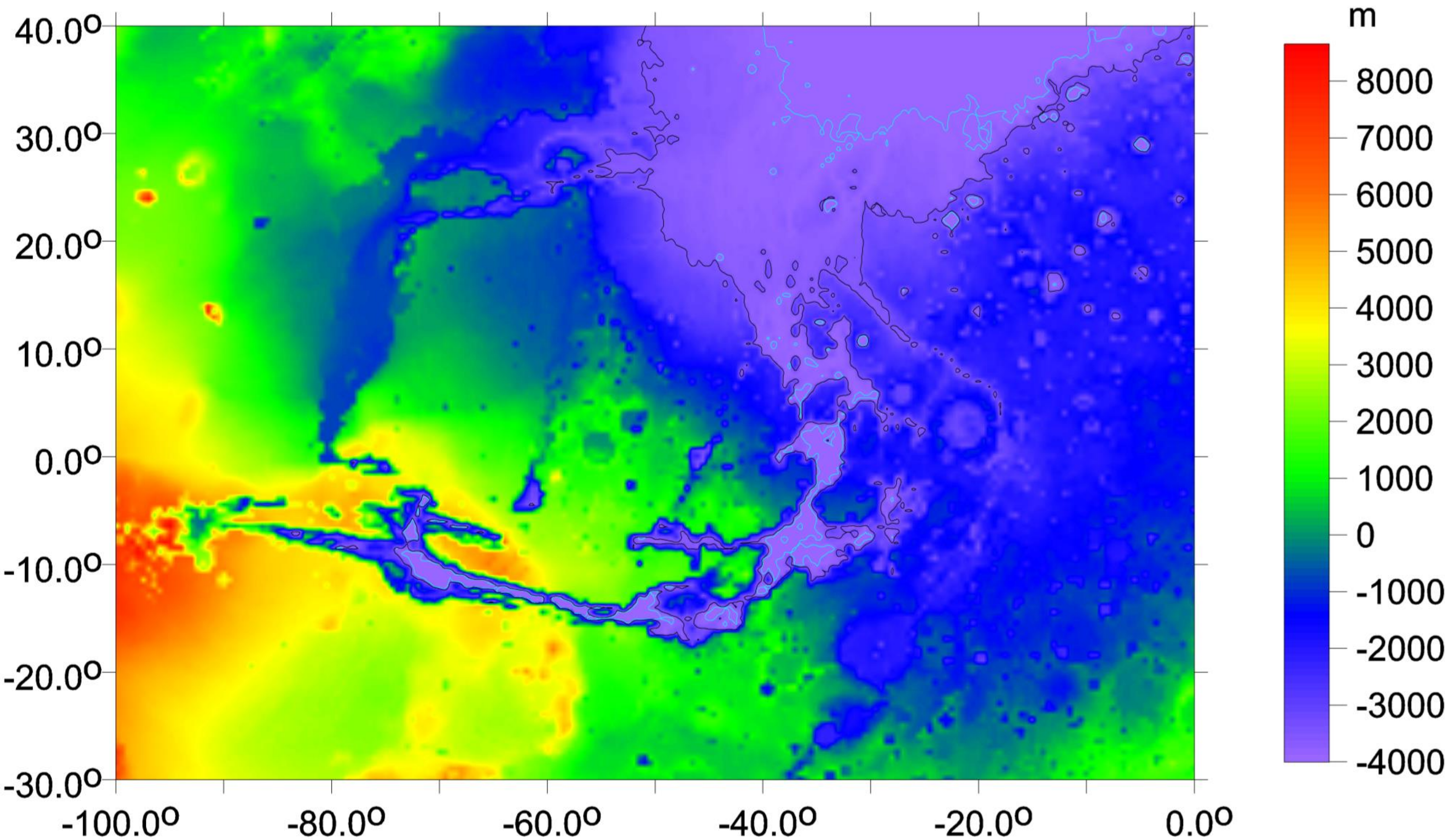


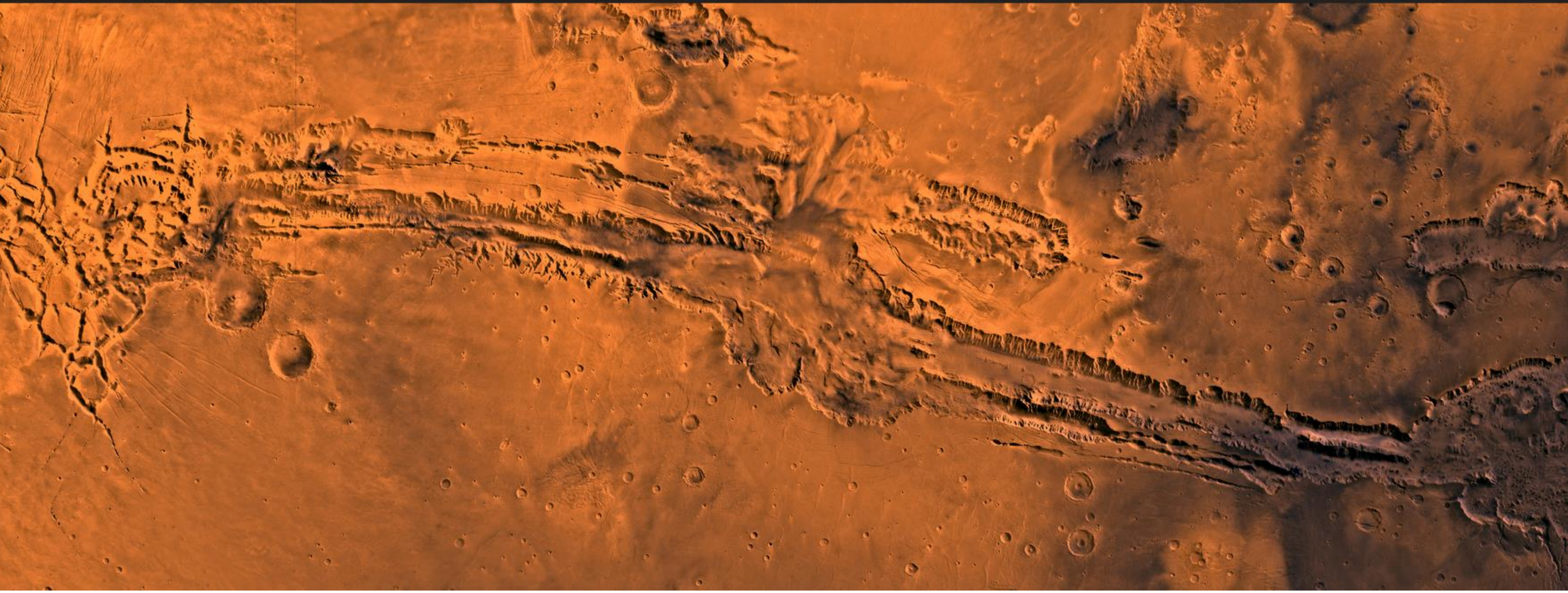
Fig. S3: 13
MOLA
Topography
Paleoocean

Fig. S3: 14
Topography

Valles Marineris (VM) series

contour line -3500 m black
contour line -4000 m tyrkys





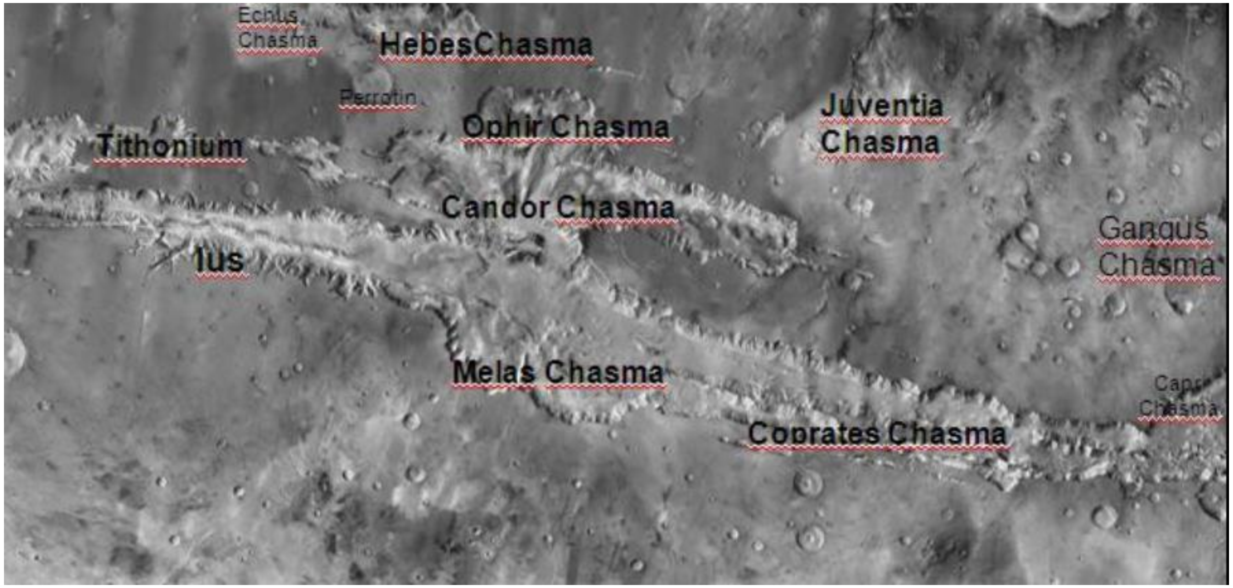


Fig. S3: 15
VM
Topography
NASA/MOLA

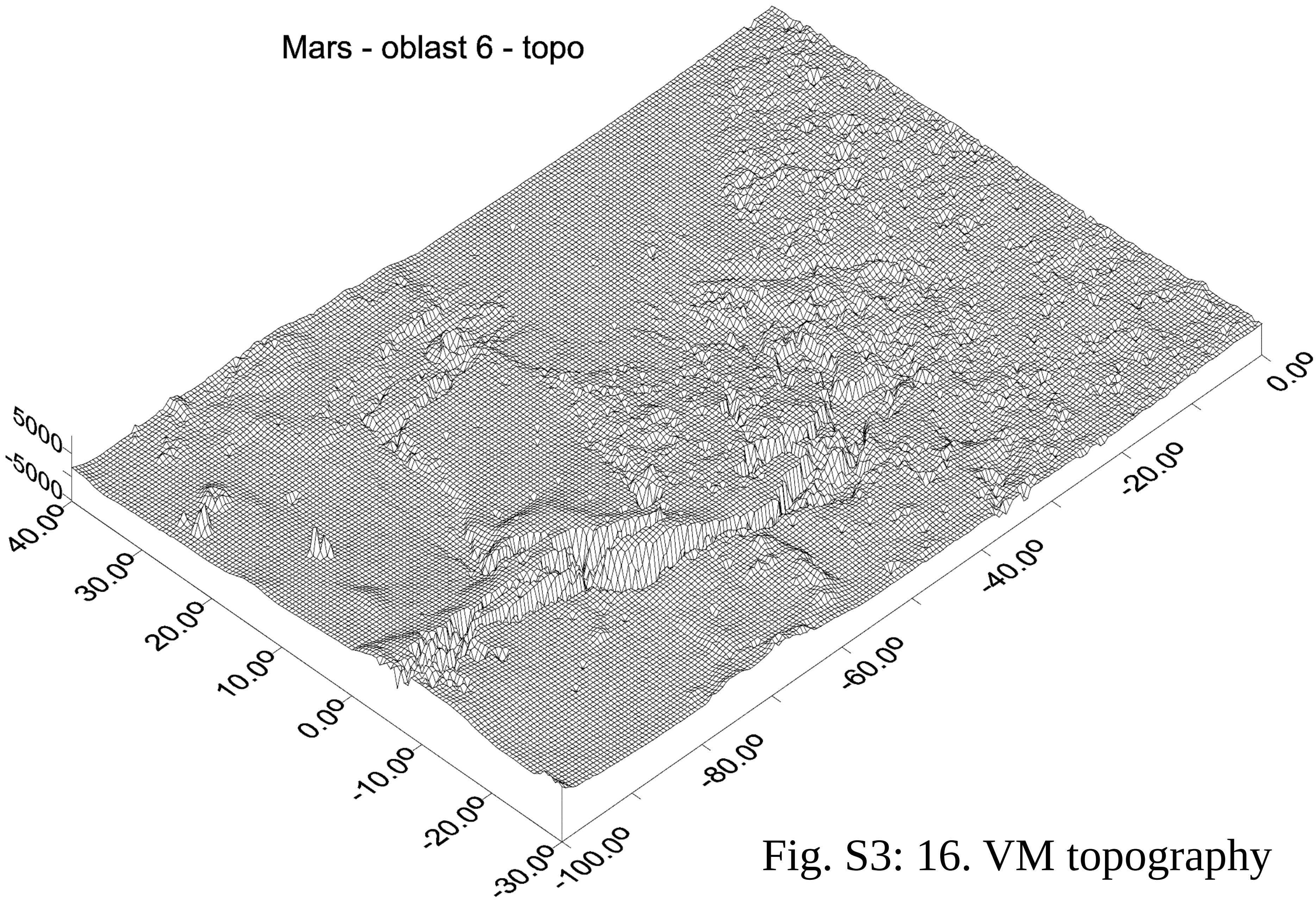
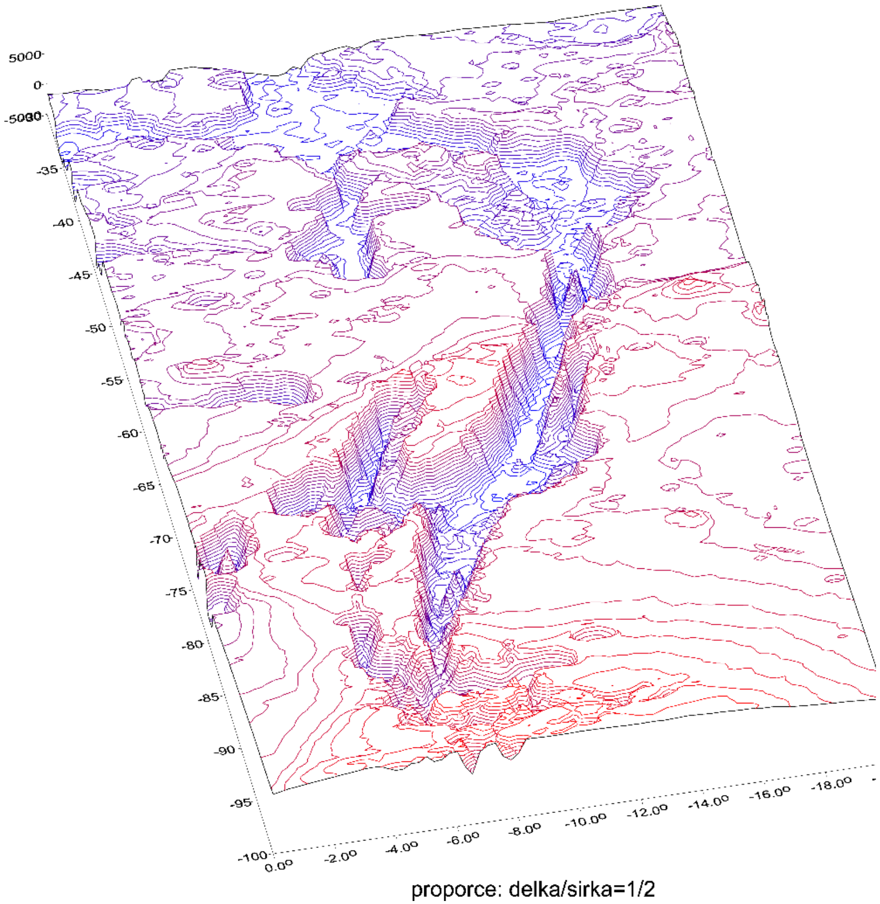


Fig. S3: 16. VM topography

Valles Mariners

from W to E (left) and from E to W (right)
grid 0.25 deg



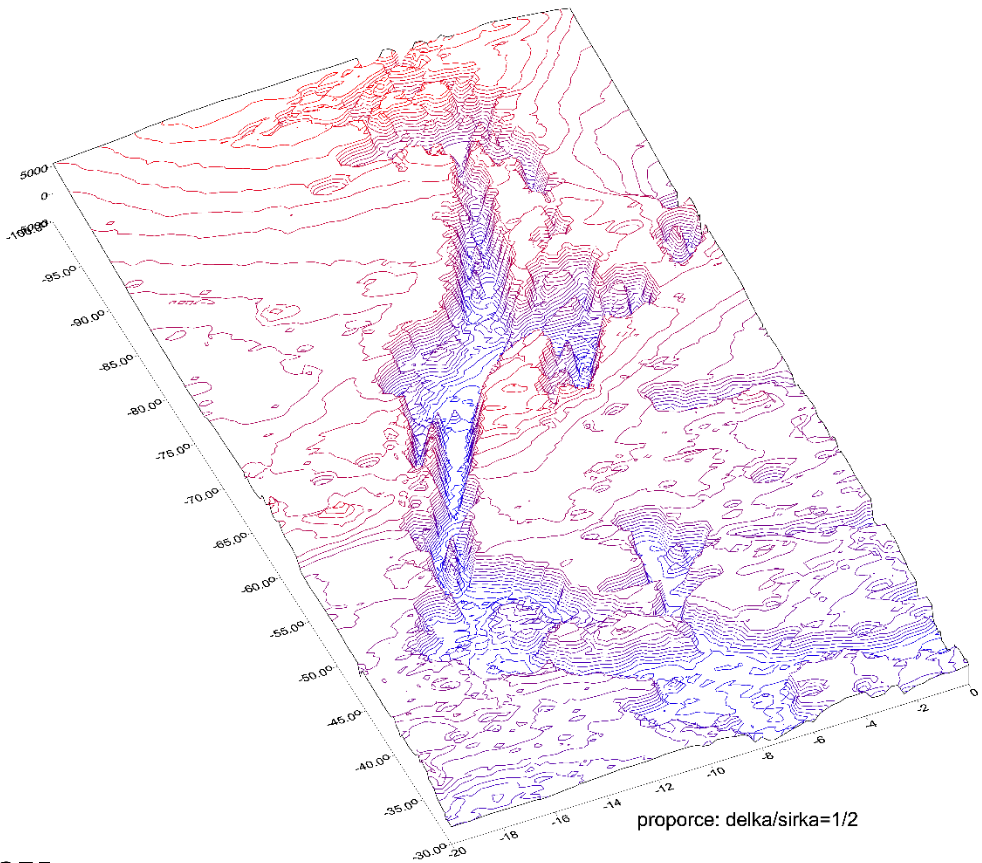


Fig. S3: 17. VM, 3D topography

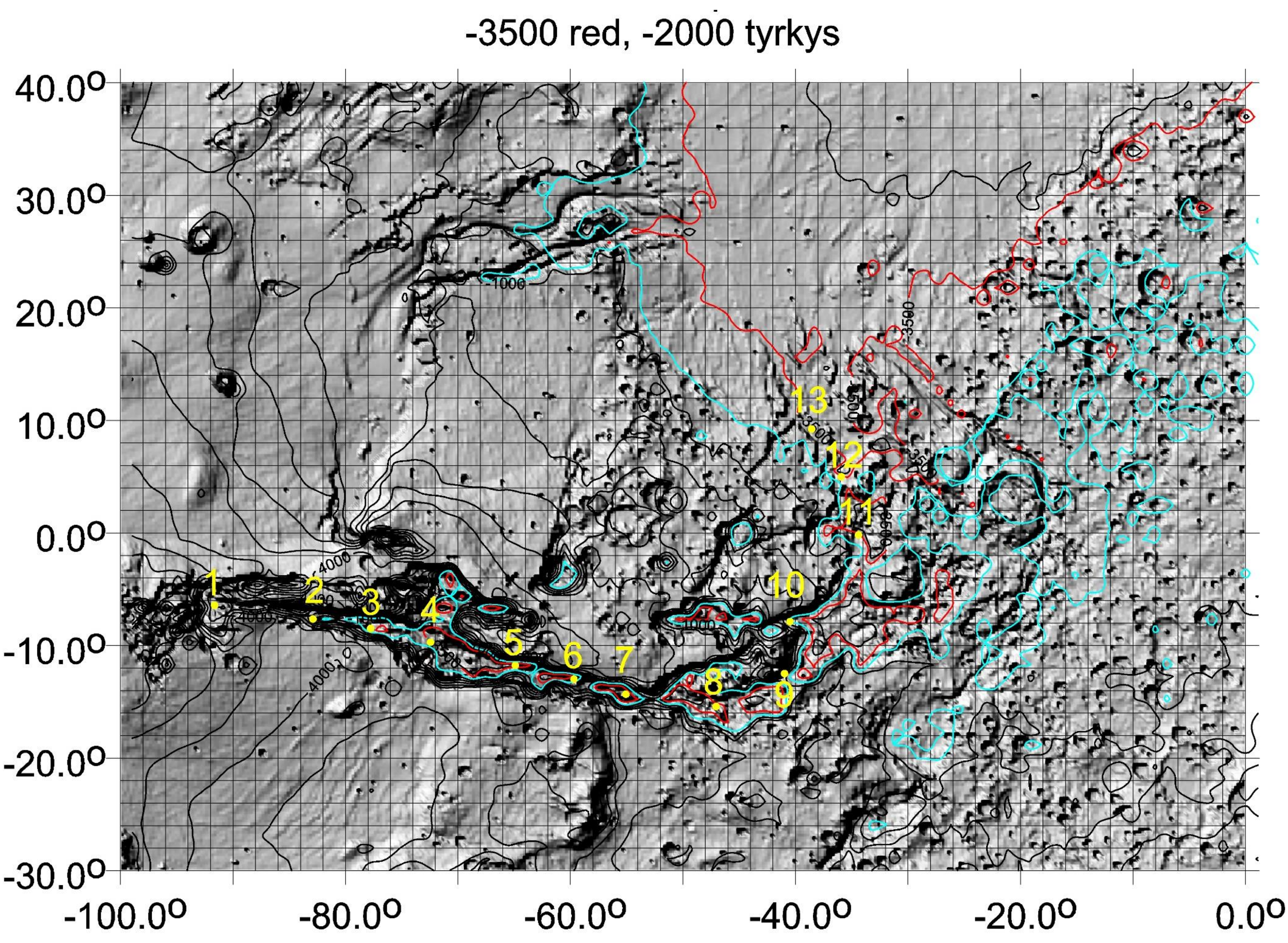


Fig. S3: 18. VM, topography, see the main text

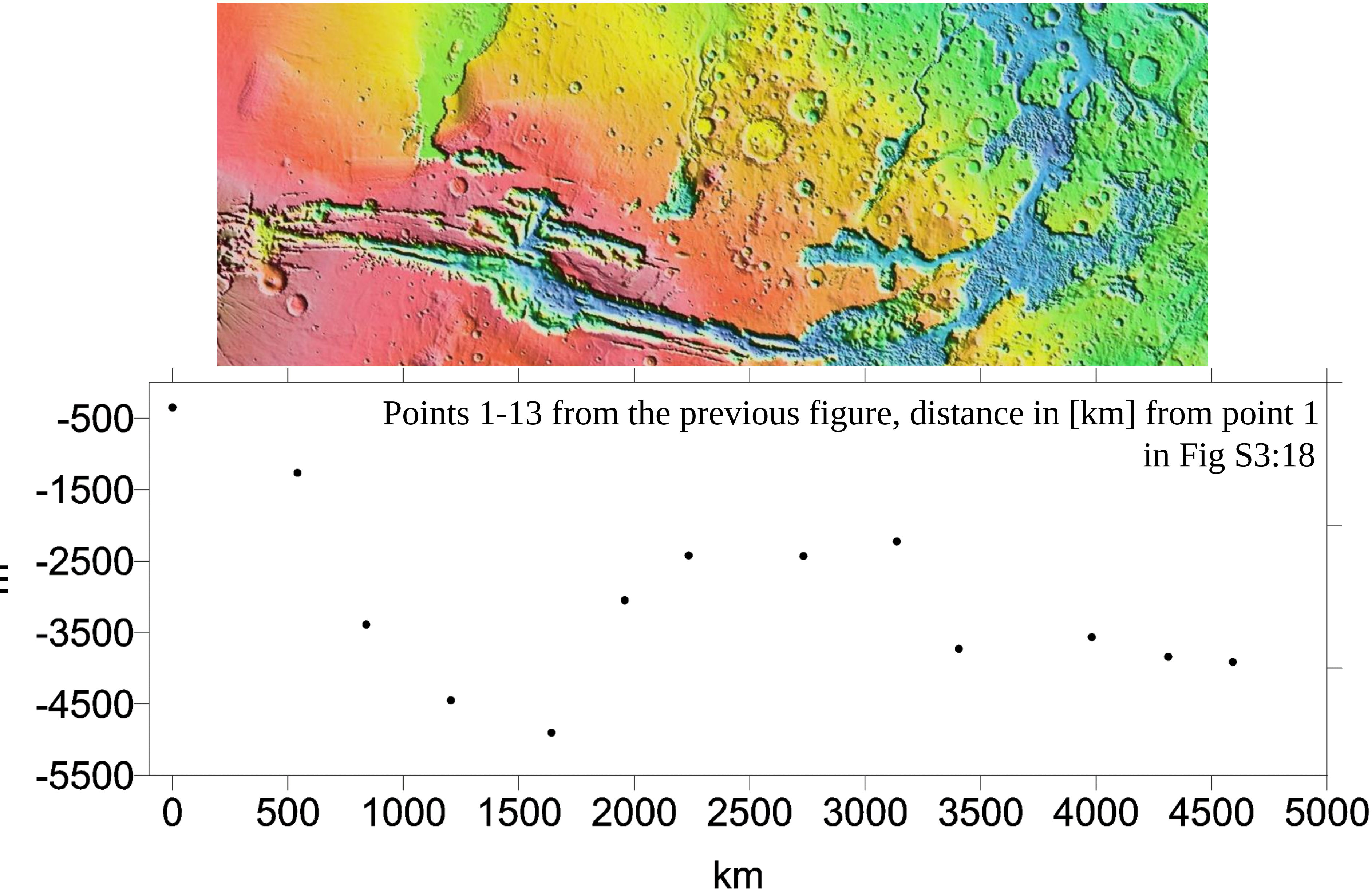


Fig. S3: 19. VM, topography, see the main text

The gravity aspects for zones of the Northern paleoocean 1-5

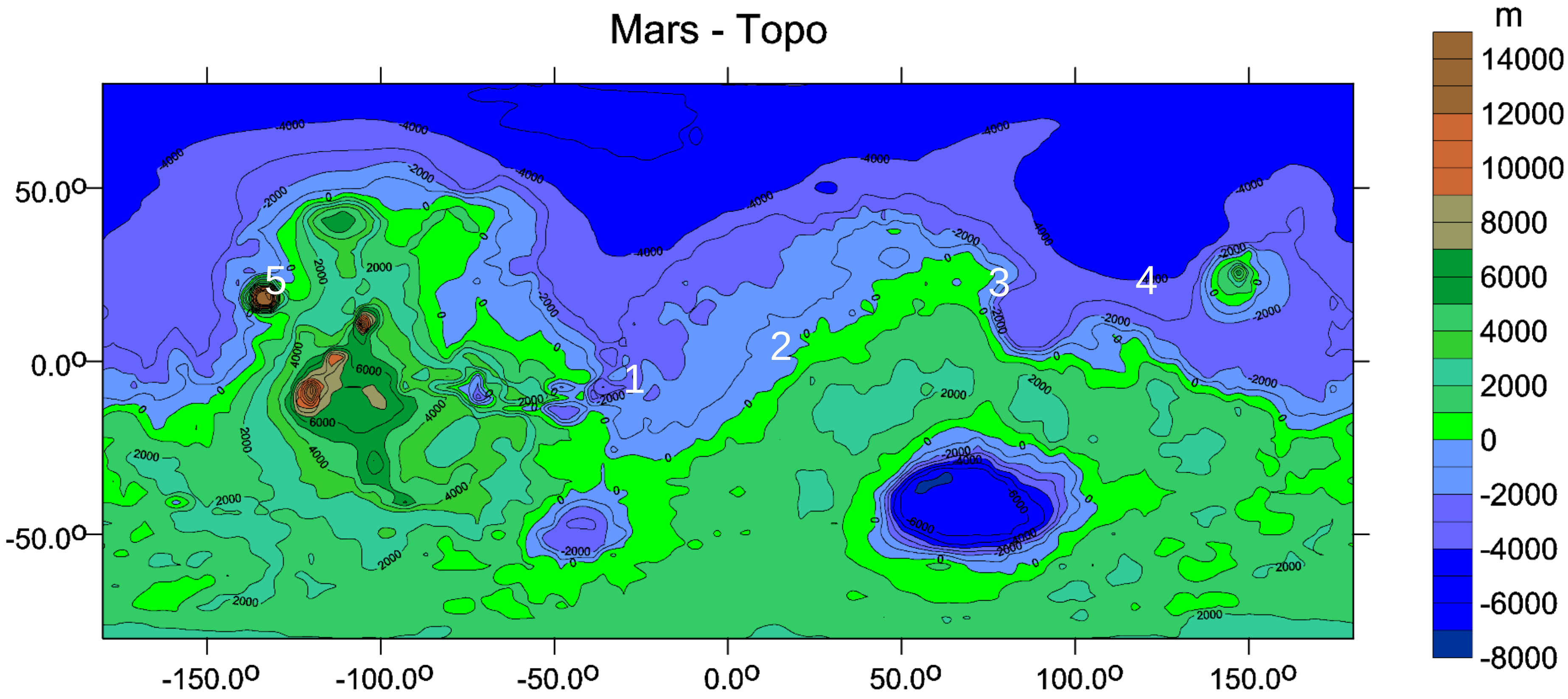


Fig. S3: 20

Segment 5 series

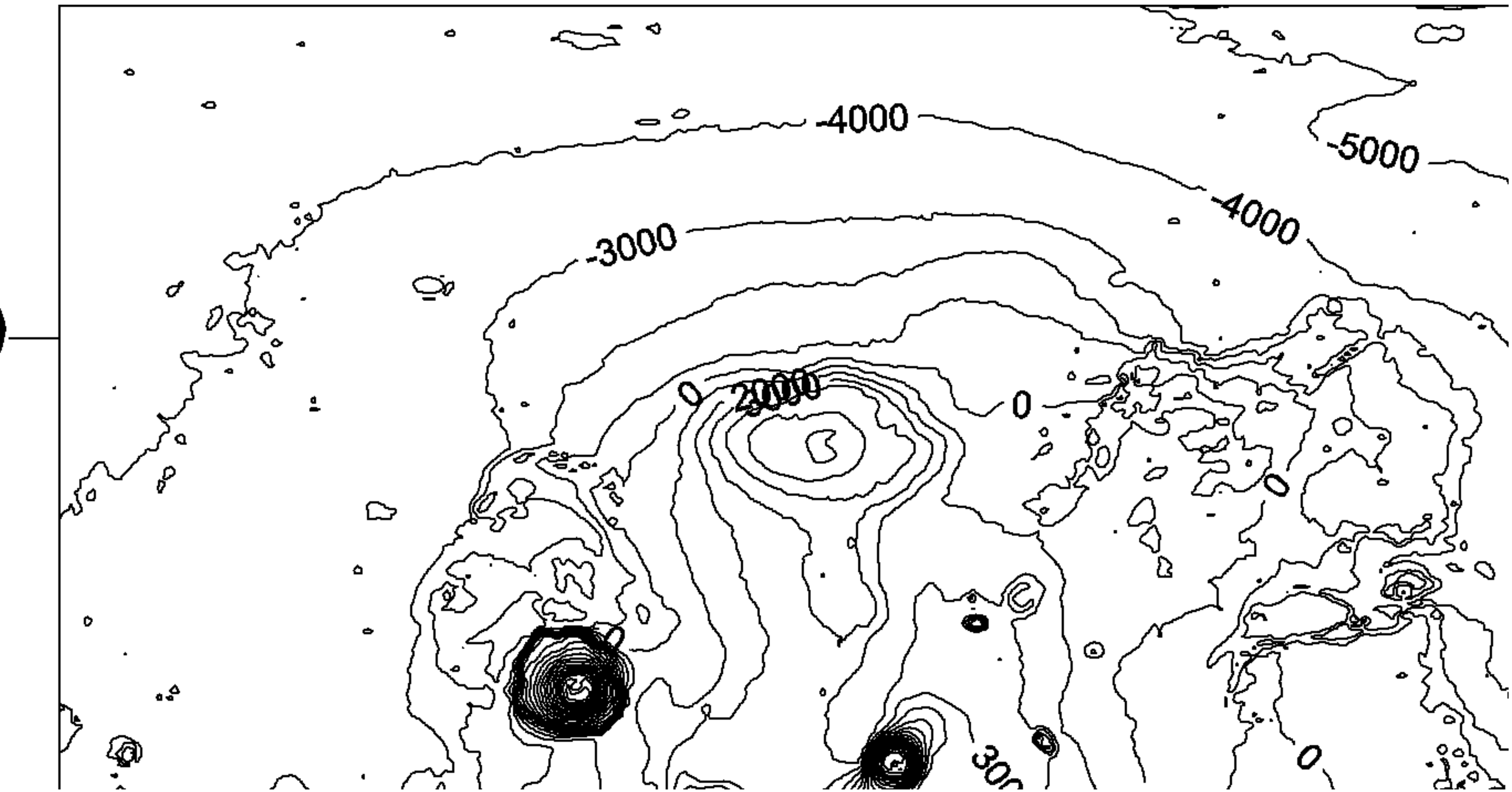


Fig. S3: 21, MOLA topography [m]

