An observational study of the response of the thermosphere of Mars to lower atmospheric dust storms

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Abstract

We examined in situ measurements of thermospheric density (120-160 km) from aerobraking accelerometers, SPICAM atmospheric profiles, and ionospheric peak from Mariner 9 and MGS. Ionospheric peak altitudes are a useful diagnostic as they indicate the height of a particular thermospheric pressure level. We find that:

(1) Thermospheric conditions can be perturbed by dust storms outside the classical “dust storm season” of Ls=180^{o}-360^{o}.

(2) The thermospheric regions affected by even a small dust event can include nearly all latitudes.

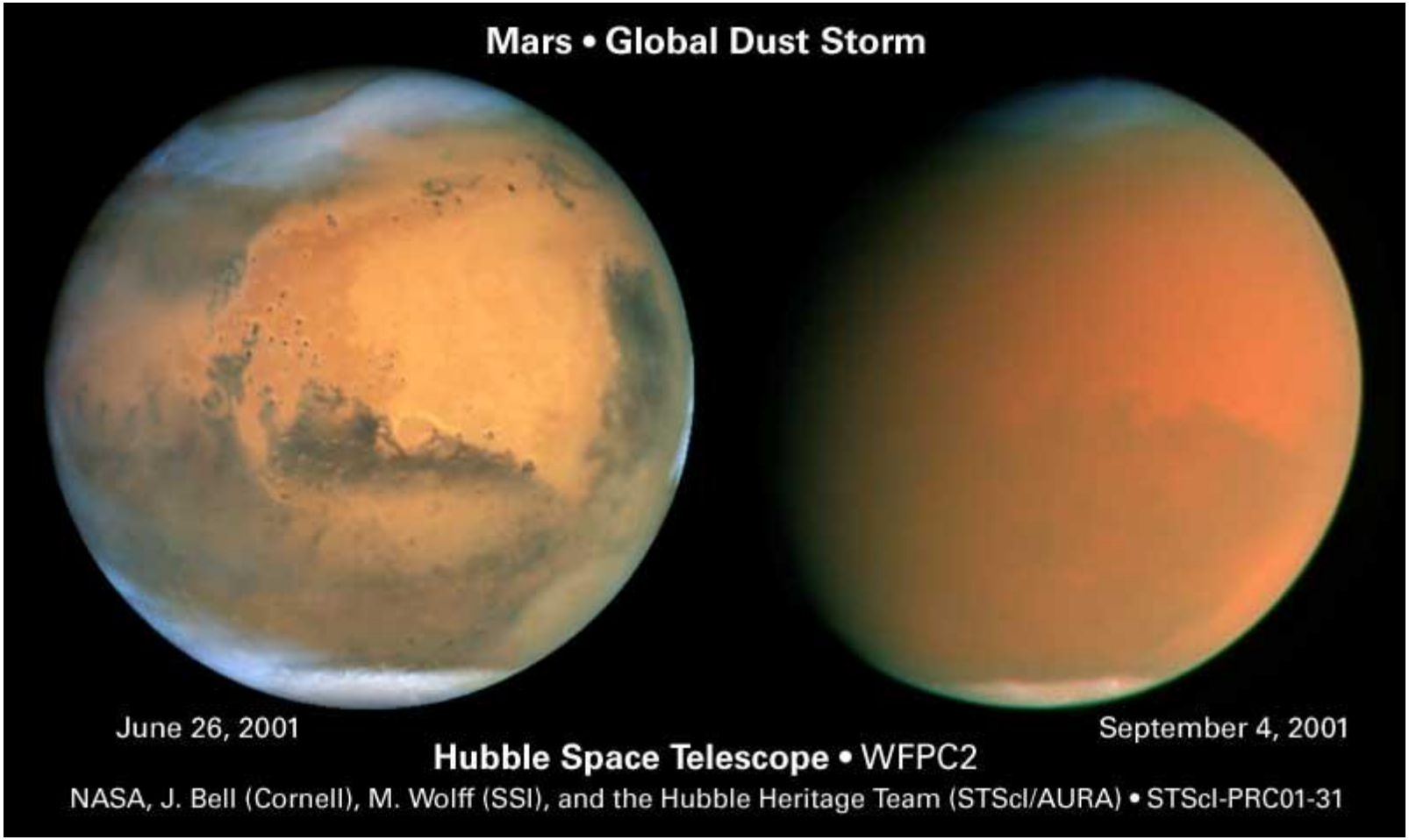
(3) Atmospheric temperatures can be affected by dust storms at altitudes as high as 100 km.

(4) The thermosphere can respond to a distant dust event on timescales of a few days or less.

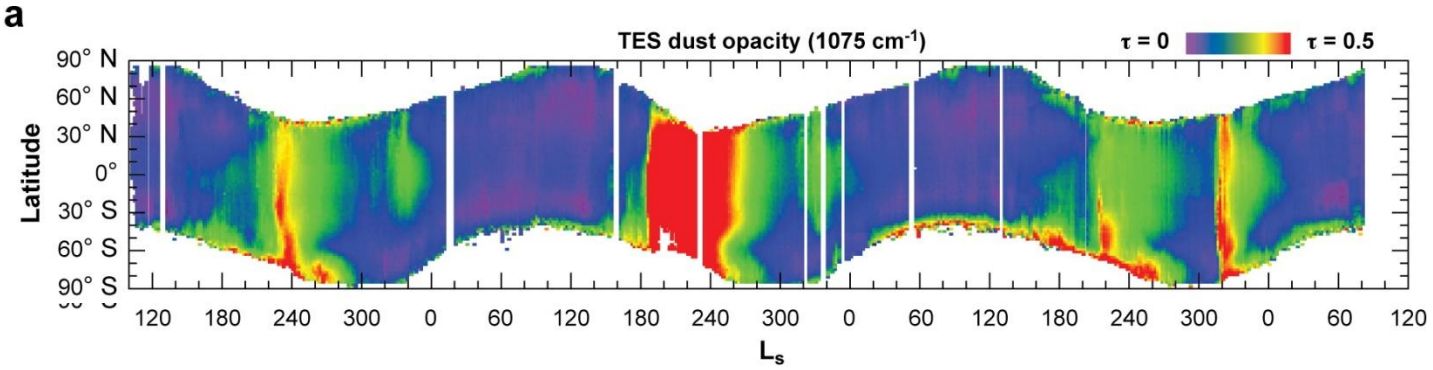
(5) The characteristic timescale for the decay of the thermospheric response to a dust event can be tens to one hundred days, and it may differ from the corresponding timescale for the lower atmosphere.

(6) Average thermospheric densities can change by factors of a few during mere regional dust storms and an order of magnitude change is possible for the largest storms. These are general trends; individual density measurements may be greater than suggested by a general trend by a factor of two due to the intrinsic variability of the thermosphere.

