Simplifying the martian carbon dioxide cycle: An empirical method for predicting surface pressure

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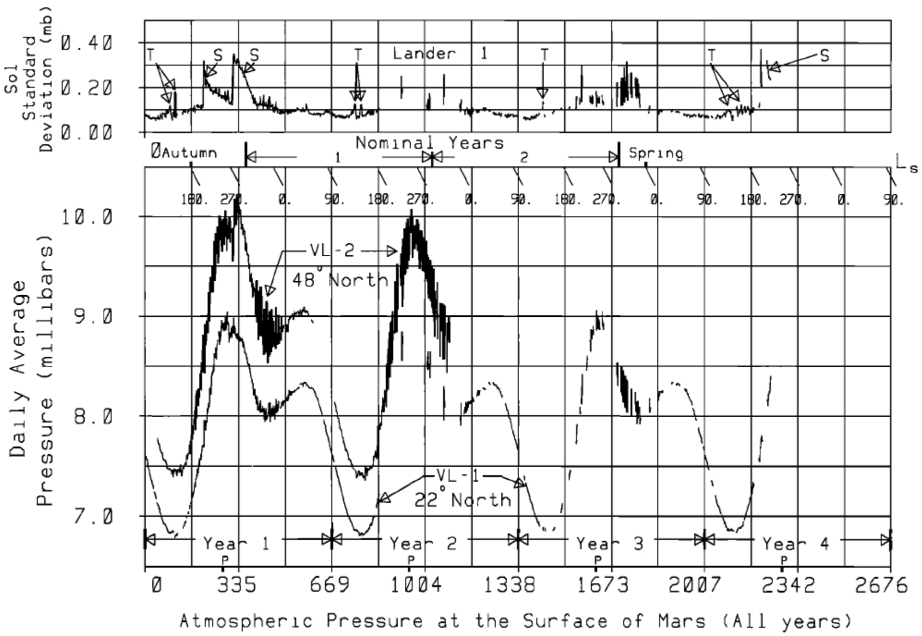
Background



Viking Lander pressure data
Fig 1 of Tillman et al. (1993)

- Martian surface pressure exhibits significant spatial and temporal variations
- Accurate predictions of surface pressure have a range of applications, including
  - Polar energy balance studies
  - Geodetic studies of rotation state and gravity field
  - Derivation of absolute altitude scales for T(p) profiles
  - Landing site evaluations
- Objective is to find a simple empirical expression that can predict diurnal-mean surface pressure
  - Ease of application, transparency desired
  - Minimize use of complicated models
  - Validate against observations
- Optimize for MSL landing conditions (Ls=120 to 180, z<+1 km, 45S to 45N), but desire adequate predictions for all conditions

Available Datasets

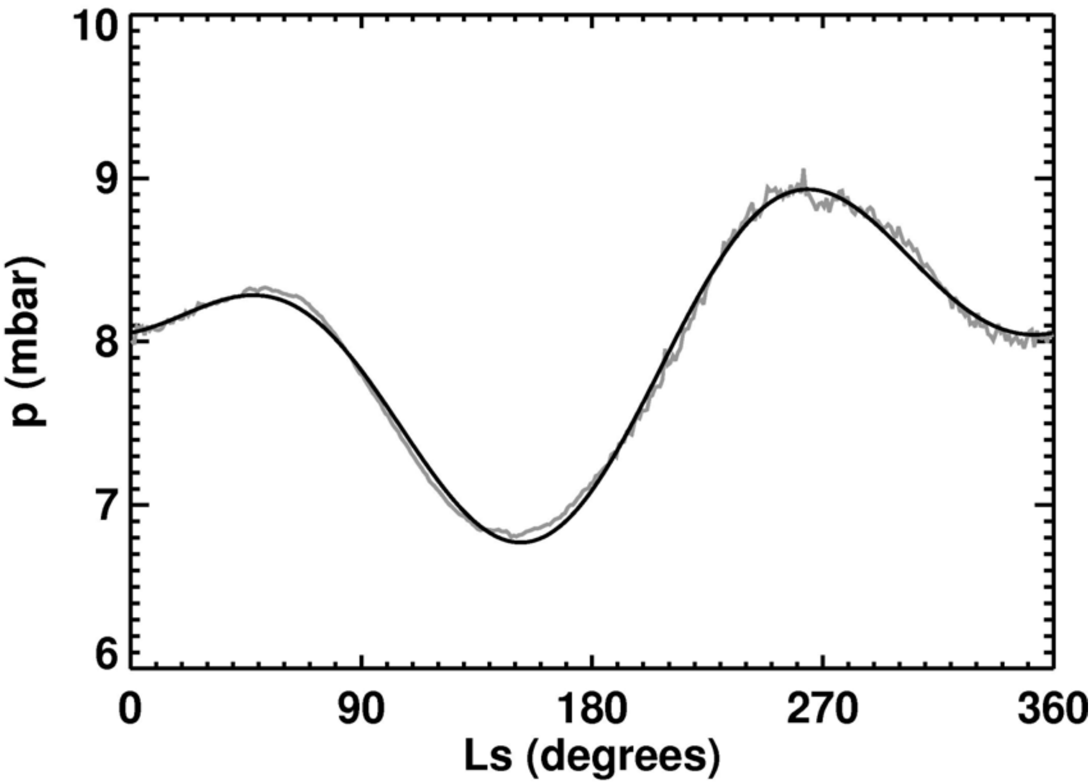
- <u>LANDERS</u>
- VL1
  - Multiple years, coarse digitization, 22N
- VL2
  - Almost one year, coarse digitization, 48N
- MPF
  - Ls=142-188, same elevation as VL1, systematic error of about 0.1 mbar, 19N
- PHX
  - Ls=76-151, 68N, large and precise dataset
  - Data from Ls=120 to 151 not yet incorporated into analysis