Segment 5 series

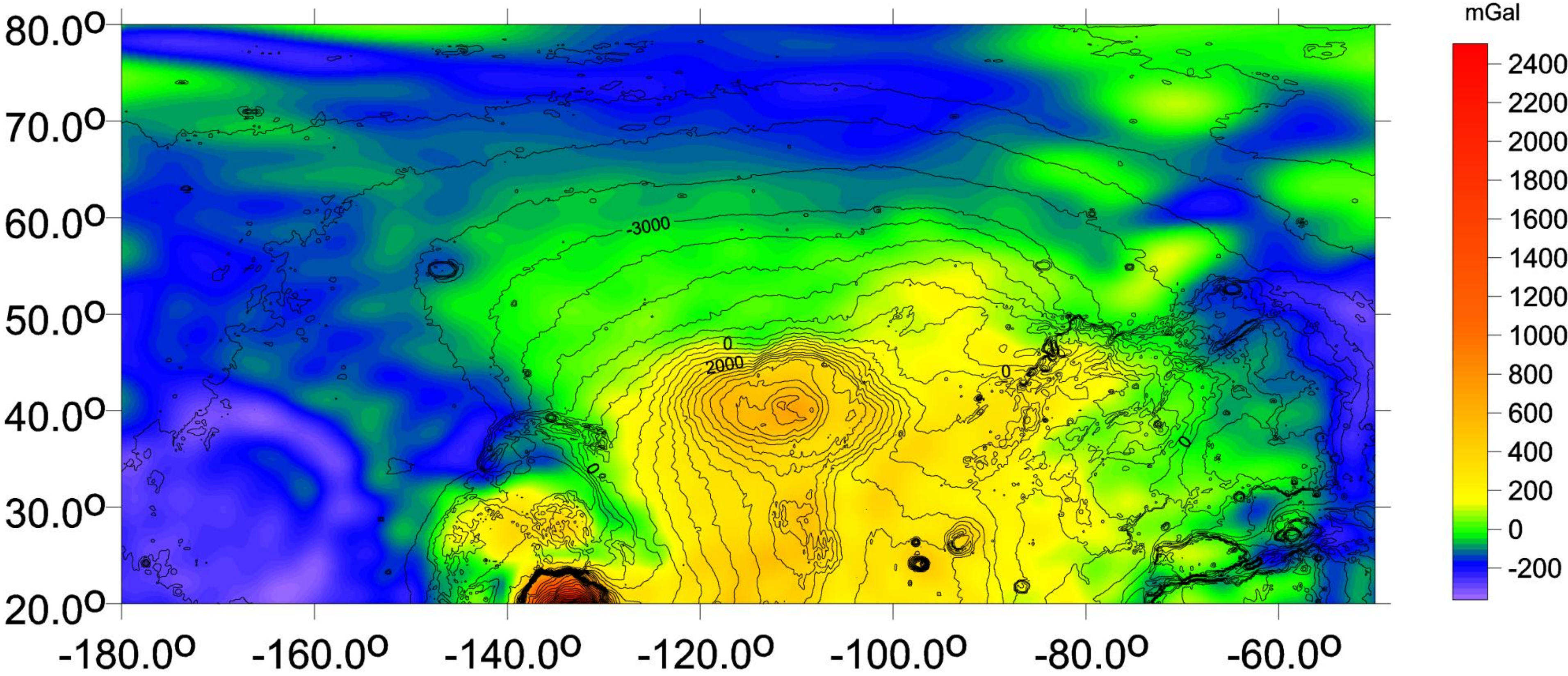


Fig. S3: 22, Δg

Segment 5 series

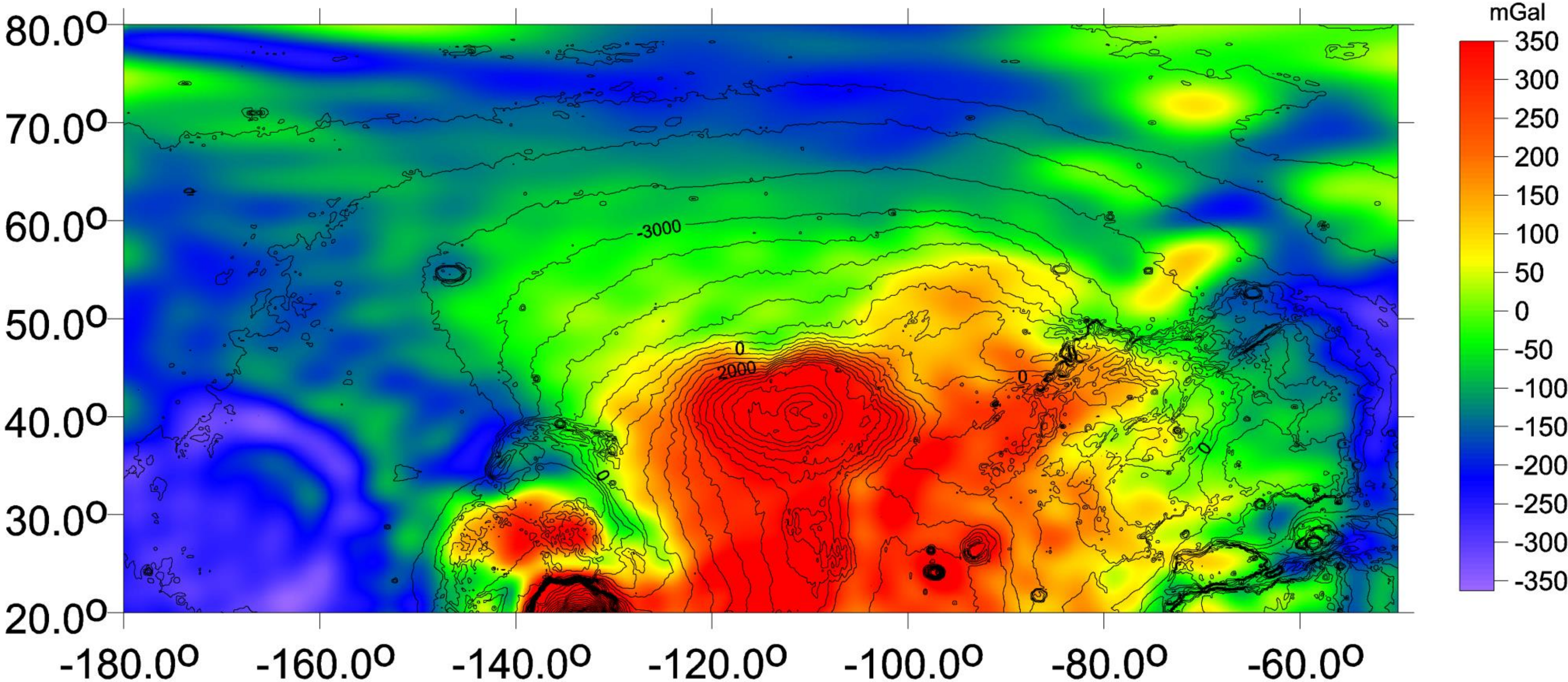


Fig. S3: 23, Δg

Segment 5 series

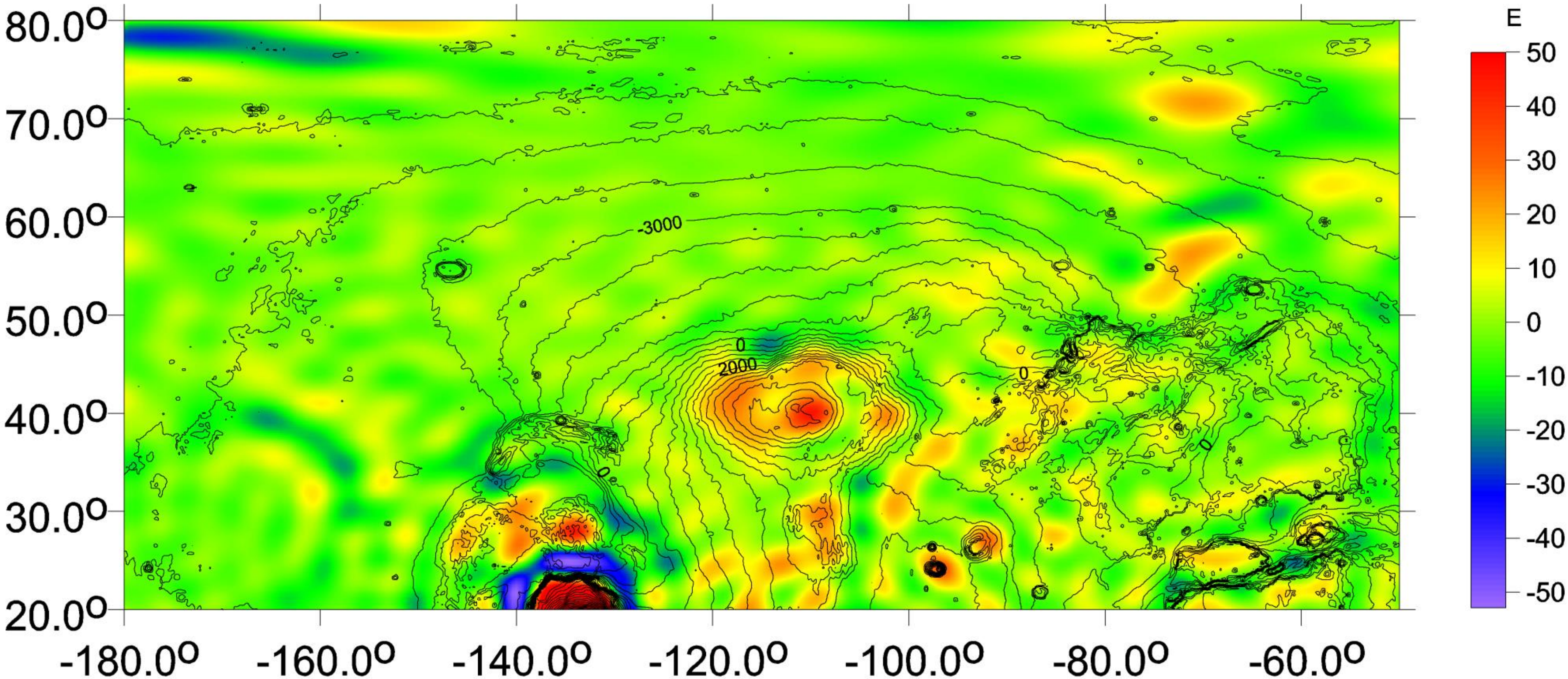


Fig. S3: 24, *Tzz*

Segment 5 series

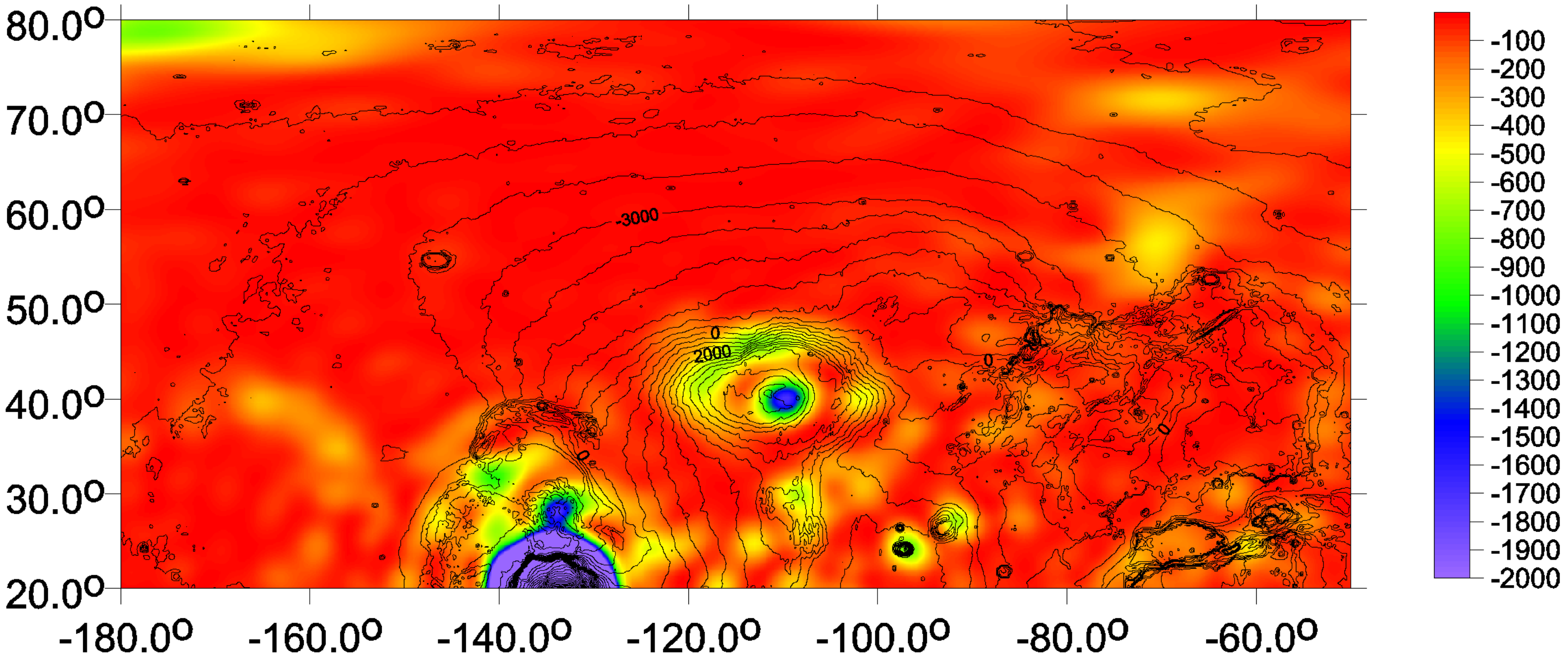


Fig. S3: 25, I_1

Segment 5 series

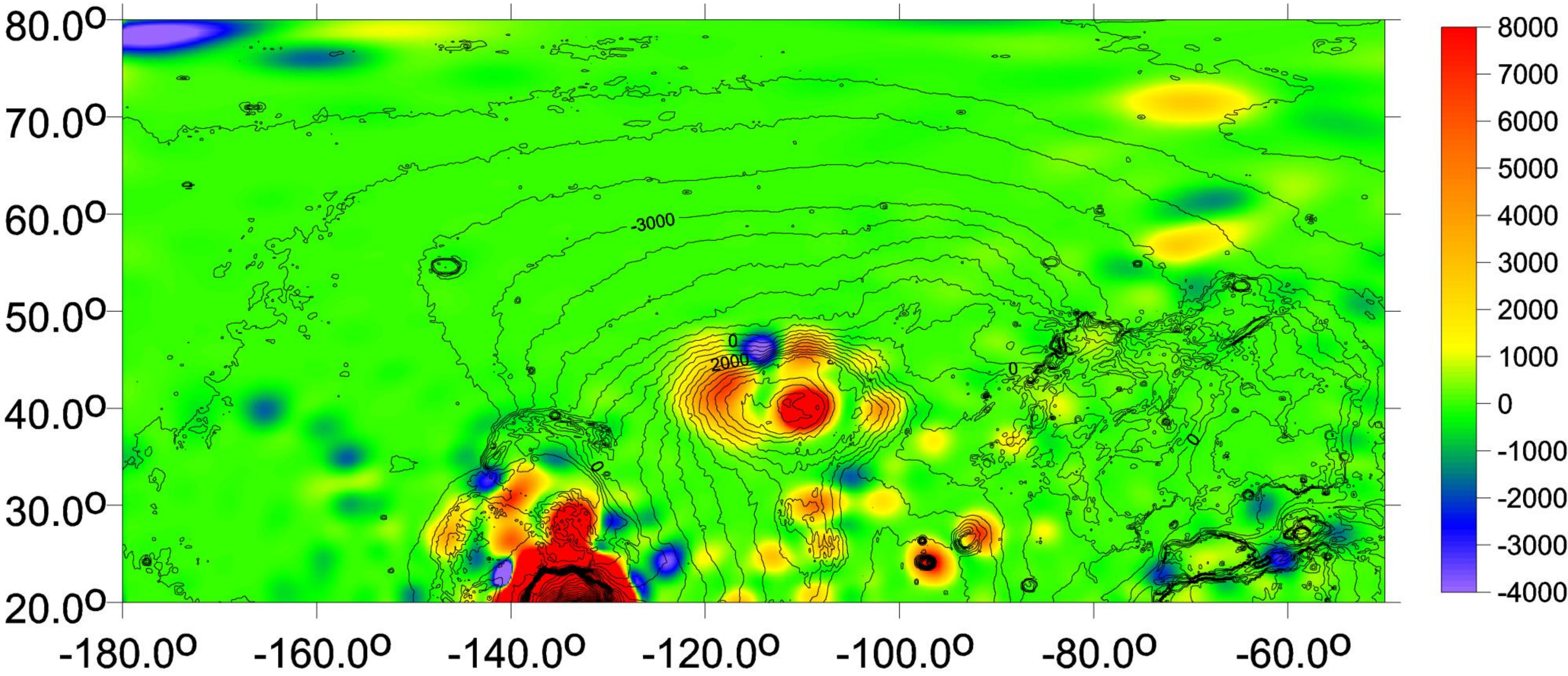


Fig. S3: 26, I_2

Segment 5 series

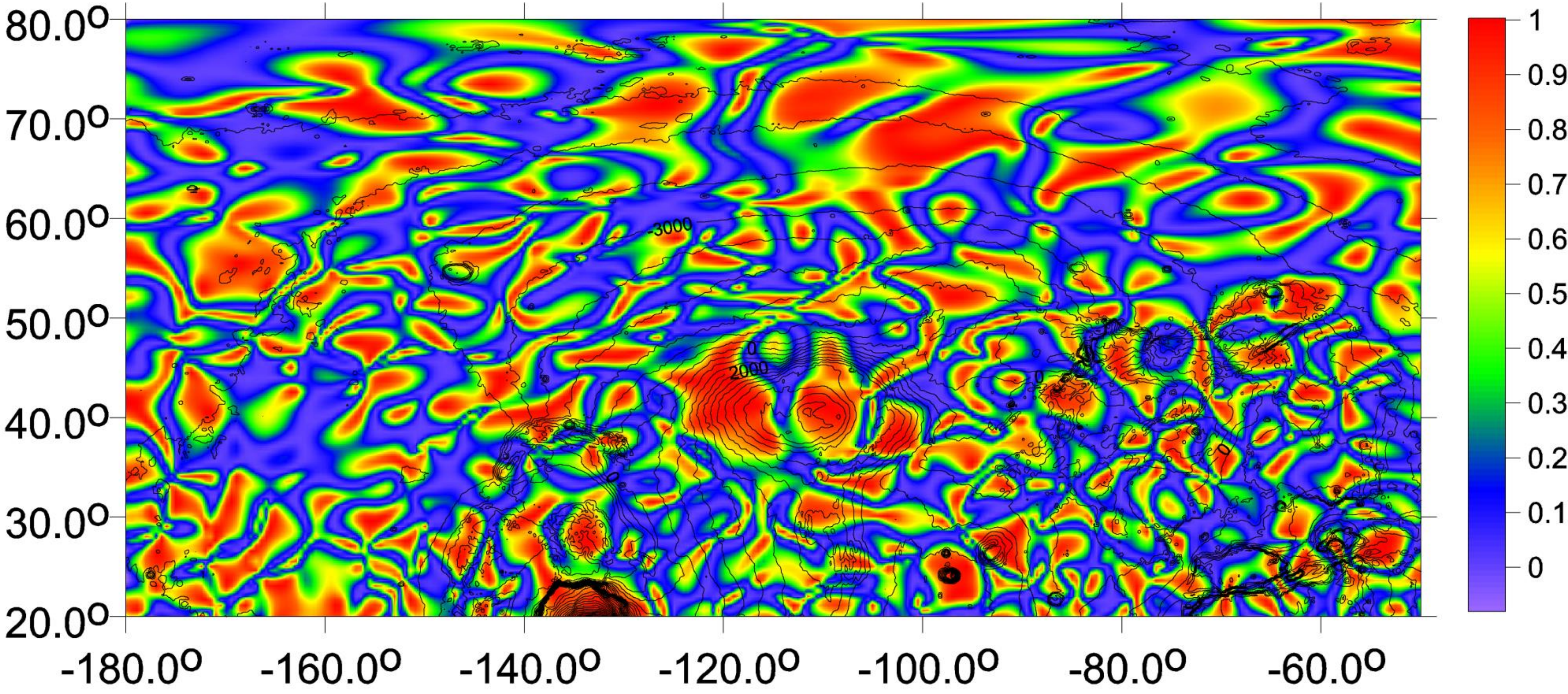


Fig. S3: 27, the ratio *I*

Segment 5 series

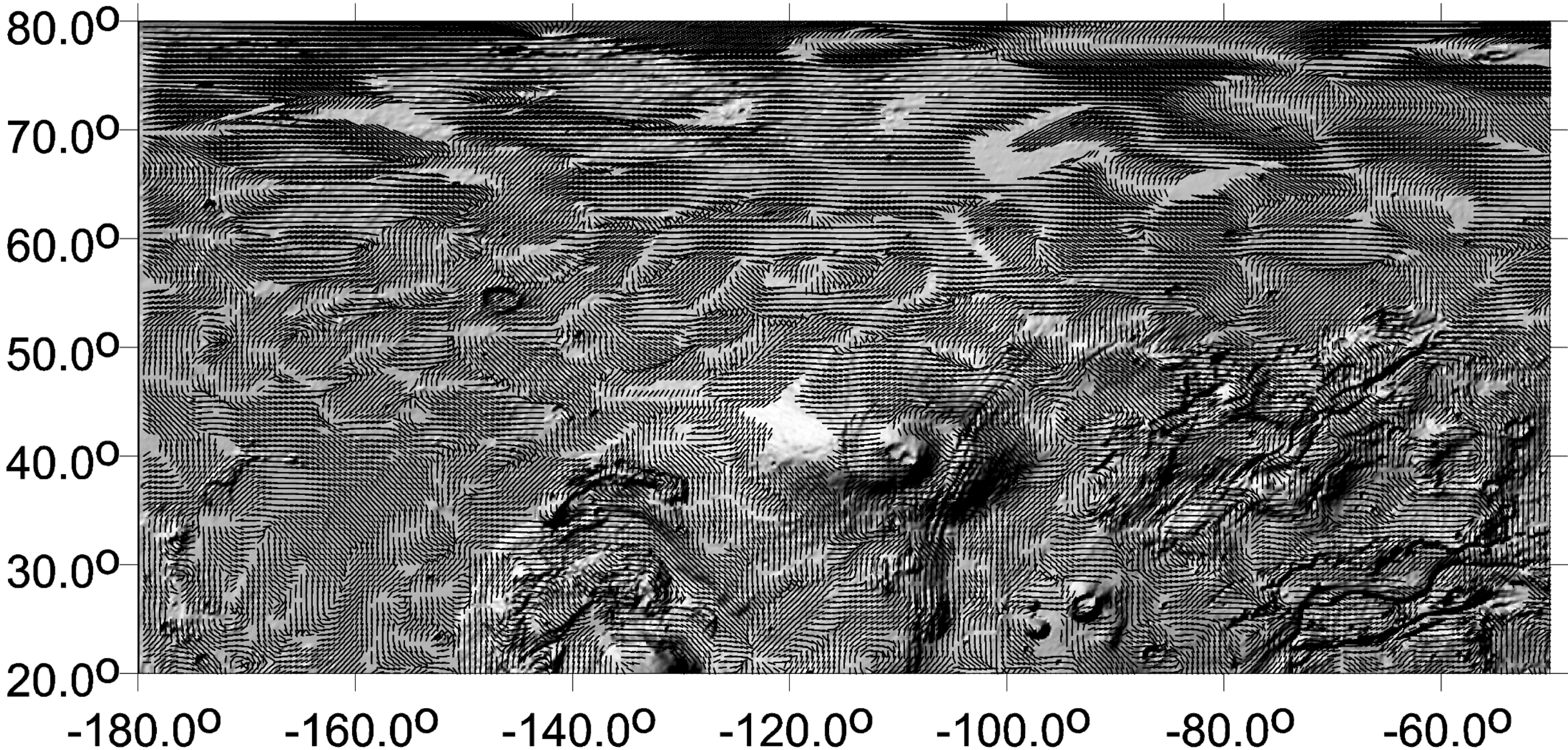


Fig. S3: 28, θ

Segment 5 series

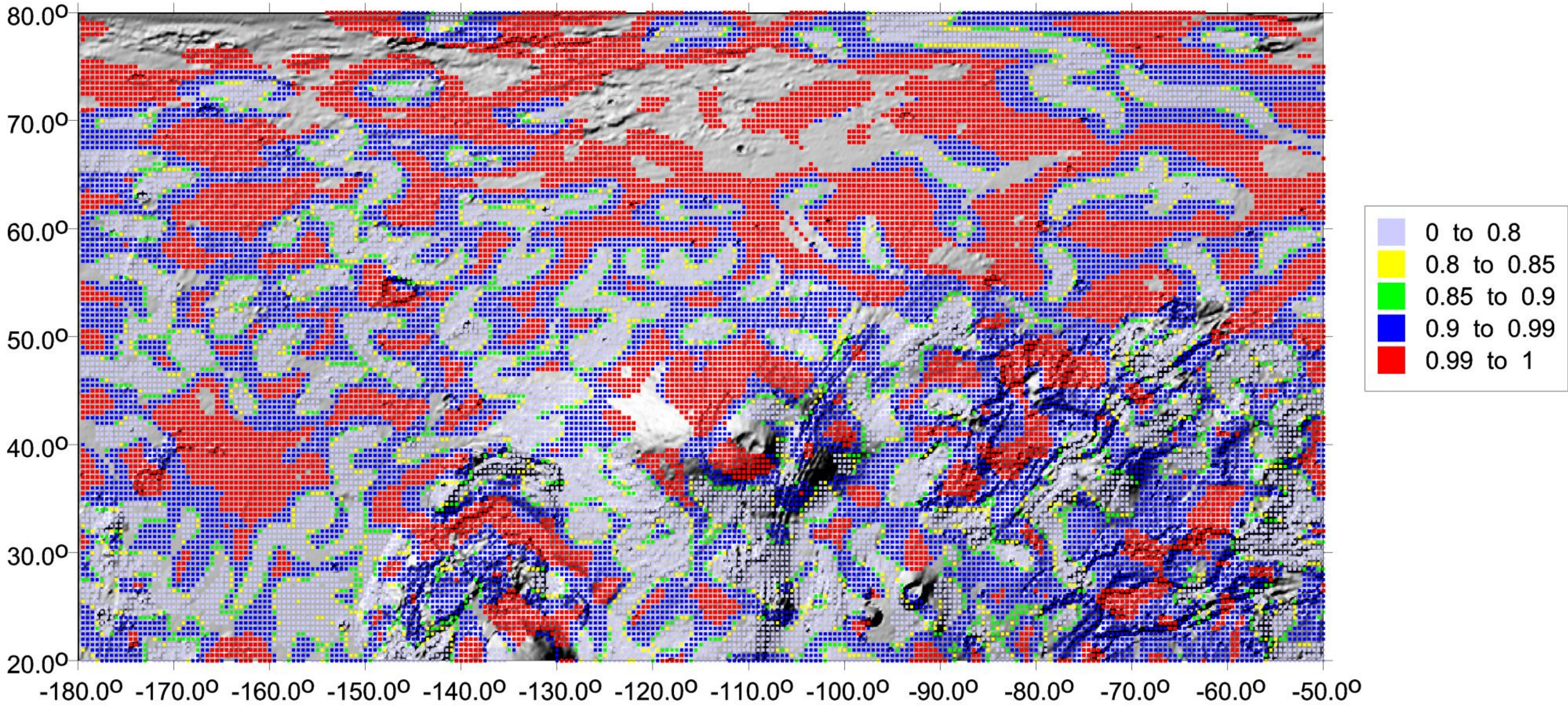


Fig. S3: 29, θ

Segment 5 series

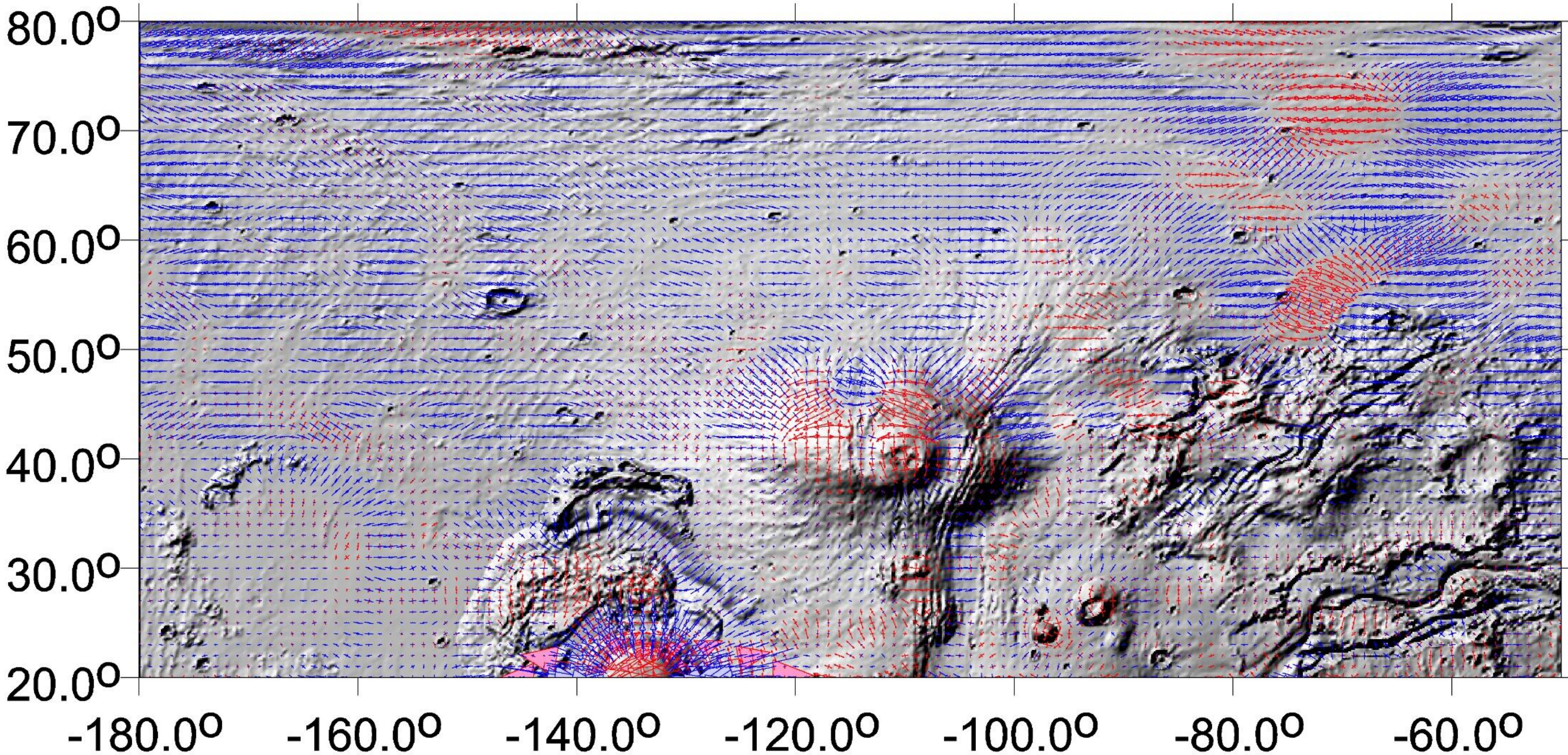


Fig. S3: 30, *vd*

Segment 5 series

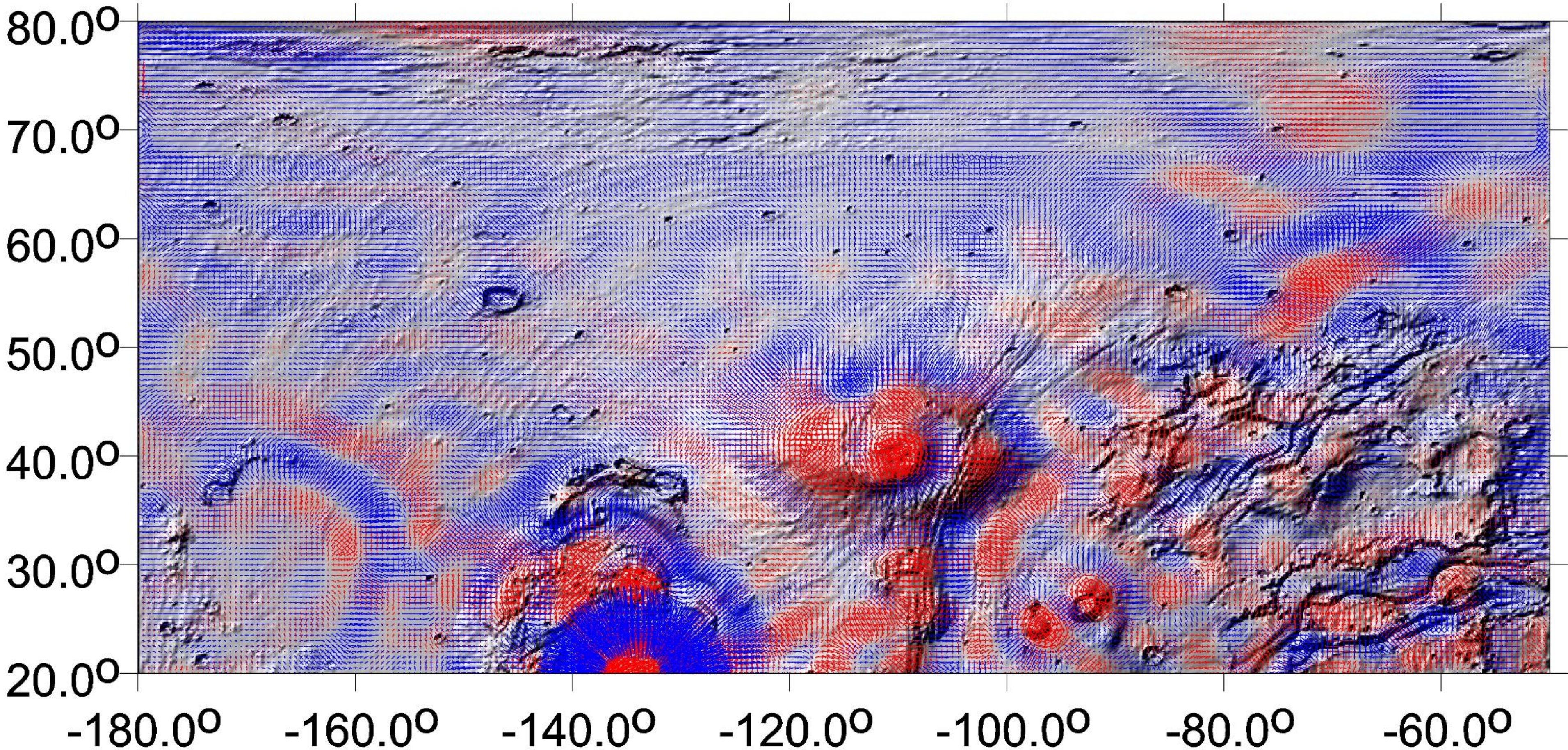
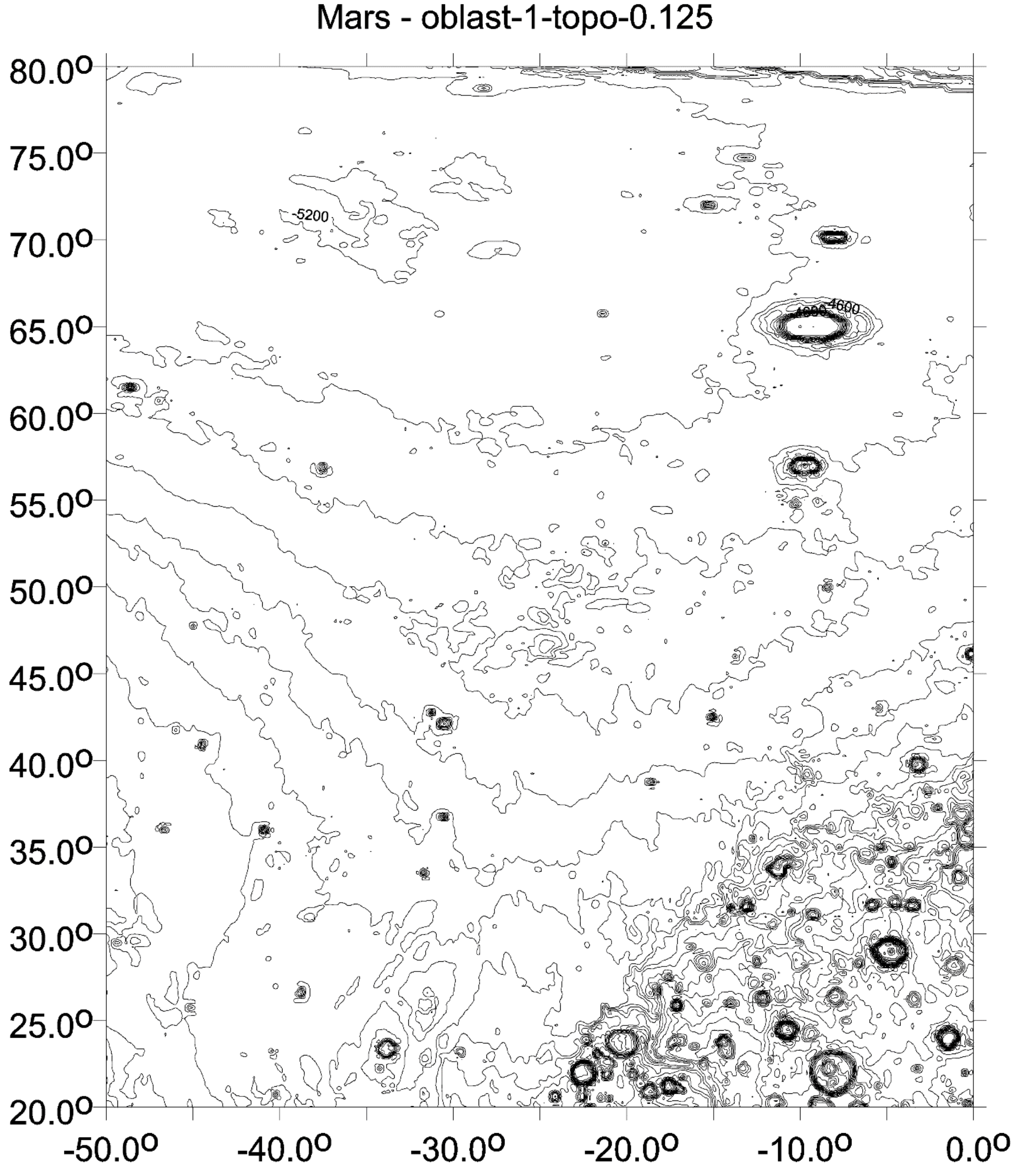


Fig. S3: 31, *vd* - two different ways how to plot the virtual deformations



Segment 1 series

Fig. S3: 32, topography

Segment 1 series

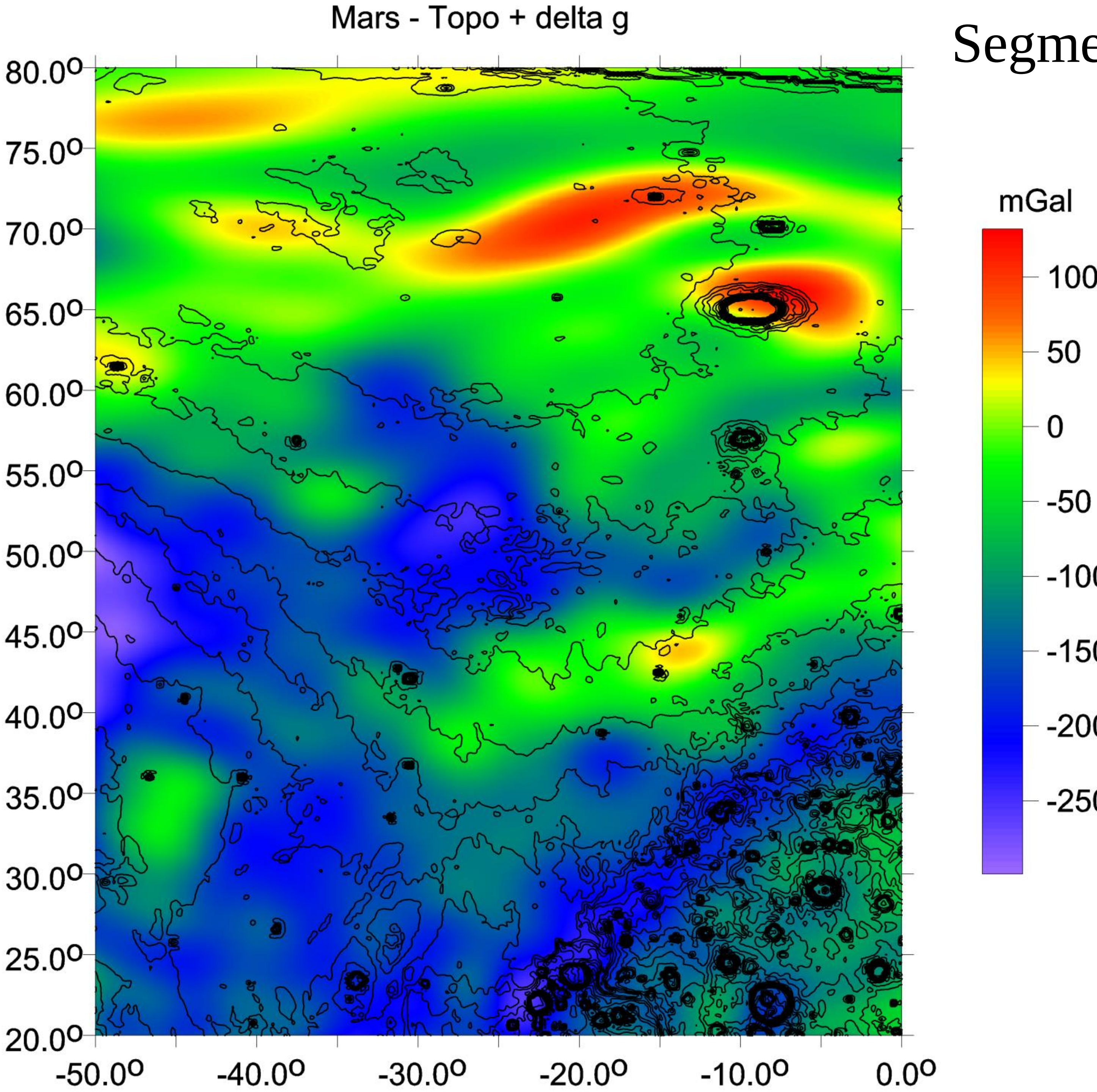
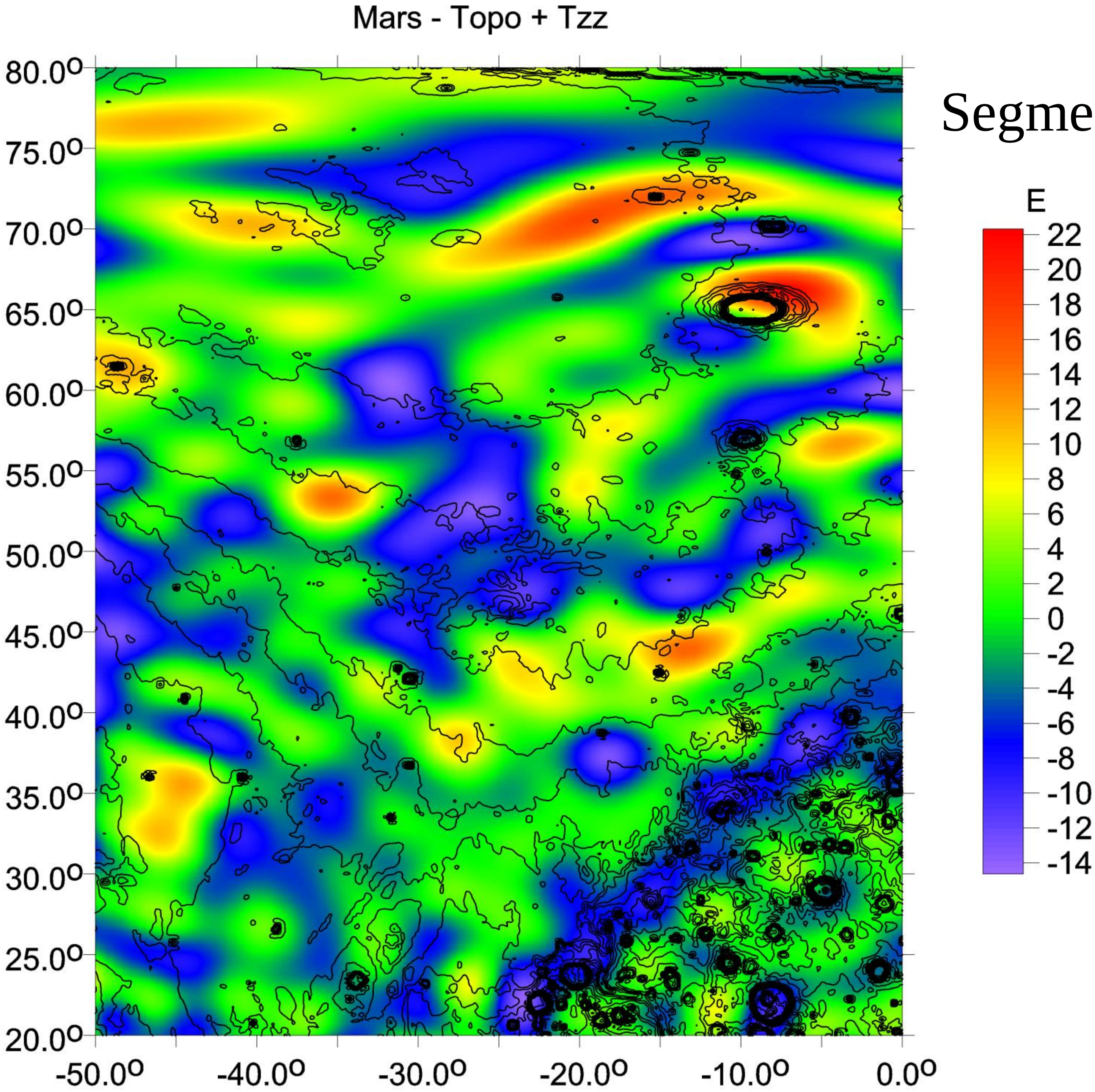
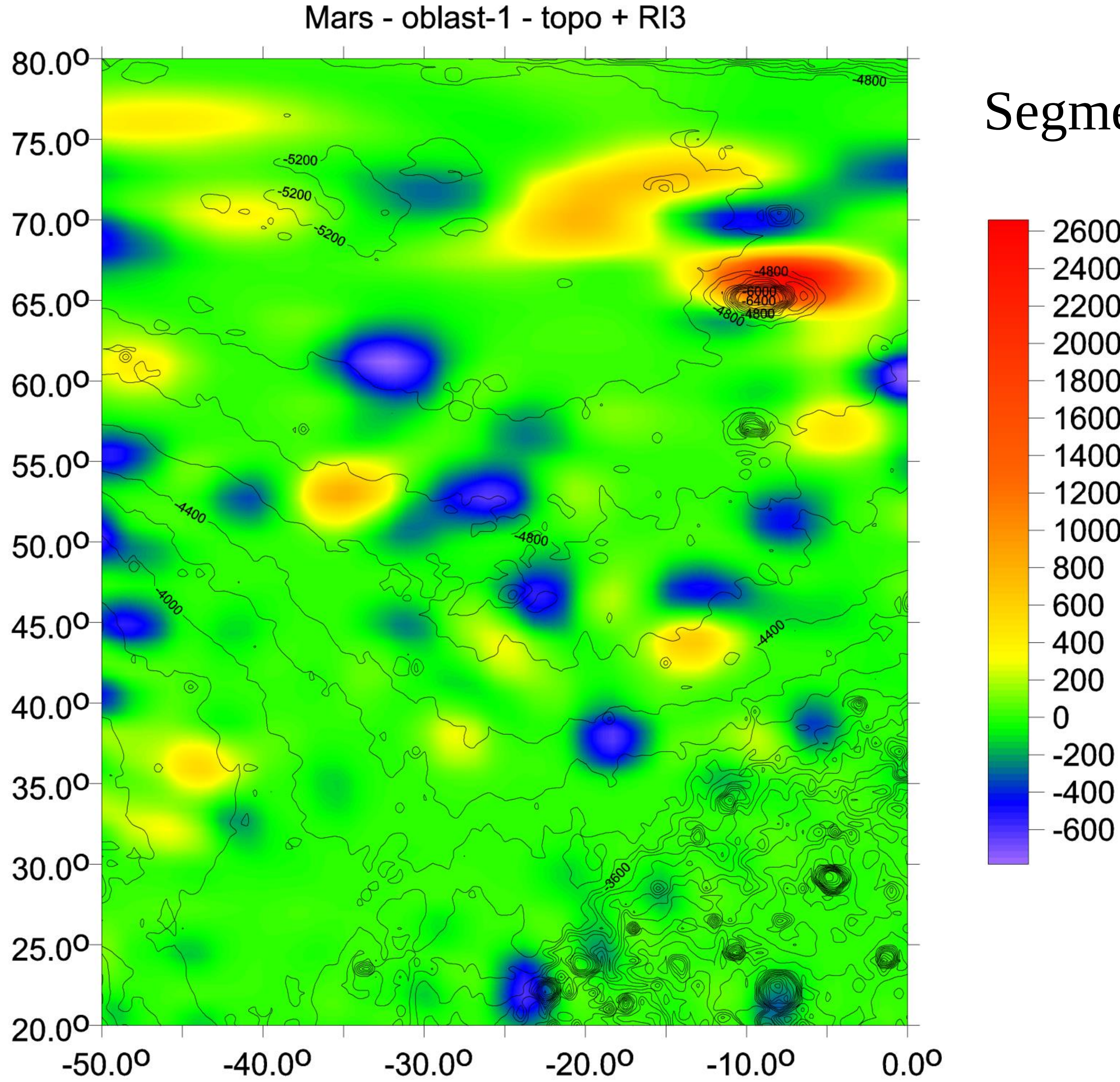


Fig. S3: 33, Δg



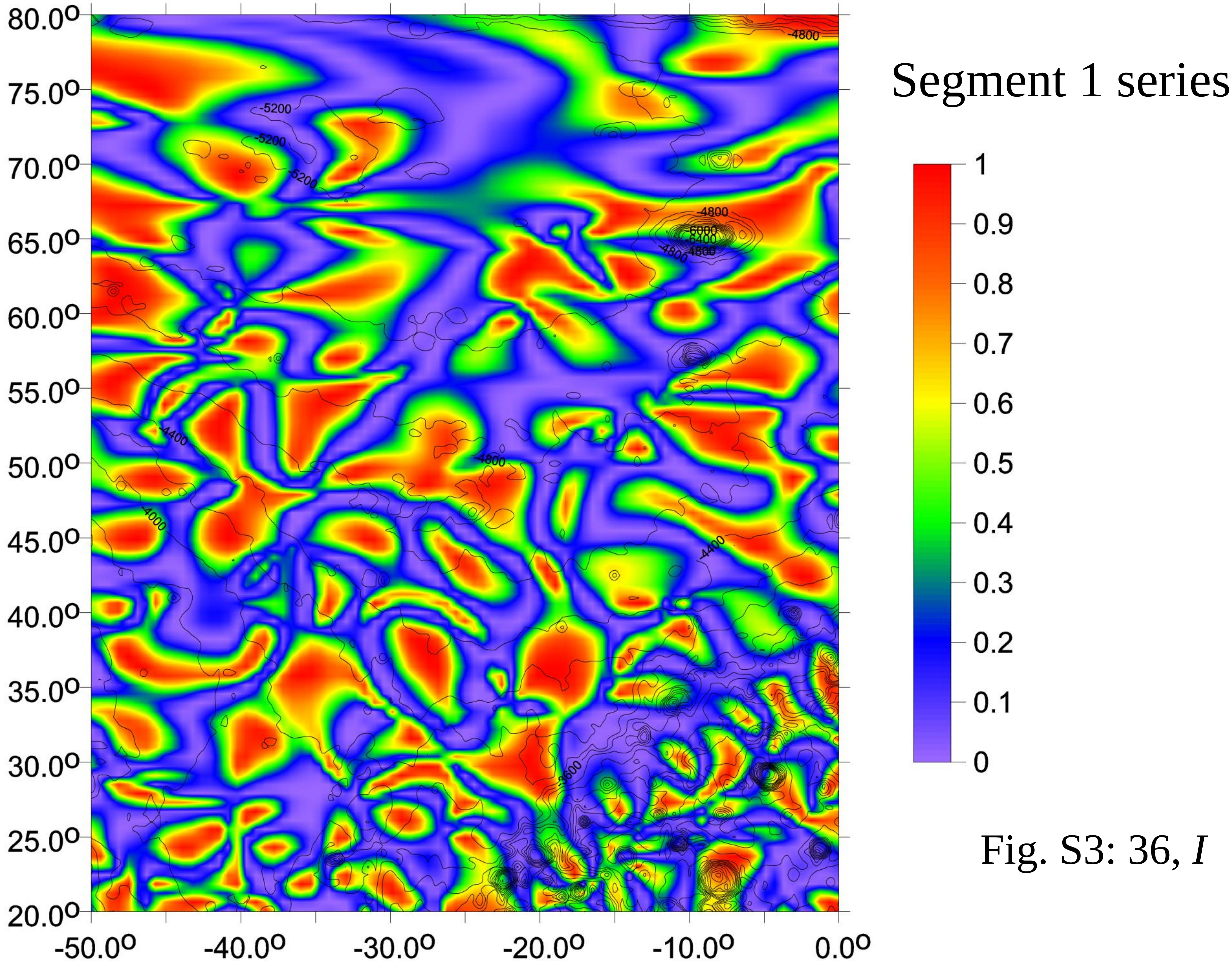
Segment 1 series

Fig. S3: 34, T_{zz}



Segment 1 series

Fig. S3: 35, I_2



Segment 1 series
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
80.0O
75.0O
70.0O
65.0O
60.0O
55.0O
50.0O
45.0O
40.0O
35.0O
30.0O
25.0O
20.0O
-50.0O
-40.0O
-30.0O
-20.0O
-10.0O
0.0O
-5200
-4800
-6000
-6400
-4400
-4000
-3600