HST view of dusty Mars



MGS TES dust opacities (MY 24-27)



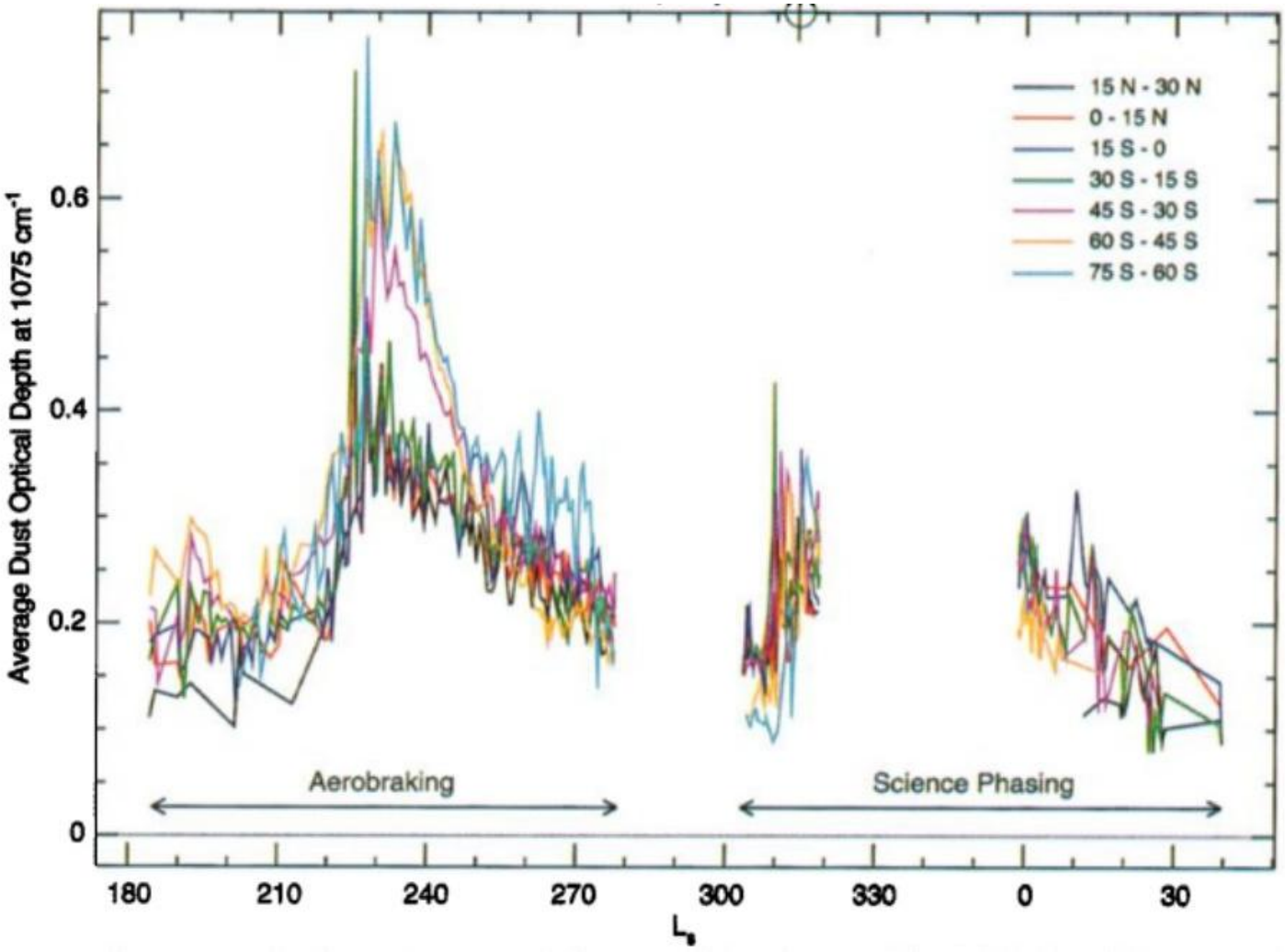
Smith MD. 2008.
Annu. Rev. Earth Planet. Sci. 36:191–219.

Major dust events are most common at Ls=180^0-360^0.

Effects on the lower atmosphere are well known

What are the effects on the upper atmosphere?