- <u>RADIO OCCULTATIONS</u>
- Mariner 9
  - Apparent inconsistencies of 10%
- VO1 and VO2
  - Barely 20 pressures reported
- MGS
  - 21243 profiles, including 297 at Ls=120-180, z<+1 km, latitude=45S to 45N
  - Extrapolate p(r) to MOLA surface and assign MOLA altitude
- MEX
  - 484 profiles, only 5 at Ls=120-180, z<+1 km, latitude=45S to 45N

Most useful datasets are: VL1 for seasonal cycle, MGS for validation and testing,

Goal is: Simple expression for DIURNAL MEAN Ps as function of season and altitude.

Approach



Grey line is 360 diurnal mean surface pressure from VL1

Black line is wave-2 fit

Parameter	VL1
p_0 (mbar)	7.9723740
s_1	-0.068622849
c_1	0.060390972
s_2	0.044663631
c_2	-0.050183946

Use expression below to predict surface pressure, Ps
zVL1 = -3.63 km
Constant and uniform H0 needed (found on next slide)

$$p_s = p_{0,VL1} \exp\left(-\left(z - z_{VL1}\right)/H_0\right) \times$$ Eqn 1

$$\left(1 + s_{1,VL1}\sin\left(1L_s\right) + c_{1,VL1}\cos\left(1L_s\right) + s_{2,VL1}\sin\left(2L_s\right) + c_{2,VL1}\cos\left(2L_s\right)\right)$$

Optimize with Delta metric, where Delta = (p-pred – p-meas) / p-meas

Finding H0 from MGS

- Quickly find that H0<10 km and H0>12 km have problems at low and high altitudes
- MGS measurements at z<+1 km and 45S to 45N divide neatly into seven Ls blocks