Fig. S3: 36, *I*

Segment 1 series

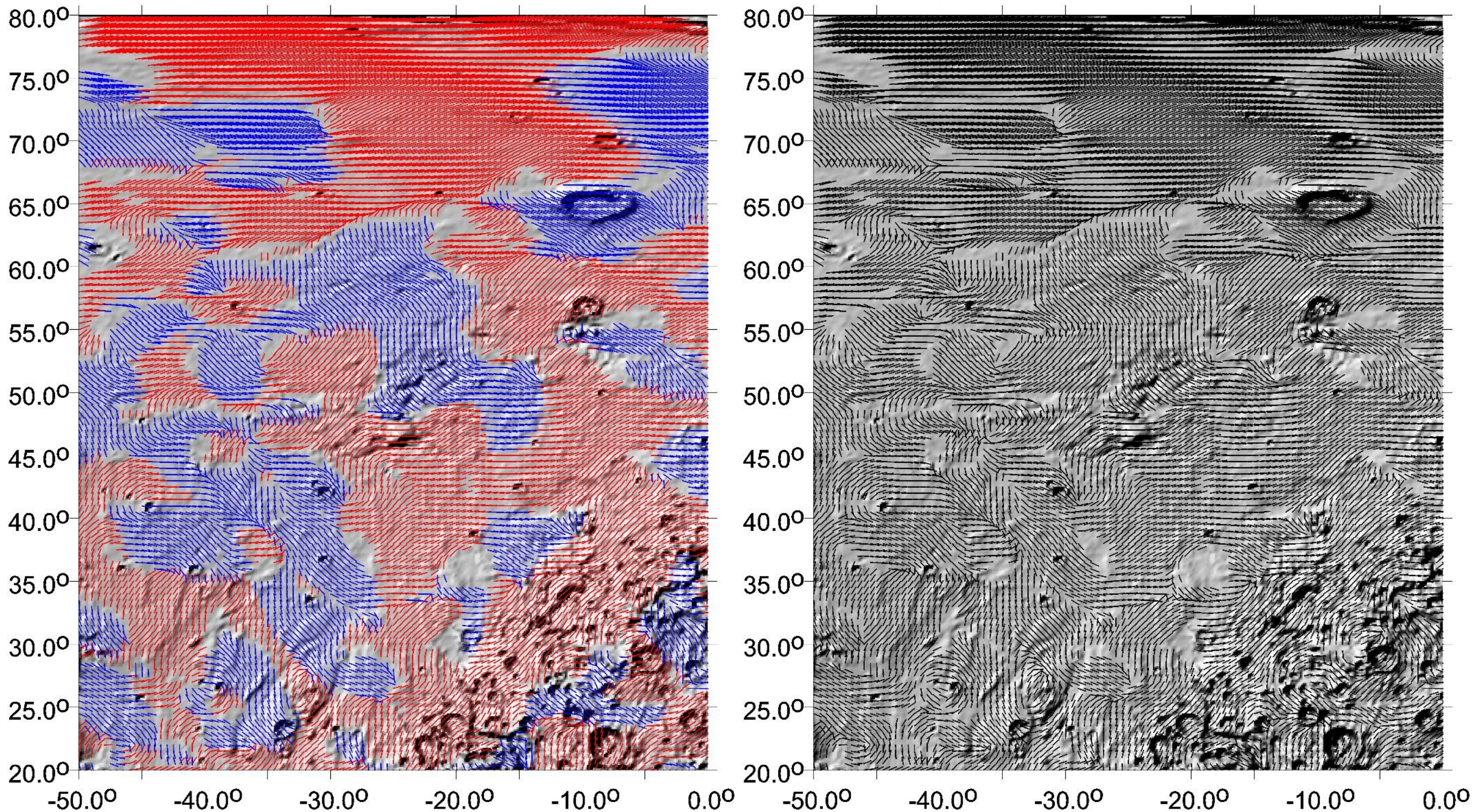
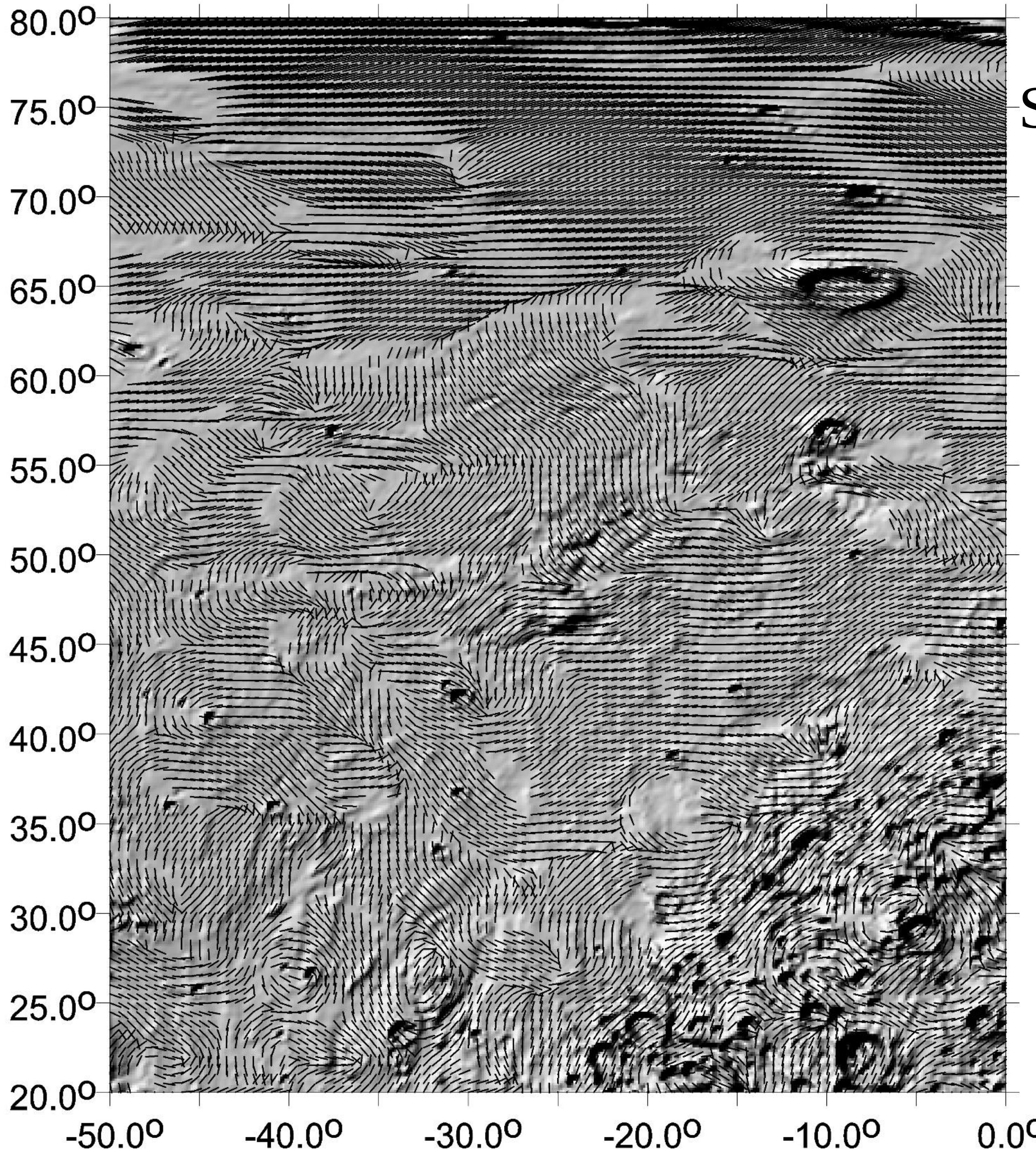
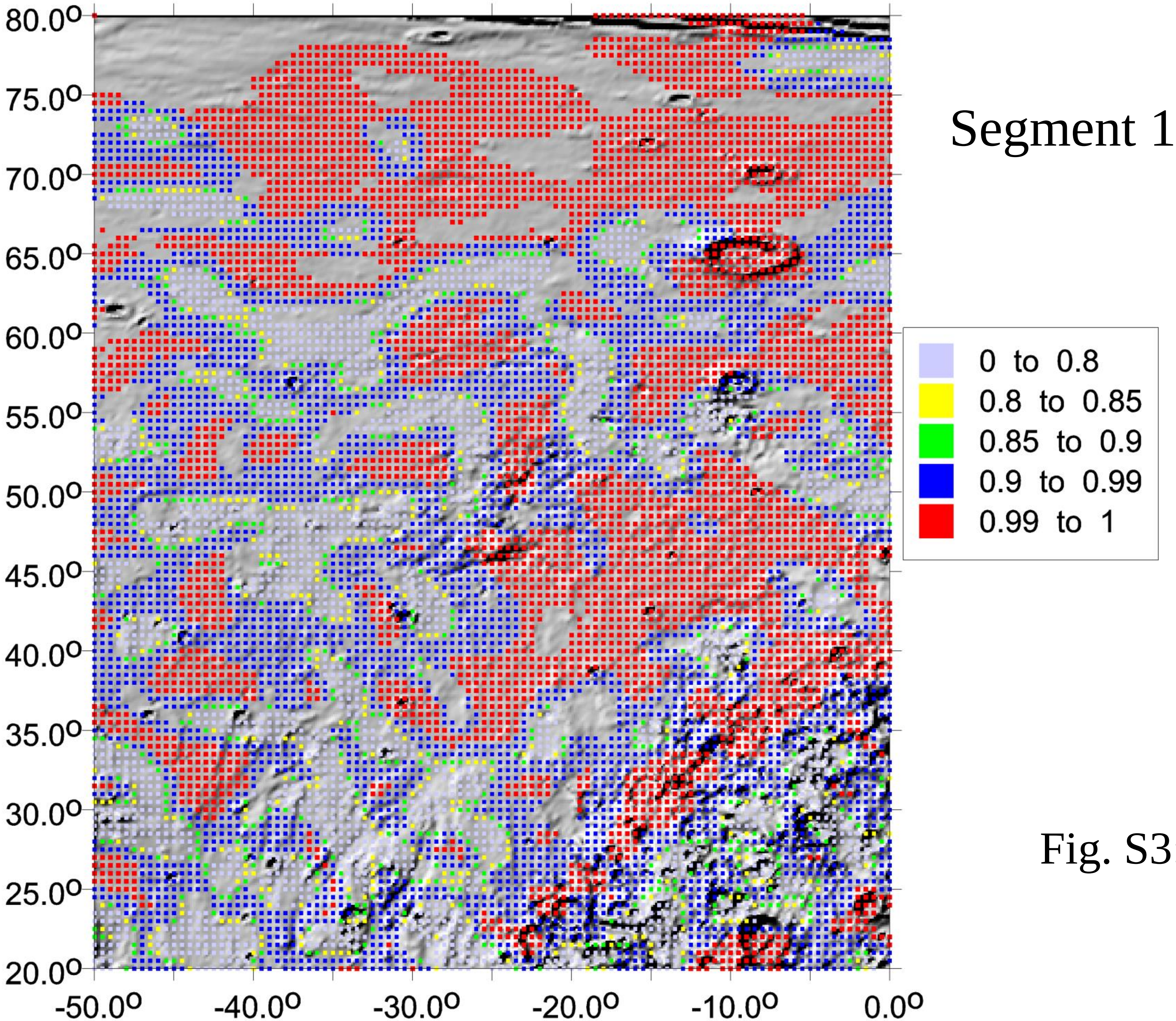


Fig. S3: 37, θ



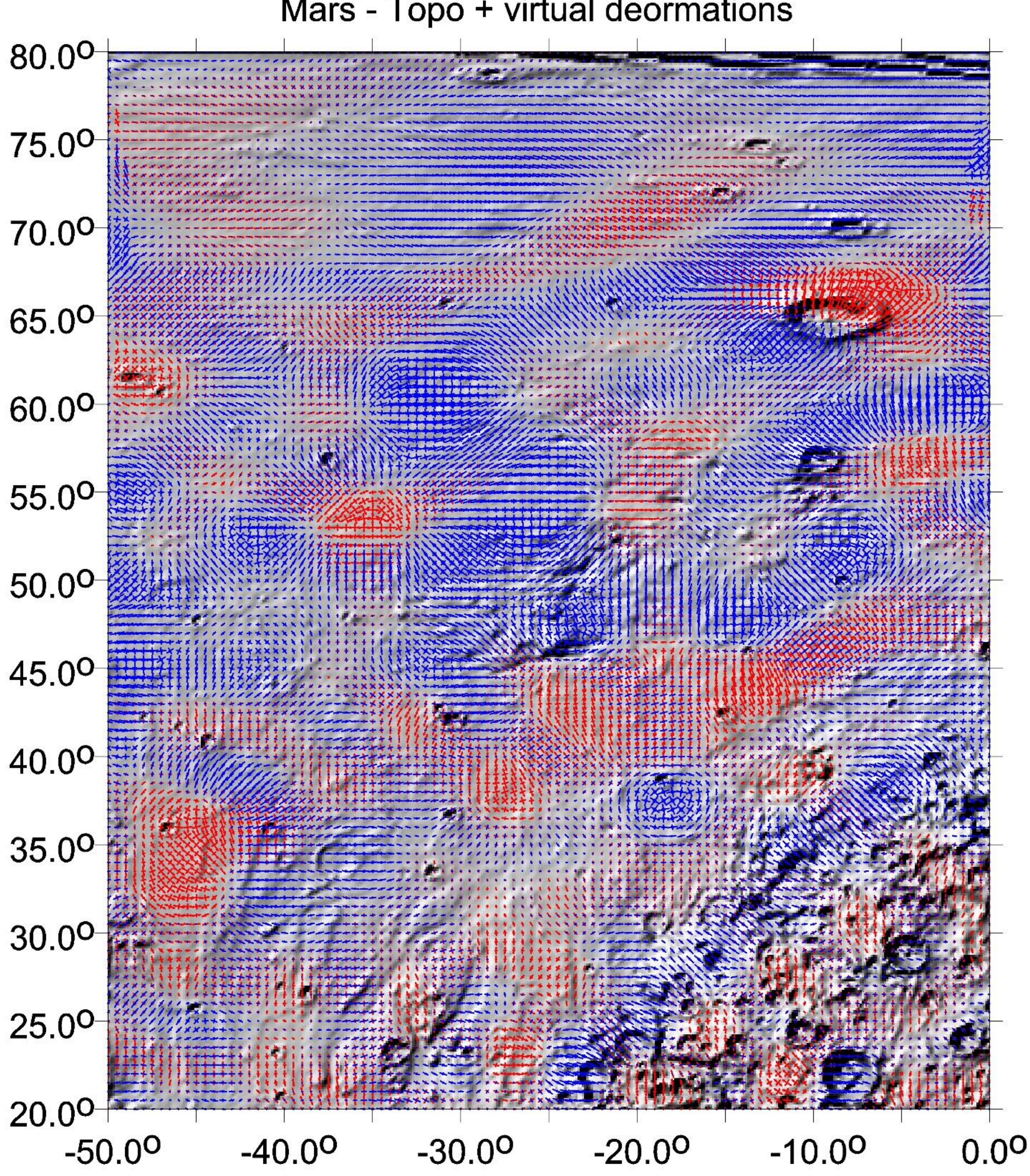
Segment 1 series

Fig. S3: 38, θ



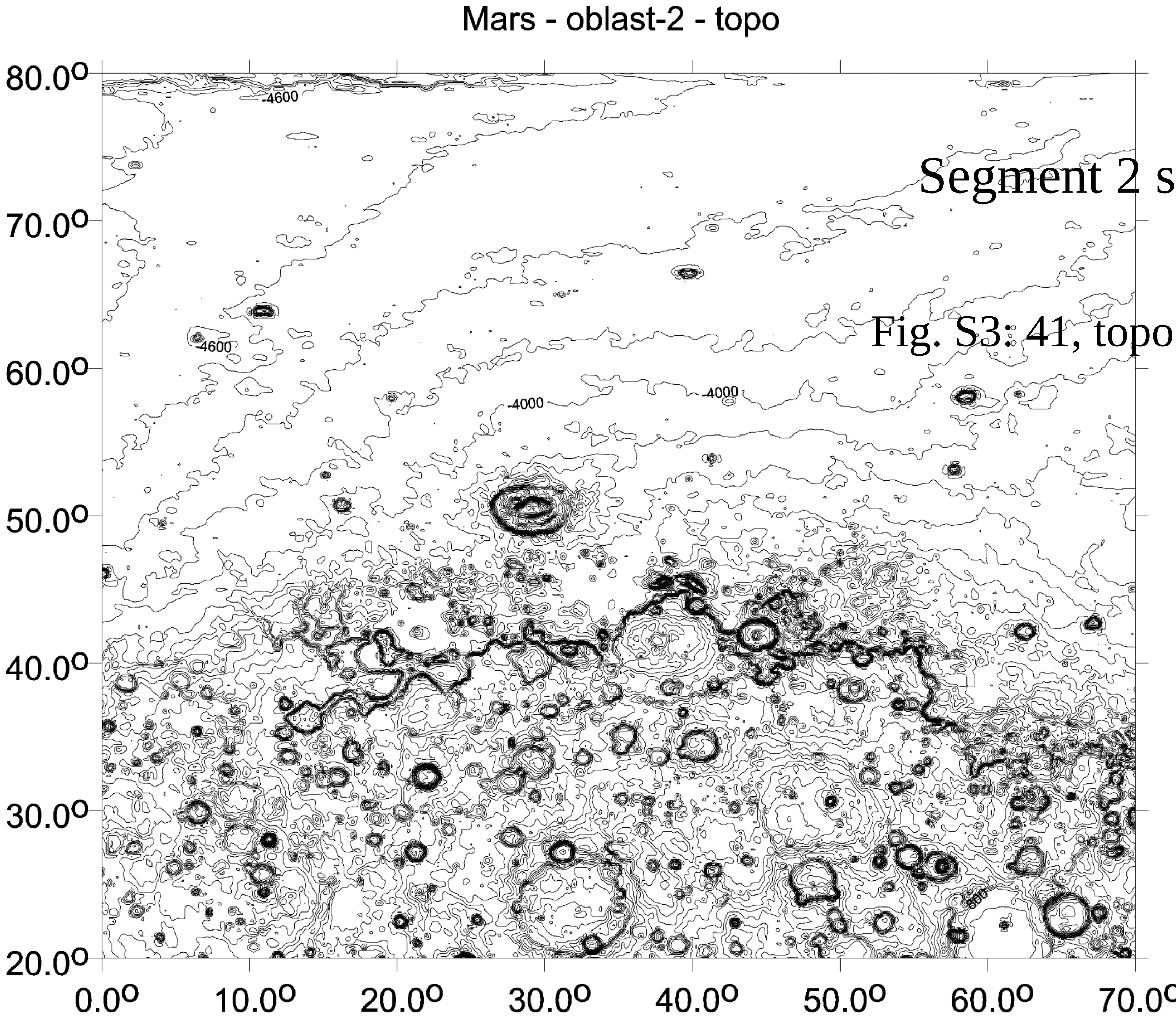
Segment 1 series

Fig. S3: 39, θ



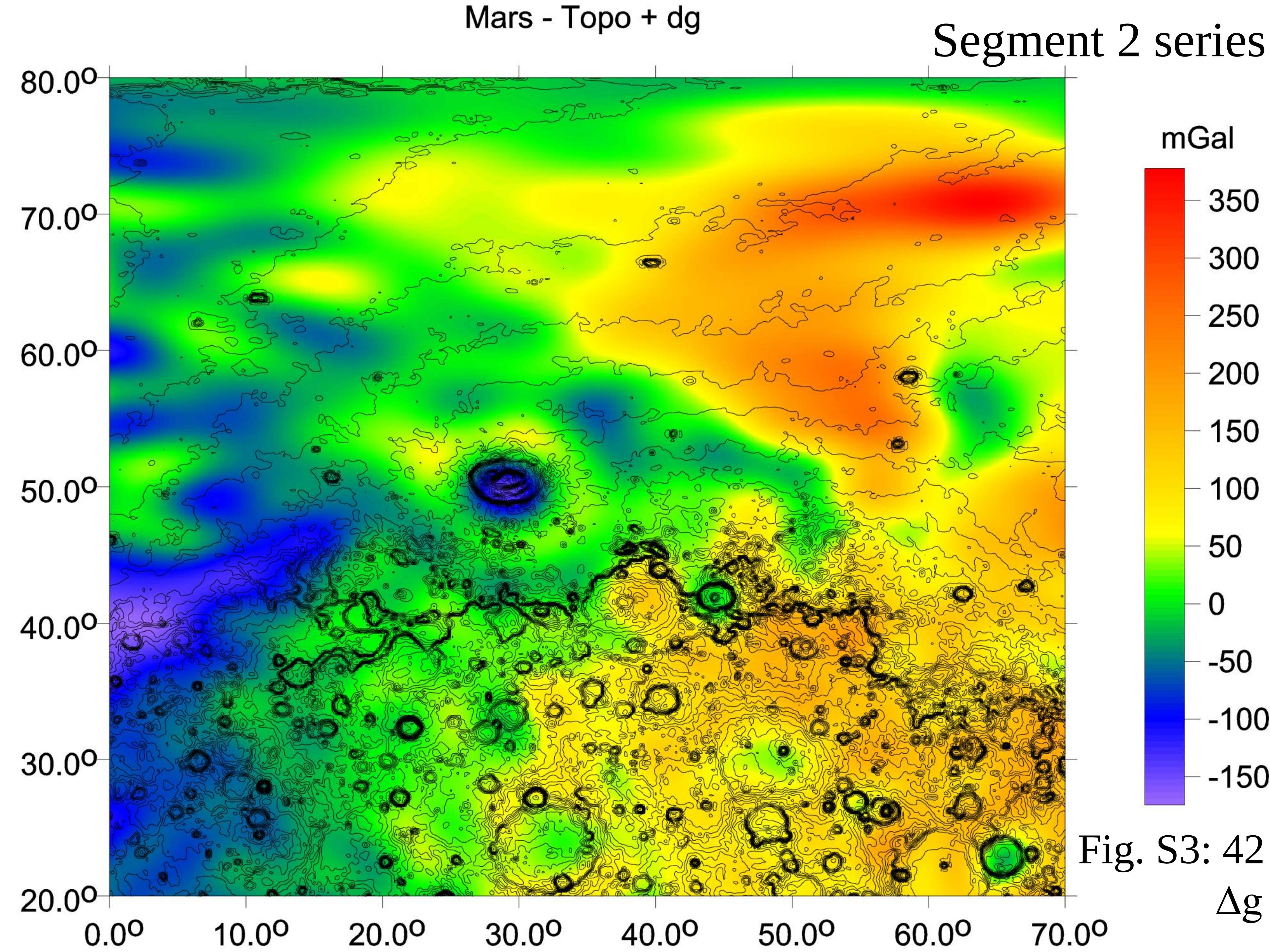
Segment 1 series

Fig. S3: 40, *vd*



Segment 2 series

Fig. S3: 41, topography



Segment 2 series

Fig. S3: 42
Δg

Segment 2 series

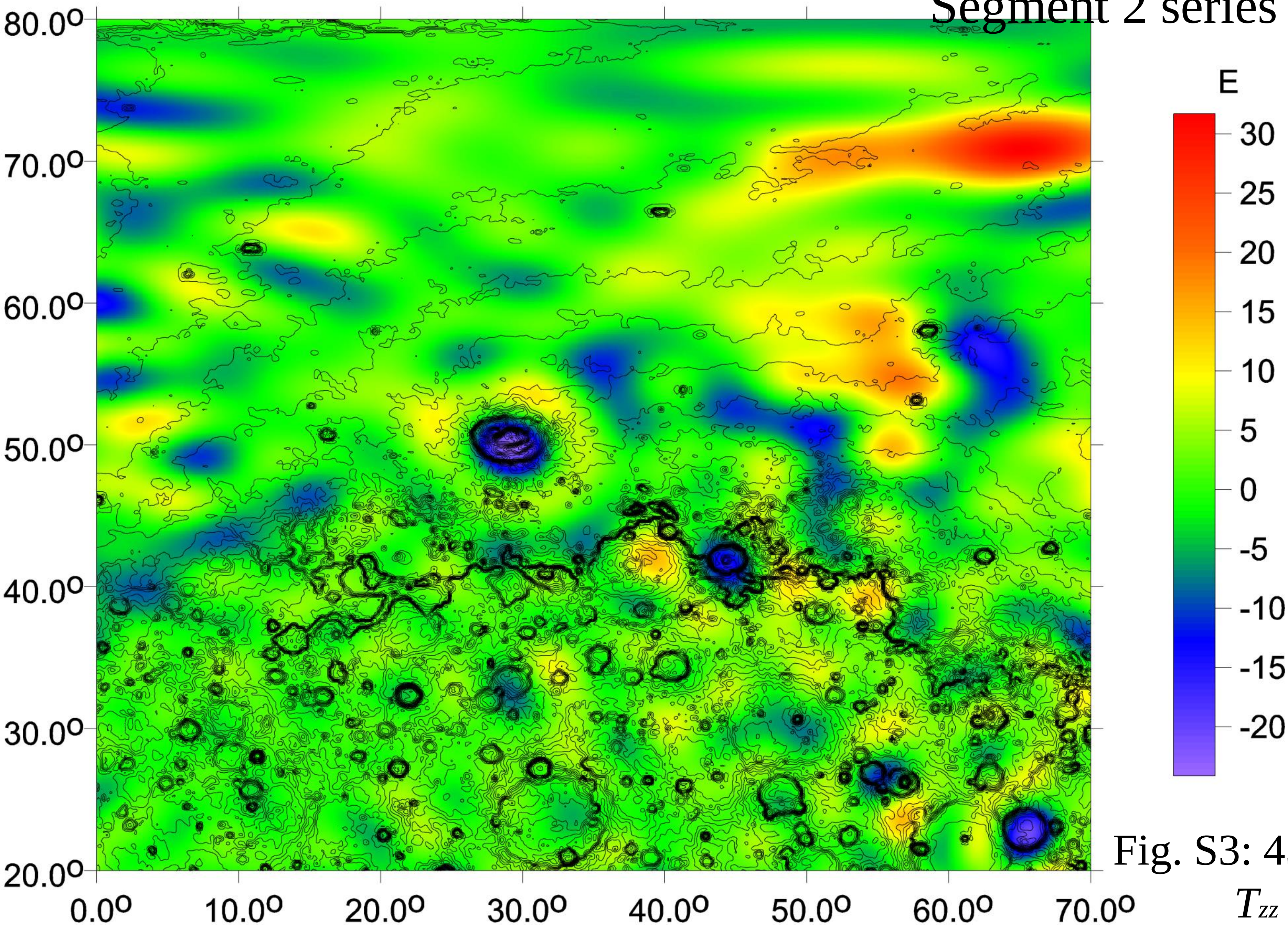


Fig. S3: 43

T_{zz}

Segment 2 series

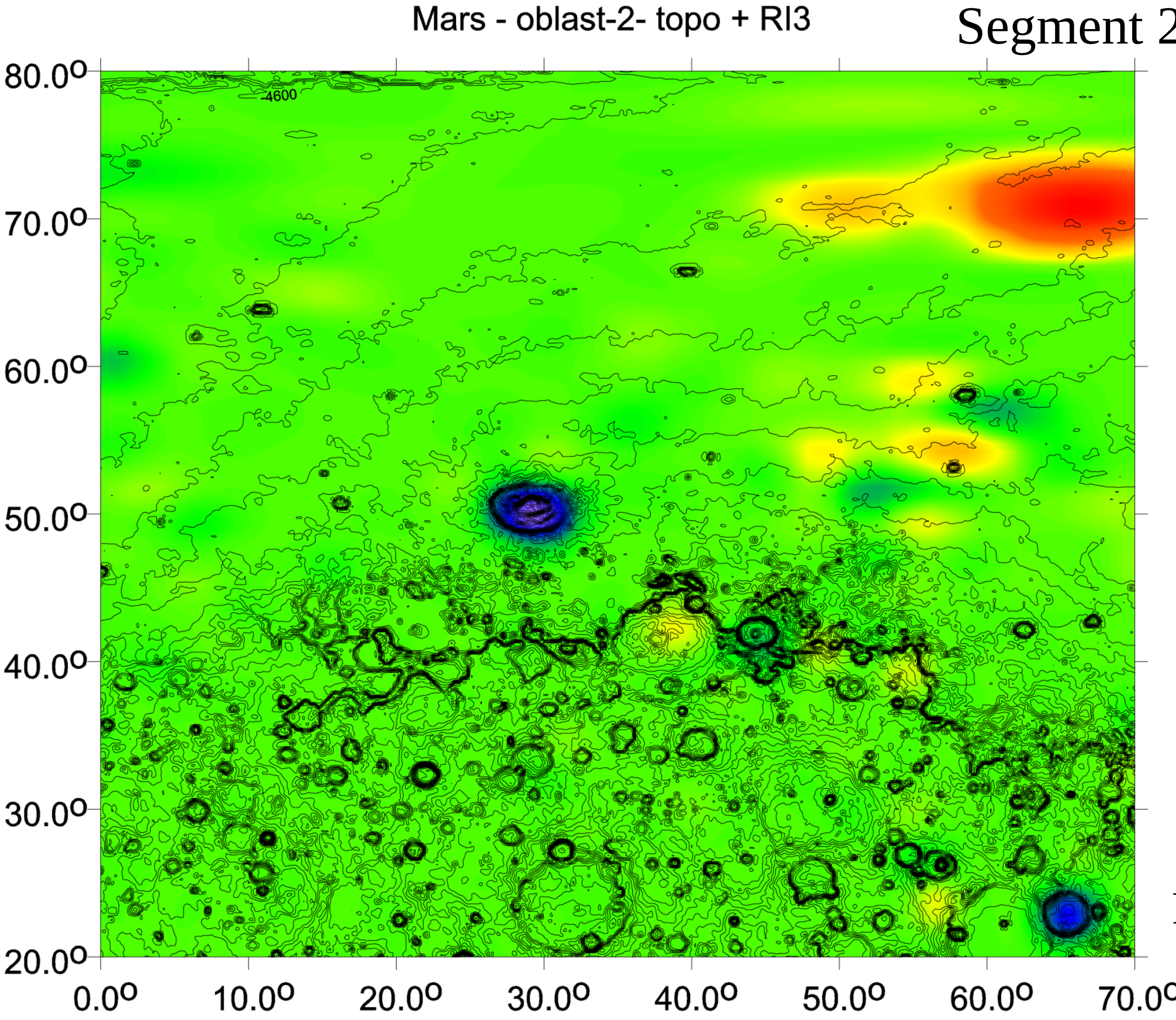


Fig. S3: 44

I_2

Segment 2 series

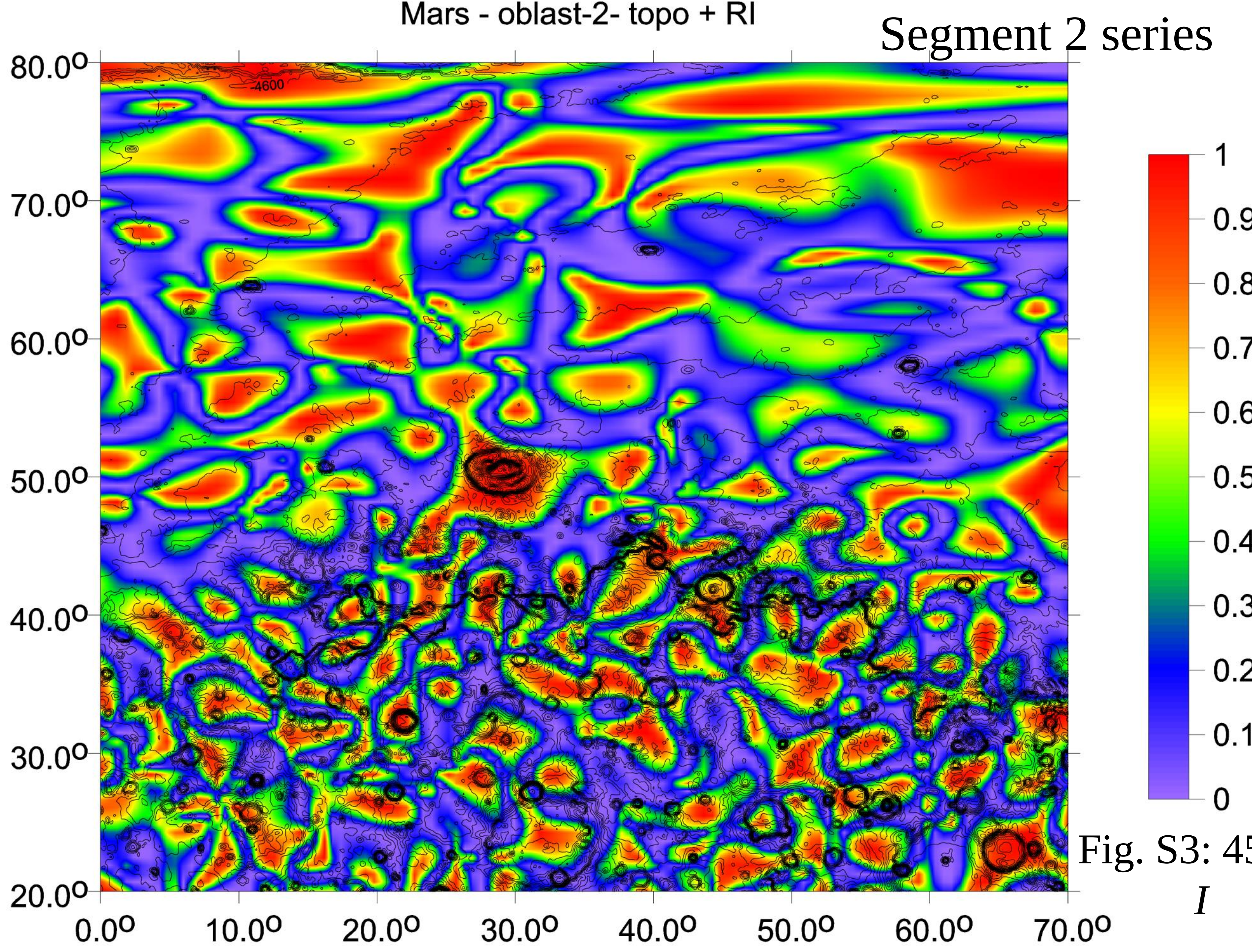
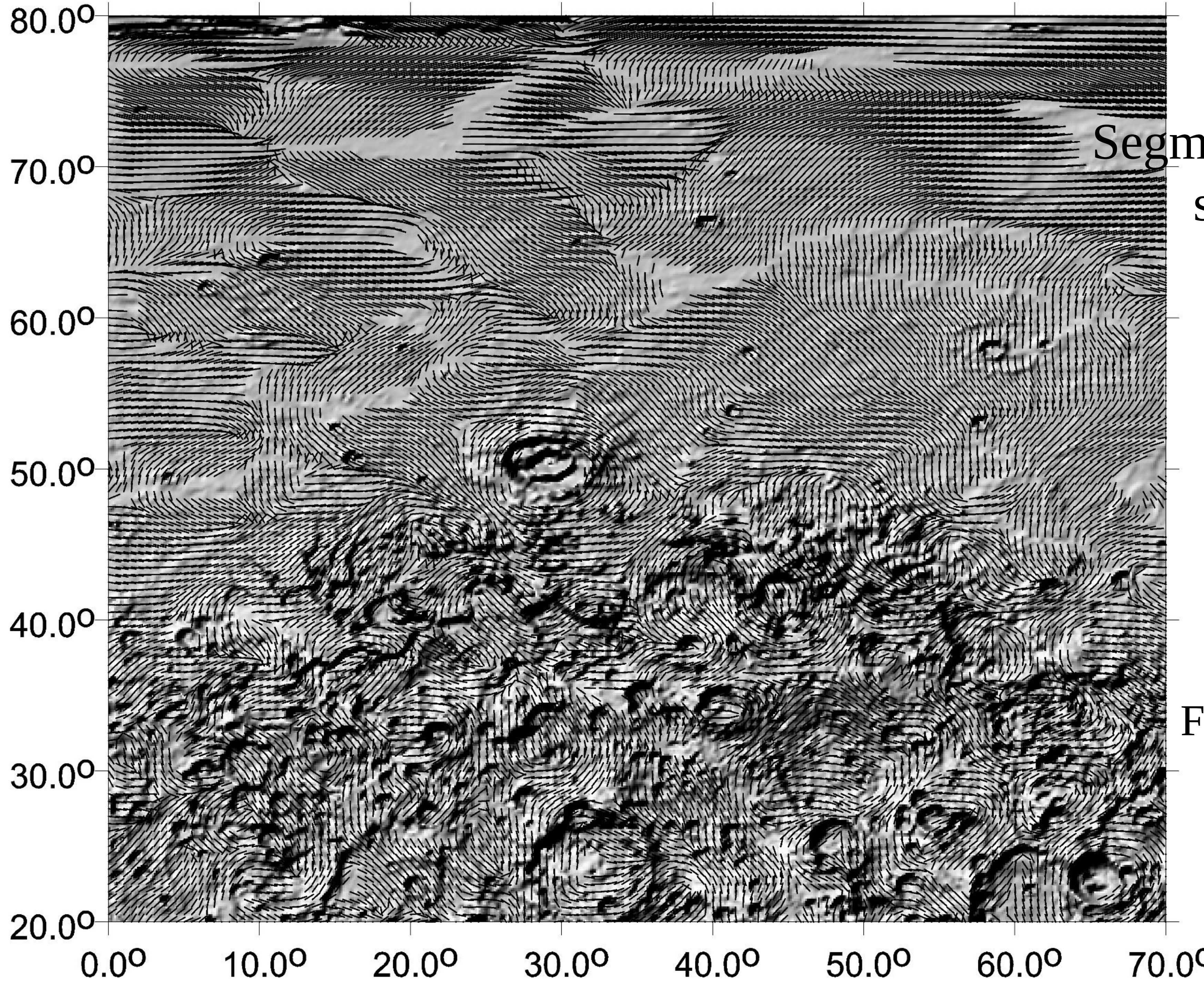
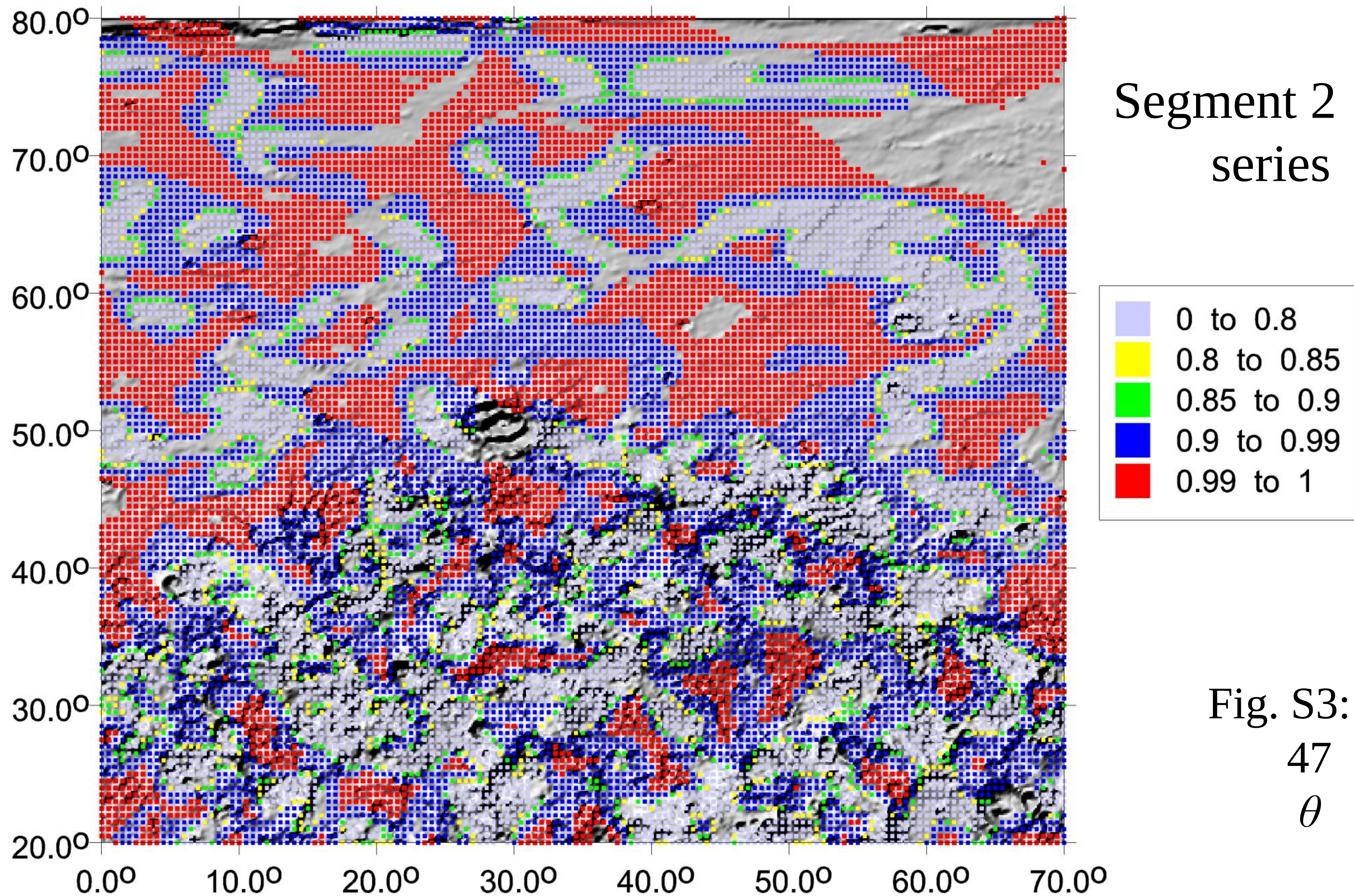