Dust opacity during Noachis storm

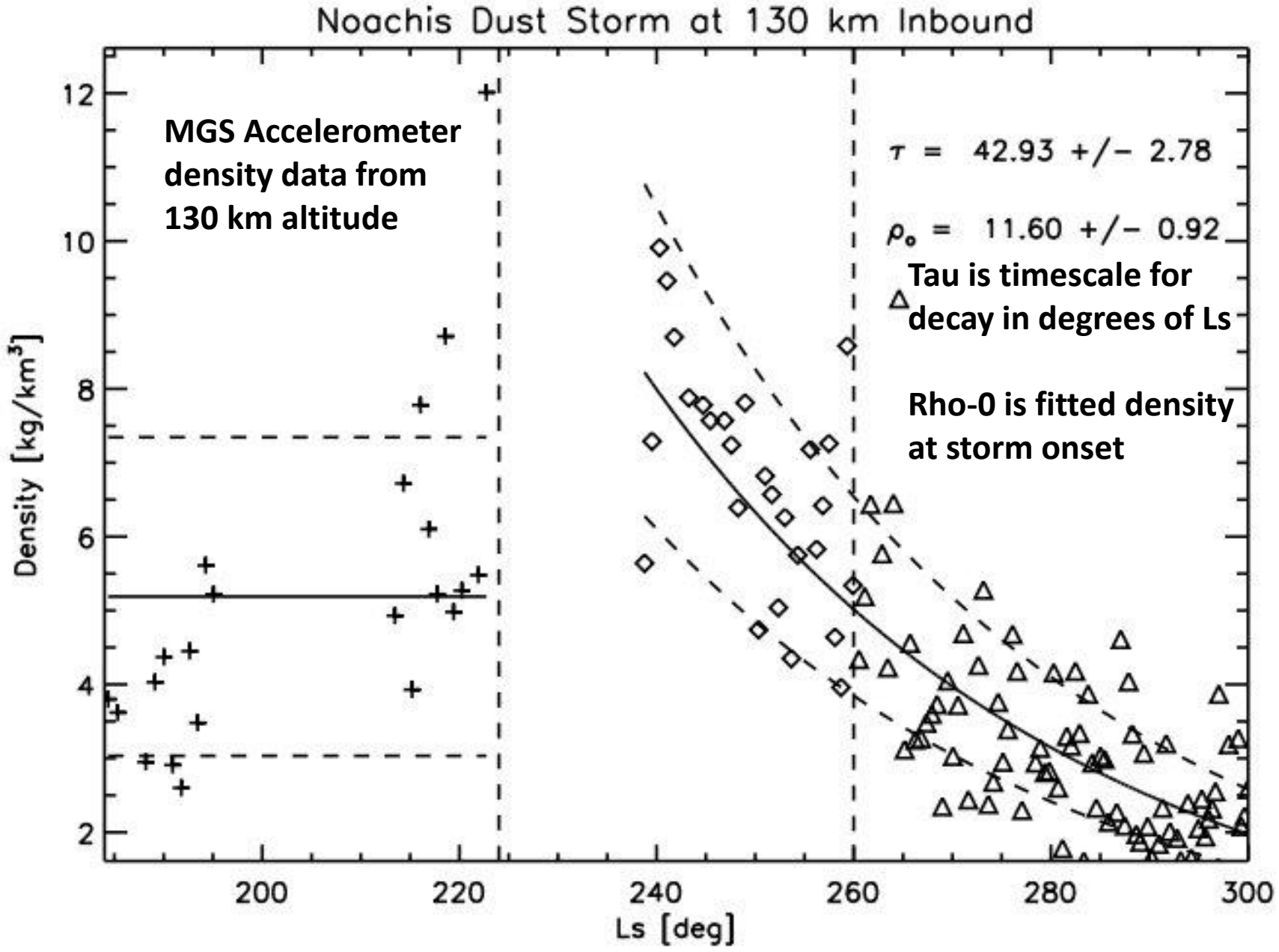


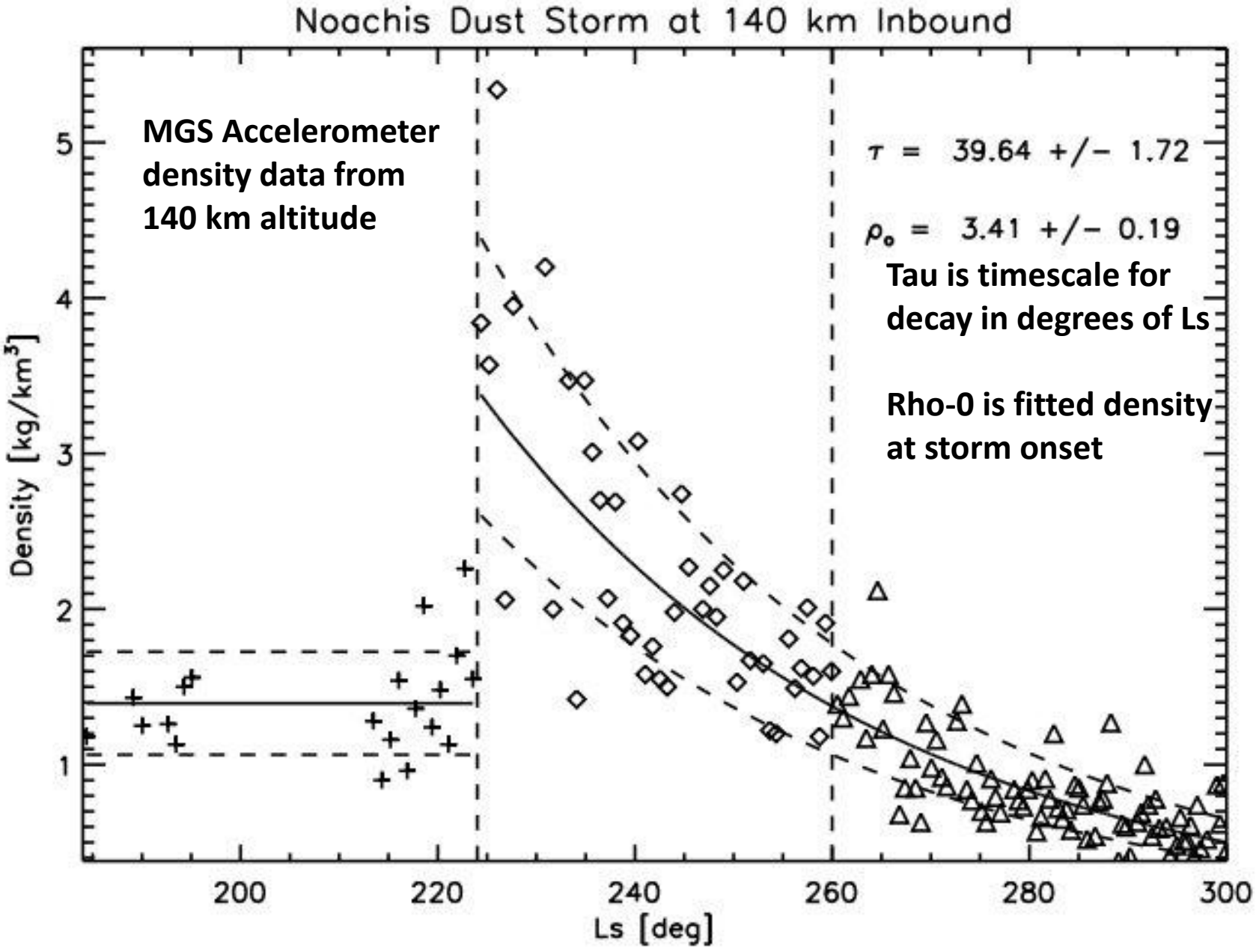
A moderate dust storm occurred at <u>southern</u> latitudes during MGS aerobraking

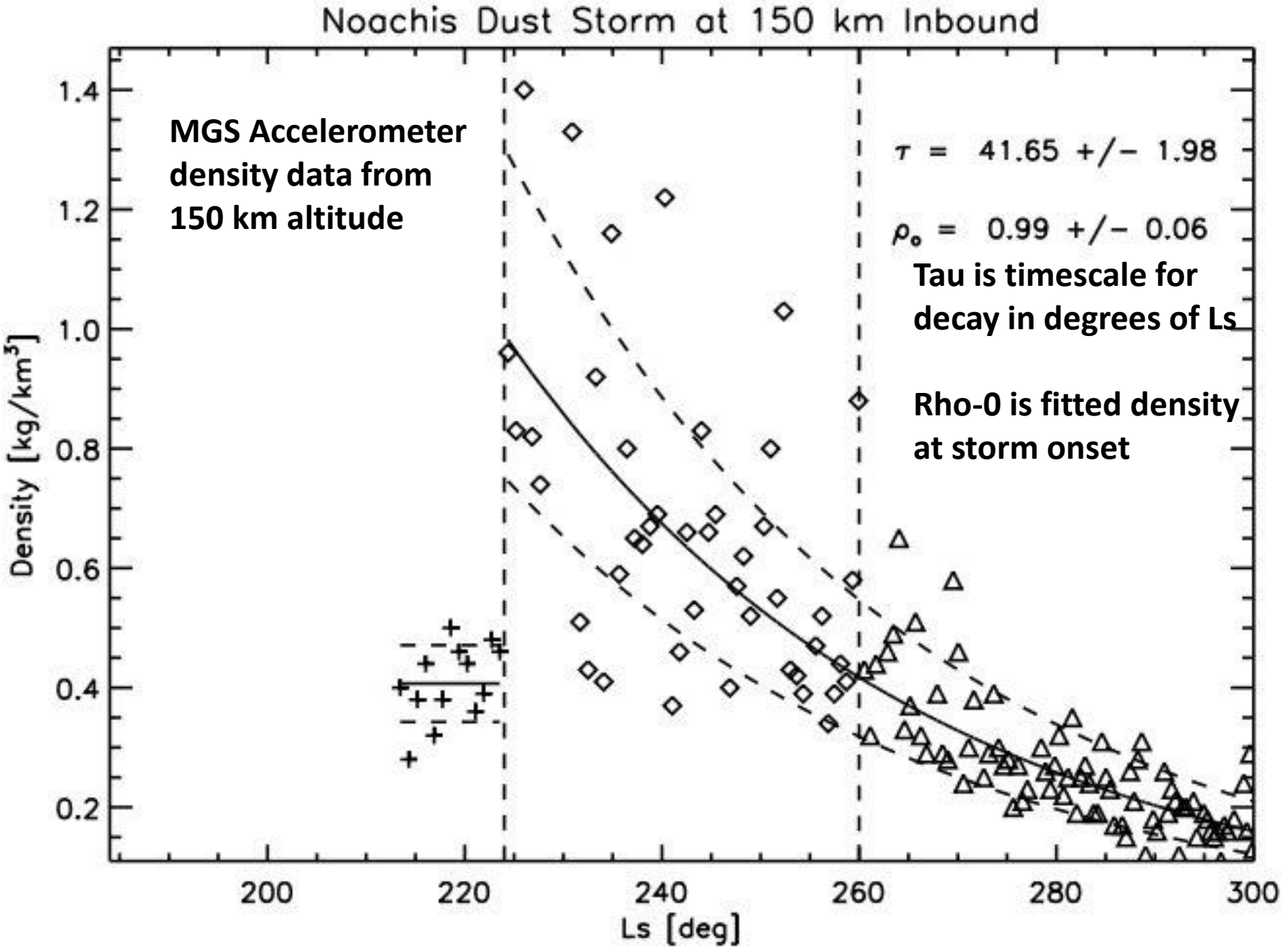
This adversely affected aerobraking operations

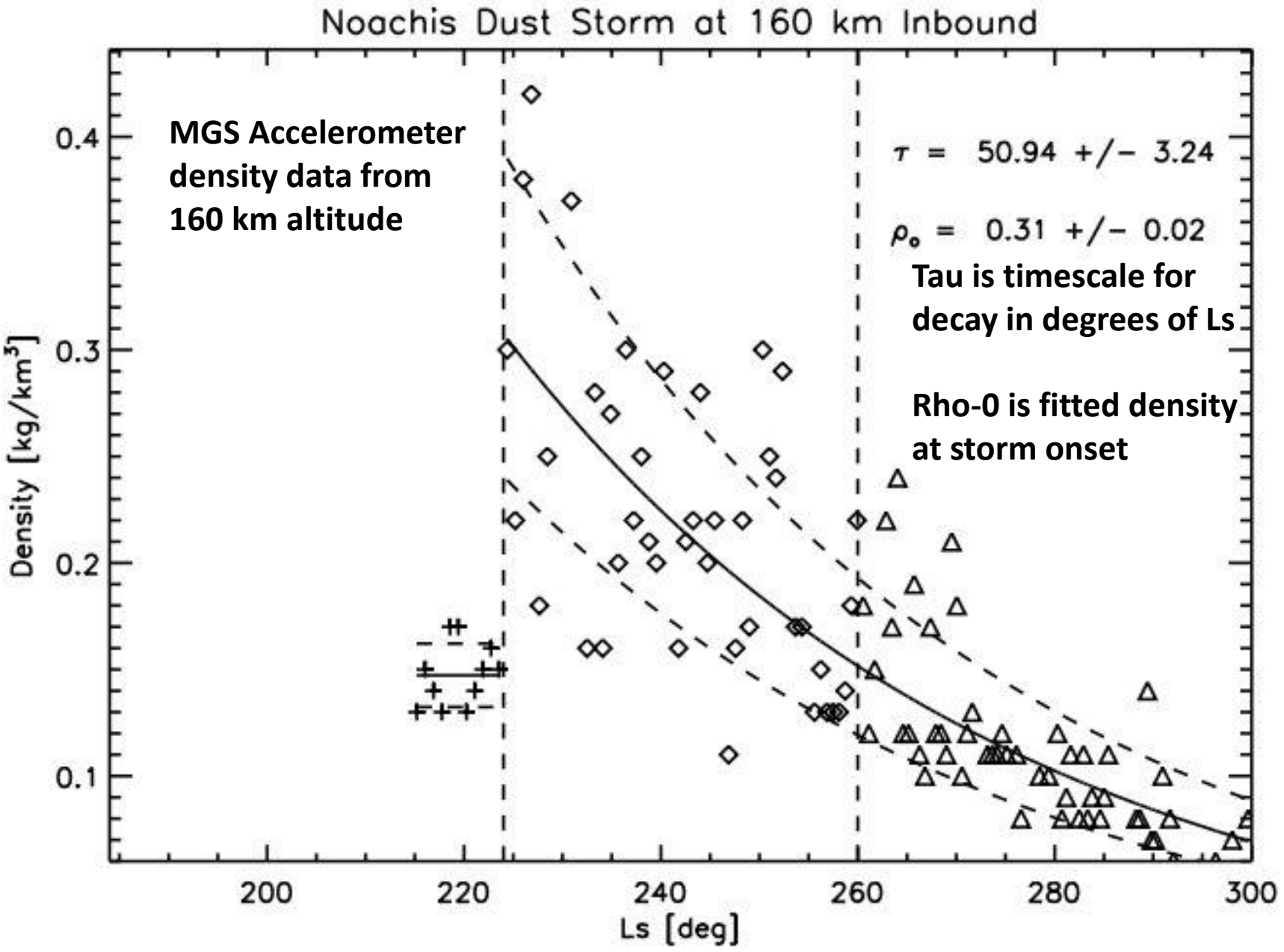
Conversely, that meant atmospheric density data were available from these times