Fig. S3: 45



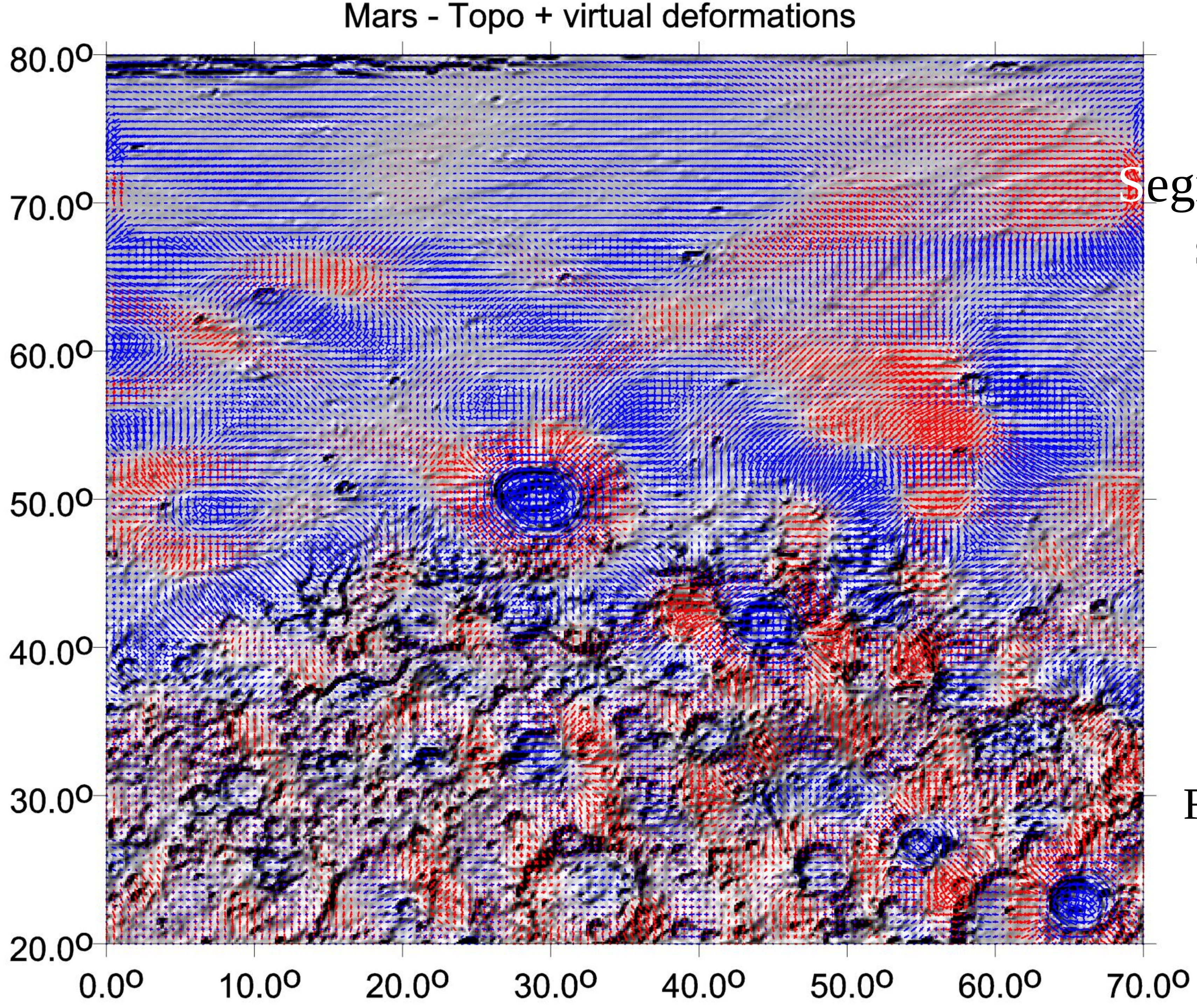
Segment 2 series

Fig. S3: 46 θ



Segment 2 series

Fig. S3: 47 θ



Segment 2 series

Fig. S3: 48, *vd*

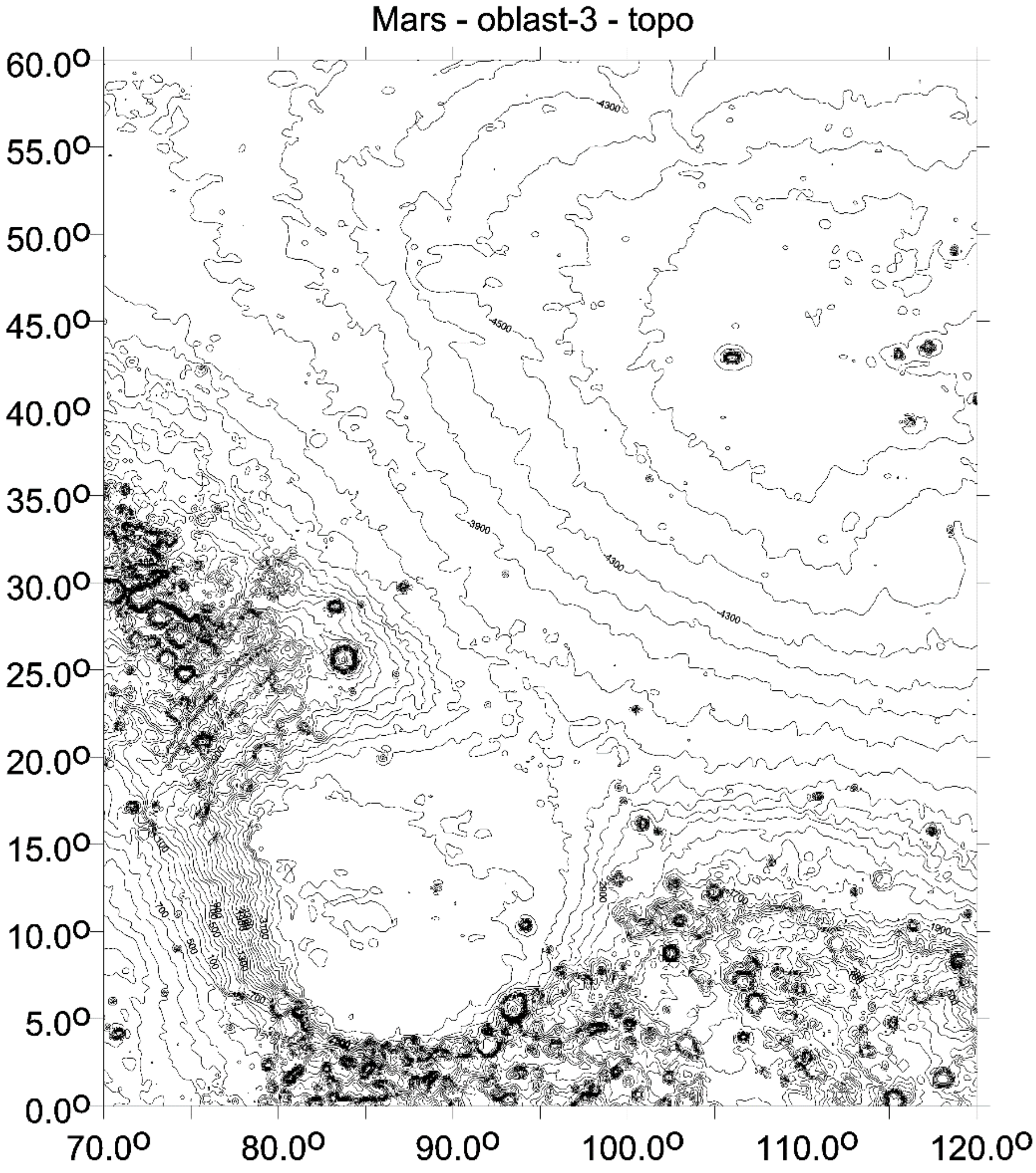


Fig. S3: 49, topography

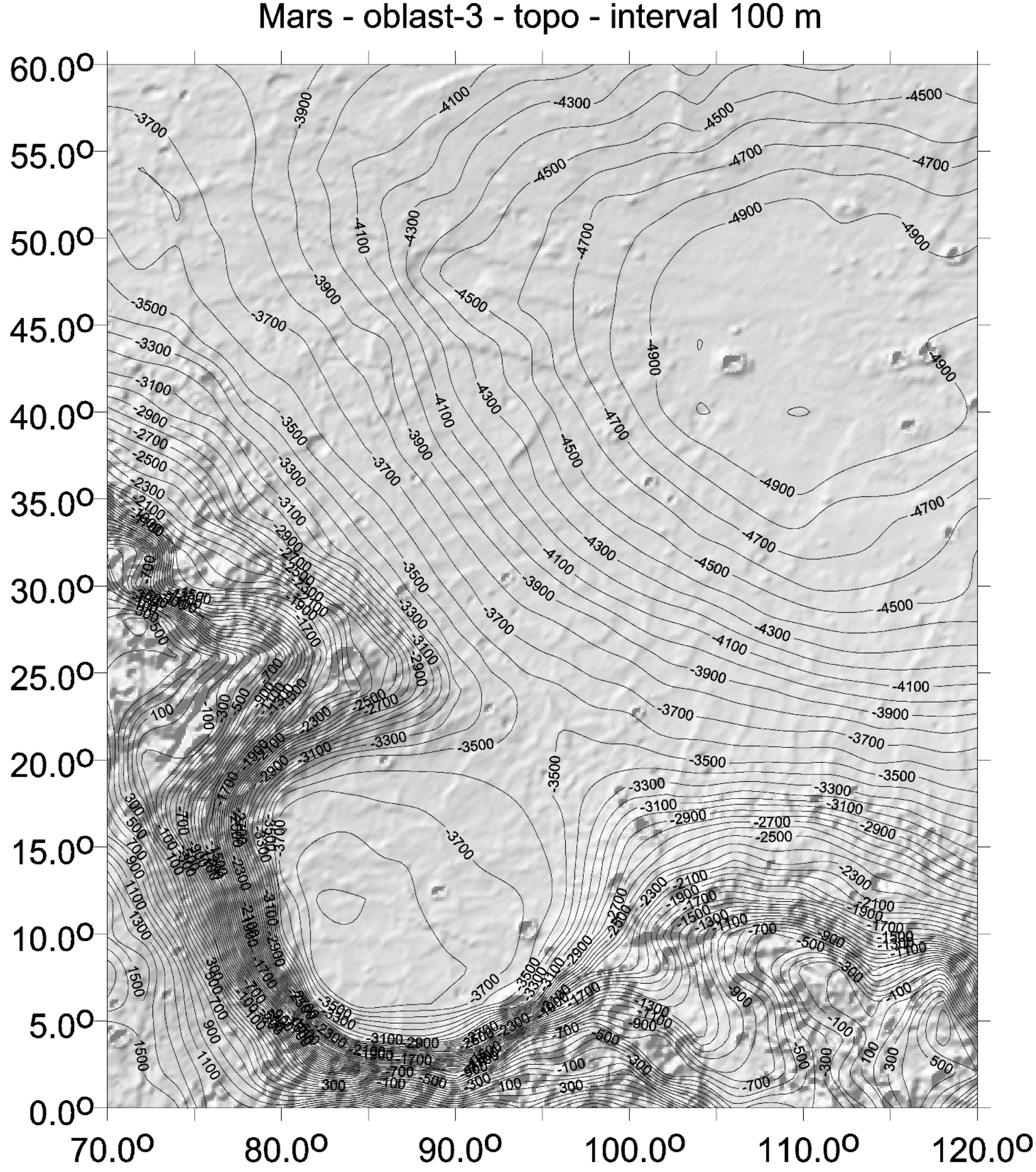


Fig. S3: 50, topography

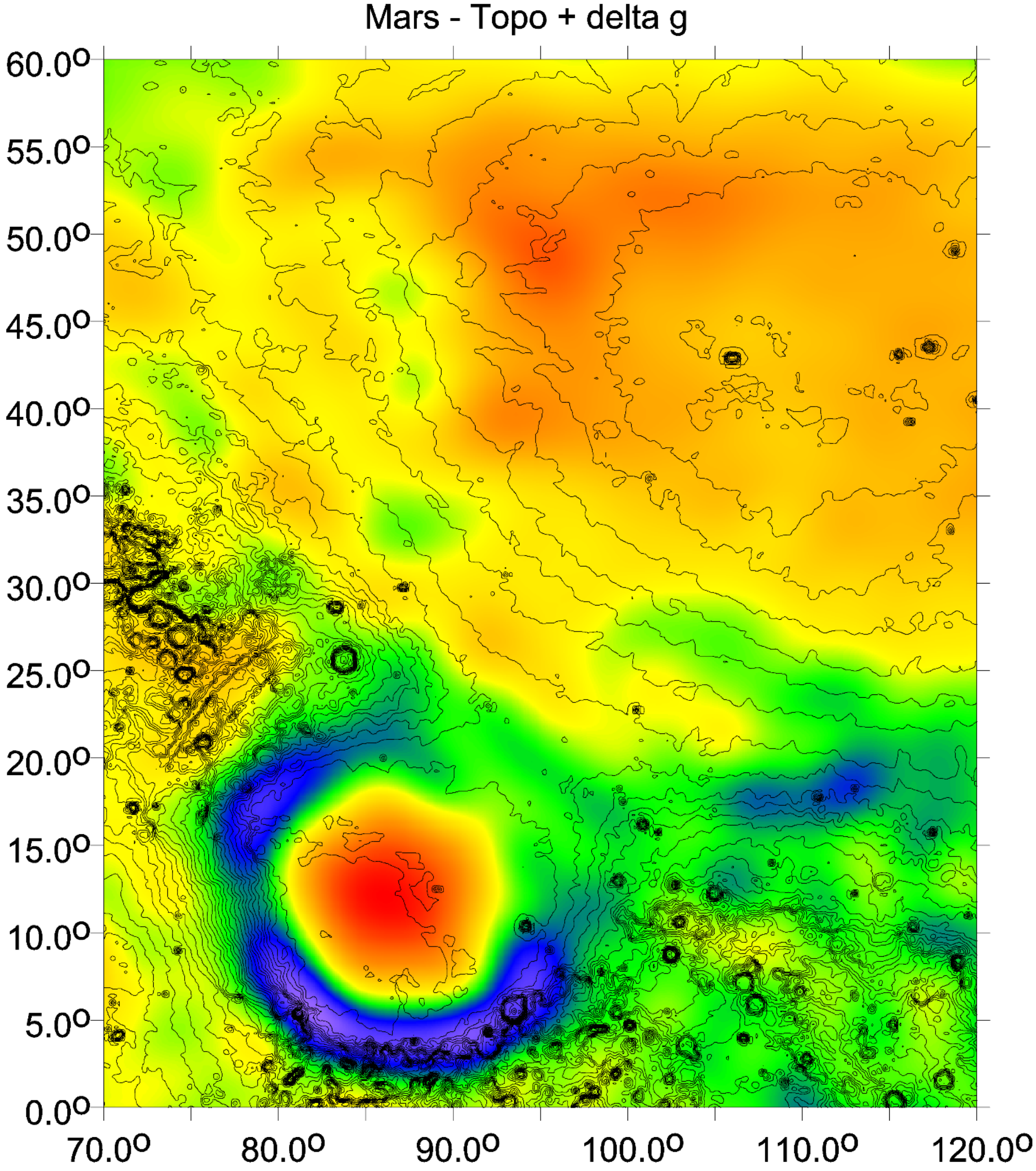


Fig. S3: 51, Δg

ISIDIS = volcano?

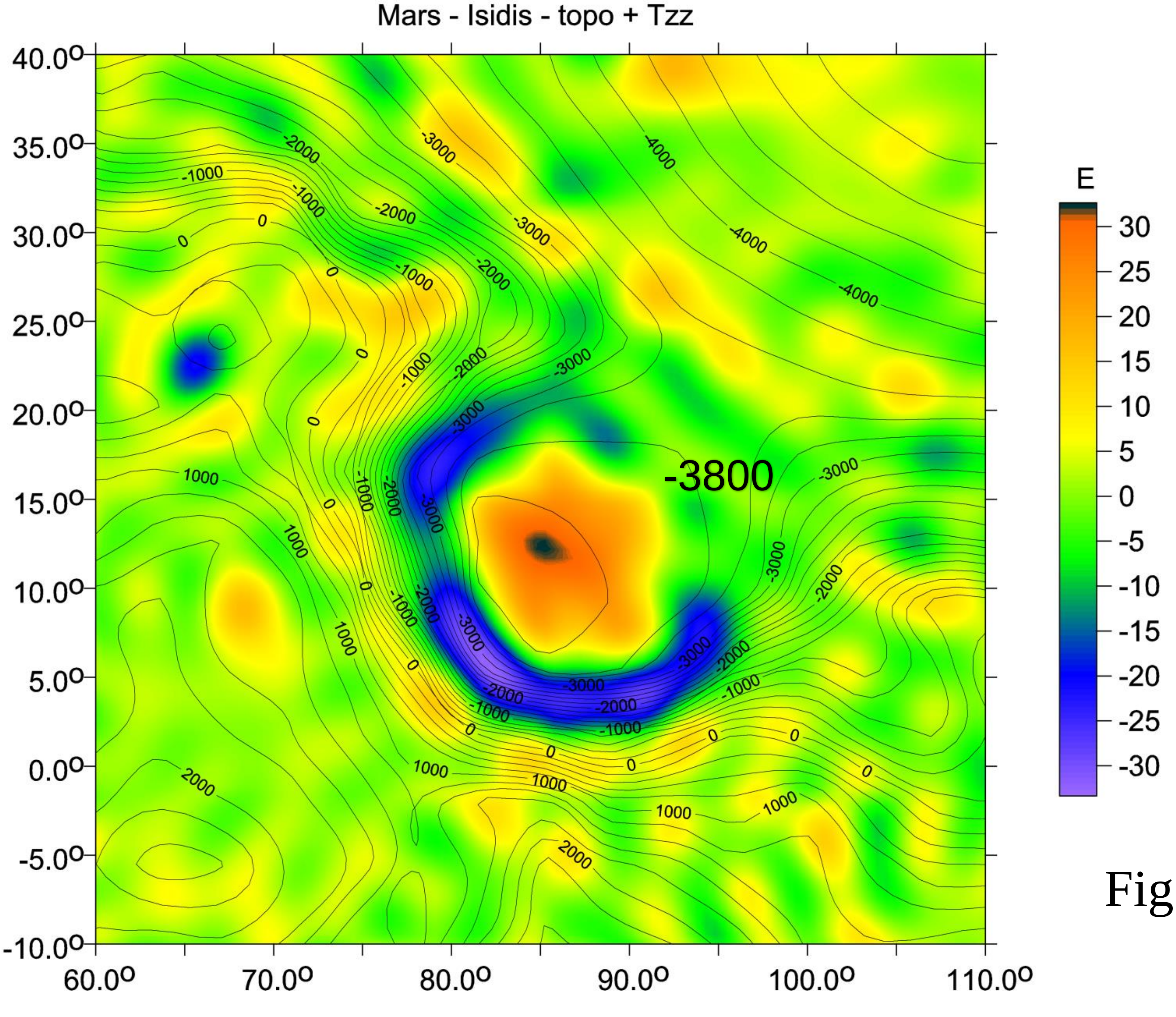


Fig. S3: 52, T_{zz}

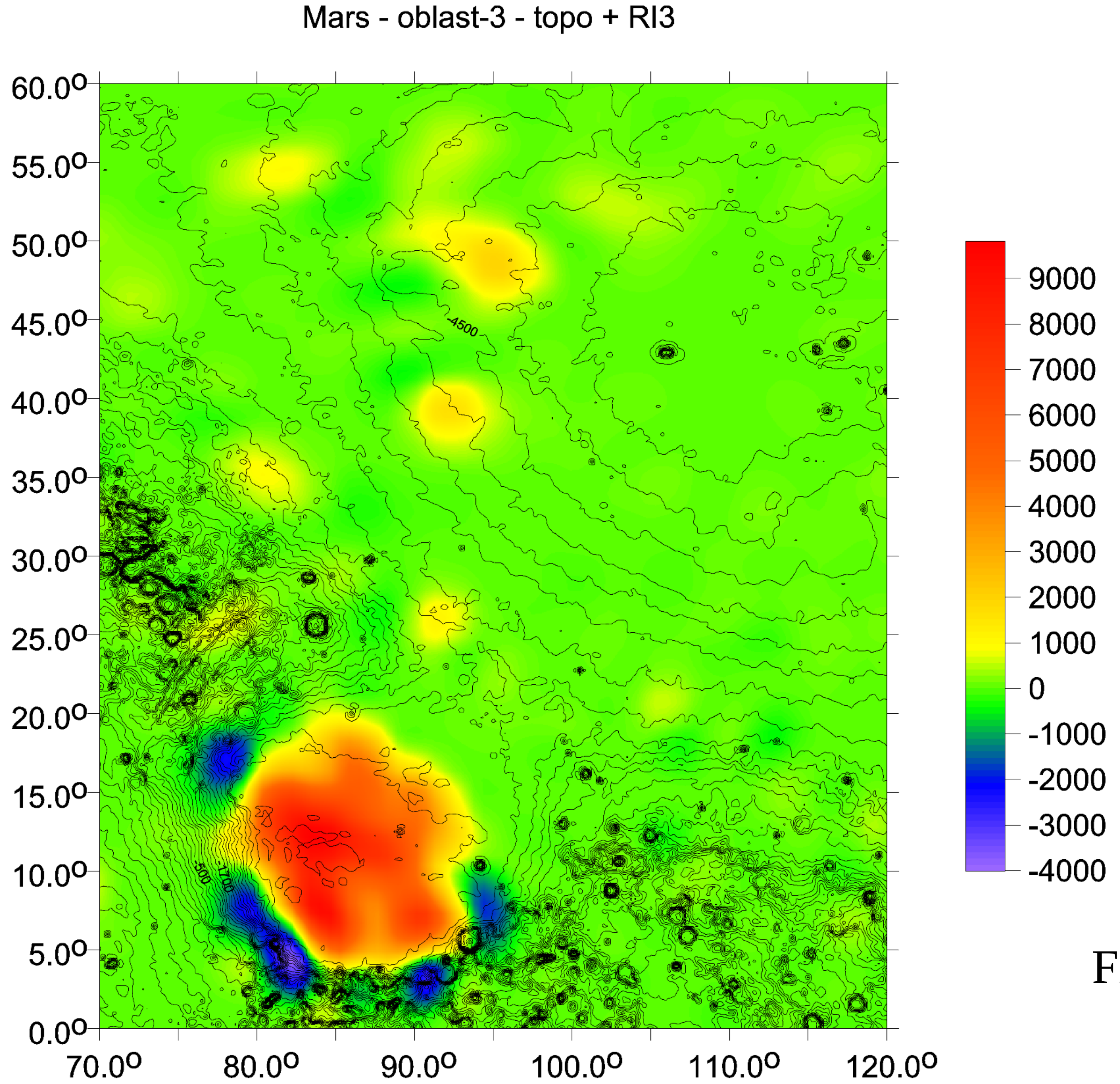
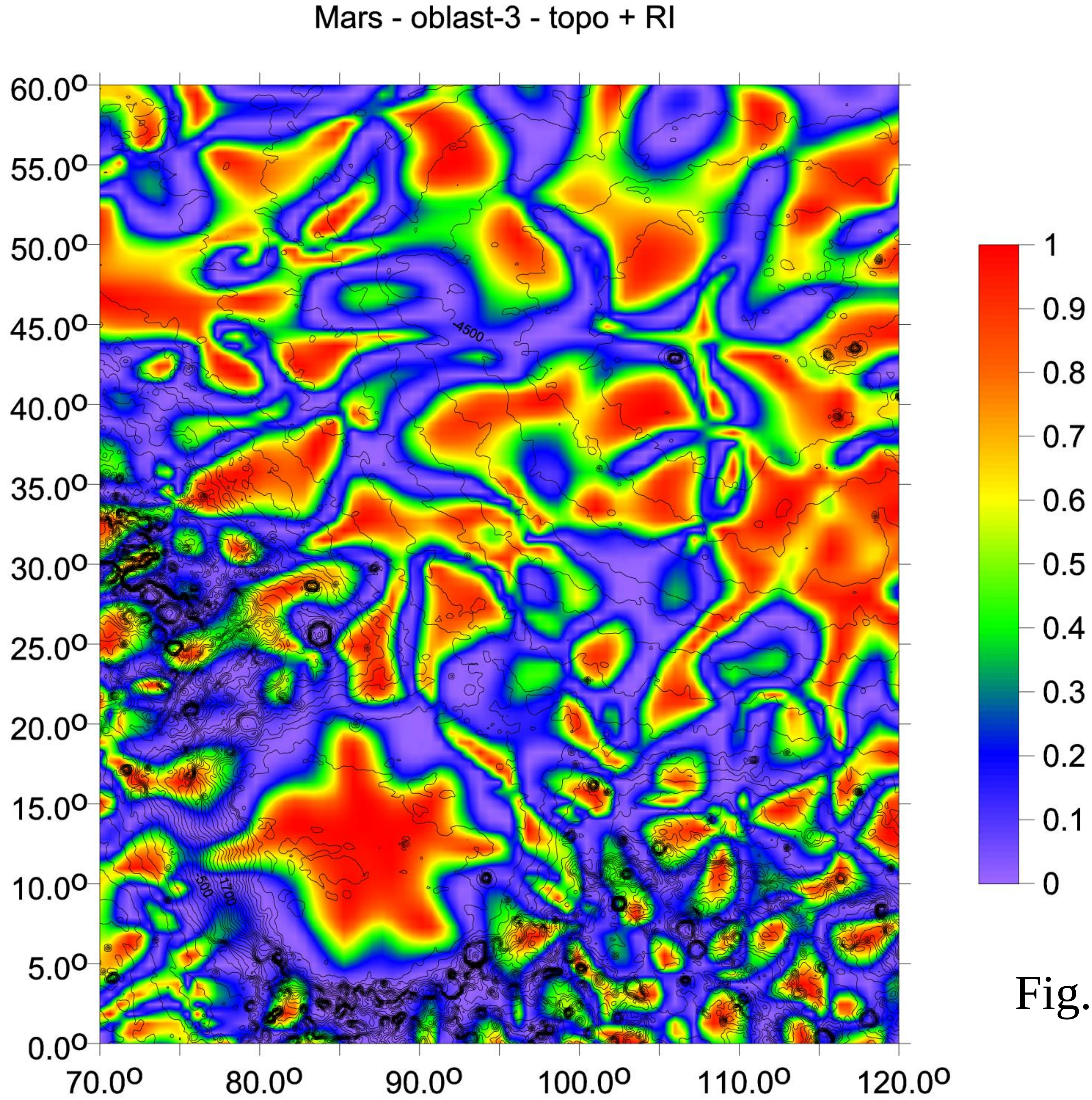

Mars - oblast-3 - topo + RI3
60.0o
55.0o
50.0o
45.0o
40.0o
35.0o
30.0o
25.0o
20.0o
15.0o
10.0o
5.0o
0.0o
70.0o
80.0o
90.0o
100.0o
110.0o
120.0o
-4500
-500
-1700
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000

Fig. S3: 53, I_2



Mars - oblast-3 - topo + RI
60.0°
55.0°
50.0°
45.0°
40.0°
35.0°
30.0°
25.0°
20.0°
15.0°
10.0°
5.0°
0.0°
70.0°
80.0°
90.0°
100.0°
110.0°
120.0°
-4500
-500
1700
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

Fig. S3: 54, *I*

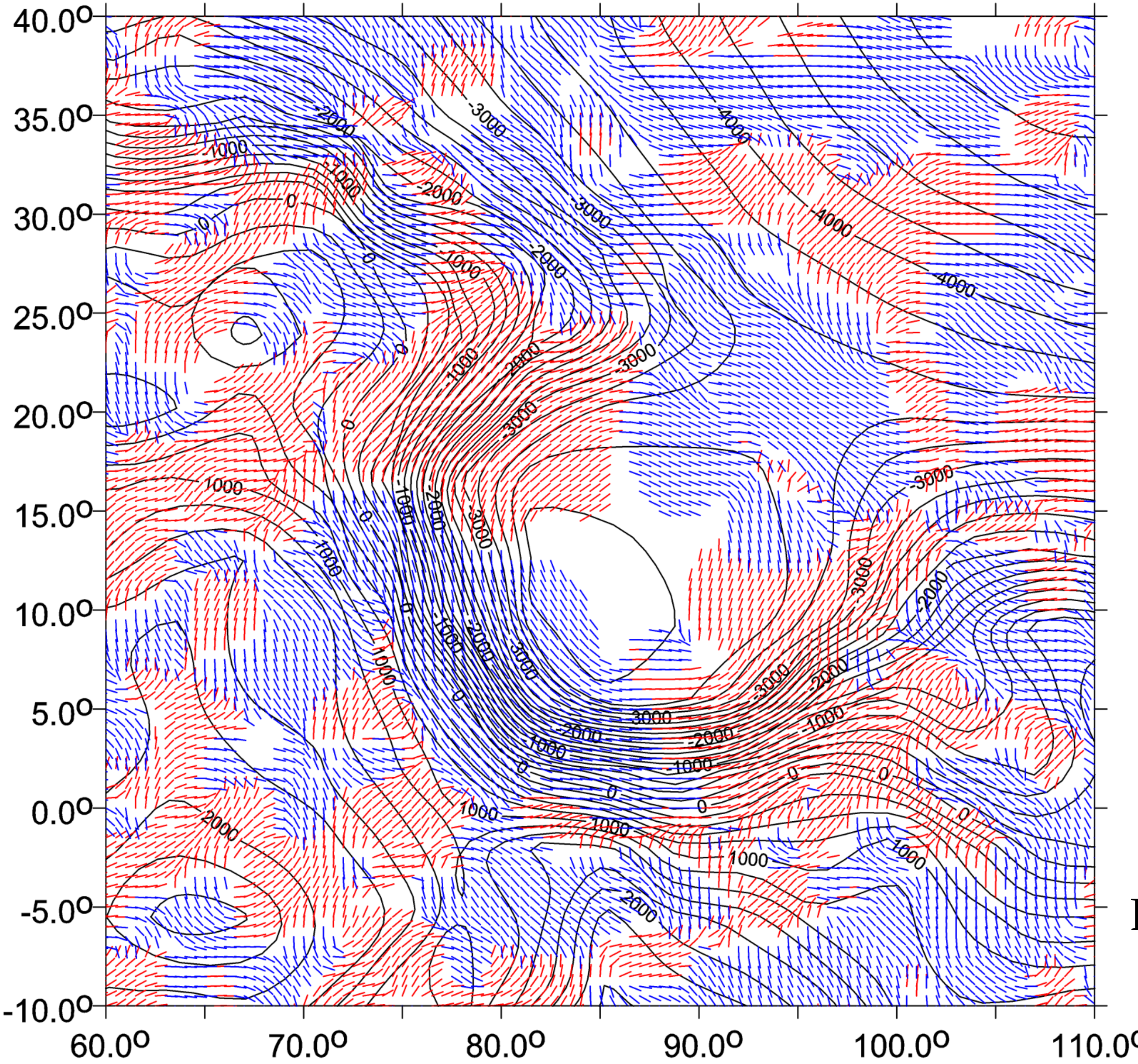


Fig. S3: 55, θ

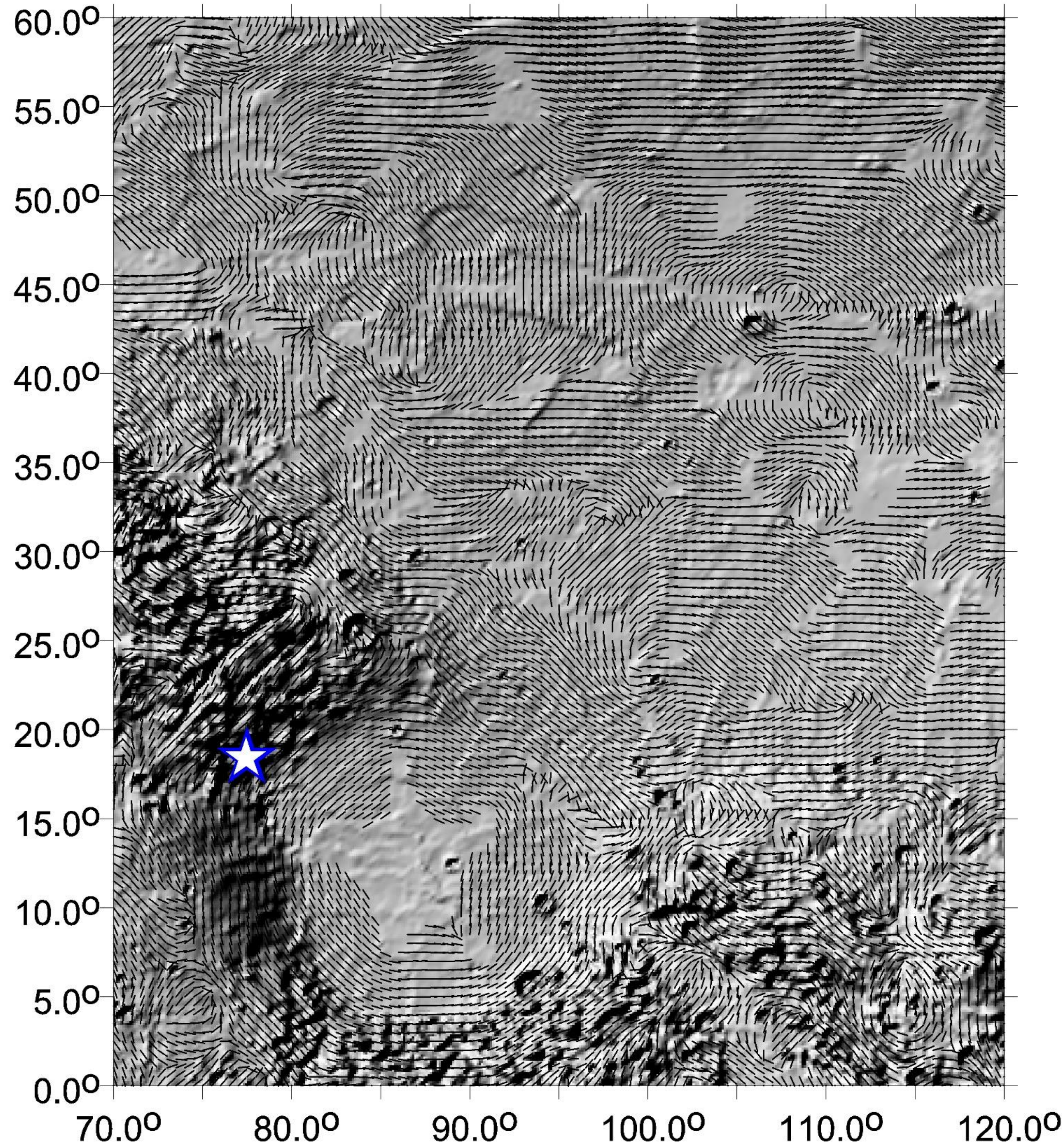


Fig. S3: 56, θ *plus landing site of Perseverance*

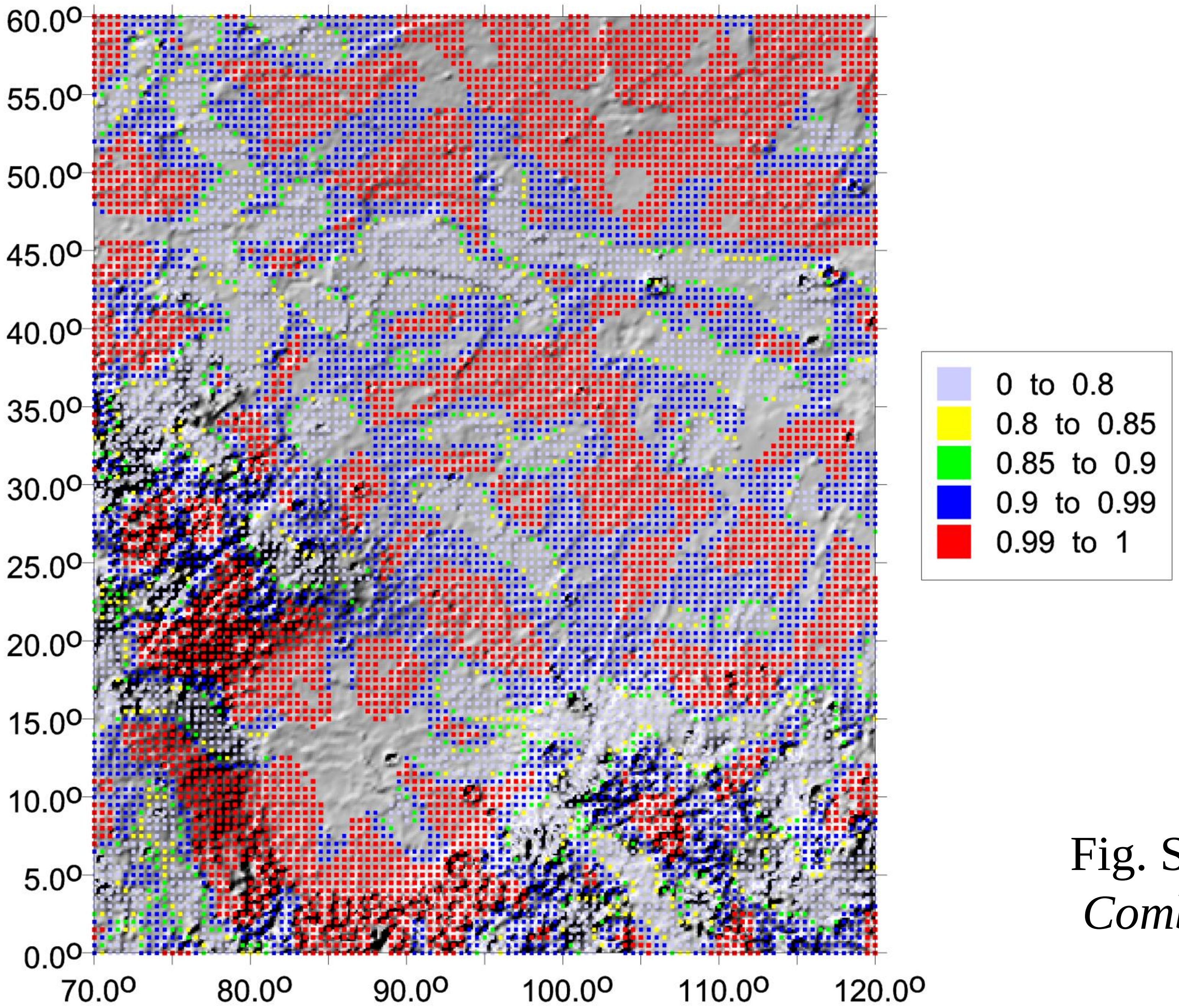


Fig. S3: 57, θ
Comb factor

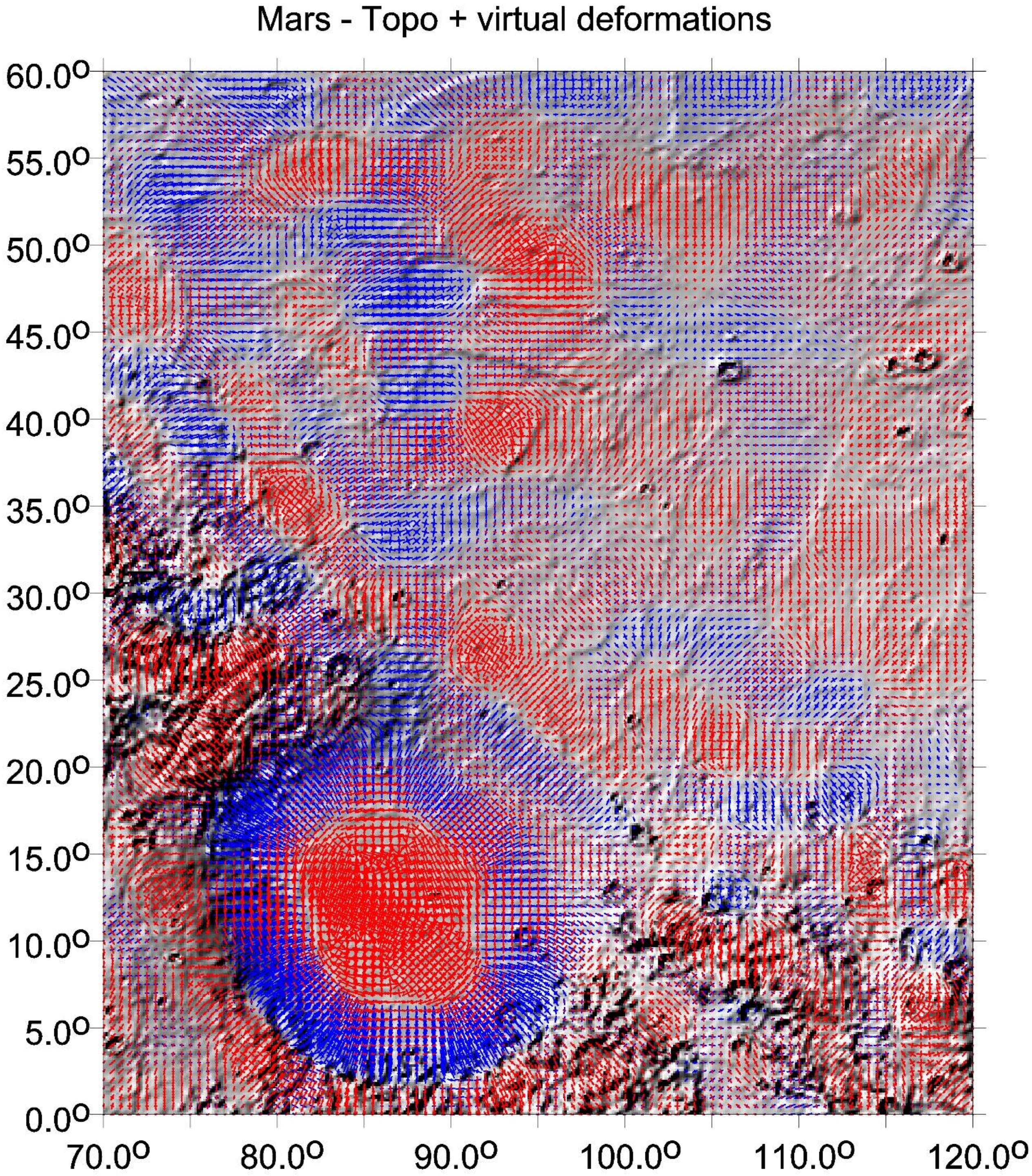
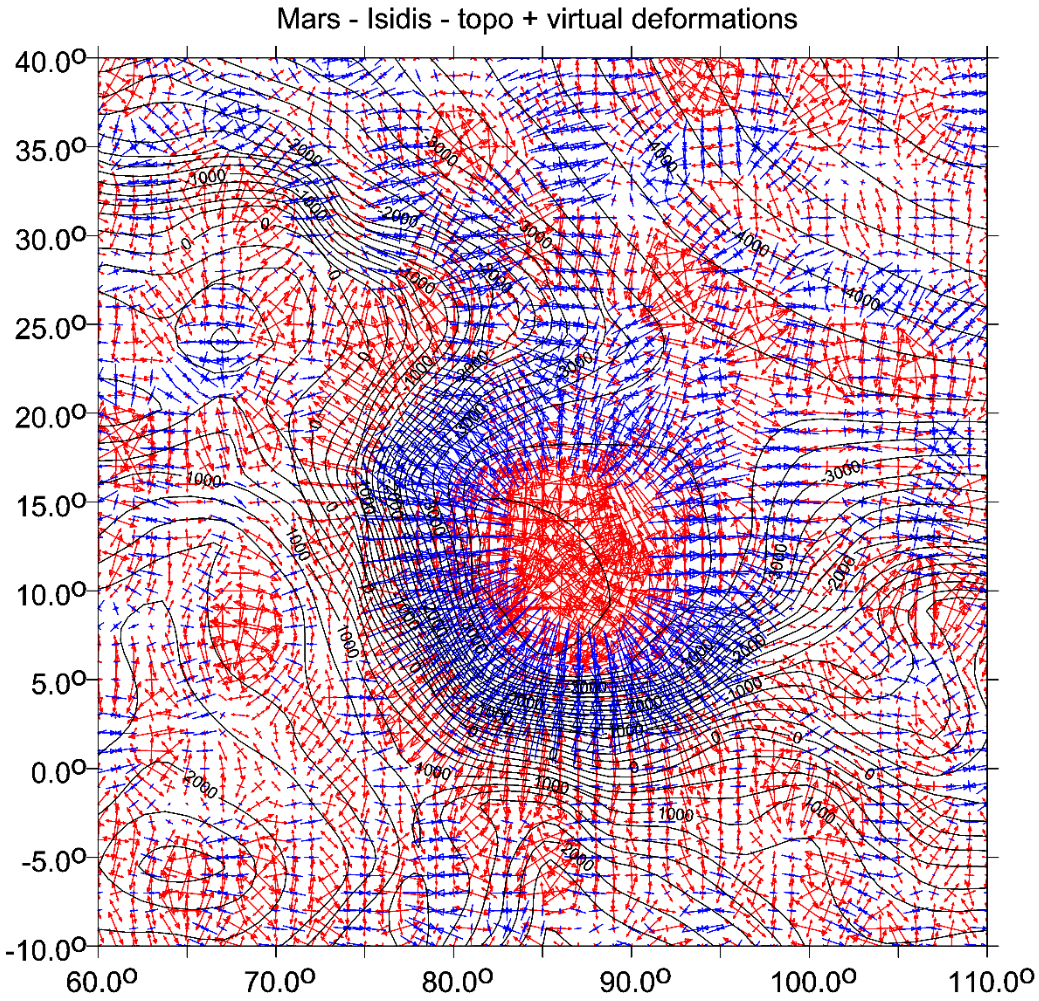

Mars - Topo + virtual deformations
60.0°
55.0°
50.0°
45.0°
40.0°
35.0°
30.0°
25.0°
20.0°
15.0°
10.0°
5.0°
0.0°
70.0°
80.0°
90.0°
100.0°
110.0°
120.0°

Fig. S3: 58, *vd*



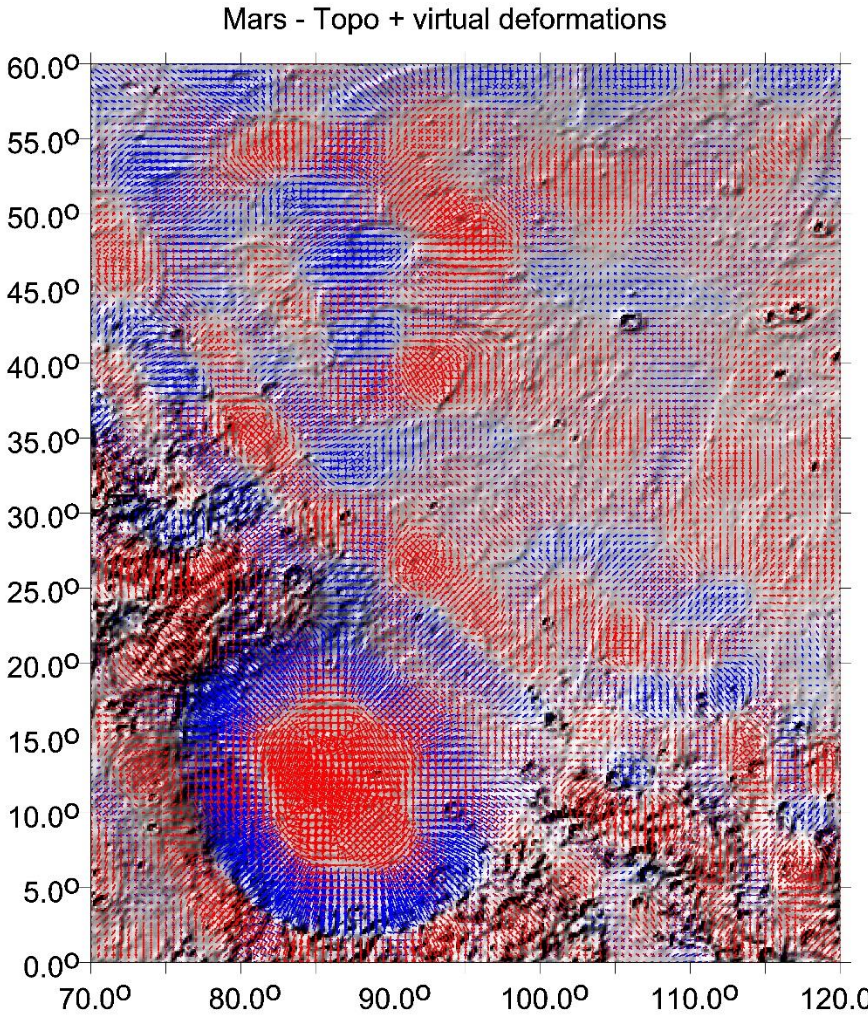


Fig. S3: 59, *vd*, two different ways how to plot the virtual deformations

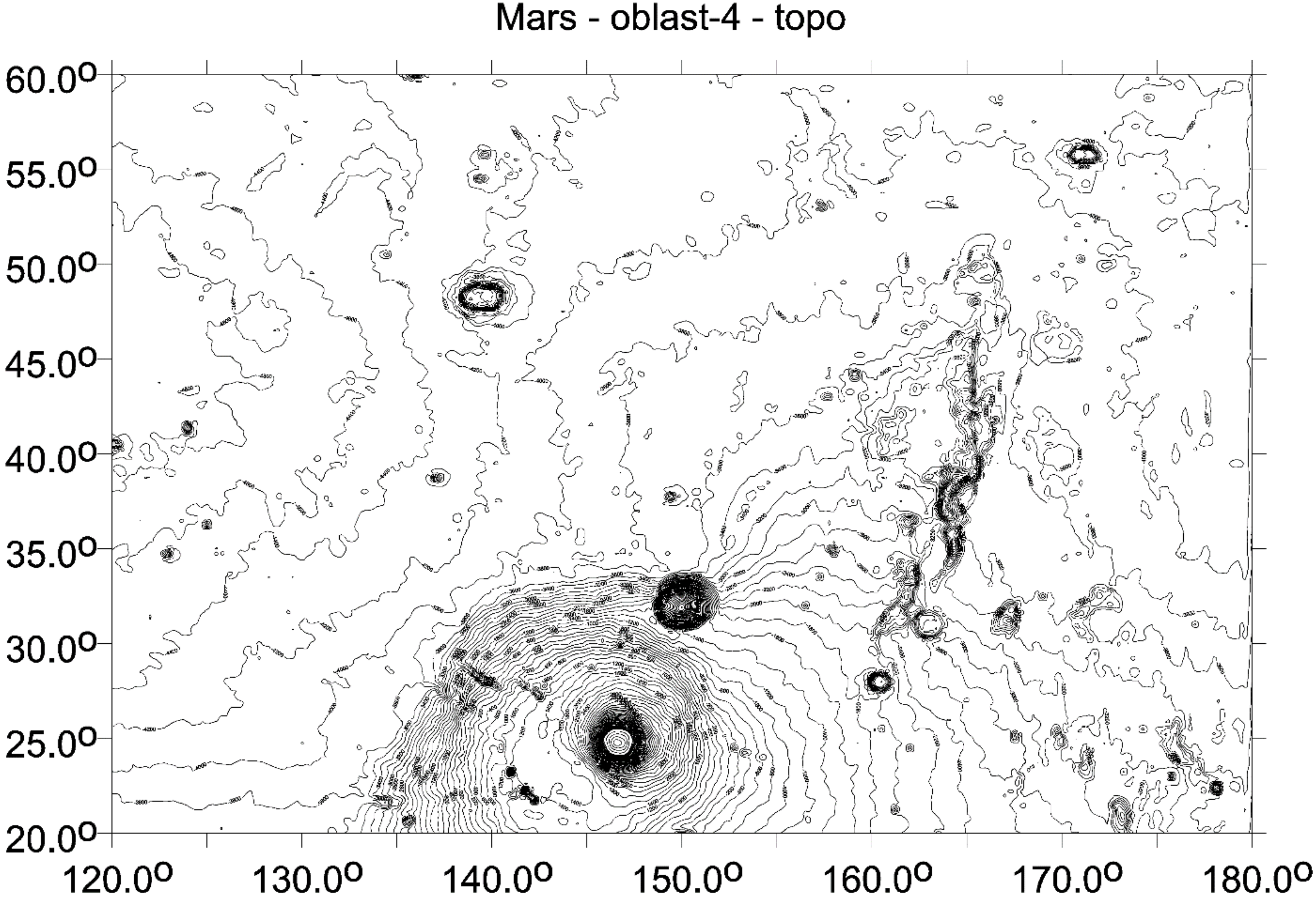


Fig. S3: 60, topography

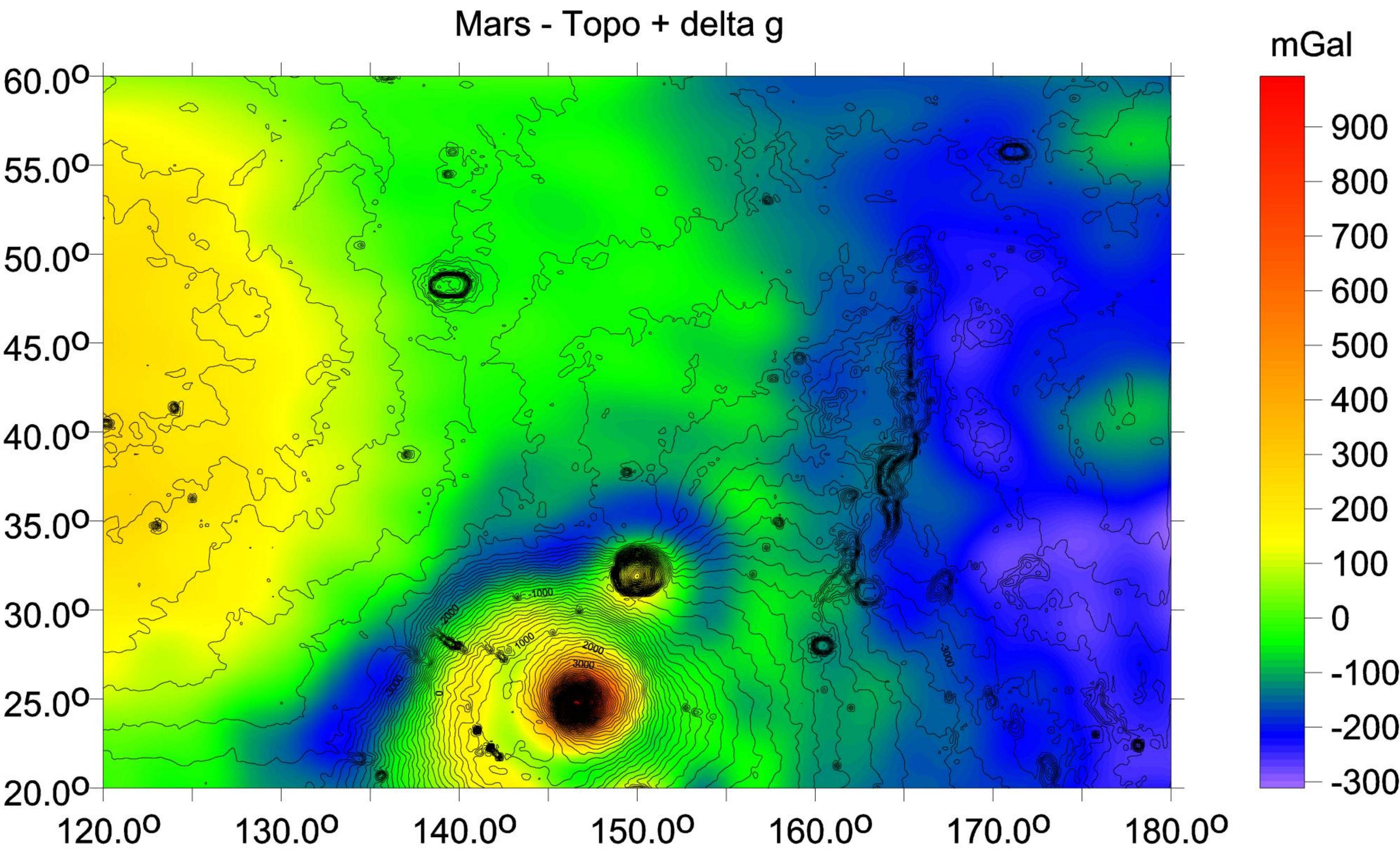


Fig. S3: 61, Δg

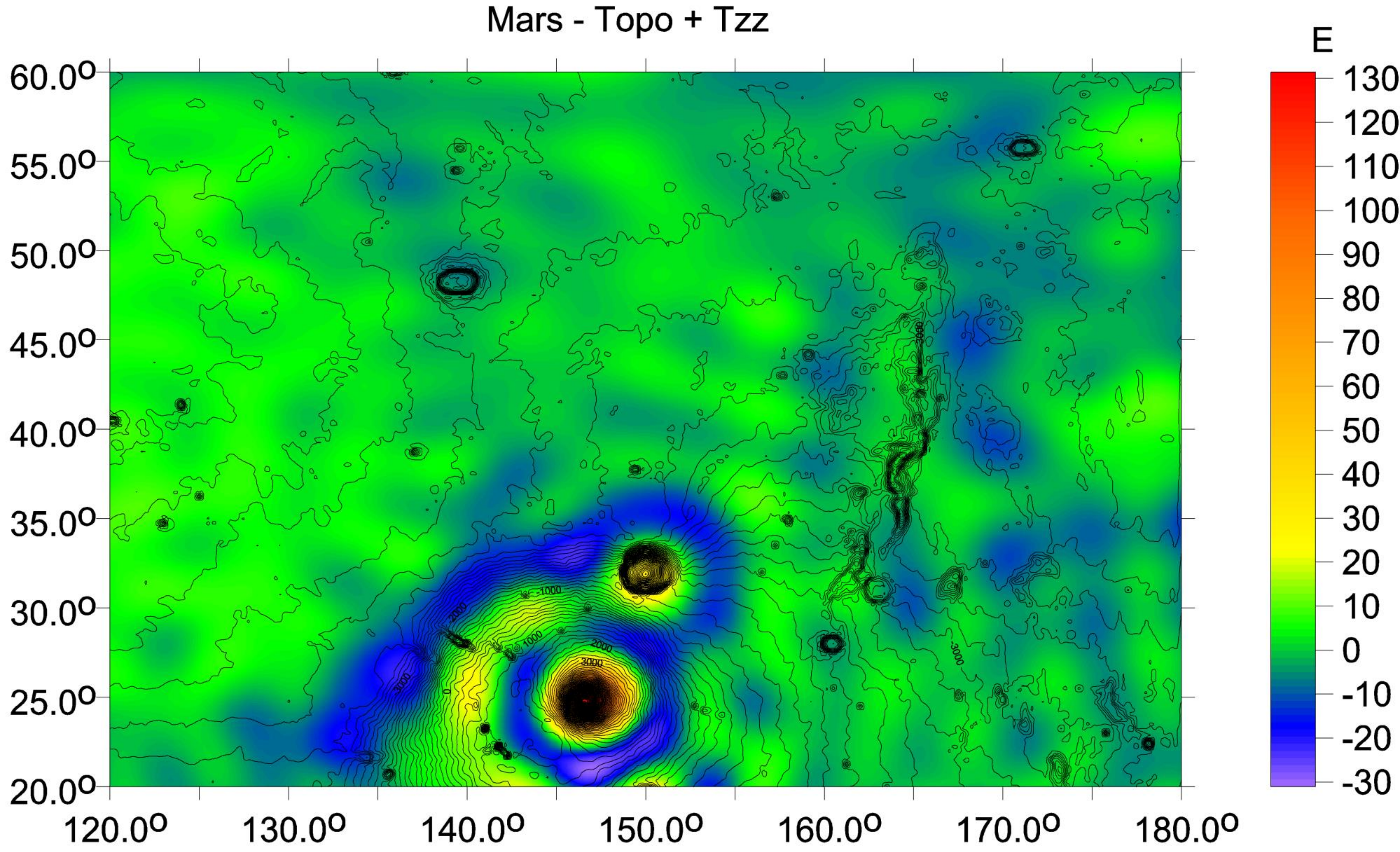

Mars - Topo + Tzz
E
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
60.0°
55.0°
50.0°
45.0°
40.0°
35.0°
30.0°
25.0°
20.0°
120.0°
130.0°
140.0°
150.0°
160.0°
170.0°
180.0°

Fig. S3: 62, T_{zz}

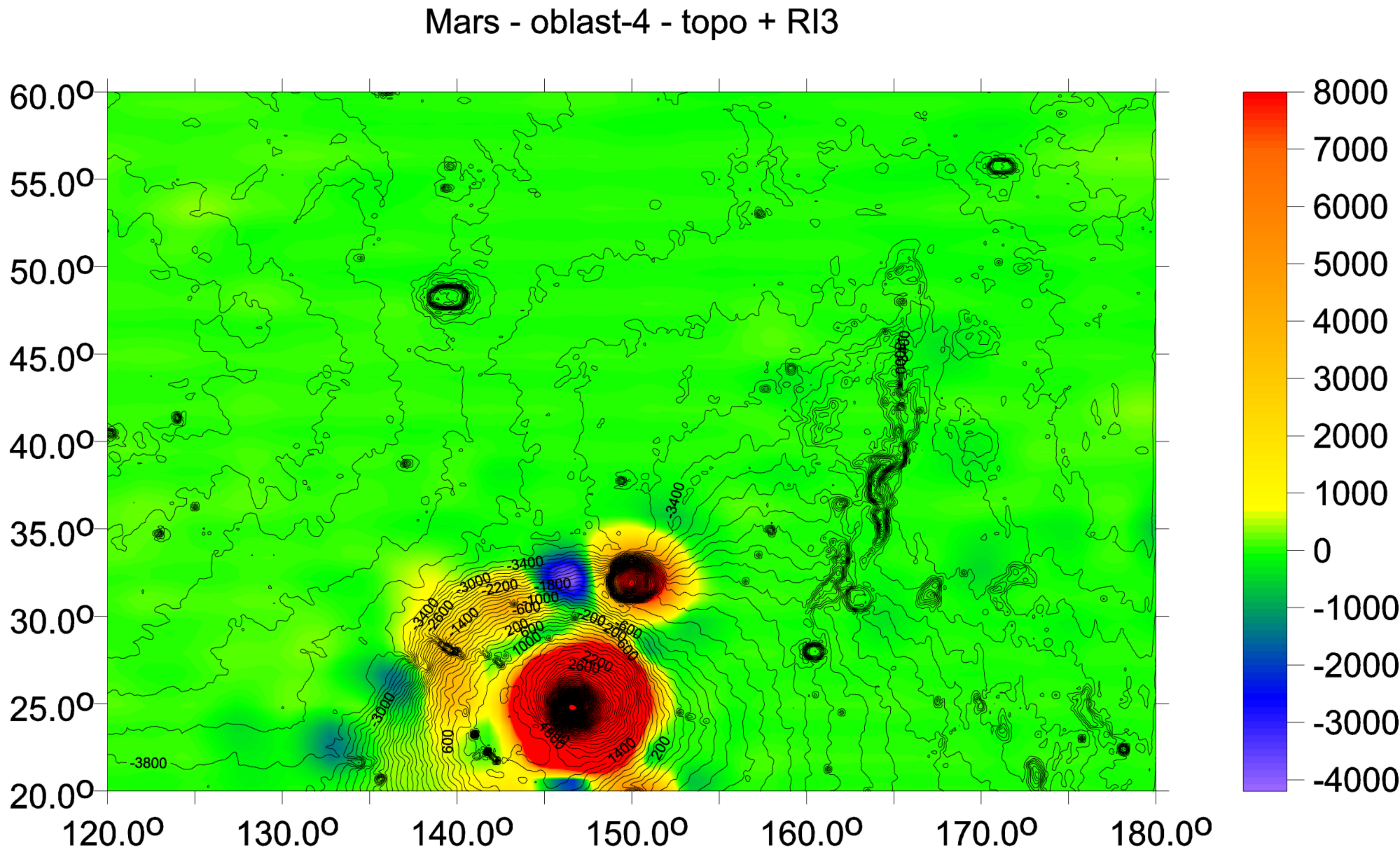

Mars - oblast-4 - topo + RI3
60.0o
55.0o
50.0o
45.0o
40.0o
35.0o
30.0o
25.0o
20.0o
120.0o
130.0o
140.0o
150.0o
160.0o
170.0o
180.0o
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000

Fig. S3: 63, I_2

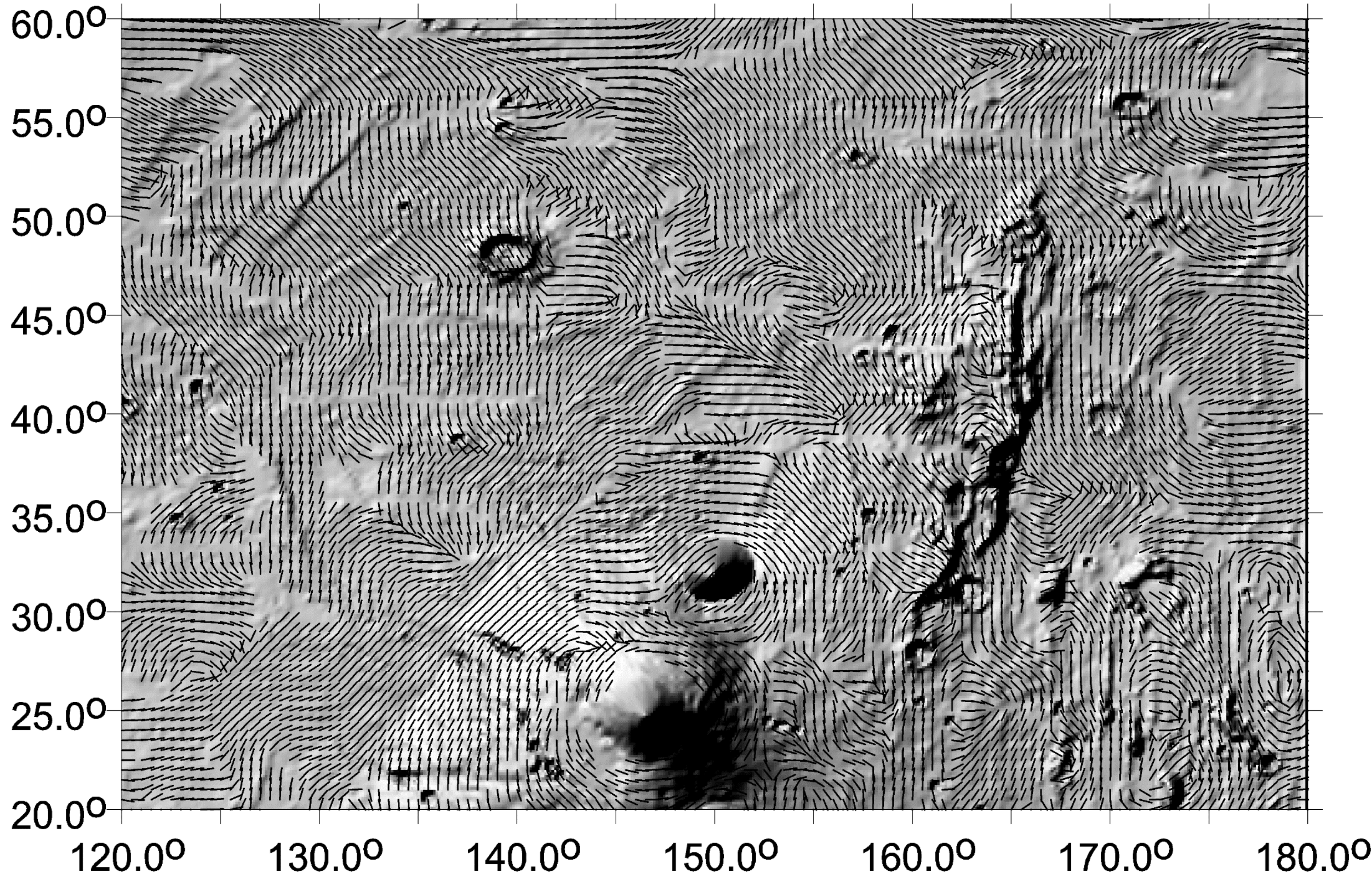


Fig. S3: 64, θ

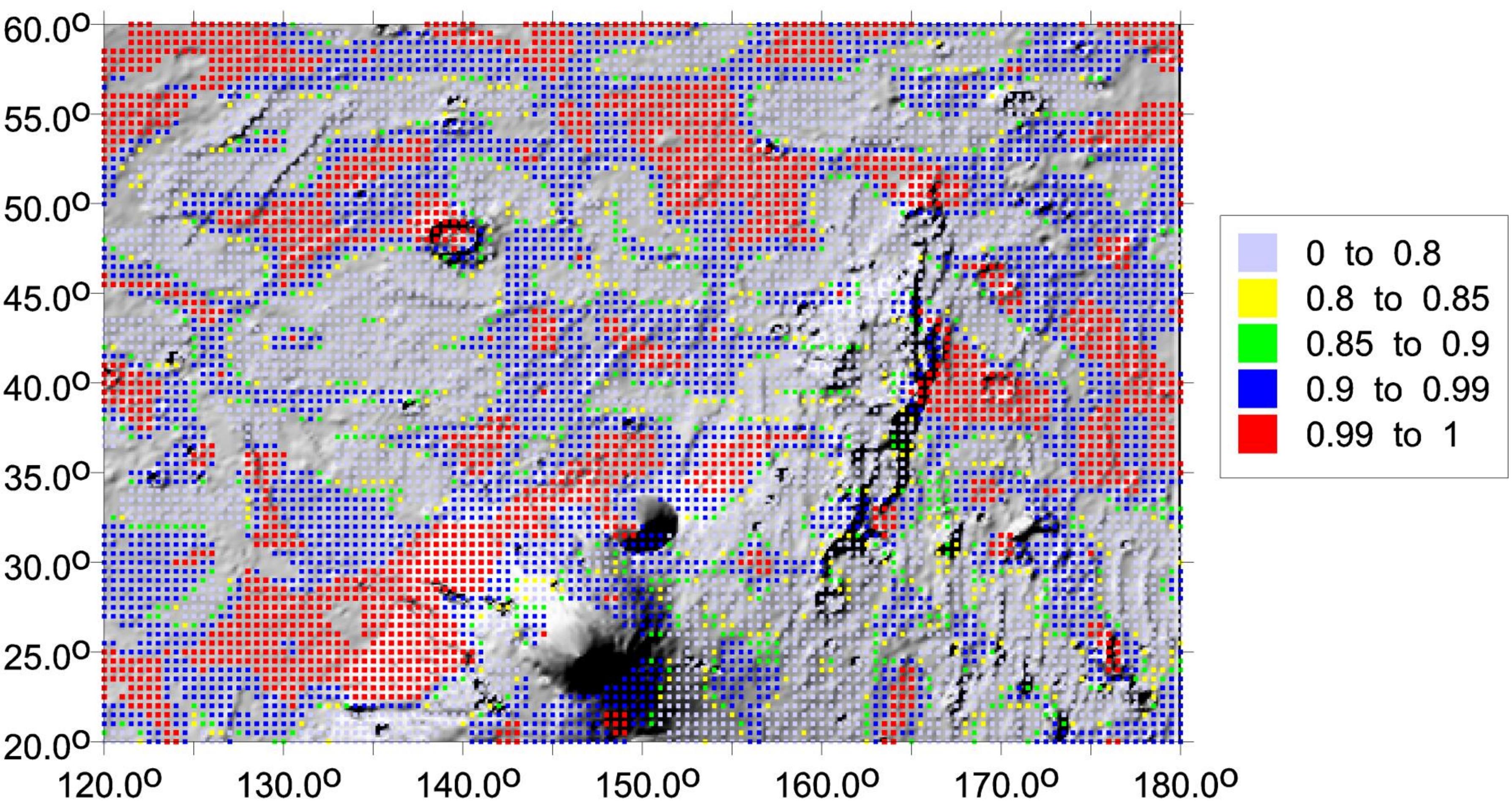


Fig. S3: 65, *θ, Comb* factor

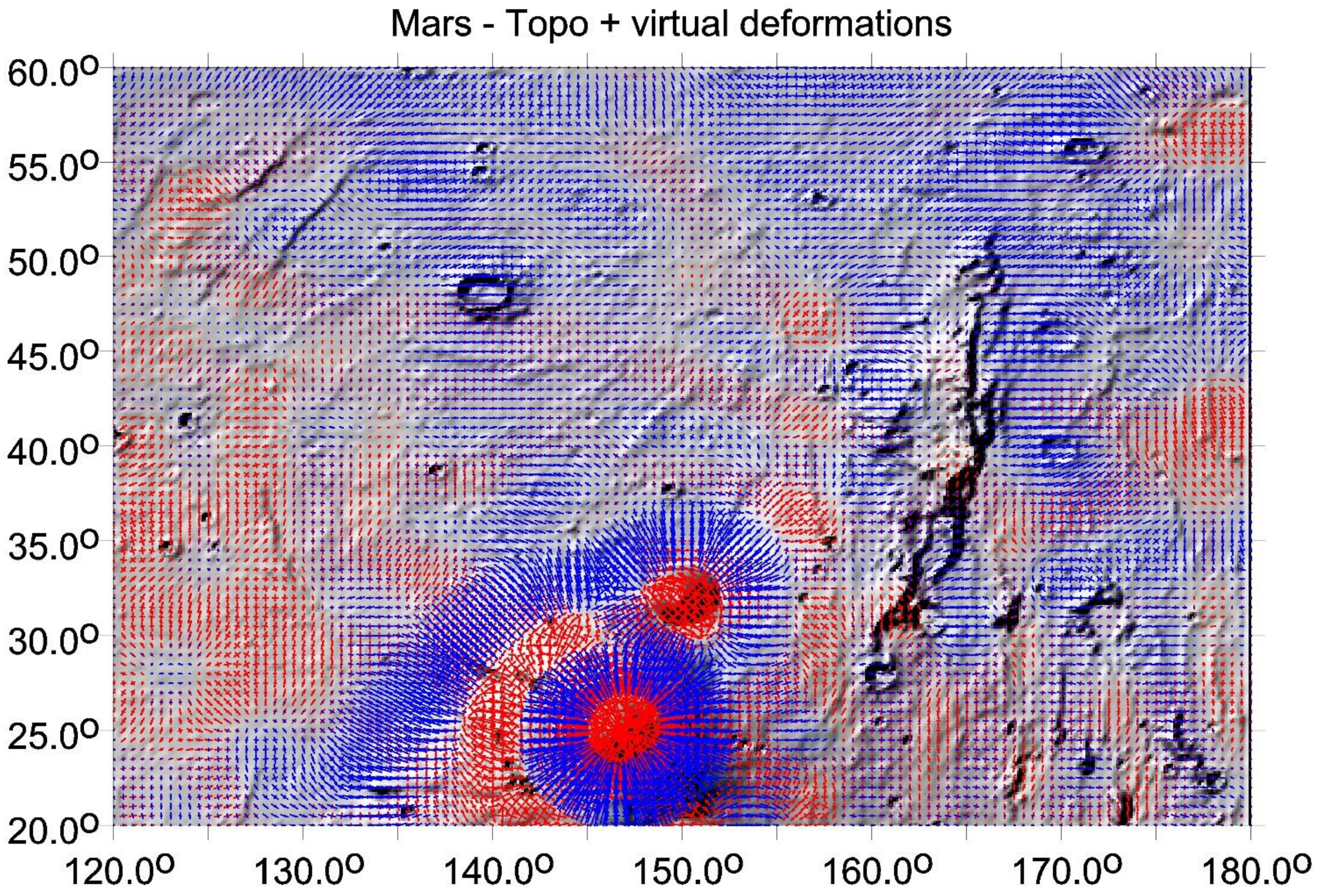

Mars - Topo + virtual deformations
60.0°
55.0°
50.0°
45.0°
40.0°
35.0°
30.0°
25.0°
20.0°
120.0°
130.0°
140.0°
150.0°
160.0°
170.0°
180.0°

Fig. S3: 66, *vd*

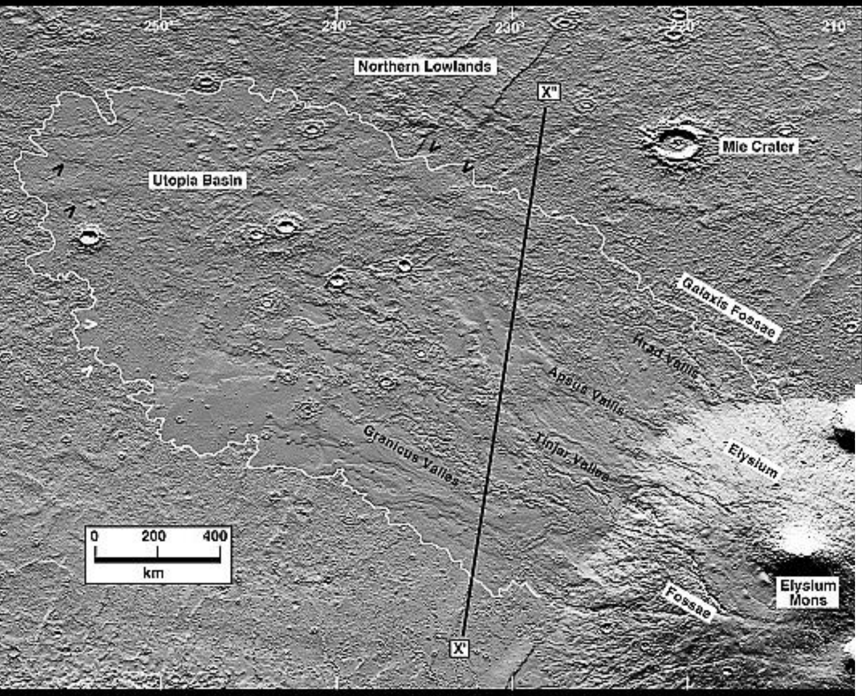
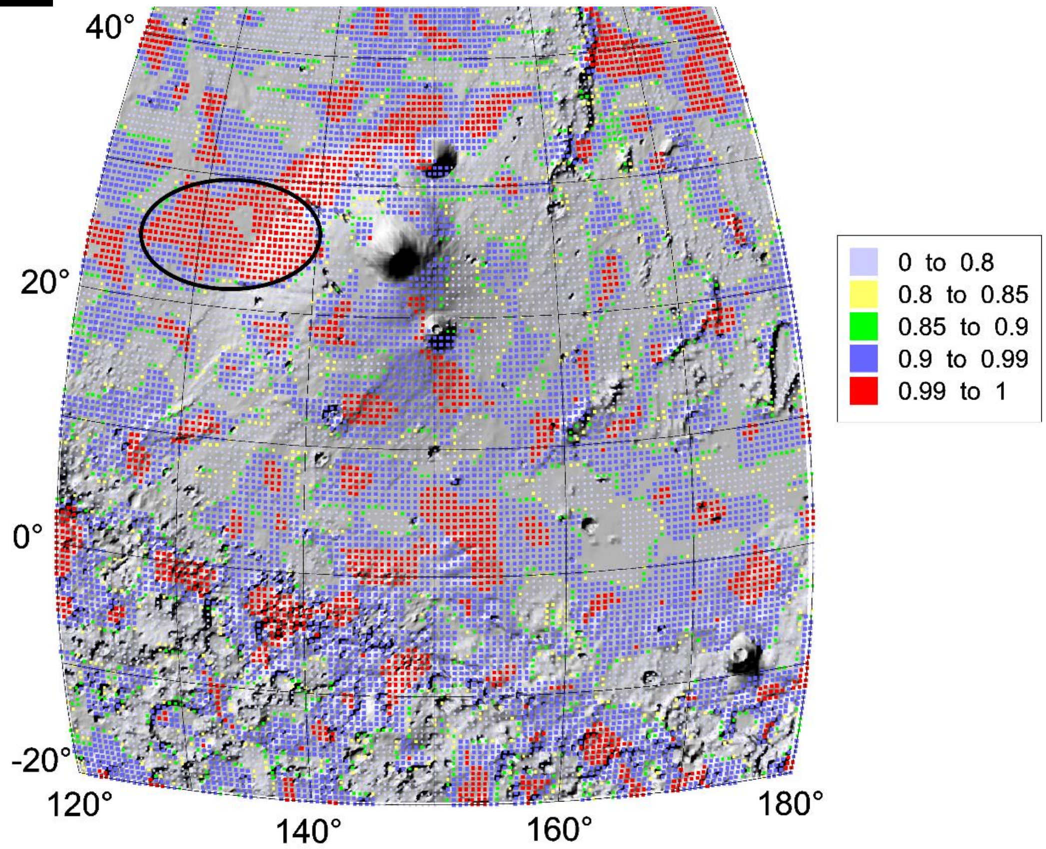


Fig. S3: 67, θ.

Left: example from literature;
right: our figure S3: 65

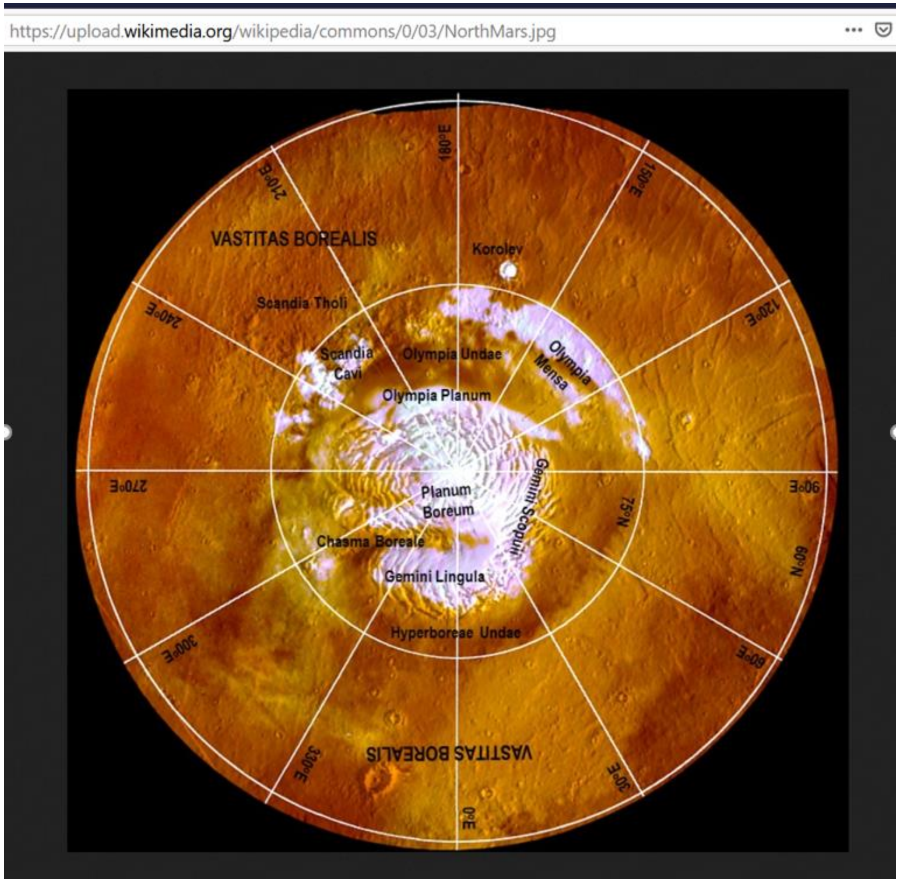


Lahars on Mars,
example NW of Elysium Mt.

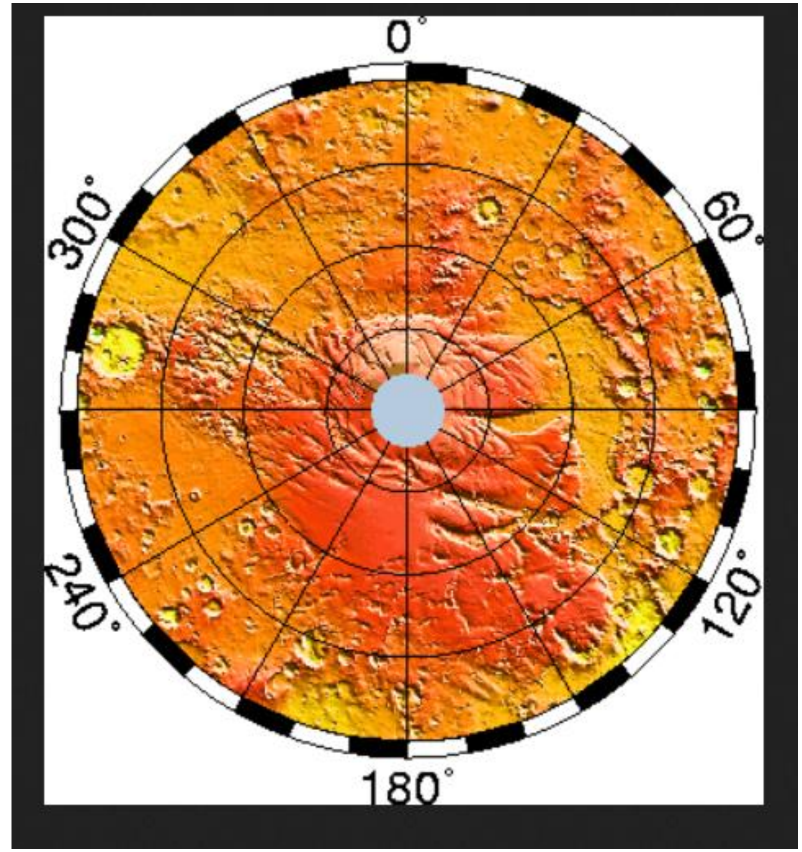
Reference for the lahars:
Christiansen E. H. et al (1989).
Lahars in the Elysium region of Mars.
Geology 17 (3): 203-206.
https://doi.org/10.1130/0091-7613(1989)017<0203:LITERO>2.3.CO;2

Polar caps of Mars

Northern cap



Southern cap



Assymetry around poles, different size and thickness (southern smaller), effect of Corriolis force, see also strike angles for more study, internet

Fig. S3: 69

Mars - north pole - topography

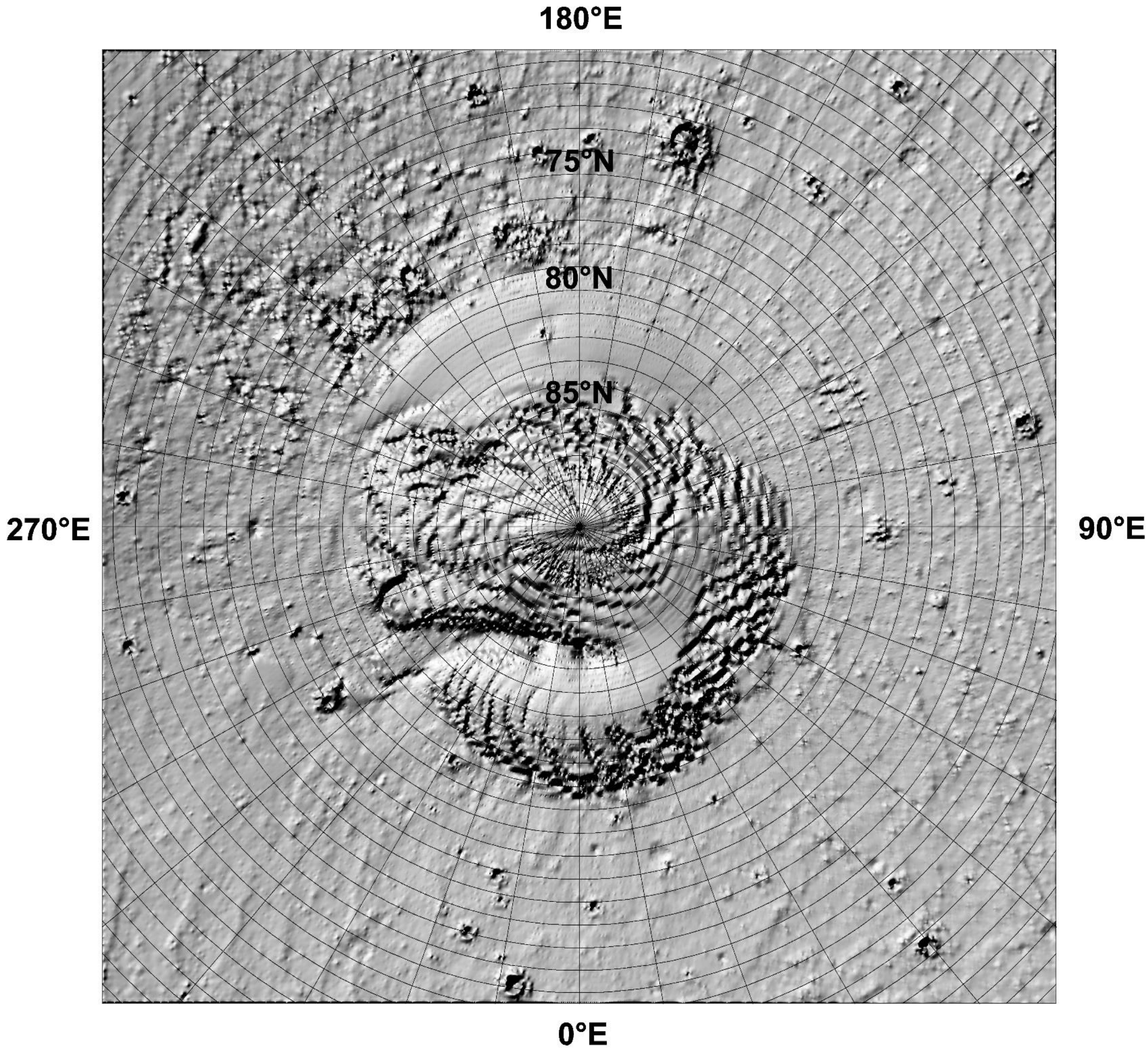
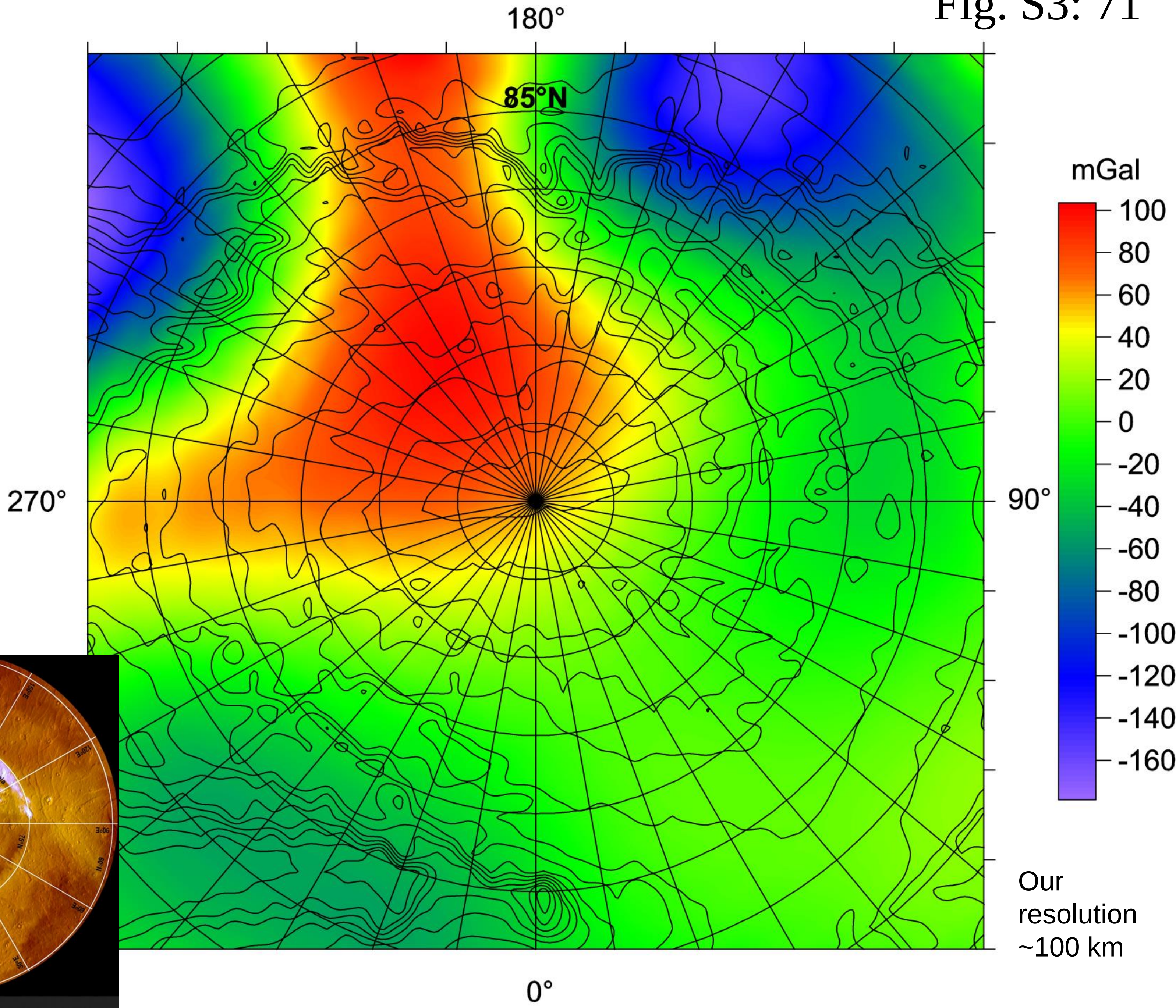
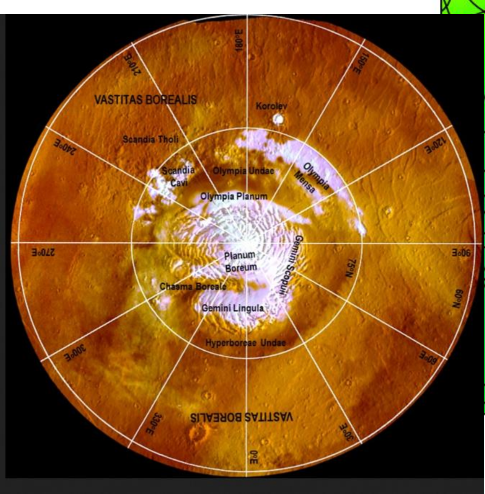