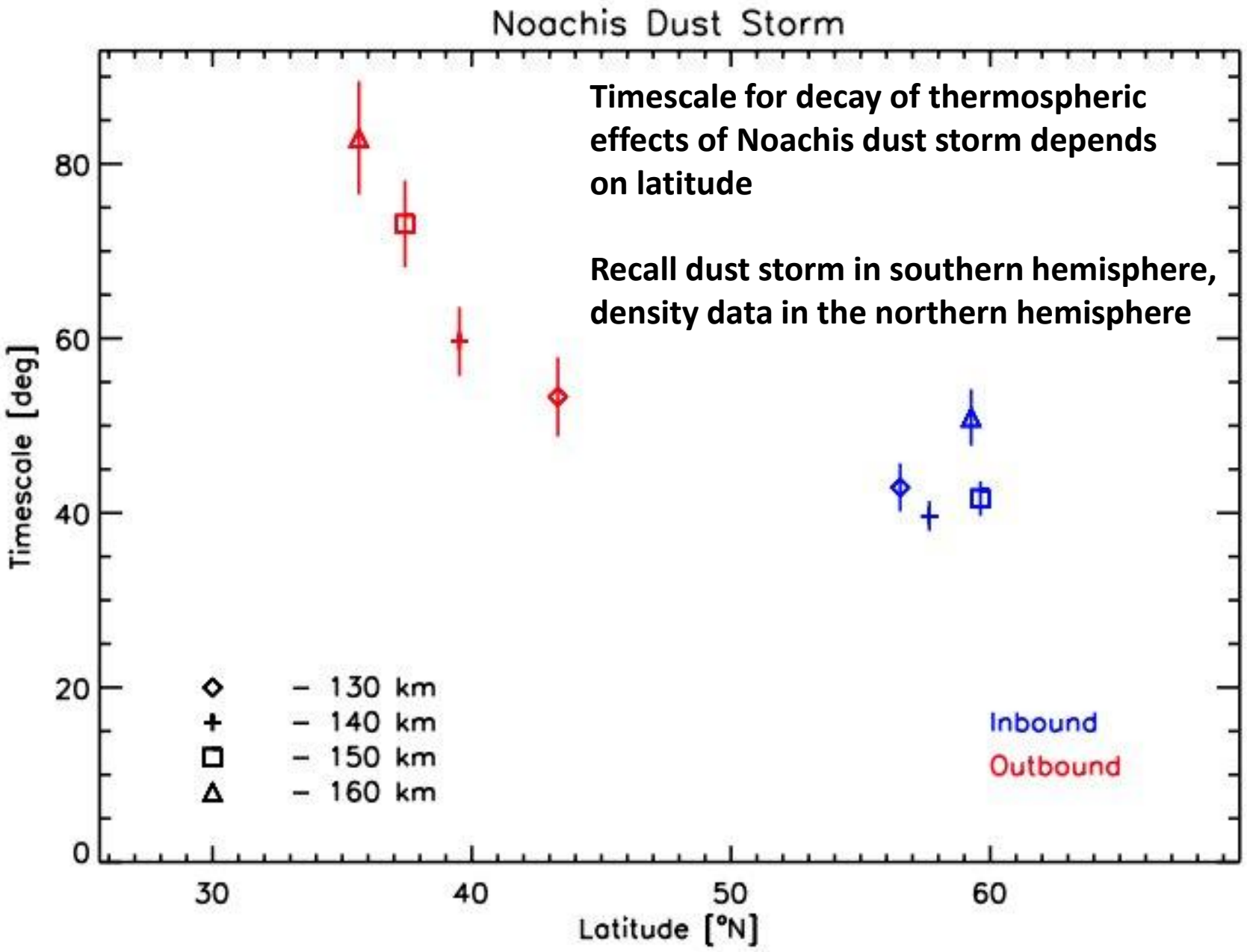
MGS TES data from MY 23-24

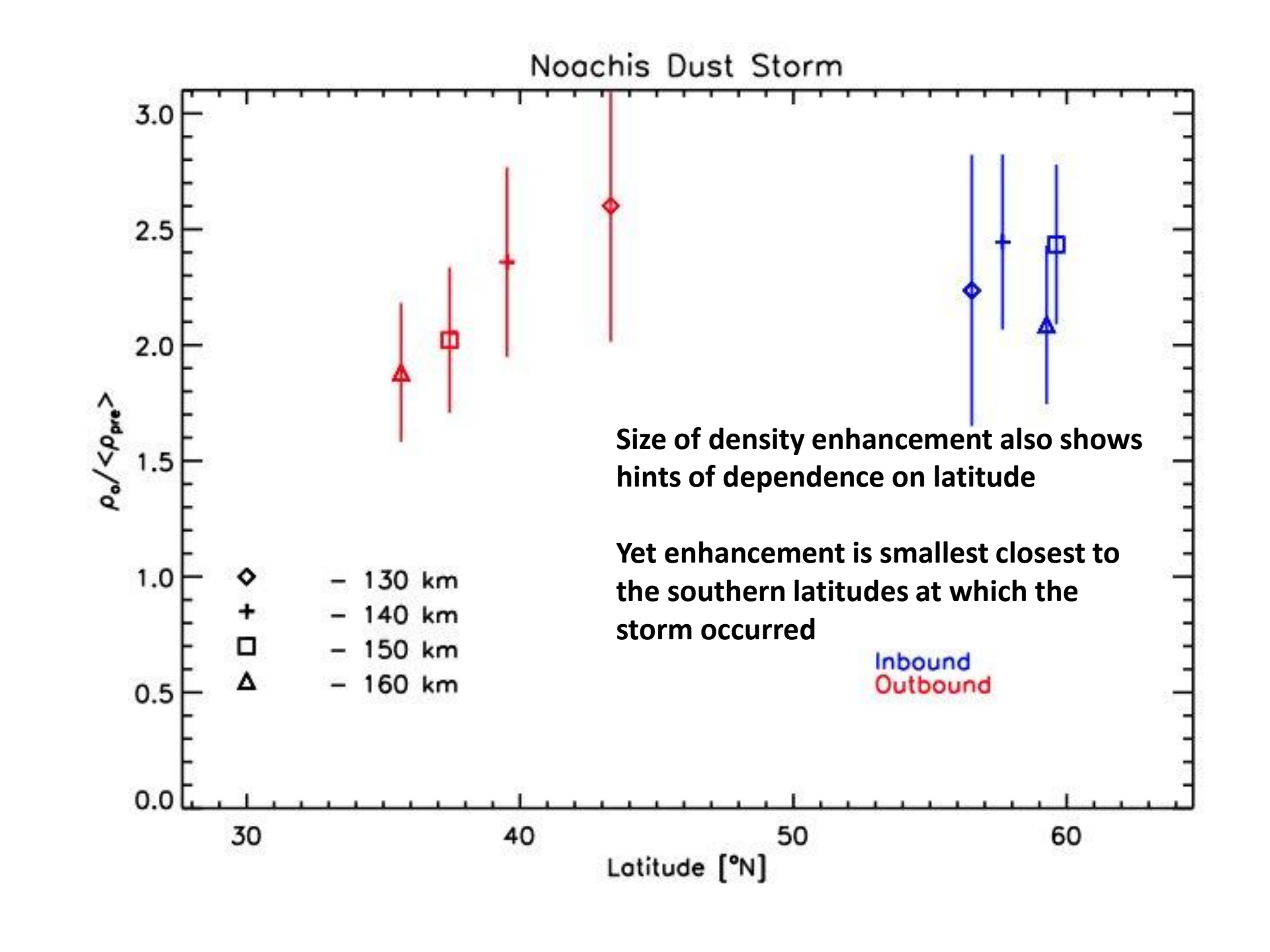

Noachis Dust Storm at 130 km Inbound
MGS Accelerometer density data from 130 km altitude
τ = 42.93 +/- 2.78
ρ₀ = 11.60 +/- 0.92
Tau is timescale for decay in degrees of Ls
Rho-0 is fitted density at storm onset
Density [kg/km³]
Ls [deg]
12
10
8
6
4
2
200
220
240
260
280
300


Noachis Dust Storm at 140 km Inbound
MGS Accelerometer density data from 140 km altitude
τ = 39.64 +/- 1.72
ρ₀ = 3.41 +/- 0.19
Tau is timescale for decay in degrees of Ls
Rho-0 is fitted density at storm onset
Density [kg/km³]
Ls [deg]
1
2
3
4
5
200
220
240
260
280
300

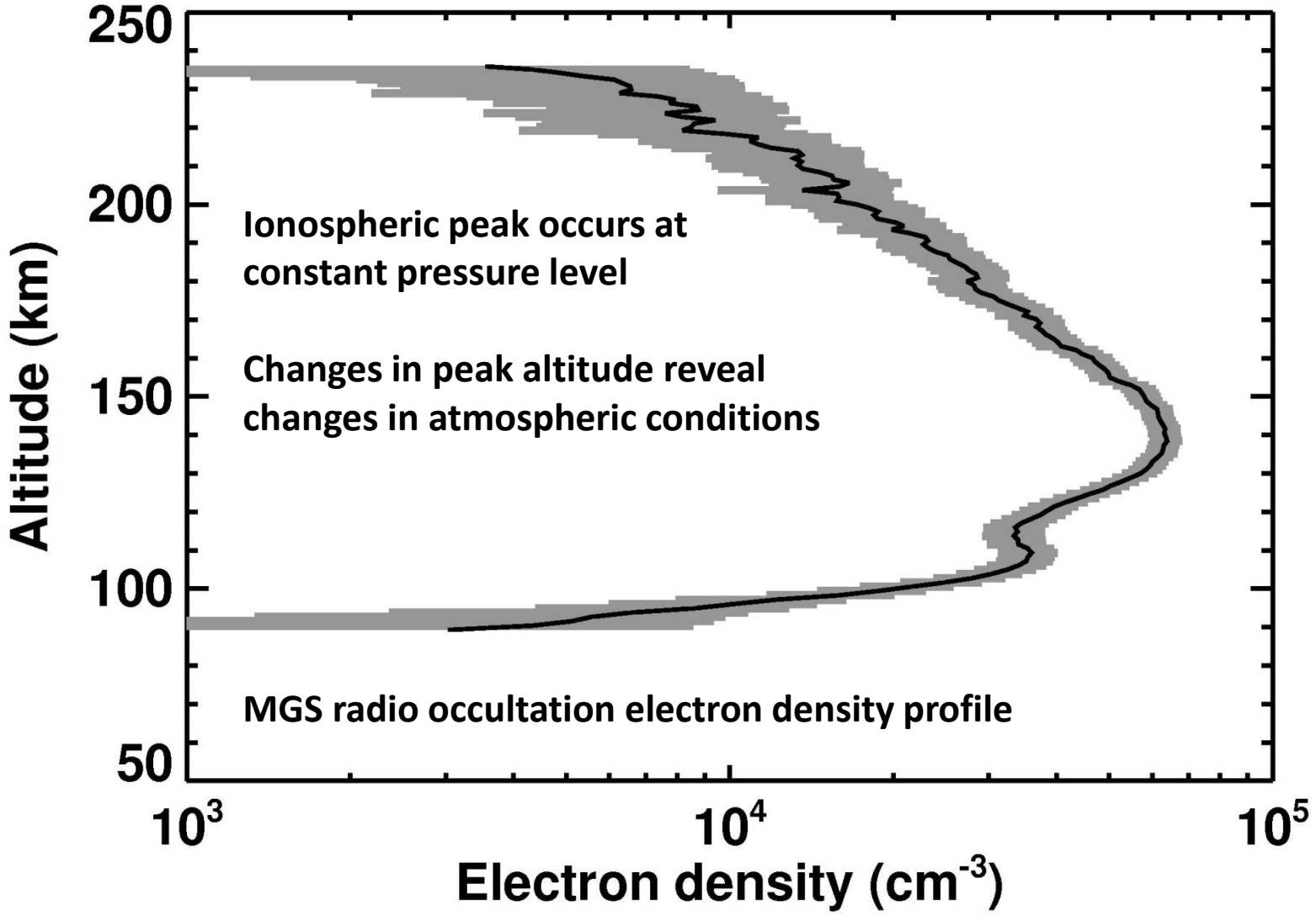

Noachis Dust Storm at 150 km Inbound
MGS Accelerometer density data from 150 km altitude
τ = 41.65 +/− 1.98
ρ₀ = 0.99 +/− 0.06
Tau is timescale for decay in degrees of Ls
Rho-0 is fitted density at storm onset
Density [kg/km³]
Ls [deg]
1.4
1.2
1.0
0.8
0.6
0.4
0.2
200
220
240
260
280
300