Fig. S3: 70

Mars - north pole - Topography + delta g

Fig. S3: 71





Our resolution ~100 km

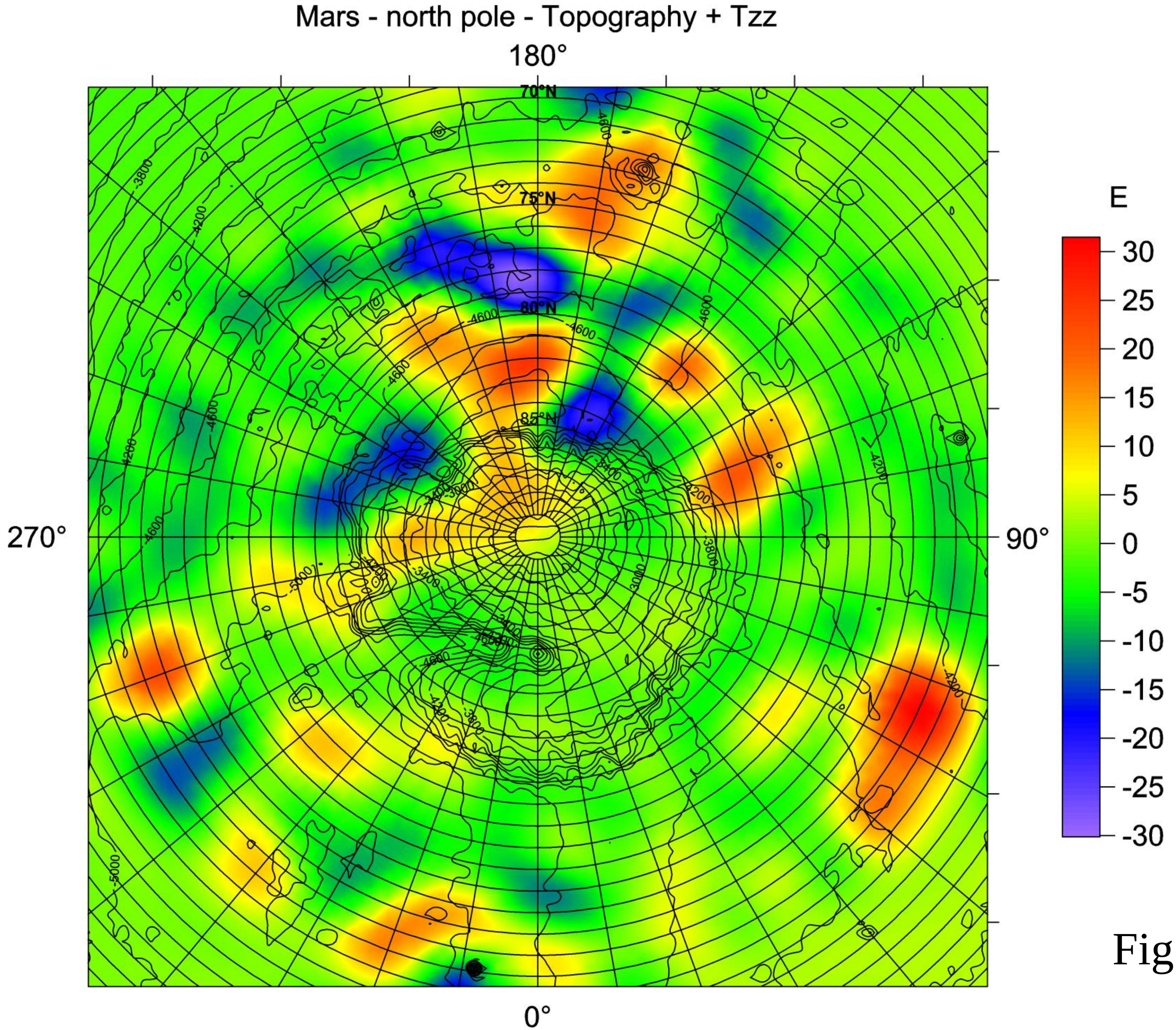

Mars - north pole - Topography + Tzz
180°
270°
90°
0°
70°N
75°N
80°N
85°N
E
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30

Fig. S3: 72

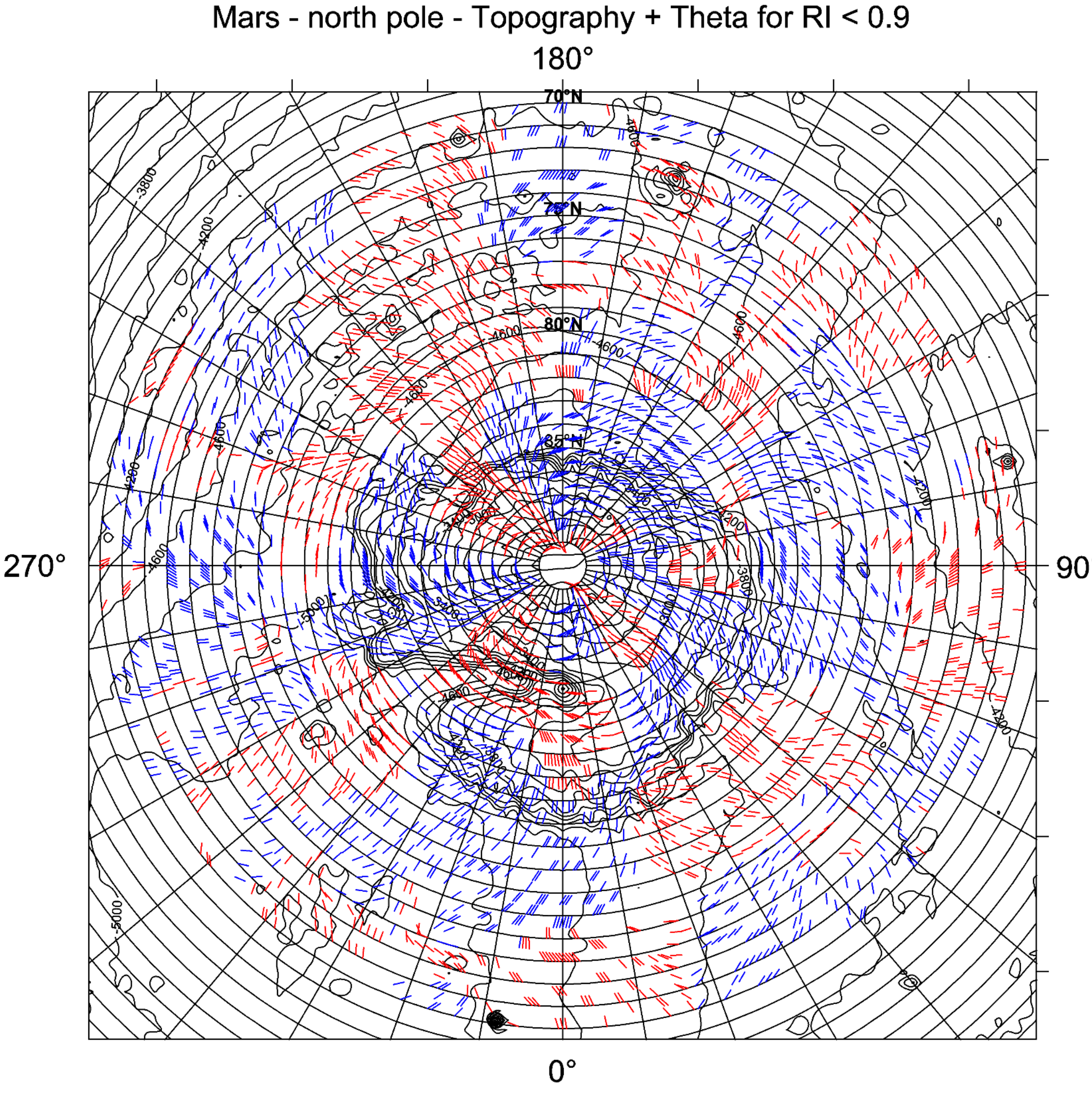

Mars - north pole - Topography + Theta for RI < 0.9
180°
70°N
75°N
80°N
85°N
270°
90°
0°
-3800
-4200
-4600
-5000

Fig. S3: 73

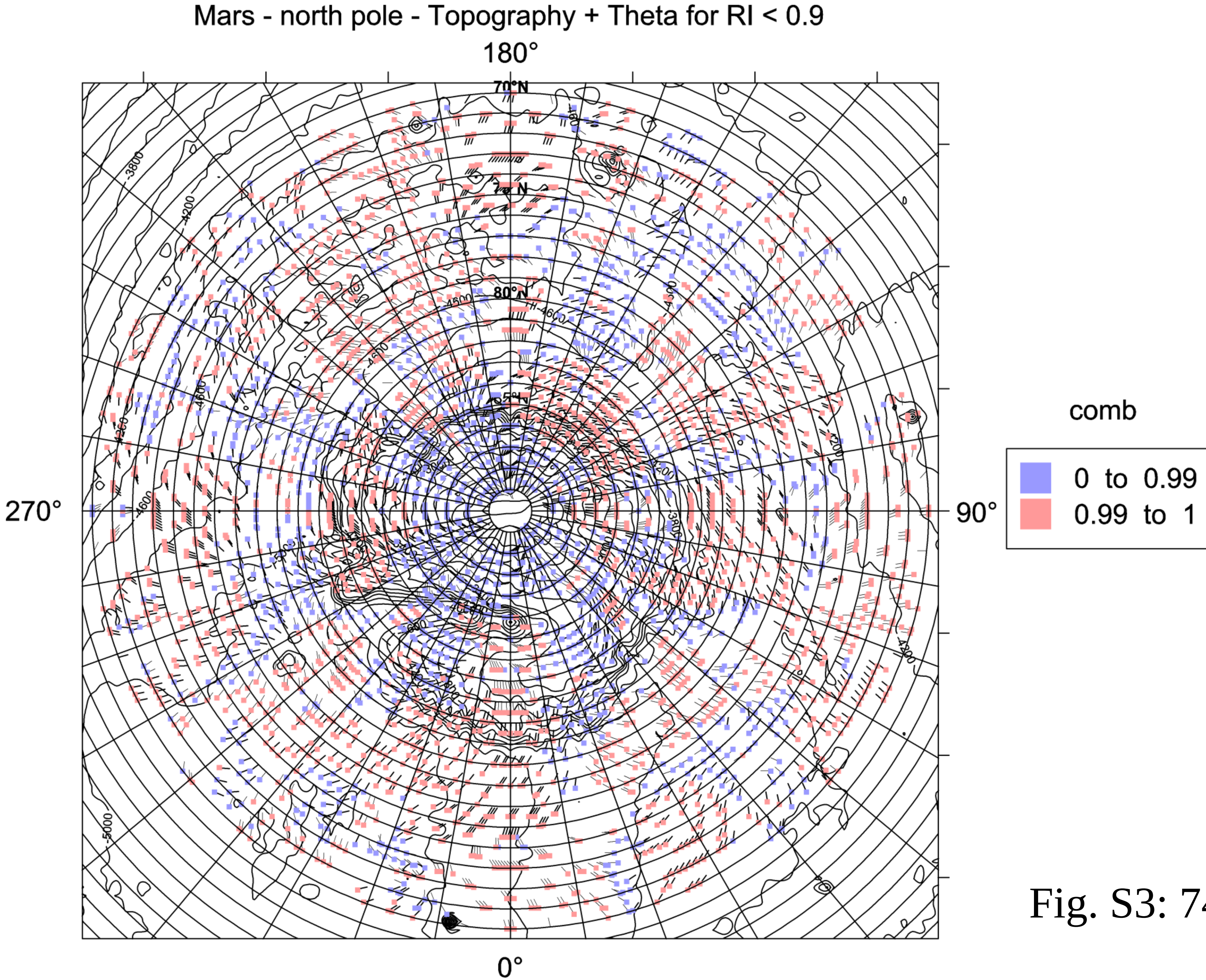

Mars - north pole - Topography + Theta for RI < 0.9
180°
270°
90°
0°
70°N
80°N
comb
0 to 0.99
0.99 to 1
-3800
-4200
-4600
-5000

Fig. S3: 74

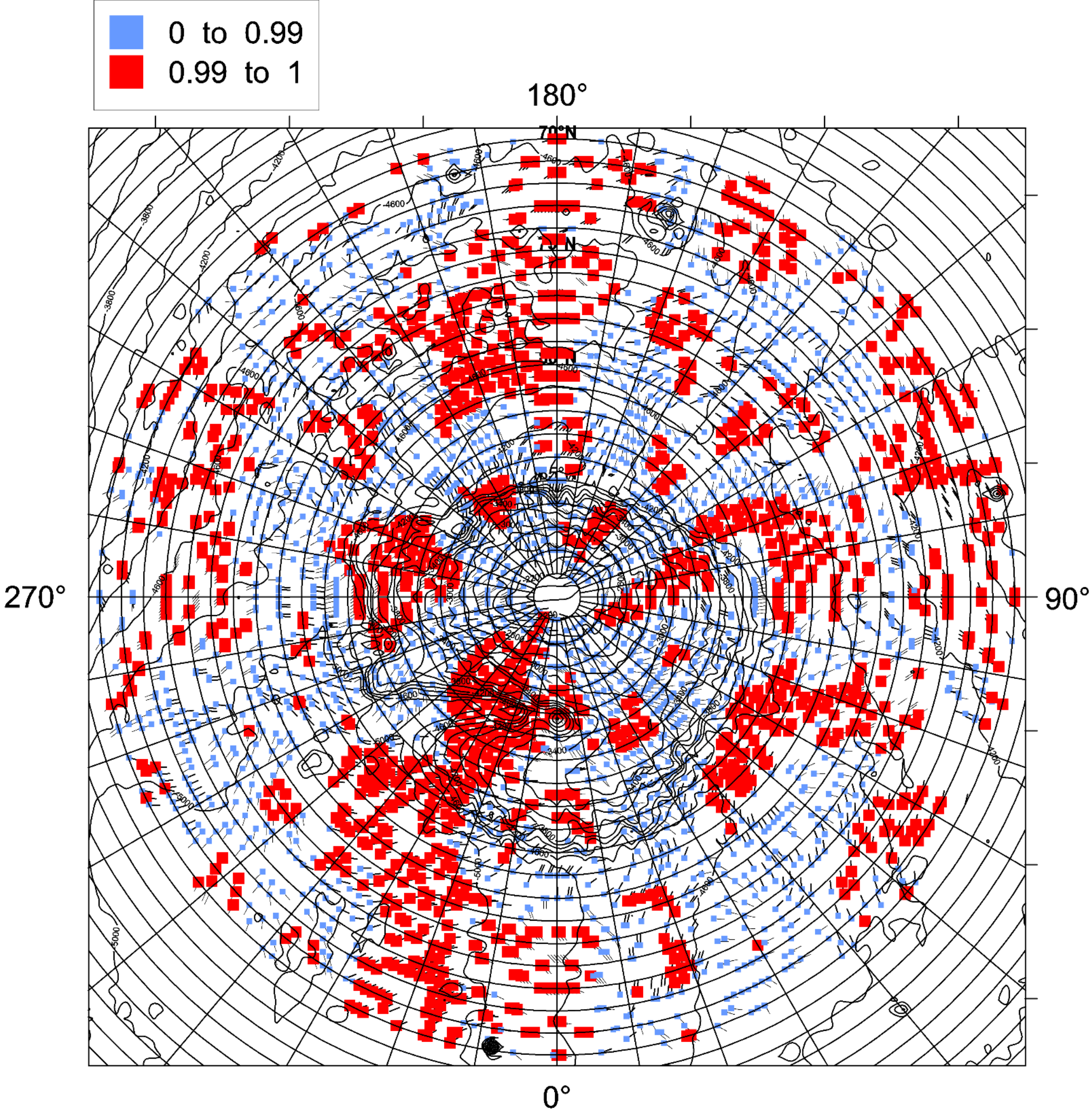


Fig. S3: 75

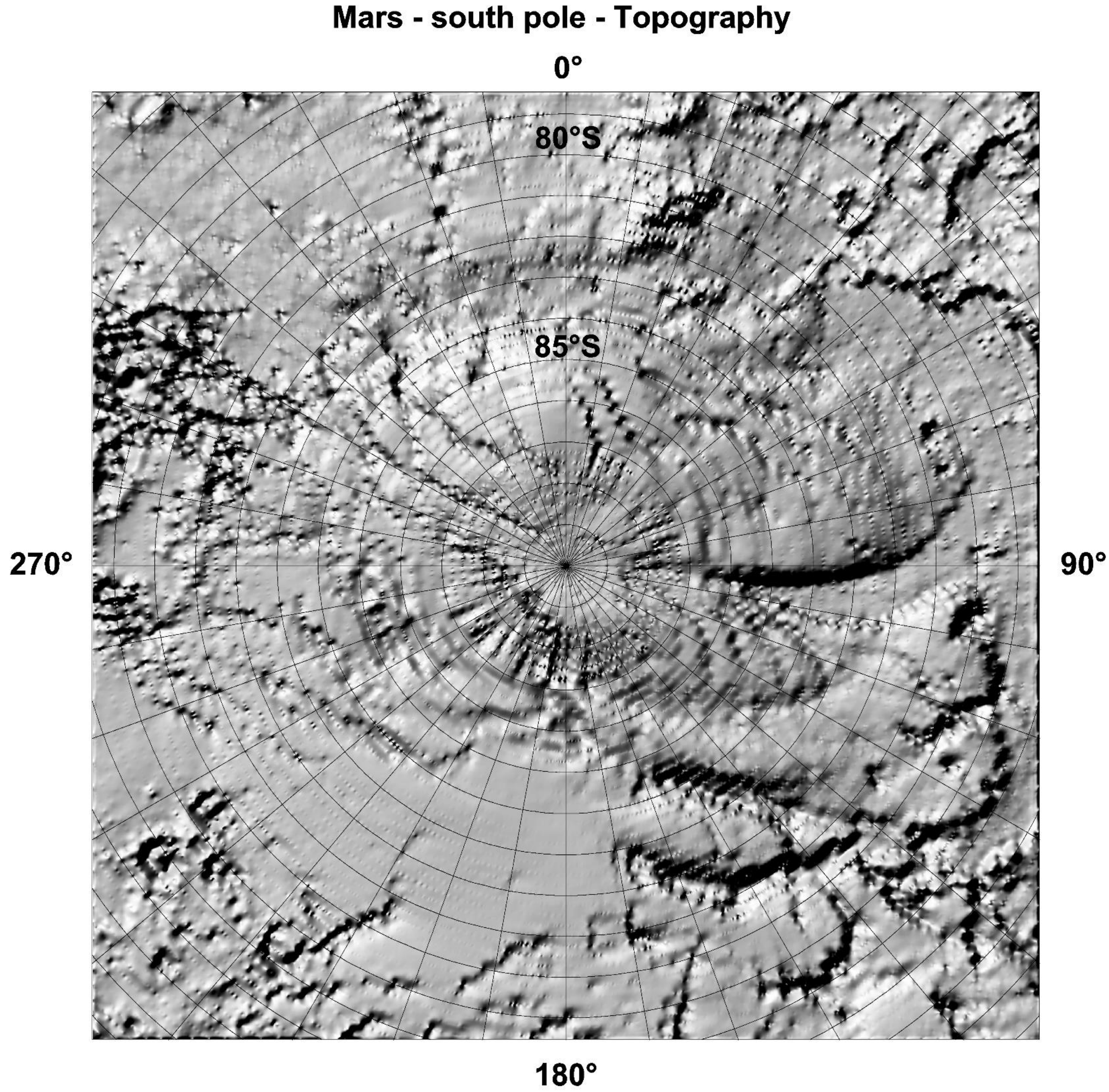
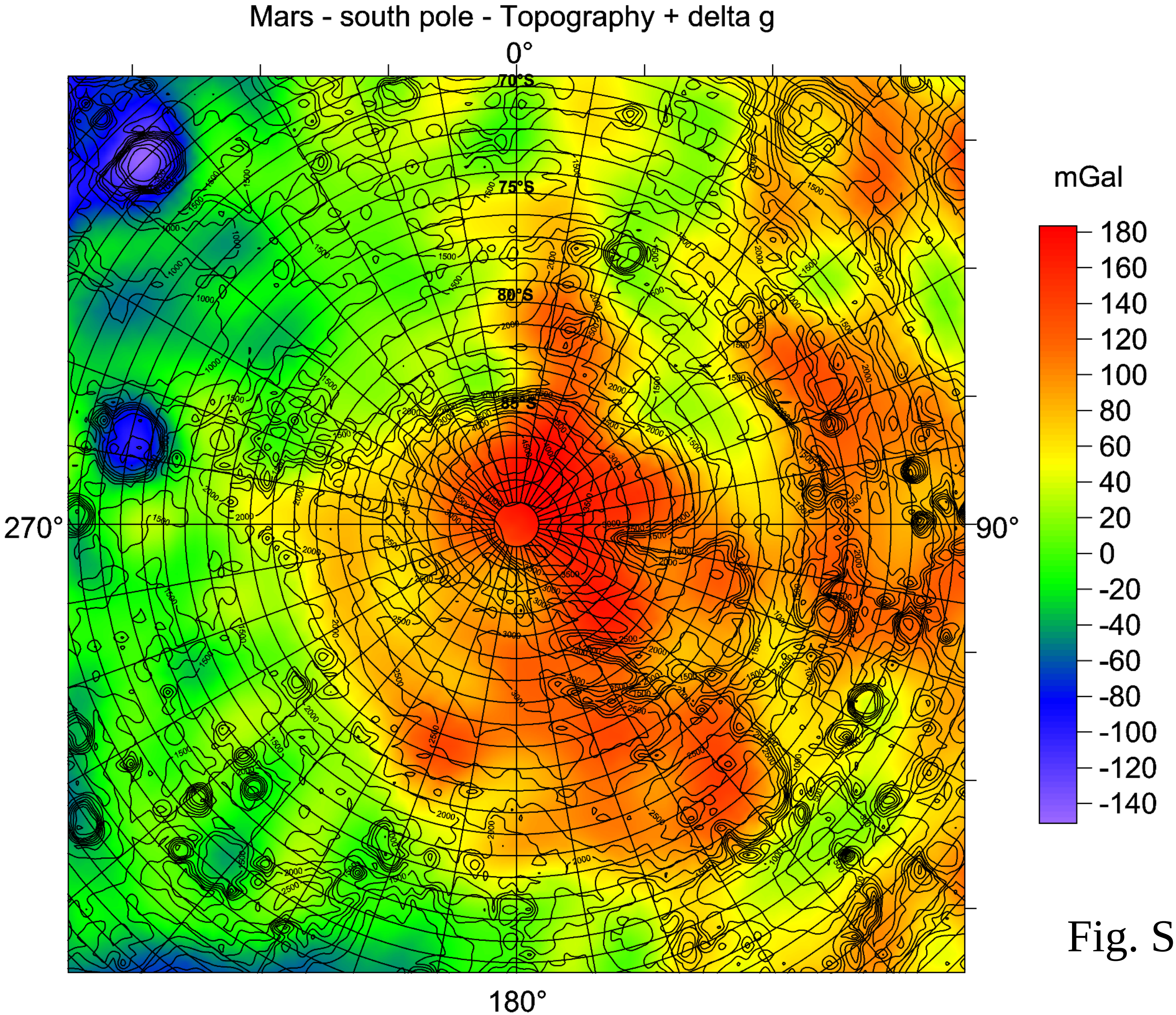
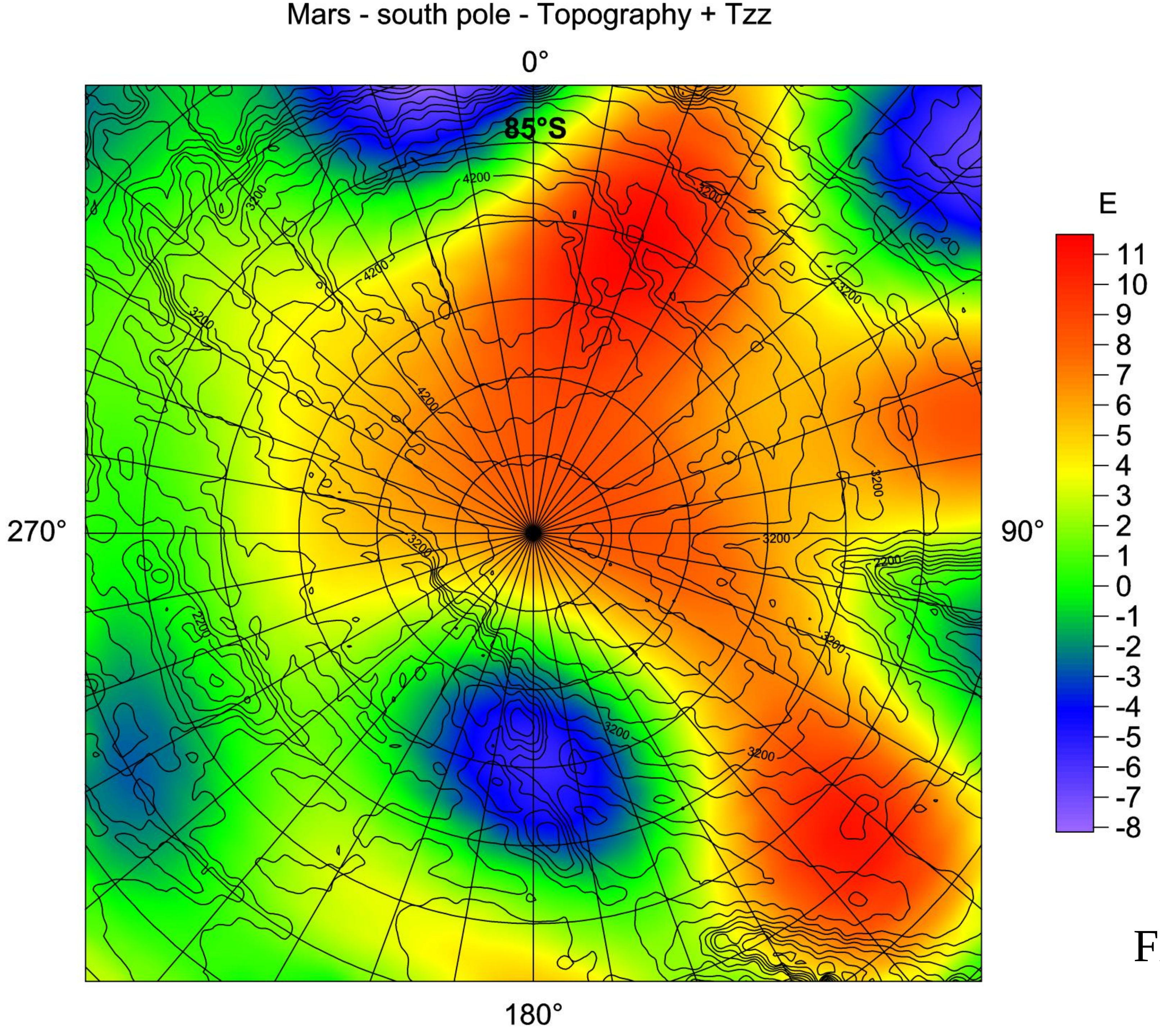


Fig. S3: 76



Mars - south pole - Topography + delta g
0°
70°S
75°S
80°S
85°S
270°
90°
180°
mGal
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140

Fig. S3: 77



Mars - south pole - Topography + Tzz
0°
85°S
4200
3200
2200
270°
90°
180°
E
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8

Fig. S3: 78

Mars - south pole - Topography + Theta for RI < 0.9

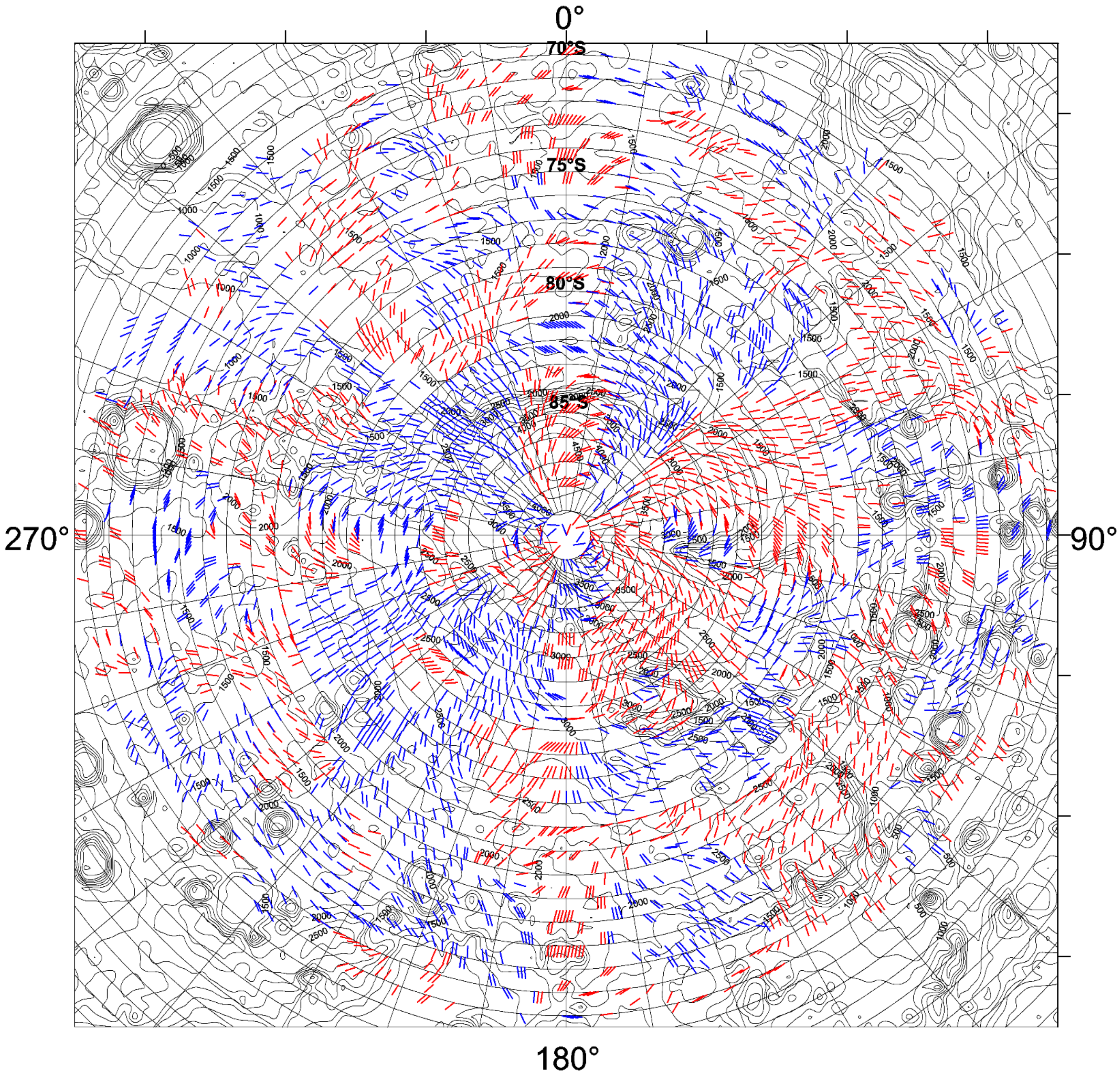


Fig. S3: 79

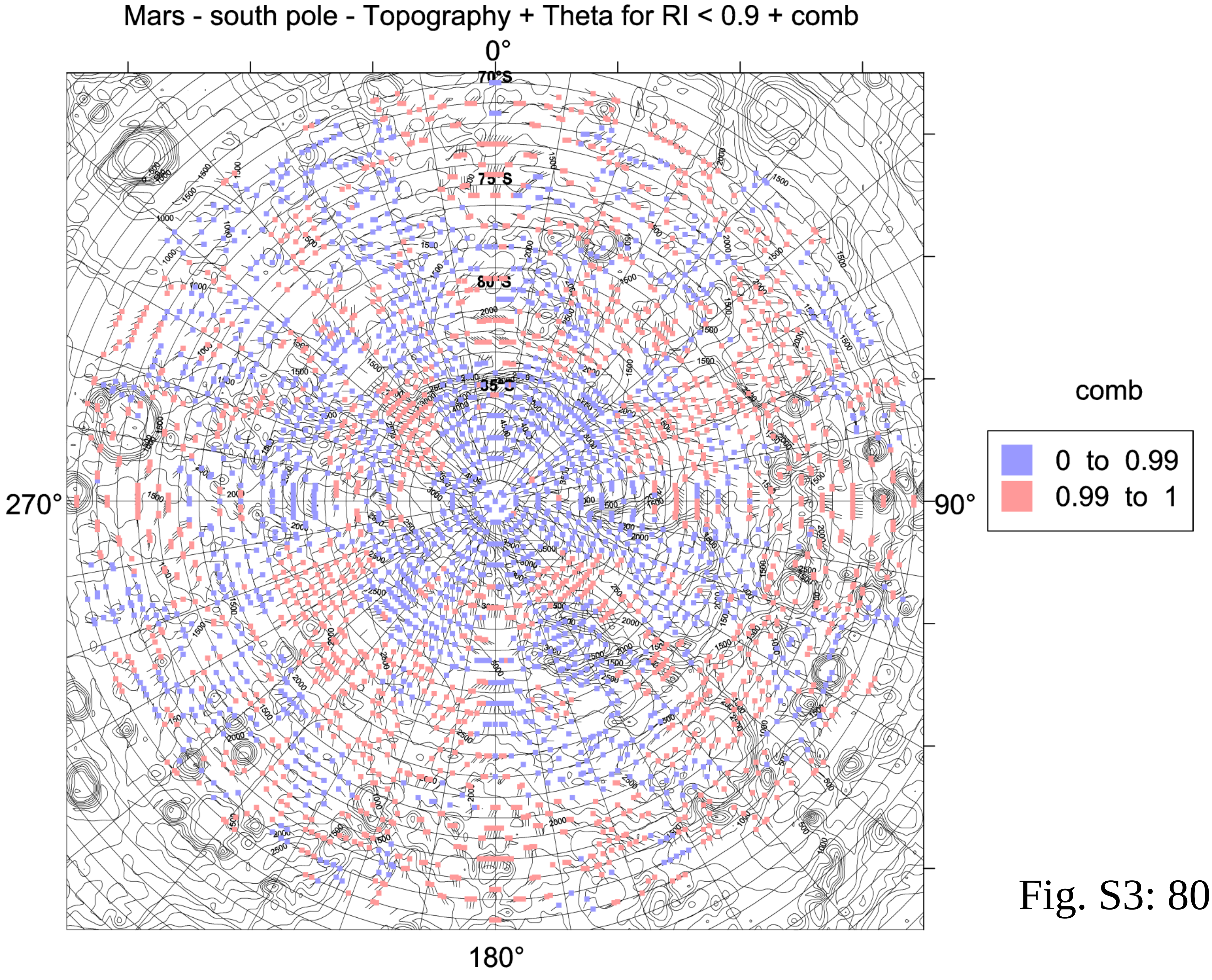

Mars - south pole - Topography + Theta for RI < 0.9 + comb
0°
90°
180°
270°
70°S
75°S
80°S
85°S
comb
0 to 0.99
0.99 to 1

Fig. S3: 80

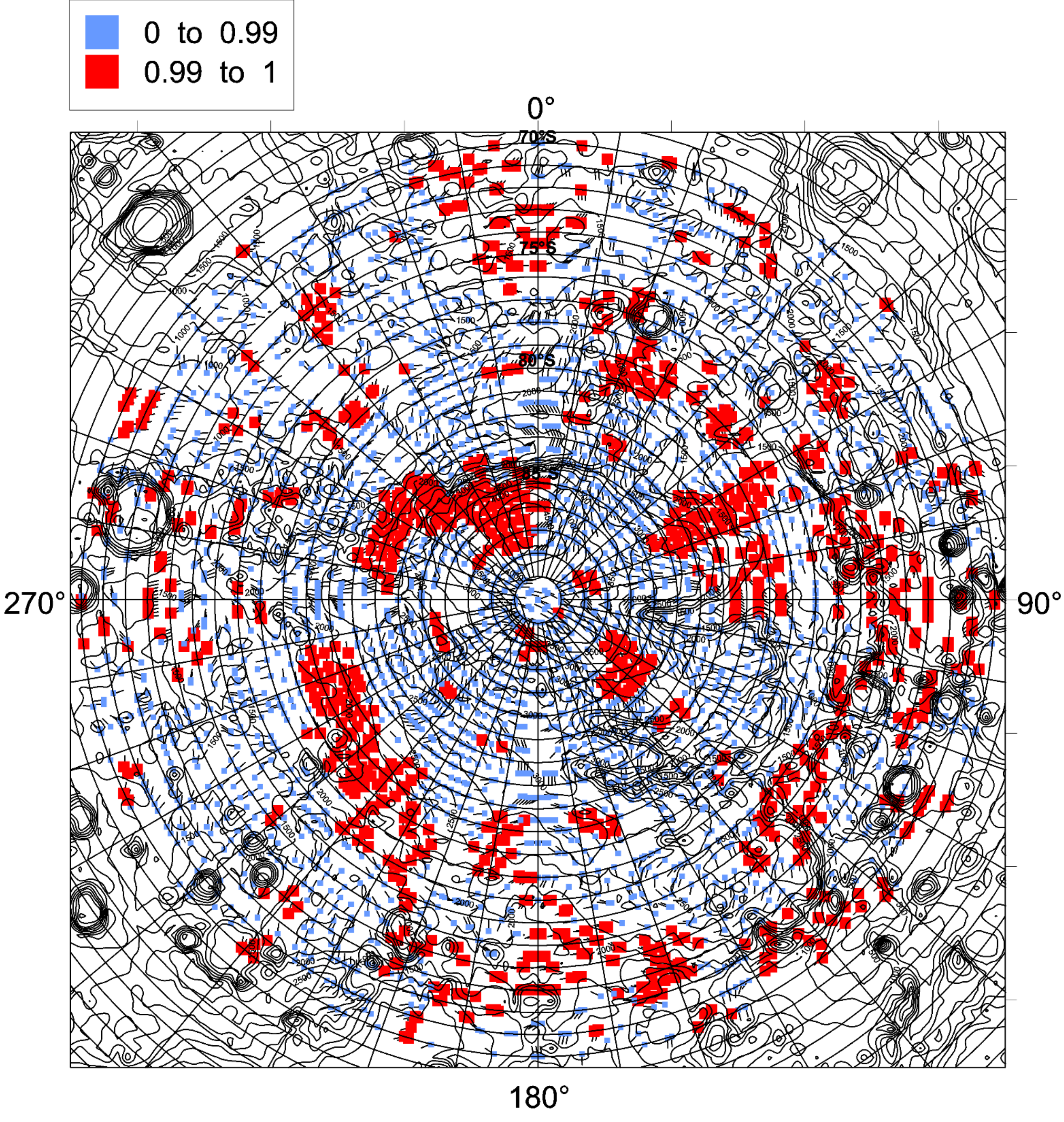


Fig. S3: 81

Mars dichotomy

The crustal dichotomy of Mars describes the topographic division between the plains in the northern hemisphere and the terrain in the southern hemisphere.
The two hemispheres' geography differ in elevation by 1 to 3 km. The average thickness of the Martian crust is 45 km, with 32 km in the northern lowlands region, and 58 km in the southern highlands.
The boundary between the two regions is quite complex in places. One distinctive type of topography is called fretted terrain. It contains mesas, knobs, and flat-floored valleys having walls about a mile high. The Martian dichotomy boundary includes the regions called Deuteronilus Mensae, Protonilus Mensae, and Nilosyrtis Mensae. All three regions have been studied extensively because they contain landforms believed to have been produced by the movement of ice[12][13] or paleoshorelines questioned as formed by volcanic erosion.[14]
The northern lowlands comprise about one-third of the surface of Mars and are relatively flat, with as many impact craters as the southern hemisphere.[15] The other two-thirds of the Martian surface are the highlands of the southern hemisphere. The difference in elevation between the hemispheres is dramatic.
Three major hypotheses have been proposed for the origin of the crustal dichotomy: endogenic (by mantle processes), single impact, or multiple impact. Both impact-related hypotheses involve processes that could have occurred before the end of the primordial bombardment, implying that the crustal dichotomy has its origins early in the history of Mars.
wikipedia

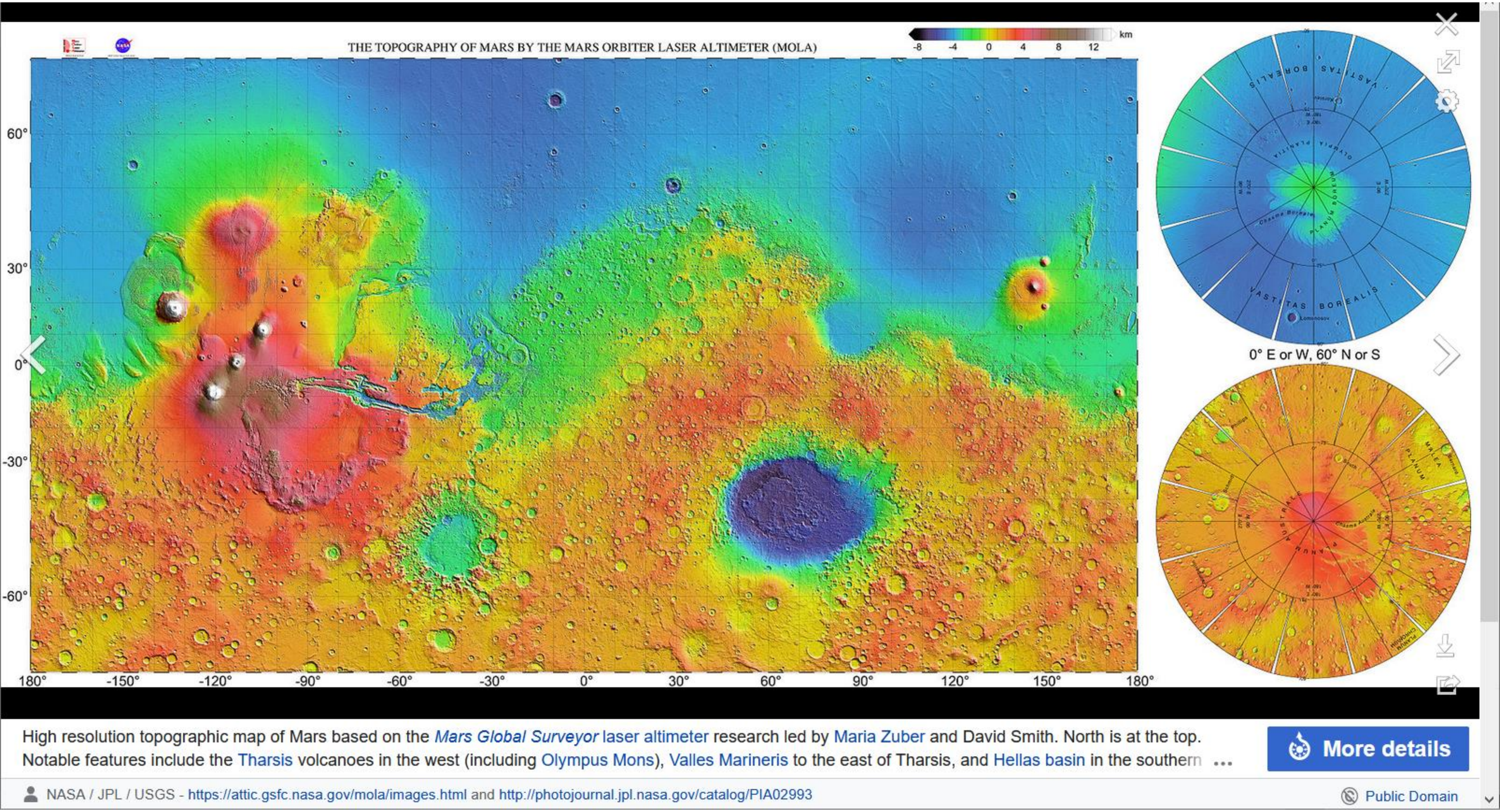


Fig. S3: 83. Mars MOLA topography, review from internet

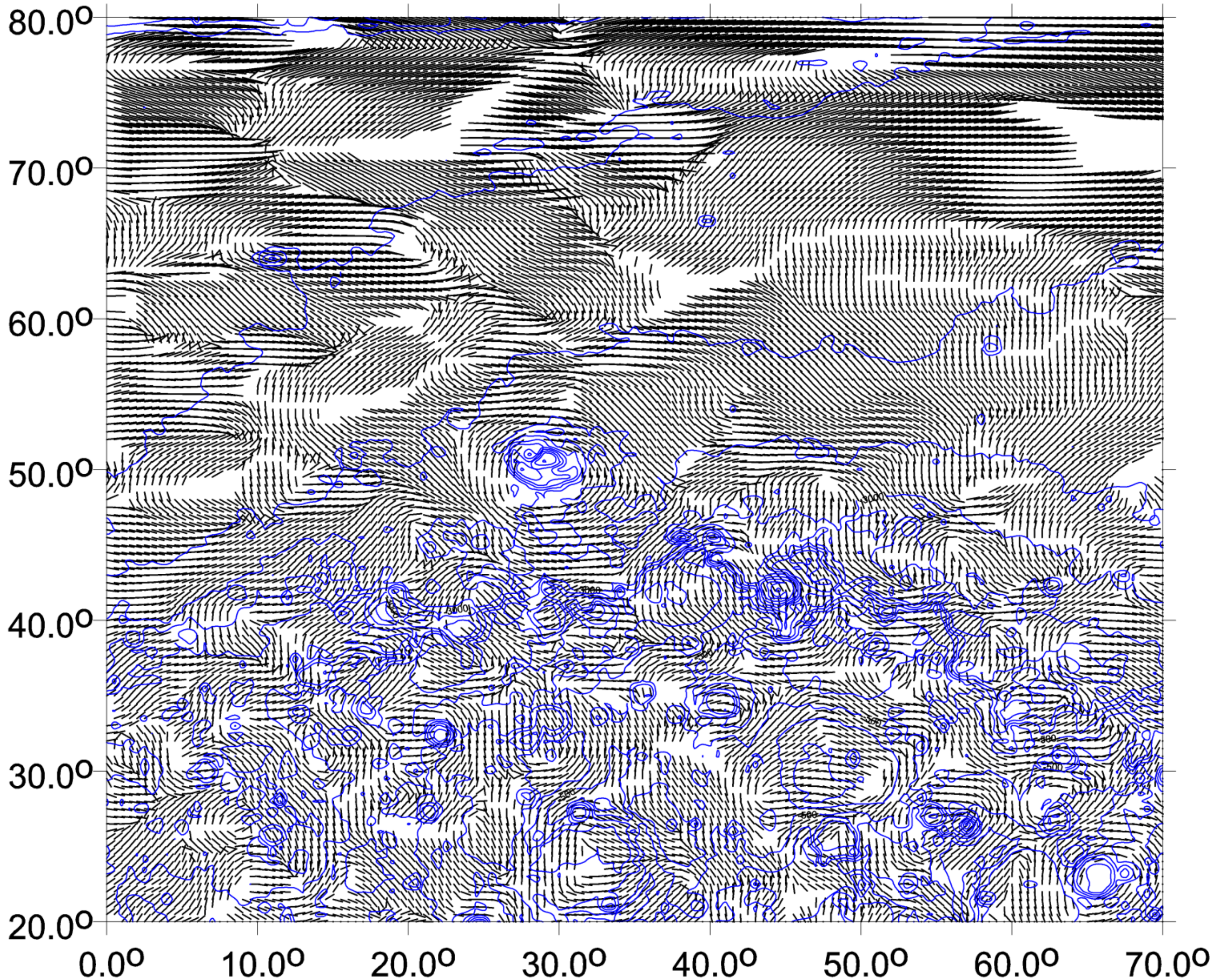


Fig. S3: 84

Typical situation: the northern lowlands are highly combed in large “plates” over relatively gravitationally “silent” terrain (thick layer of sediments), while diverse features on the southern highlands do not permit such large-scale alignment.