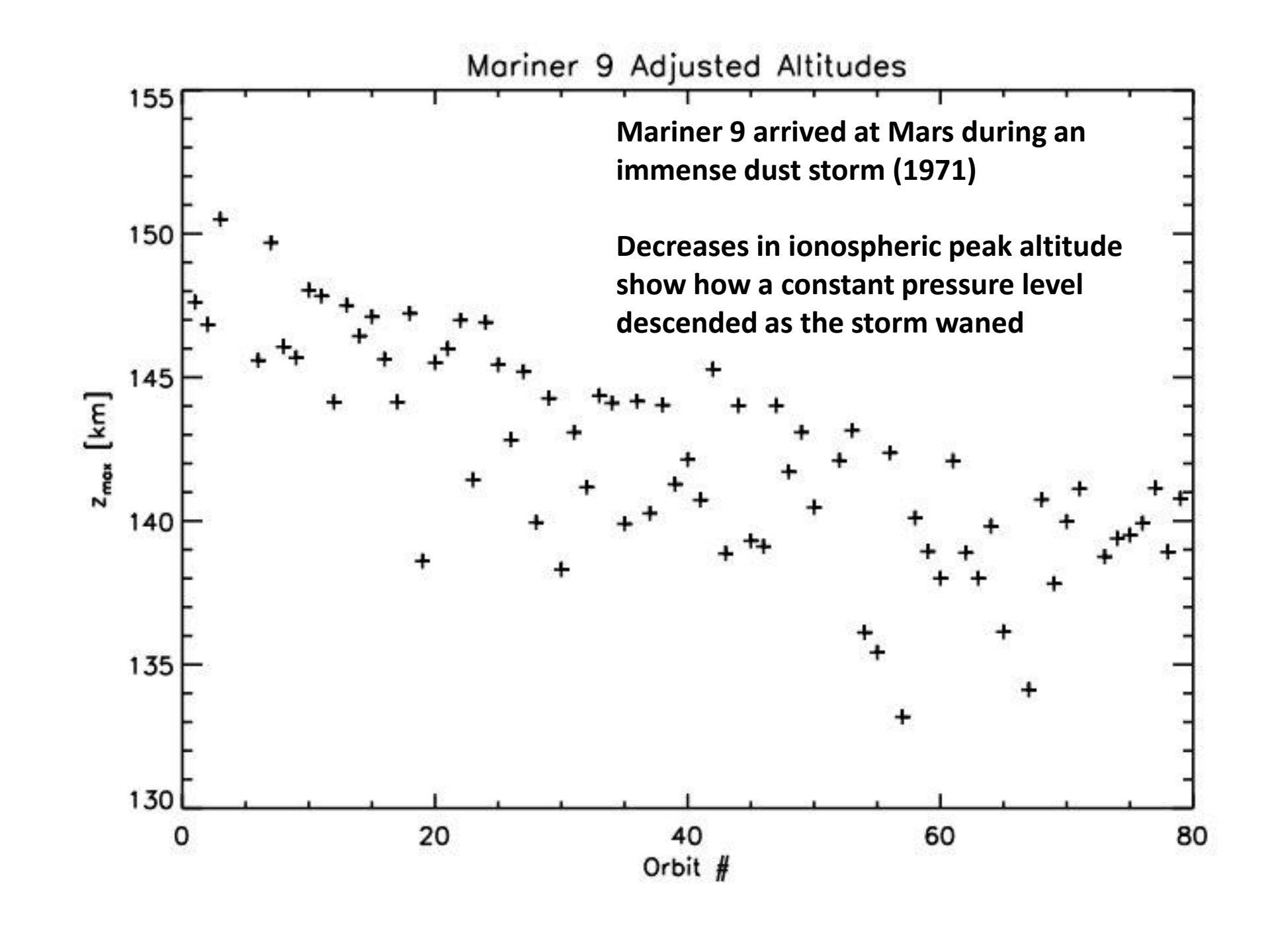

Noachis Dust Storm at 160 km Inbound
MGS Accelerometer density data from 160 km altitude
τ = 50.94 +/− 3.24
ρ₀ = 0.31 +/− 0.02
Tau is timescale for decay in degrees of Ls
Rho-0 is fitted density at storm onset
Density [kg/km³]
0.4
0.3
0.2
0.1
200
220
240
260
280
300
Ls [deg]

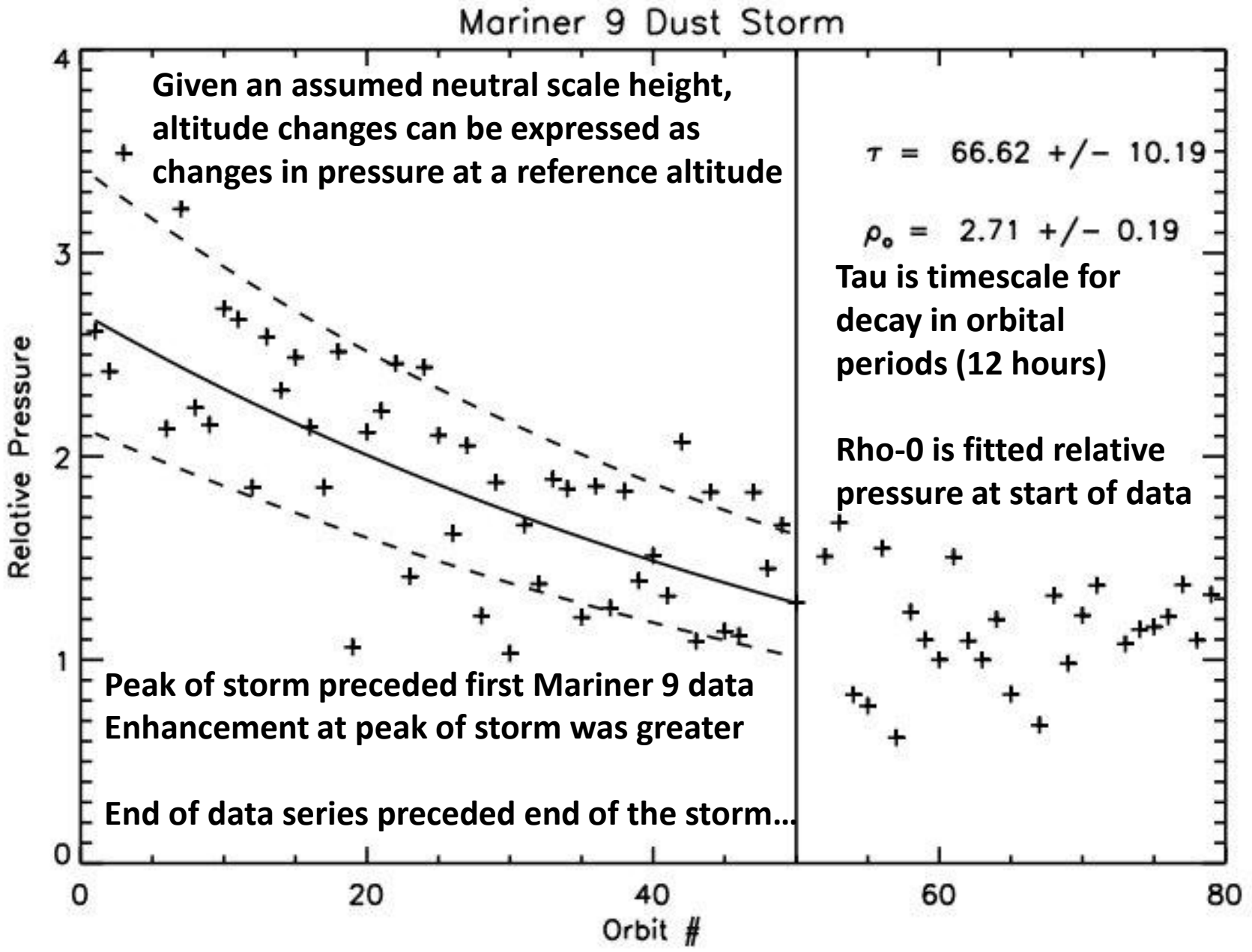

Noachis Dust Storm
Timescale for decay of thermospheric effects of Noachis dust storm depends on latitude
Recall dust storm in southern hemisphere, density data in the northern hemisphere
Timescale [deg]
Latitude [°N]
0
20
40
60
80
30
40
50
60
– 130 km
– 140 km
– 150 km
– 160 km
Inbound
Outbound

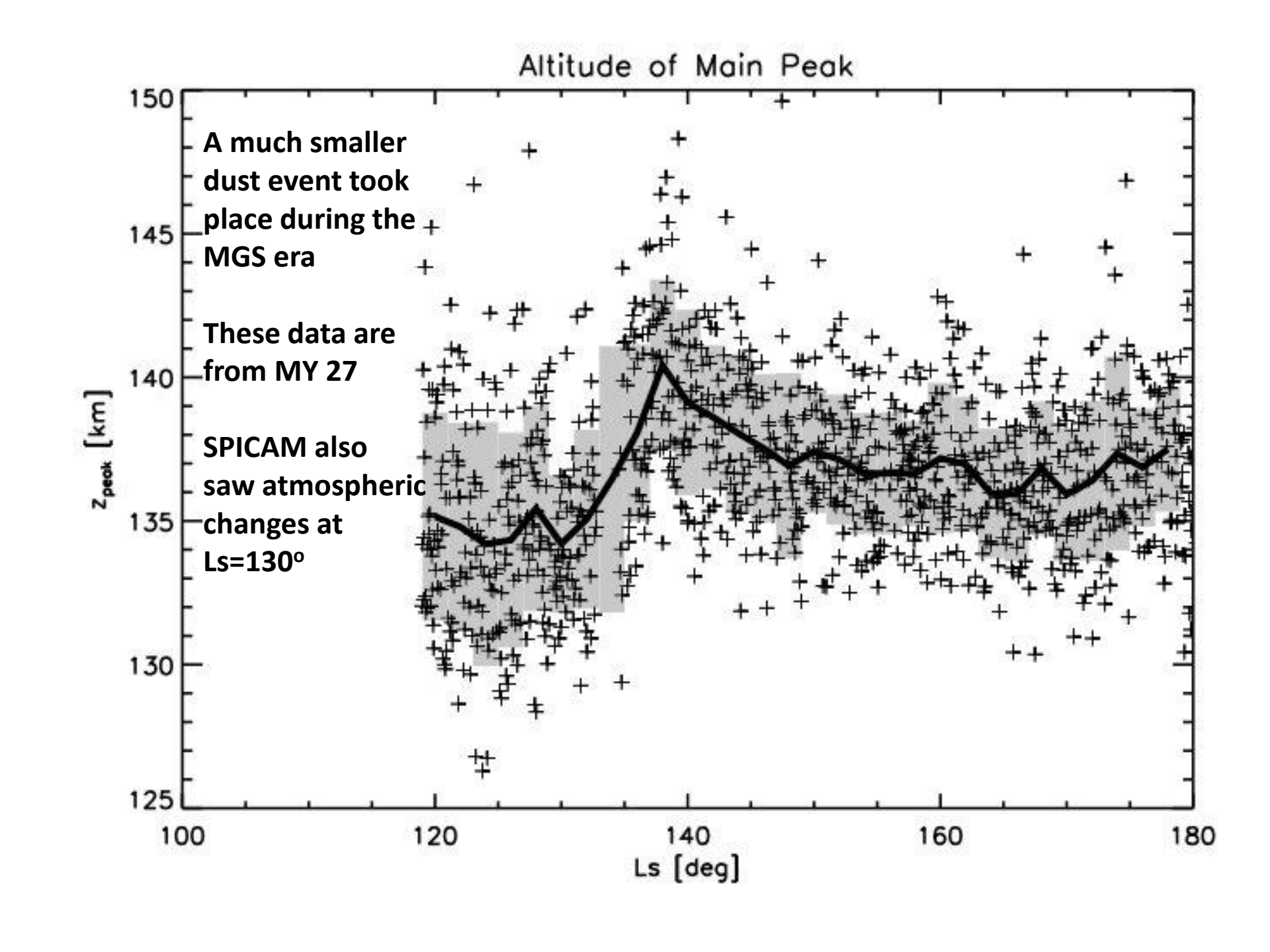

Noachis Dust Storm
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$\rho_o/\langle\rho_{pre}\rangle$
30
40
50
60
Latitude [°N]
– 130 km
– 140 km
– 150 km
– 160 km
Size of density enhancement also shows hints of dependence on latitude
Yet enhancement is smallest closest to the southern latitudes at which the storm occurred
Inbound
Outbound

Ionospheric electron density profile

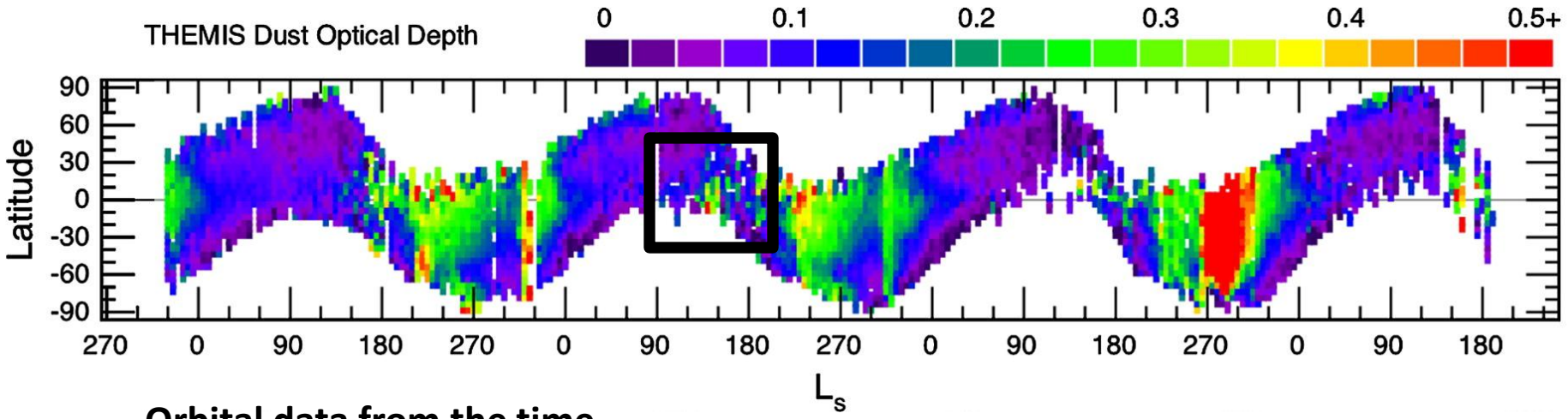



Mariner 9 Adjusted Altitudes
Mariner 9 arrived at Mars during an immense dust storm (1971)
Decreases in ionospheric peak altitude show how a constant pressure level descended as the storm waned
155
150
145
140
135
130
z_{max} [km]
0
20
40
60
80
Orbit #


Mariner 9 Dust Storm
Given an assumed neutral scale height, altitude changes can be expressed as changes in pressure at a reference altitude
τ = 66.62 +/− 10.19
ρ₀ = 2.71 +/− 0.19
Tau is timescale for decay in orbital periods (12 hours)
Rho-0 is fitted relative pressure at start of data
Peak of storm preceded first Mariner 9 data
Enhancement at peak of storm was greater
End of data series preceded end of the storm…
Relative Pressure
Orbit #
0
1
2
3
4
0
20
40
60
80


Altitude of Main Peak
A much smaller dust event took place during the MGS era
These data are from MY 27
SPICAM also saw atmospheric changes at Ls=130°
150
145
140
135
130
125
100
120
140
160
180
Ls [deg]
z_peak [km]

Odyssey THEMIS dust opacities (MY 25-29)



Orbital data from the time of these MGS ionospheric data show only small signatures of dust events, yet peak altitude increases by 5 km (>0.5 H)

MGS ionospheric data are north of 60^0N while THEMIS data show no dust north of 20^0N

Spirit Mini-TES shows opacity increased to 0.8 at Ls=130^0

Similar Opportunity data show opacity increased to 0.6

Conclusions

Dust storms could affect MAVEN operations. MAVEN has no way to detect and monitor lower atmospheric dust events.

(1) Thermospheric conditions can be perturbed by dust storms outside the classical "dust storm season" of Ls=180^{o}-360^{o}.

(2) The thermospheric regions affected by even a small dust event can include nearly all latitudes.

(3) Atmospheric temperatures can be affected by dust storms at altitudes as high as 100 km.

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