Fretted terrain Mars

This terrain contains a complicated mix of cliffs, mesas, buttes, and straight-walled and sinuous canyons. It contains smooth, flat lowlands along with steep cliffs. The scarps or cliffs are usually 1 to 2 km high. Channels in the area have wide, flat floors and steep walls. Fretted terrain shows up in northern Arabia, between latitudes 30°N and 50°N and longitudes 270°W and 360°W, and in Aeolis Mensae, between 10 N and 10 S latitude and 240 W and 210 W longitude.Two good examples of fretted terrain are Deuteronilus Mensae and Protonilus Mensae. *wikipedia*

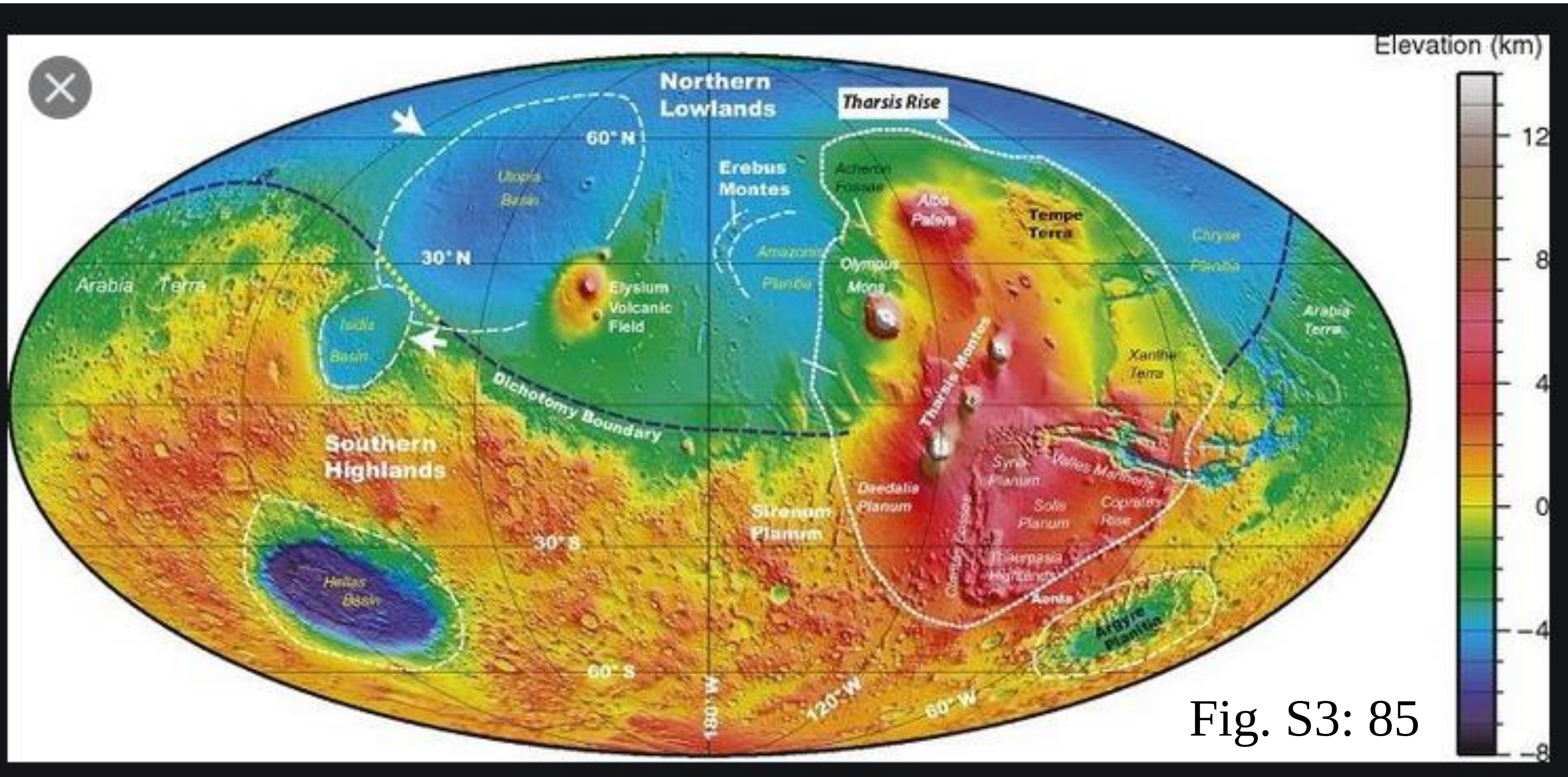
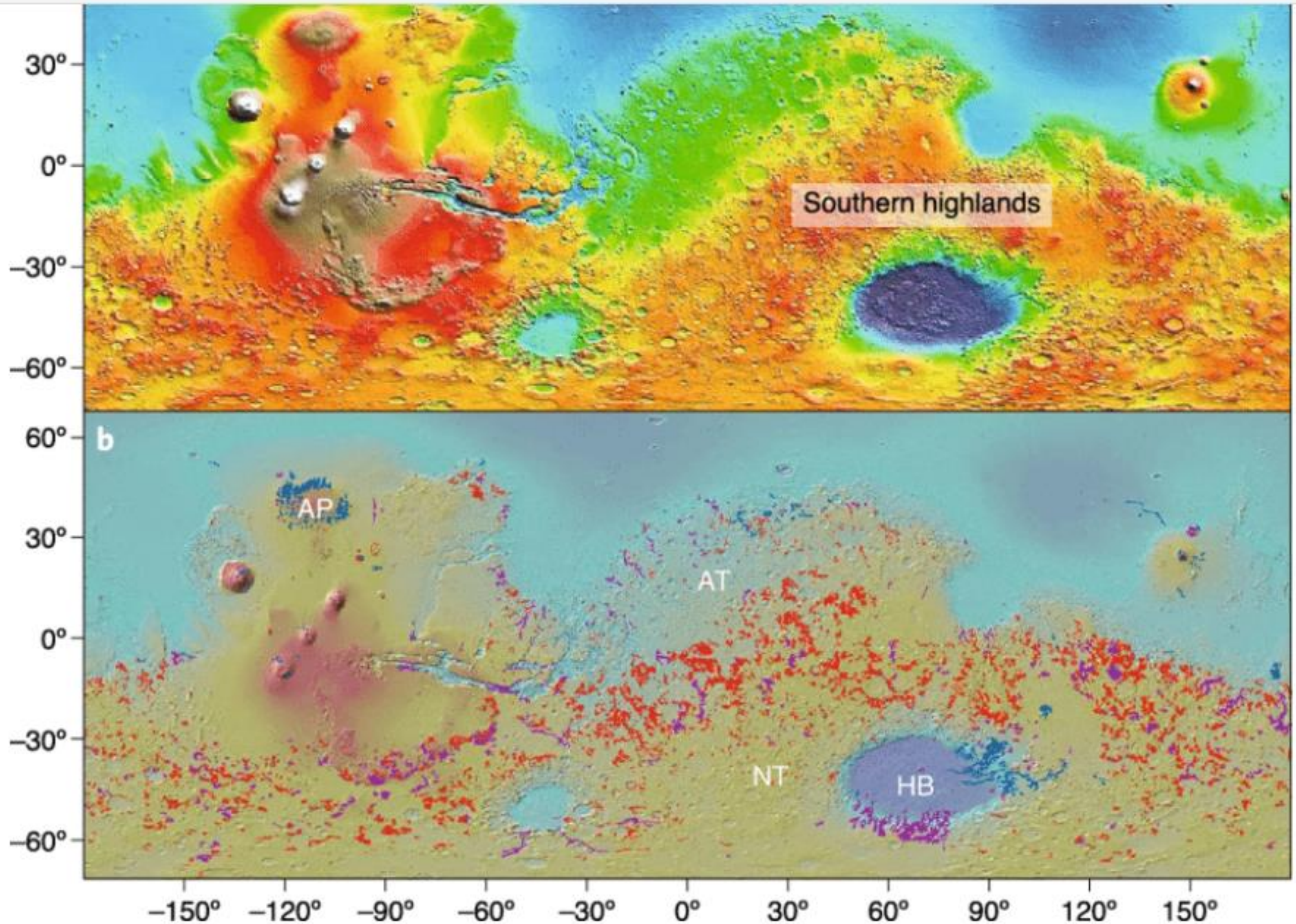


Fig. S3: 85

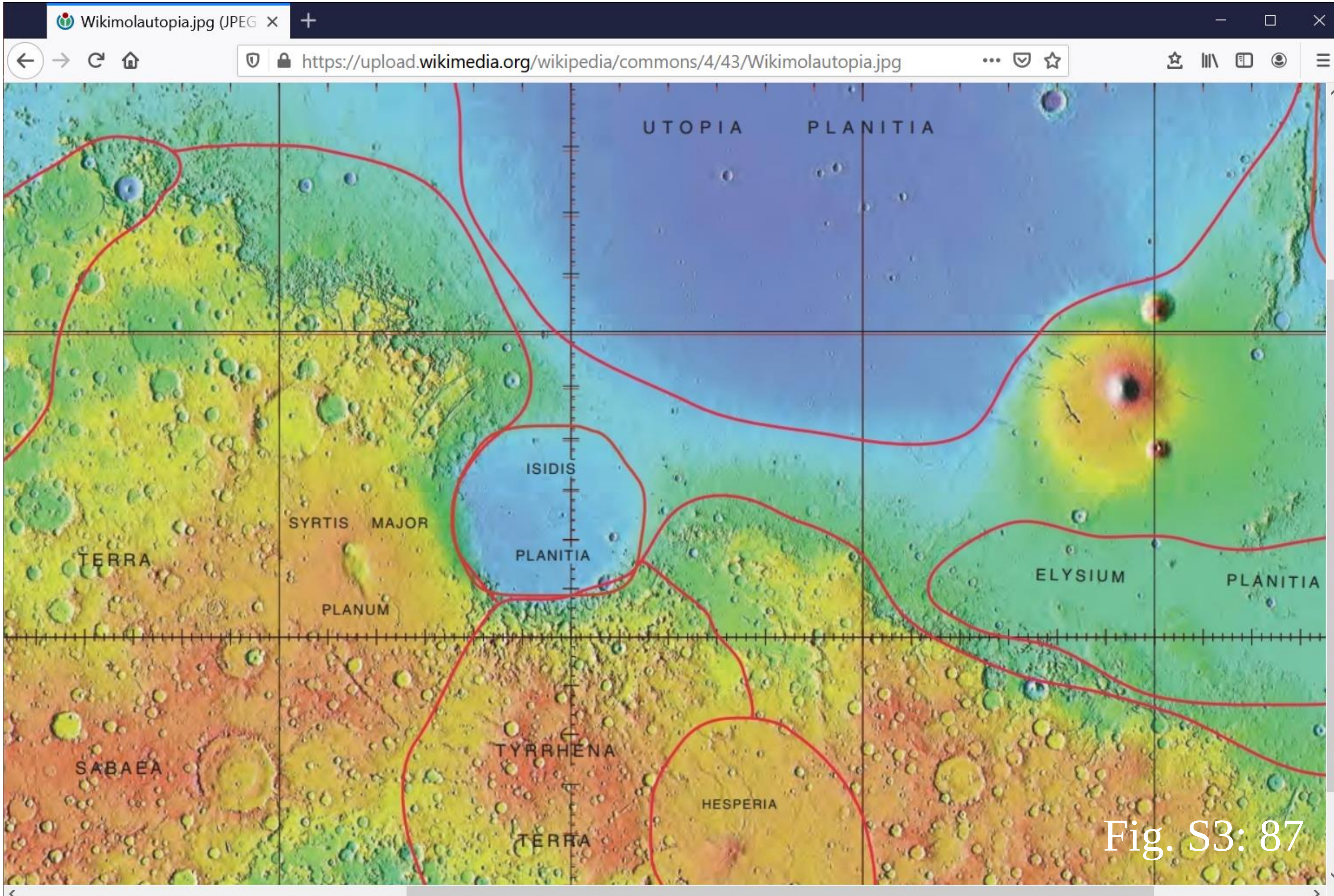


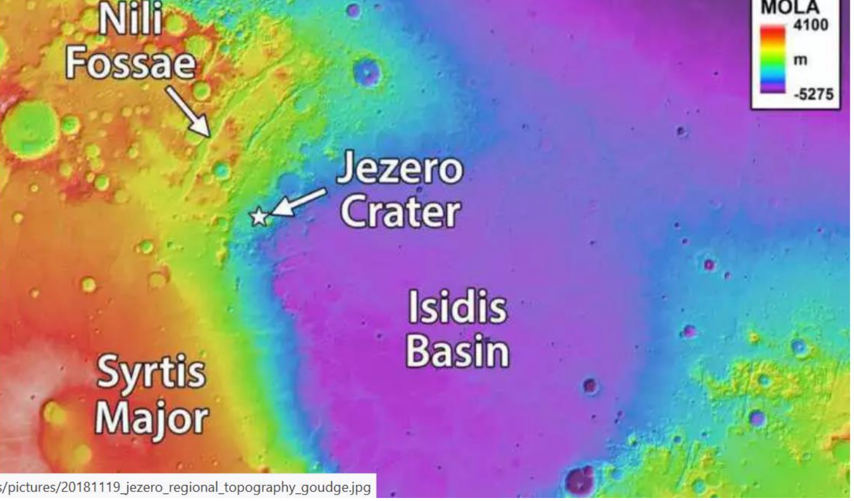
| Martian valley networks. a,b, Mars Orbiter Laser Altimeter (MOLA) elevation map with high (red) and low (blue) elevations (a) and valley network distribution (b). THEMIS data were used over a MOLA shaded relief map with Amazonian (cyan), Hesperian (purple), and Noachian (orangered) terrains. The highest concentration of valleys is on Noachian terrains near the equator. AP, Alba Patera; AT, Arabia Terra; HB, Hella Basin, NT, Noachis Terra, as mapped by Hynek et al. 15. Panel a courtesy of NASA/MOLA Science Team.

Fig. S3: 86

internet

Isidis Planitia (8.4N, 69.5E) MOLA topography
& Syrtis Major (SM) Planum

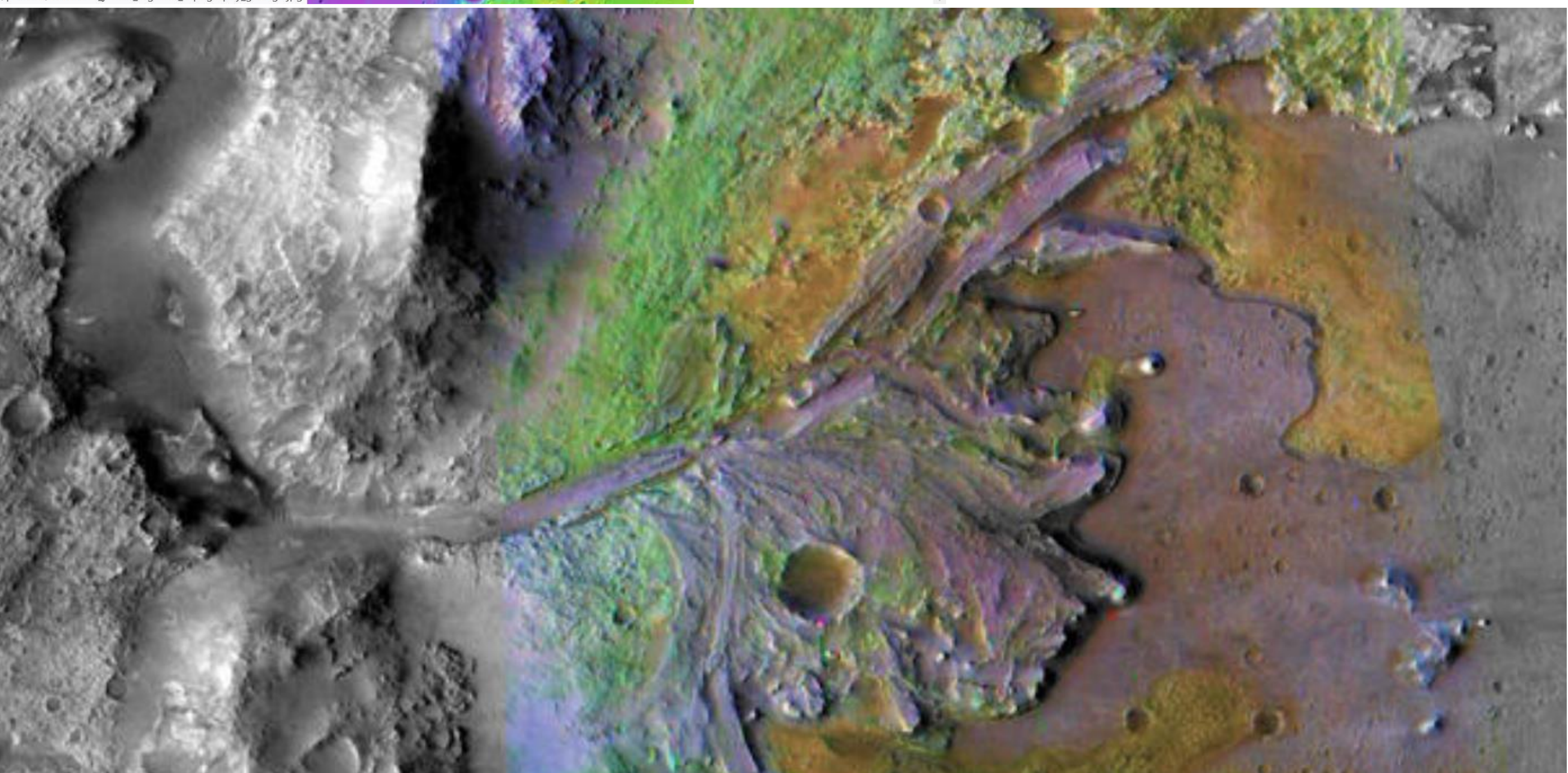


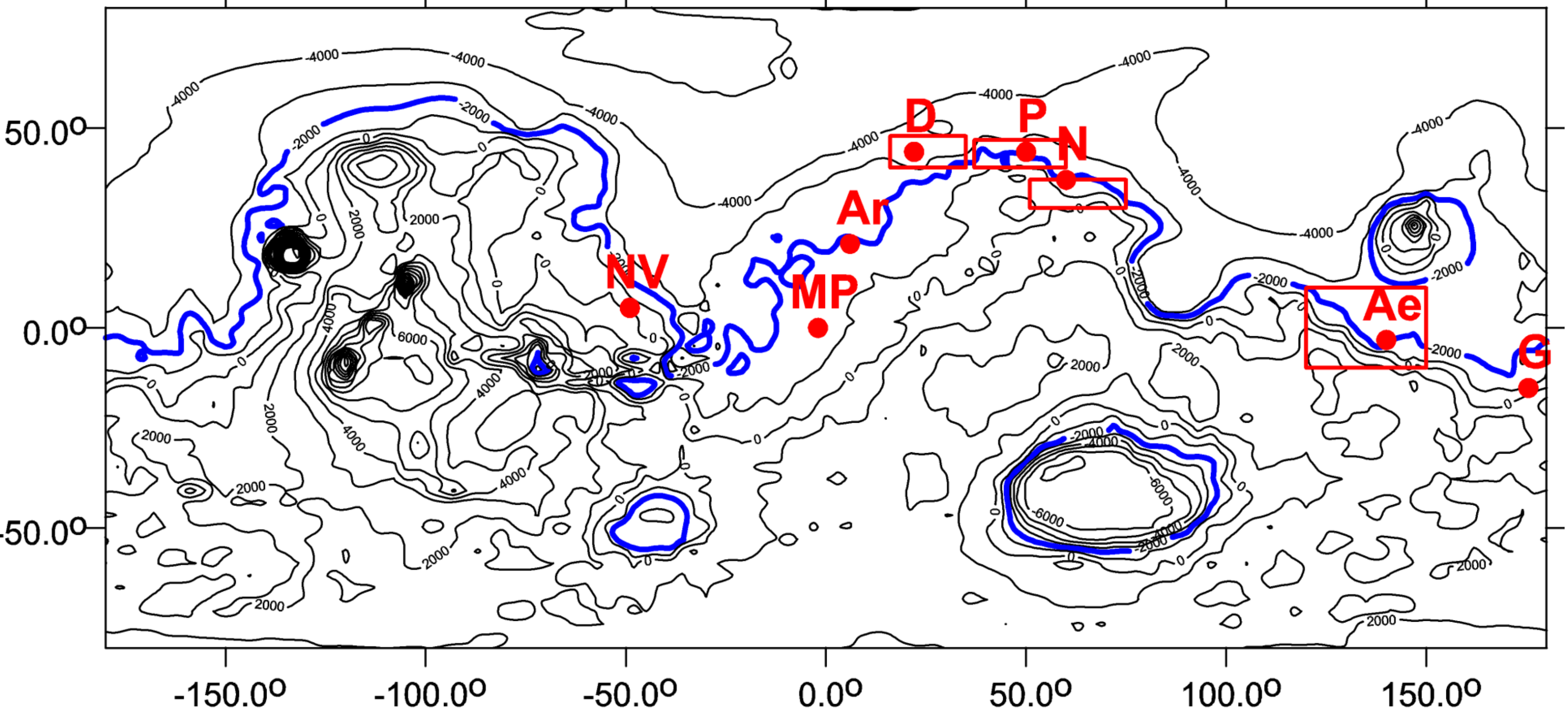


Perseverance landing site
(18N, 70E),
Jezero Crater, NASA 2022

Fig. S3: 88

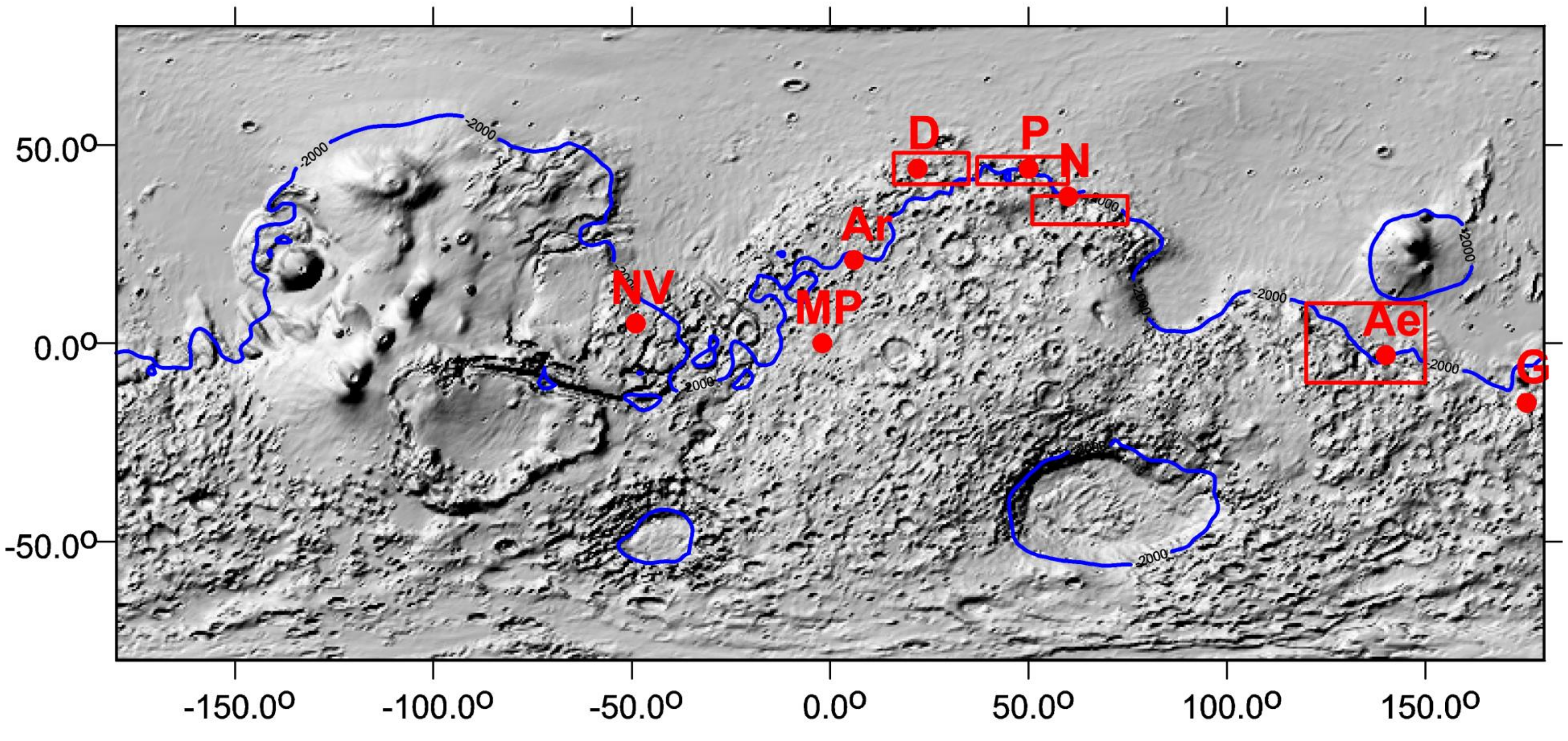
internet



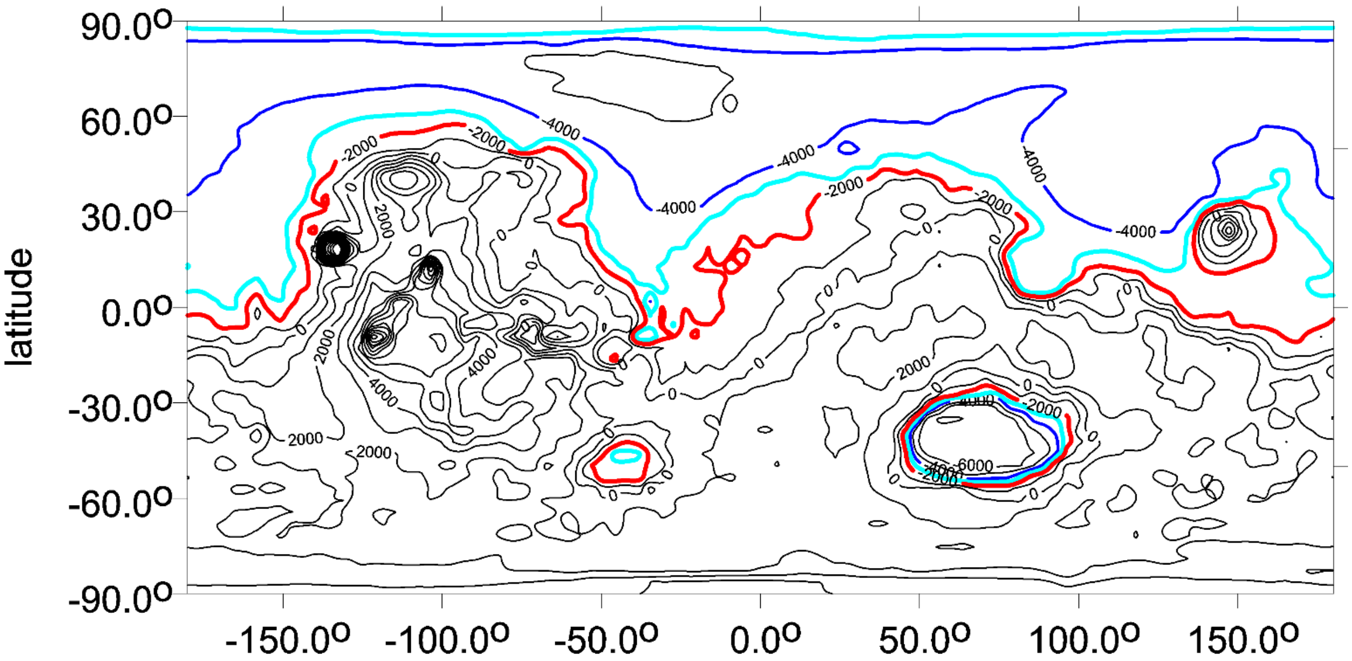


Name	centered at latitude	longitude E	range latitudes	longitudes
Arabia Terra Ar	21N	6	large area	
Aeolis Mensae Ae	3S	140	10N-10S	210-240W
Deuteronilus Mensae D	44N	22	40N-48N	325-344W
Protonilus Mensae P	44N	50	40N-47N	37-60E
Nilosyrtis Mensae N	37N	68	30N-37N	51-75E

Mars - Topo + oblasti



oblasti = regions



Estimate of extent of the paleoocean

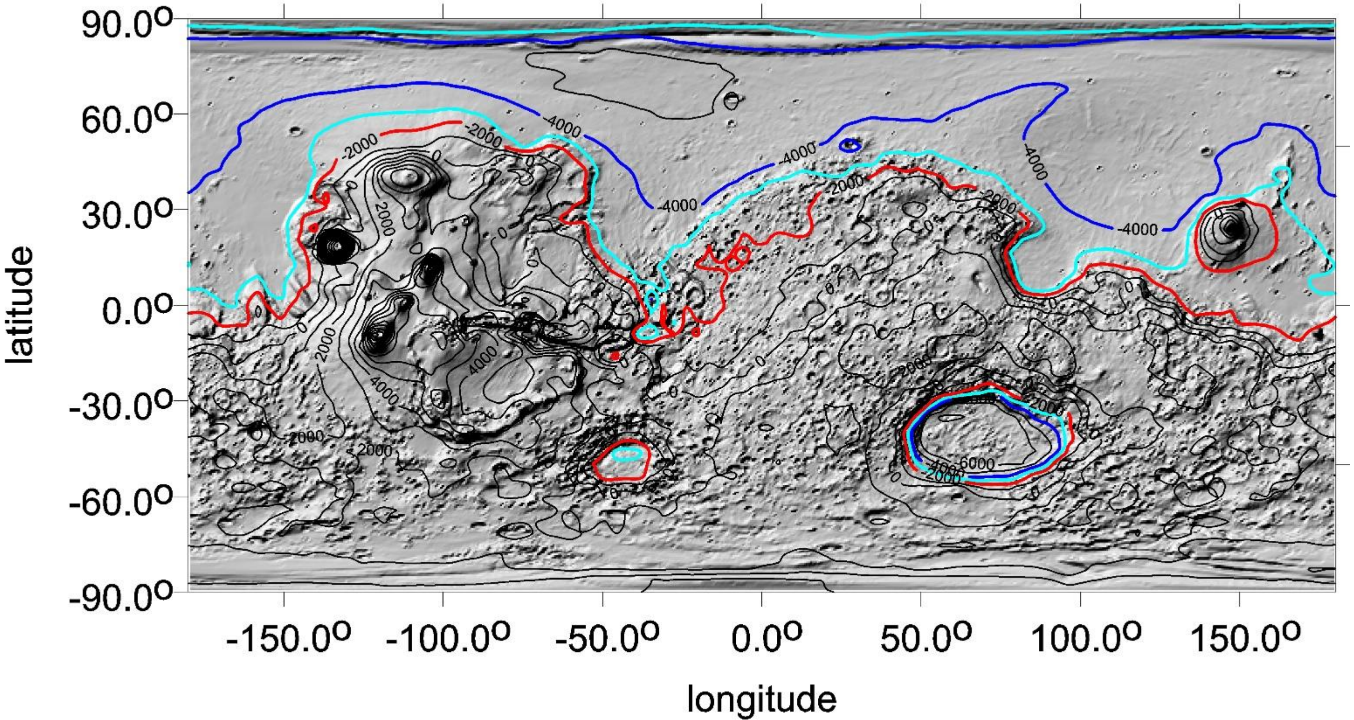


Fig. S3: 91

MOLA topography, selected contour lines, relief [m]

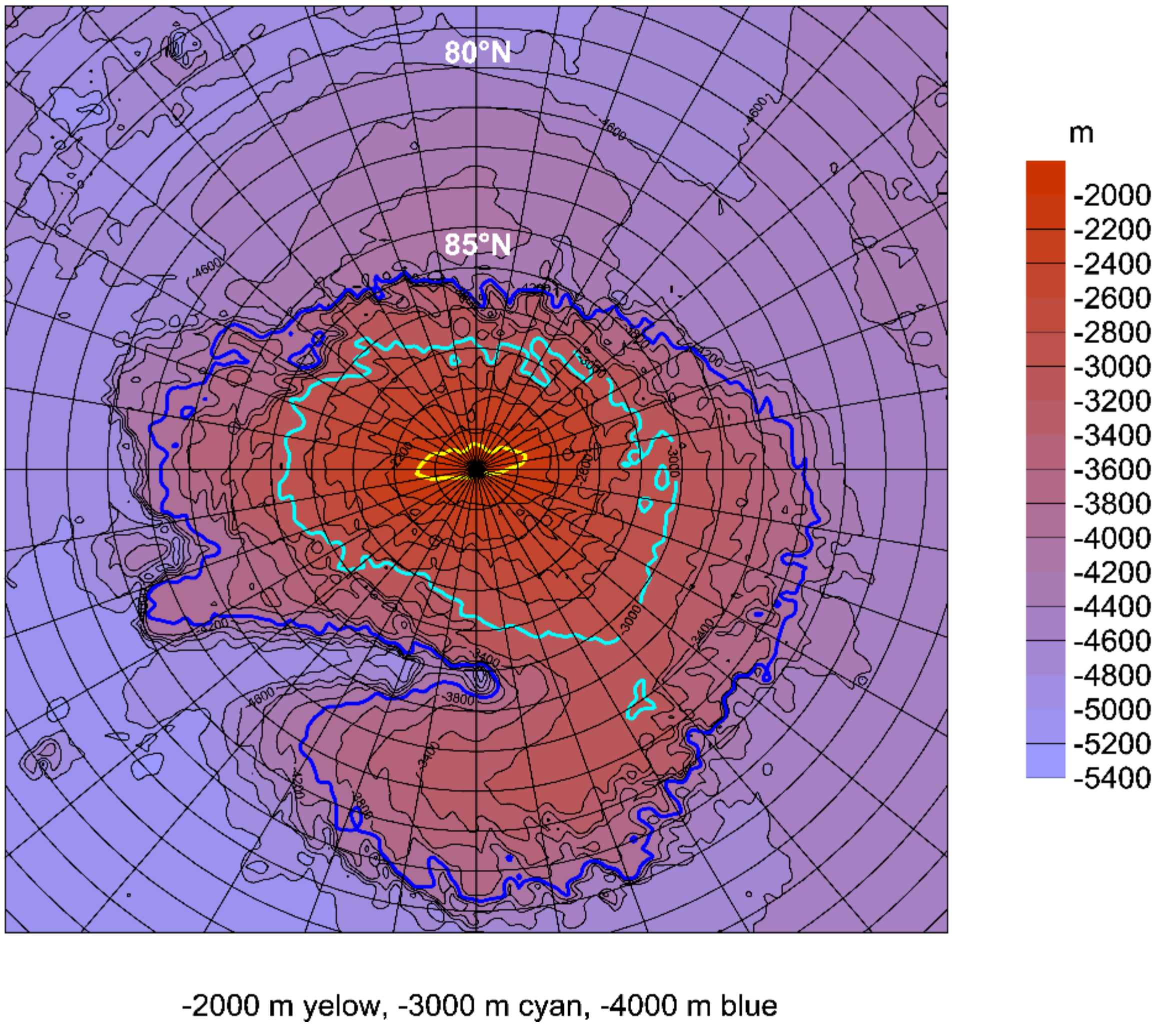


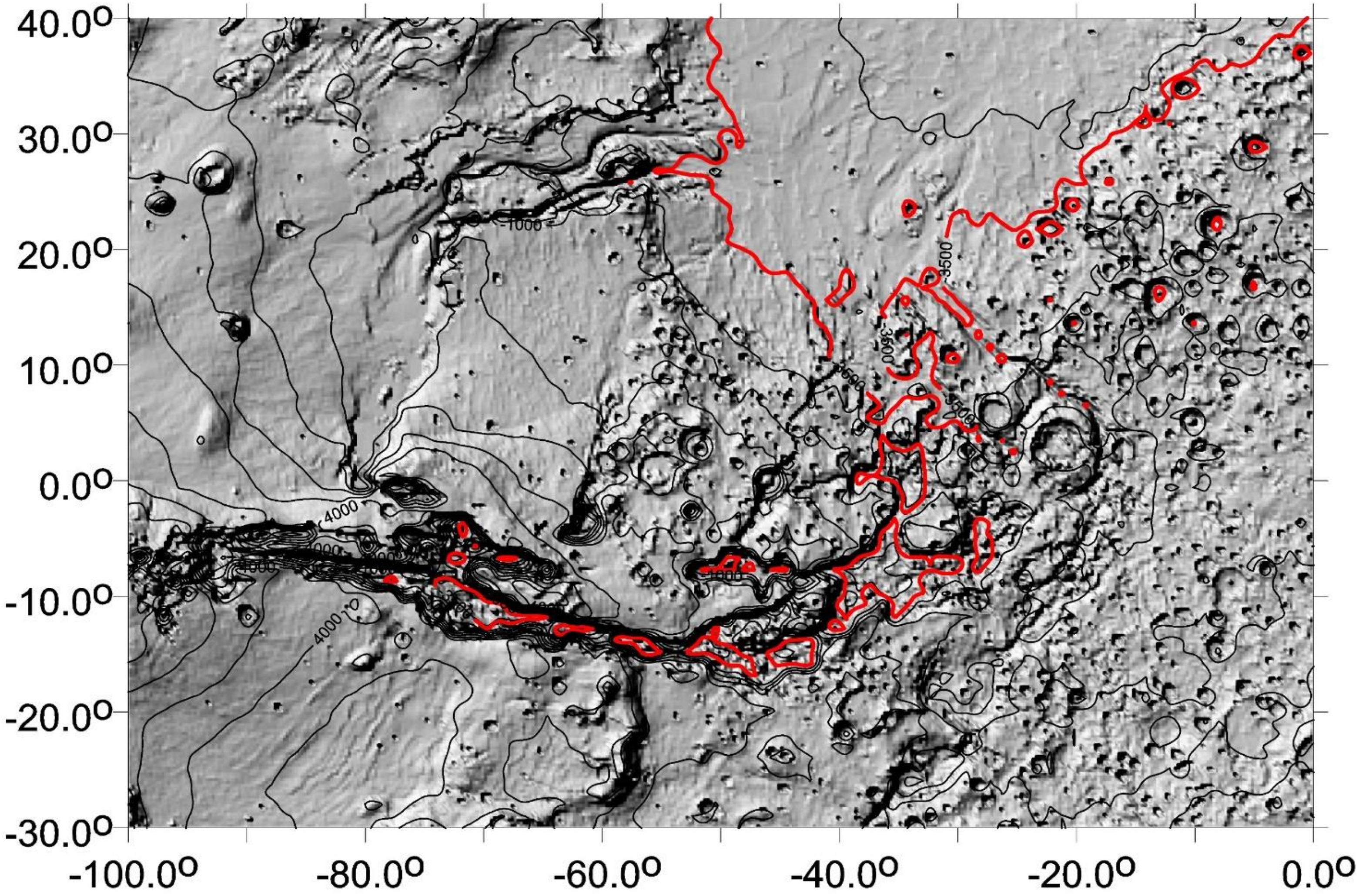
Fig. S3: 92

The northern polar cap on Mars with data from the MOLA topographic model in [m] with respect to the reference ellipsoid.
The estimated „seahore“ of the NMPO.

Valles Marineris (VM)

profile red for -3500m

Fig. S3: 93



A compromise found:

-3 500 m above reference best-fitting rotational ellipsoid, this is the model height for the hypothetical seashore of the hypothetical paleoocean.

Data: the MOLA topography [m].

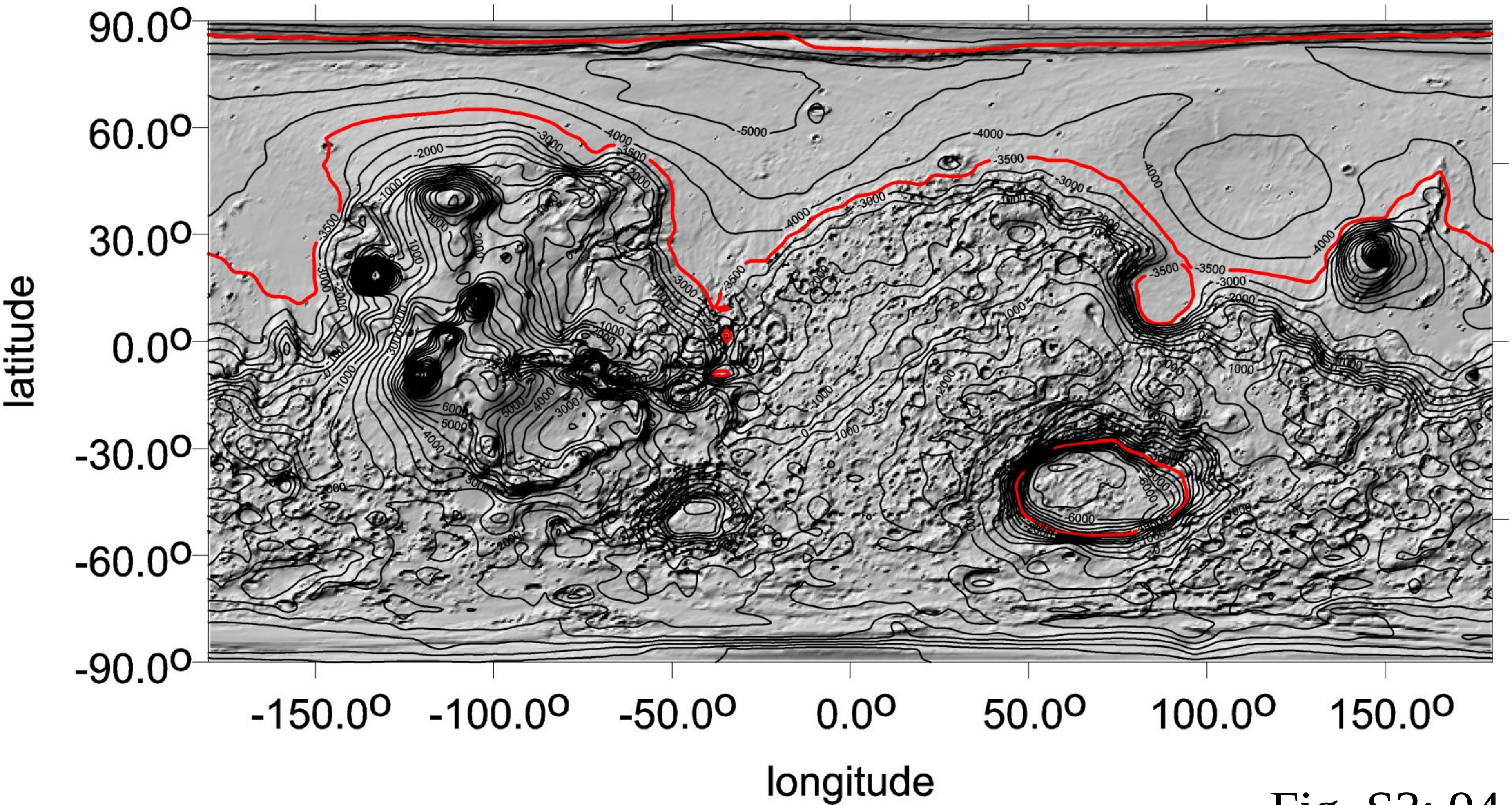
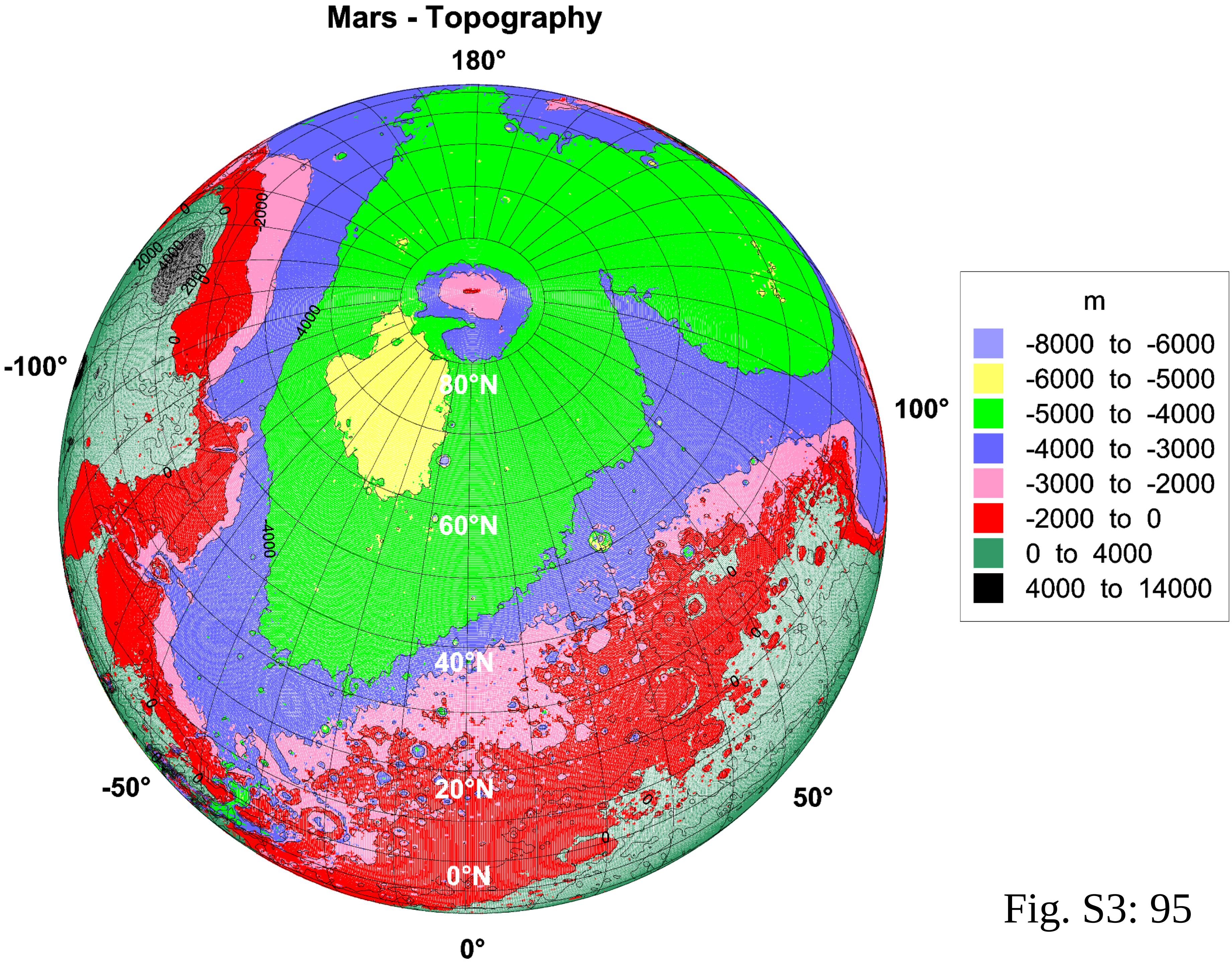
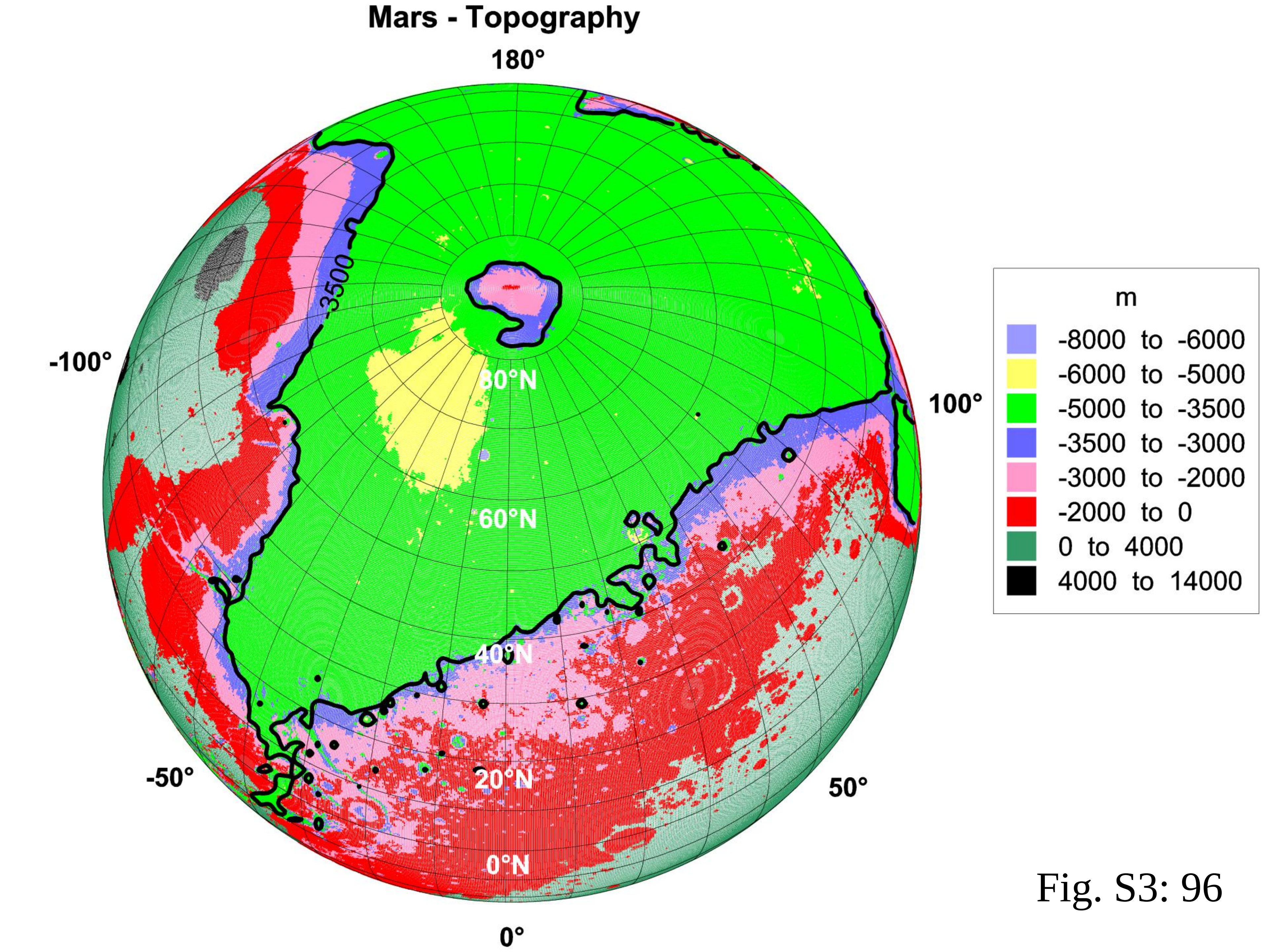


Fig. S3: 94



Mars - Topography
180°
-100°
100°
-50°
50°
0°
80°N
60°N
40°N
20°N
0°N
m
-8000 to -6000
-6000 to -5000
-5000 to -4000
-4000 to -3000
-3000 to -2000
-2000 to 0
0 to 4000
4000 to 14000

Fig. S3: 95



Mars - Topography
180°
-100°
100°
-50°
50°
0°
80°N
60°N
40°N
20°N
0°N
-3500
m
-8000 to -6000
-6000 to -5000
-5000 to -3500
-3500 to -3000
-3000 to -2000
-2000 to 0
0 to 4000
4000 to 14000

Fig. S3: 96

Mars - north pole - topography

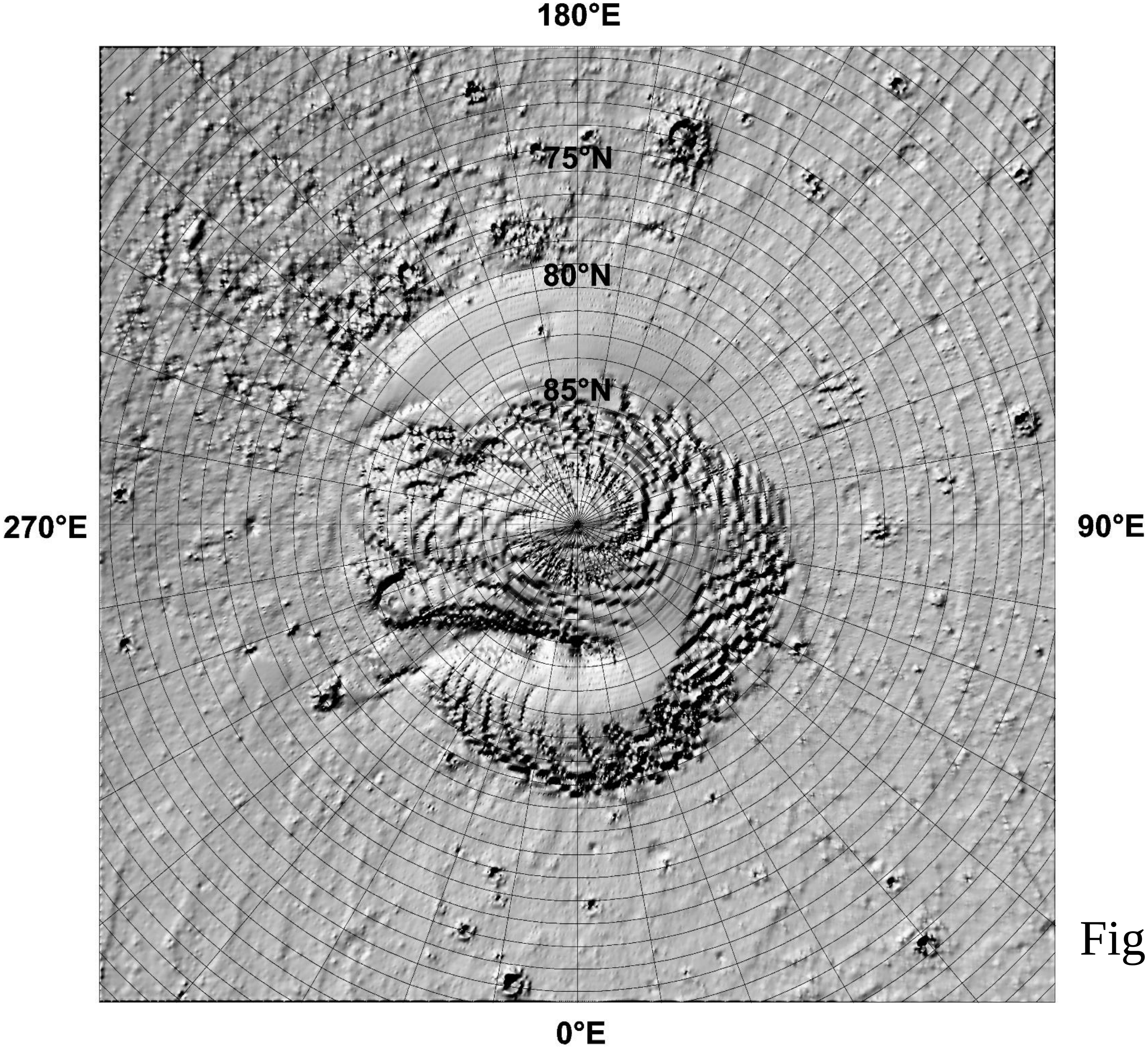


Fig. S3: 97

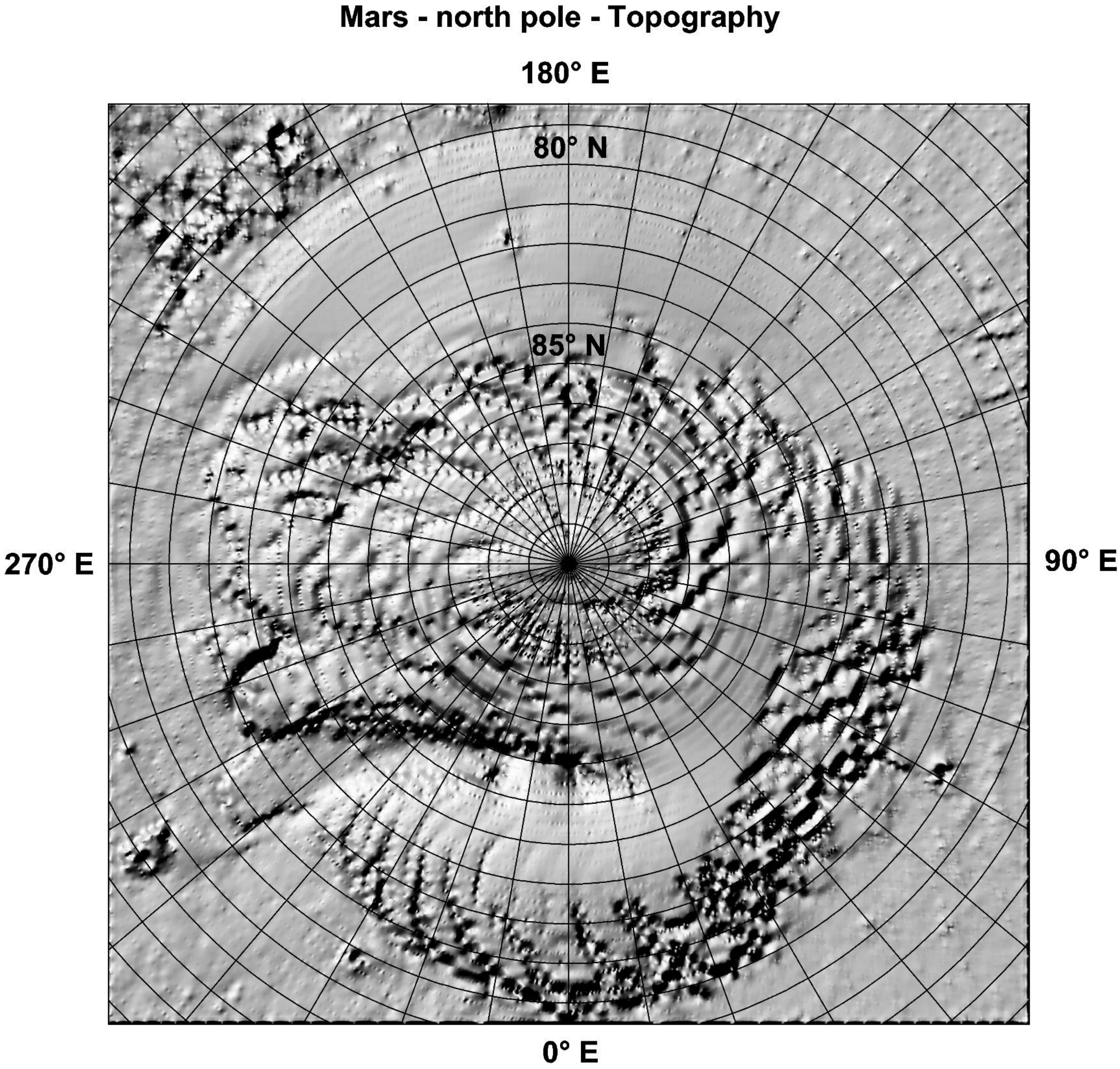


Fig. S3: 98

Mars - north pole - Topography

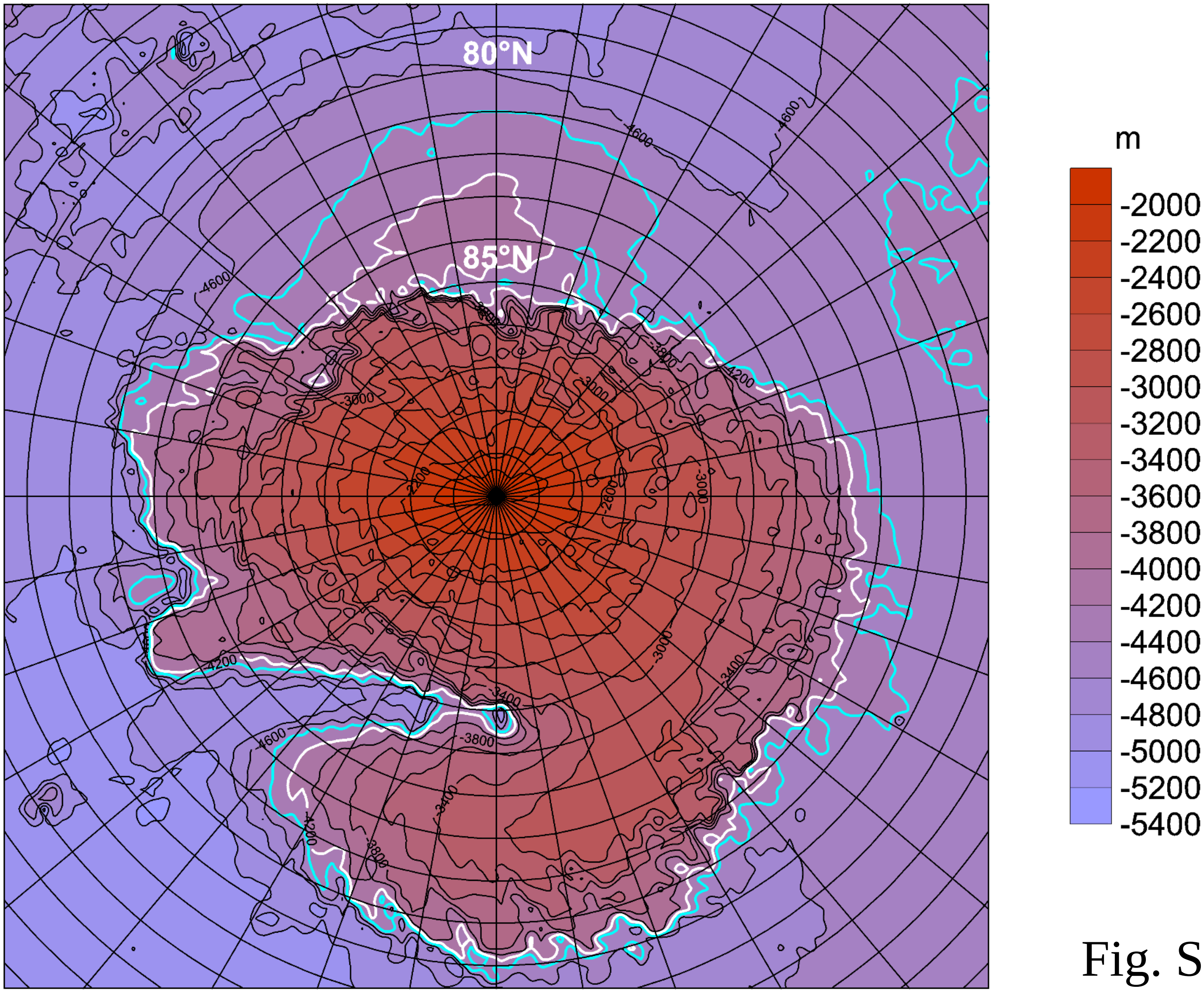


Fig. S3: 99

-4200 m white, -4400 m cyan

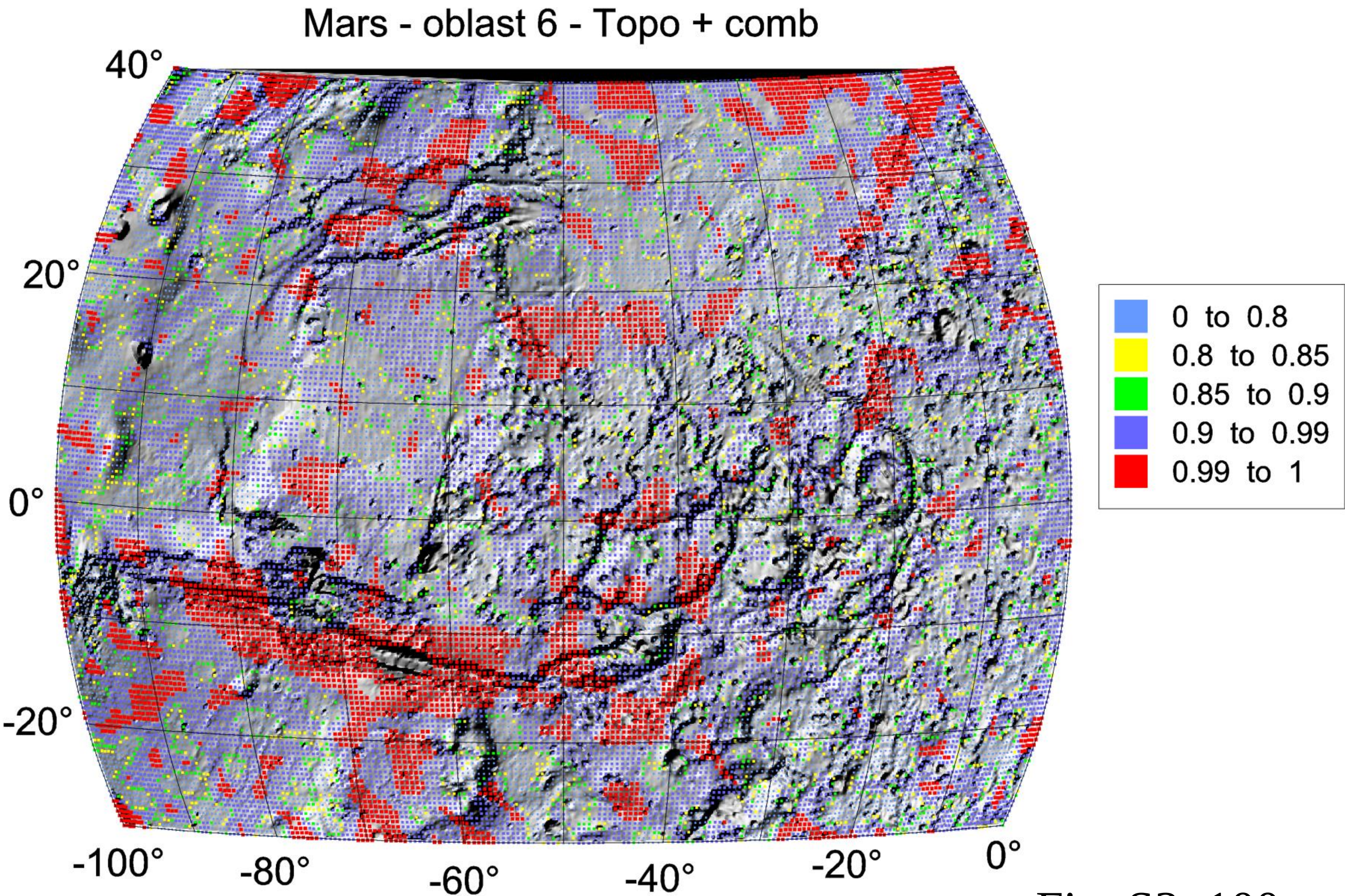
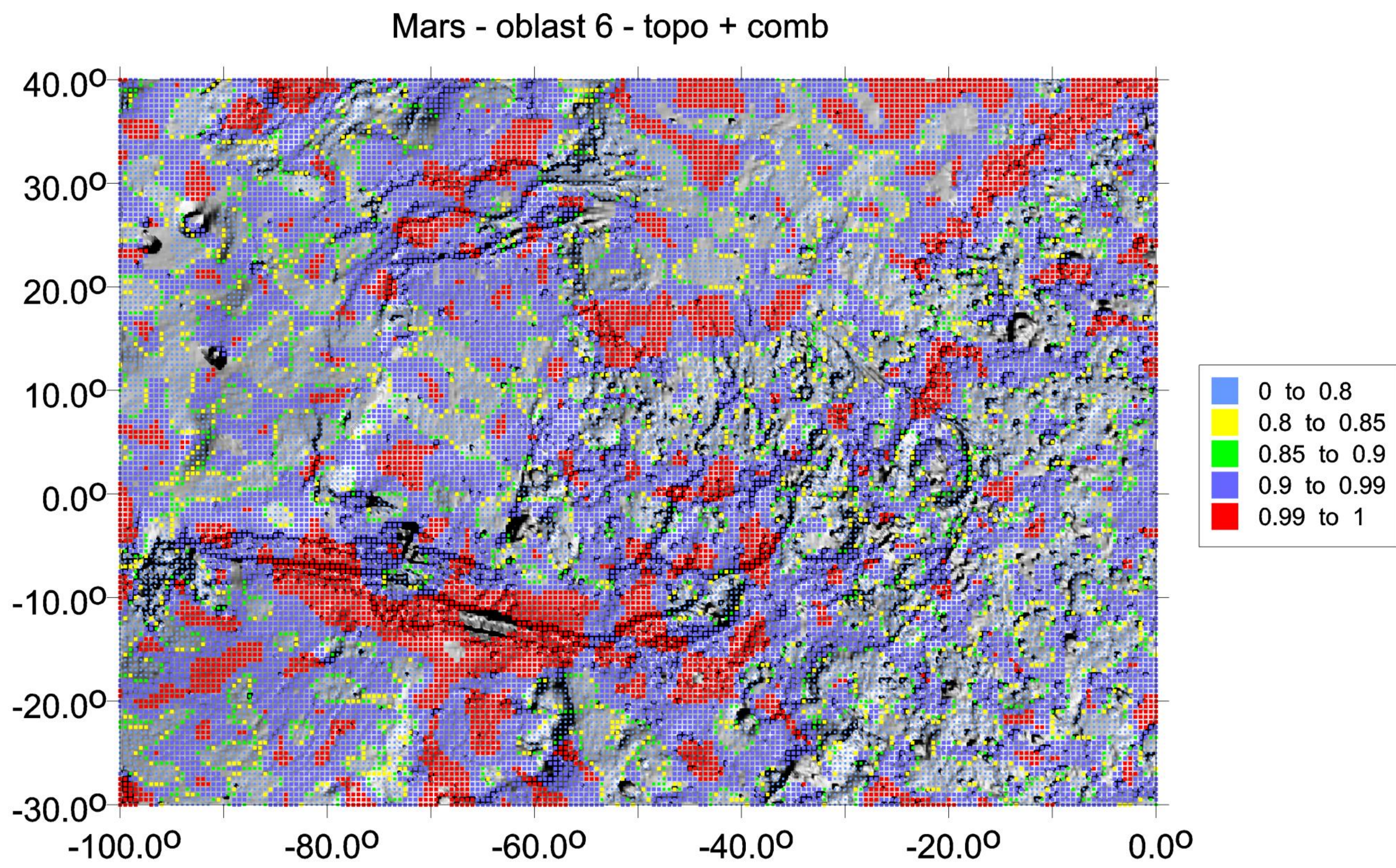
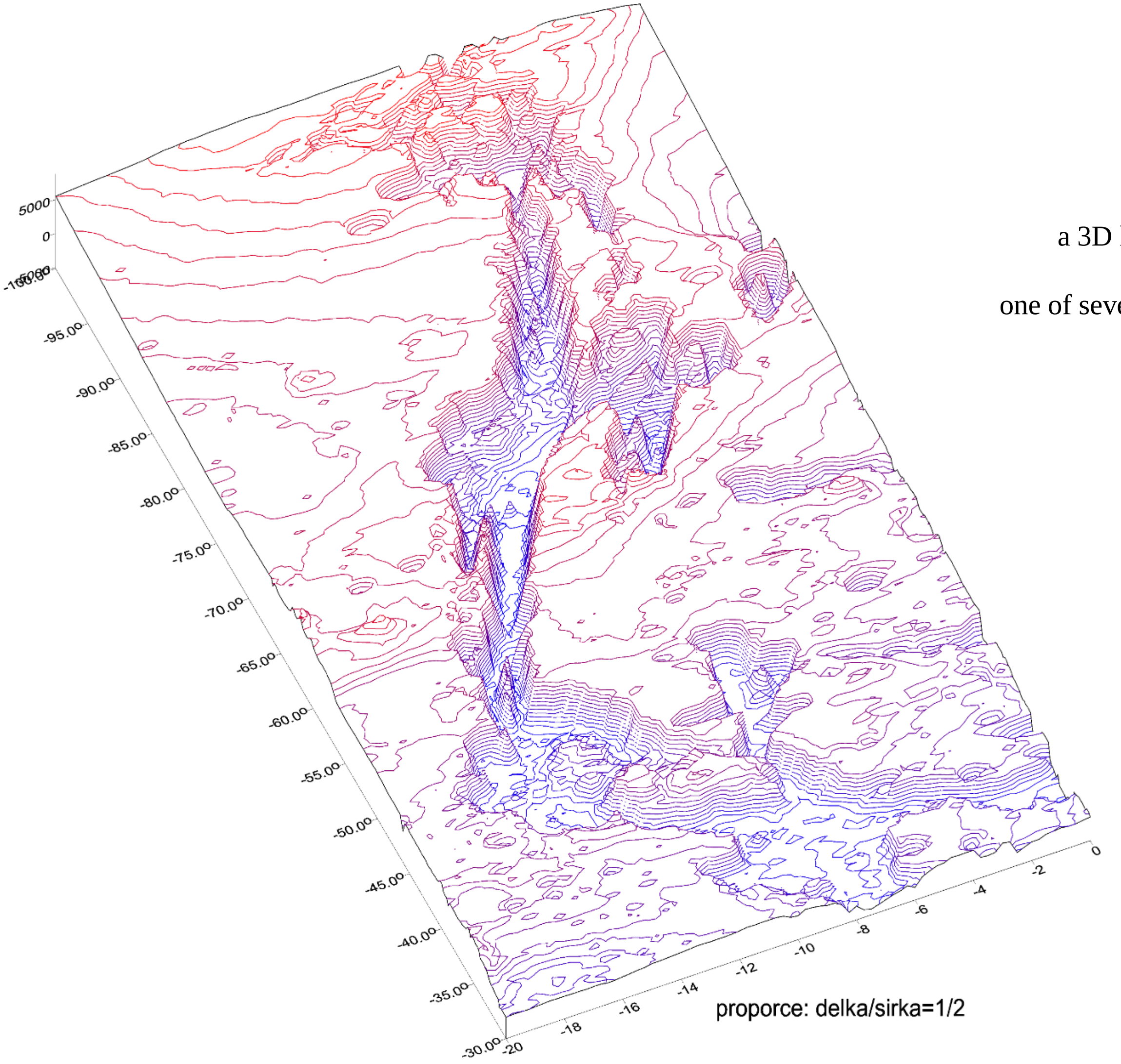

Mars - oblast 6 - Topo + comb
40°
20°
0°
-20°
-100°
-80°
-60°
-40°
-20°
0°
0 to 0.8
0.8 to 0.85
0.85 to 0.9
0.9 to 0.99
0.99 to 1

Fig. S3: 100



Mars - oblast 6 - topo + comb
40.0o
30.0o
20.0o
10.0o
0.0o
-10.0o
-20.0o
-30.0o
-100.0o
-80.0o
-60.0o
-40.0o
-20.0o
0.0o
0 to 0.8
0.8 to 0.85
0.85 to 0.9
0.9 to 0.99
0.99 to 1

Fig. S3: 101



Valles Marineris (VM)

;

a 3D look from East to West; Melas Chasma
(a deep, steep-sided canyon,
one of several such features in the system of VM)
is in centre of VM.

MOLA topography, grid 0.25^0.

Fig. S3: 102

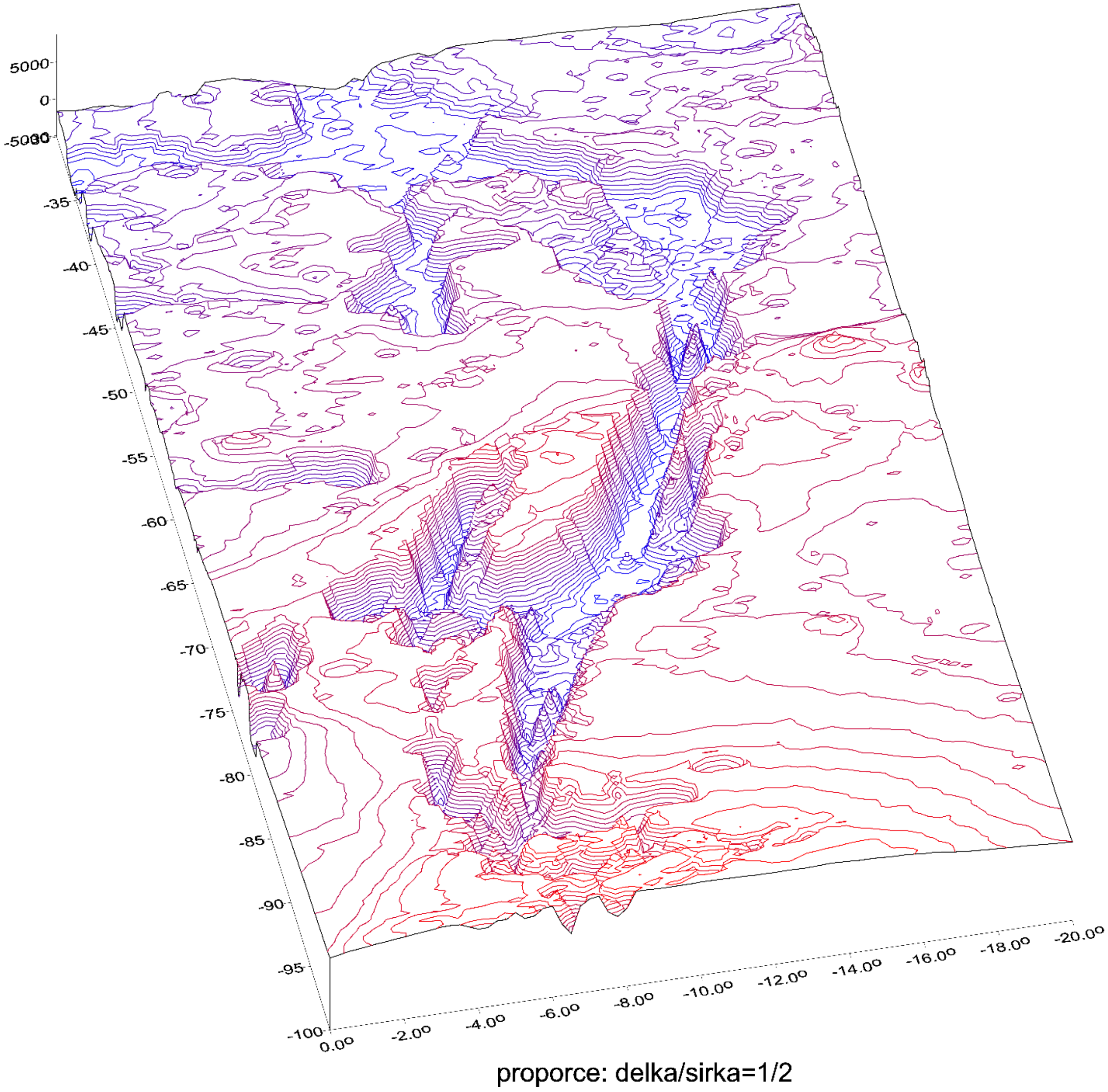

5000
0
-5000
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
proporce: delka/sirka=1/2

Fig. S3: 103

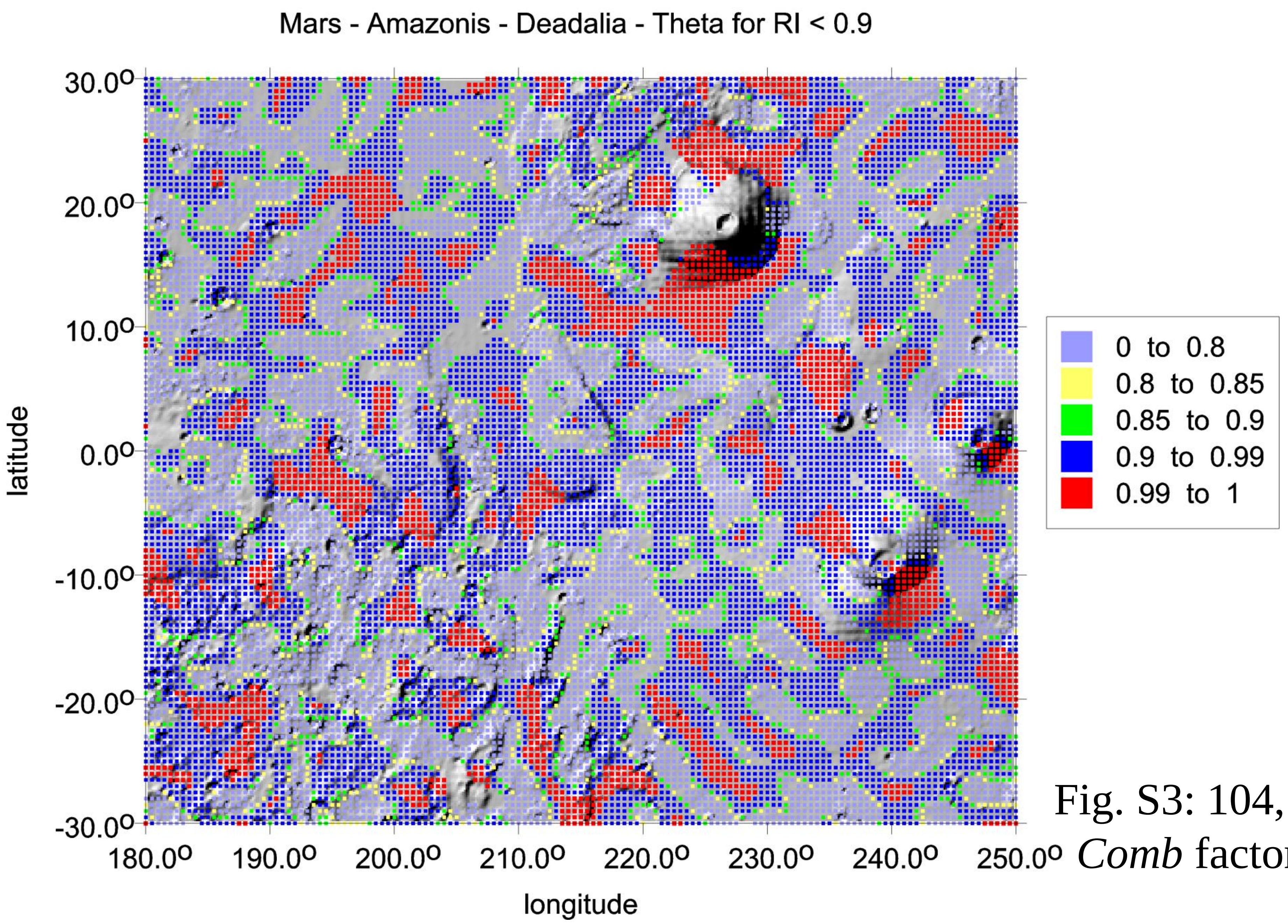


Fig. S3: 104, θ *Comb* factor

THE END