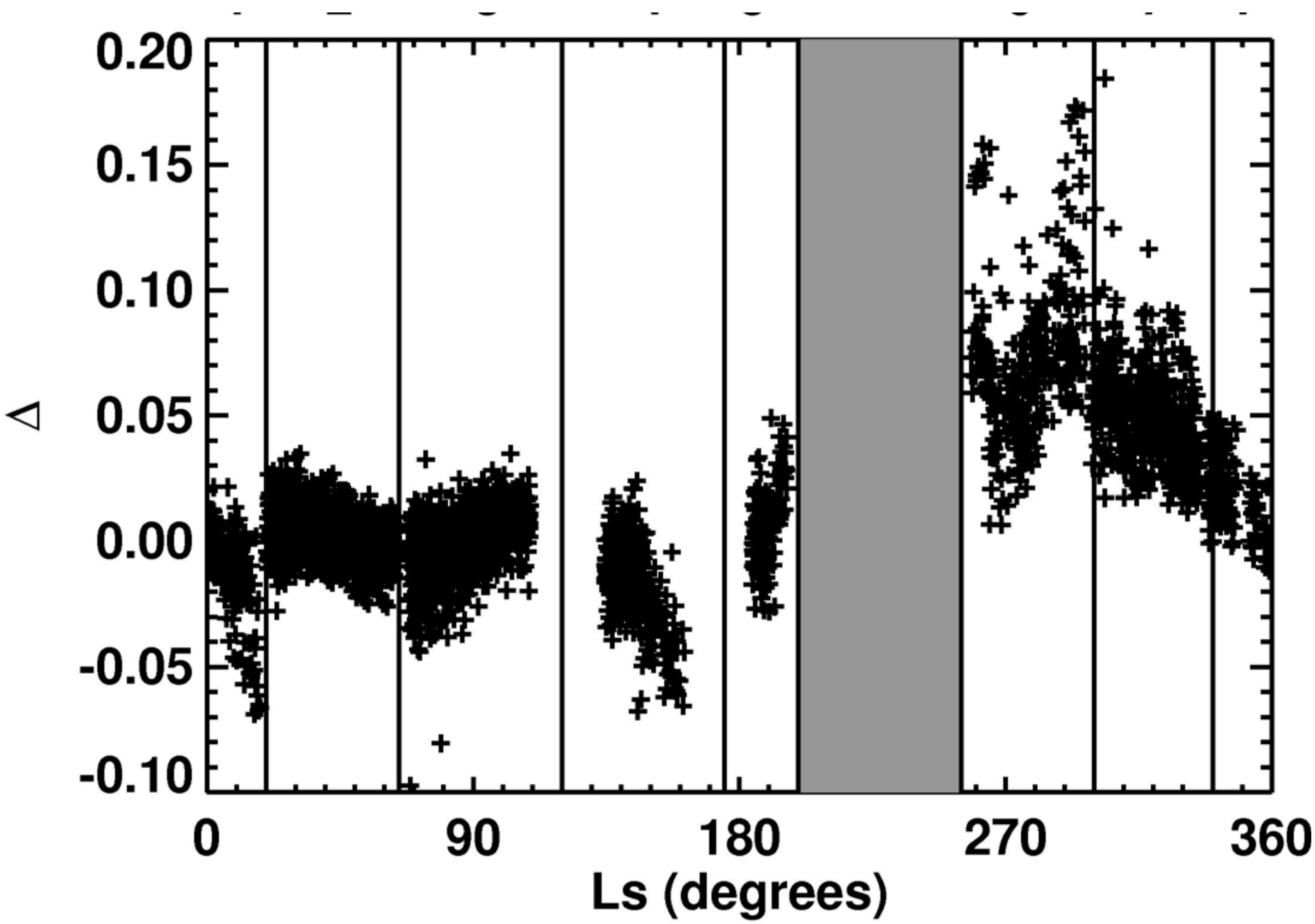
L_s range	N	$\overline{z}$ (km)	H_0 (km)	$\overline{\Delta}$	S. D. of Δ
340°–20°	293	-1.3	10.0	-2.1E-02	3.2E-02
			10.5	-9.9E-03	2.5E-02
			11.0	1.5E-04	2.3E-02
			11.5	9.5E-03	2.6E-02
			12.0	1.8E-02	3.2E-02
20°–65°	824	-2.9	10.0	-4.1E-03	1.5E-02
			10.5	-8.5E-04	1.0E-02
			11.0	2.2E-03	1.0E-02
			11.5	5.1E-03	1.4E-02
			12.0	7.7E-03	1.9E-02
65°–120°	740	-2.2	10.0	-1.4E-02	1.9E-02
			10.5	-7.2E-03	1.5E-02
			11.0	-1.1E-03	1.4E-02
			11.5	4.6E-03	1.6E-02
			12.0	9.9E-03	1.9E-02
120°–175°	297	-1.7	10.0	-3.4E-02	2.6E-02
			10.5	-2.5E-02	2.1E-02
			11.0	-1.7E-02	1.8E-02
			11.5	-9.7E-03	1.7E-02
			12.0	-2.9E-03	1.8E-02

L_s range	N	$\overline{z}$ (km)	H_0 (km)	$\overline{\Delta}$	S. D. of Δ
175°–200°	127	-2.8	10.0	-2.2E-04	1.9E-02
			10.5	3.7E-03	1.6E-02
			11.0	7.3E-03	1.6E-02
			11.5	1.1E-02	1.8E-02
			12.0	1.4E-02	2.1E-02
255°–300°	306	-1.0	10.0	4.8E-02	4.4E-02
			10.5	6.1E-02	3.7E-02
			11.0	7.3E-02	3.2E-02
			11.5	8.3E-02	2.9E-02
			12.0	9.4E-02	2.7E-02
300°–340°	479	-1.3	10.0	2.6E-02	2.9E-02
			10.5	3.8E-02	2.3E-02
			11.0	4.8E-02	2.0E-02
			11.5	5.8E-02	2.0E-02
			12.0	6.7E-02	2.3E-02

Optimal scale height is:

H0 = 11 km
Equivalent to T=215 K, which is reasonable

Delta vs Ls for MGS



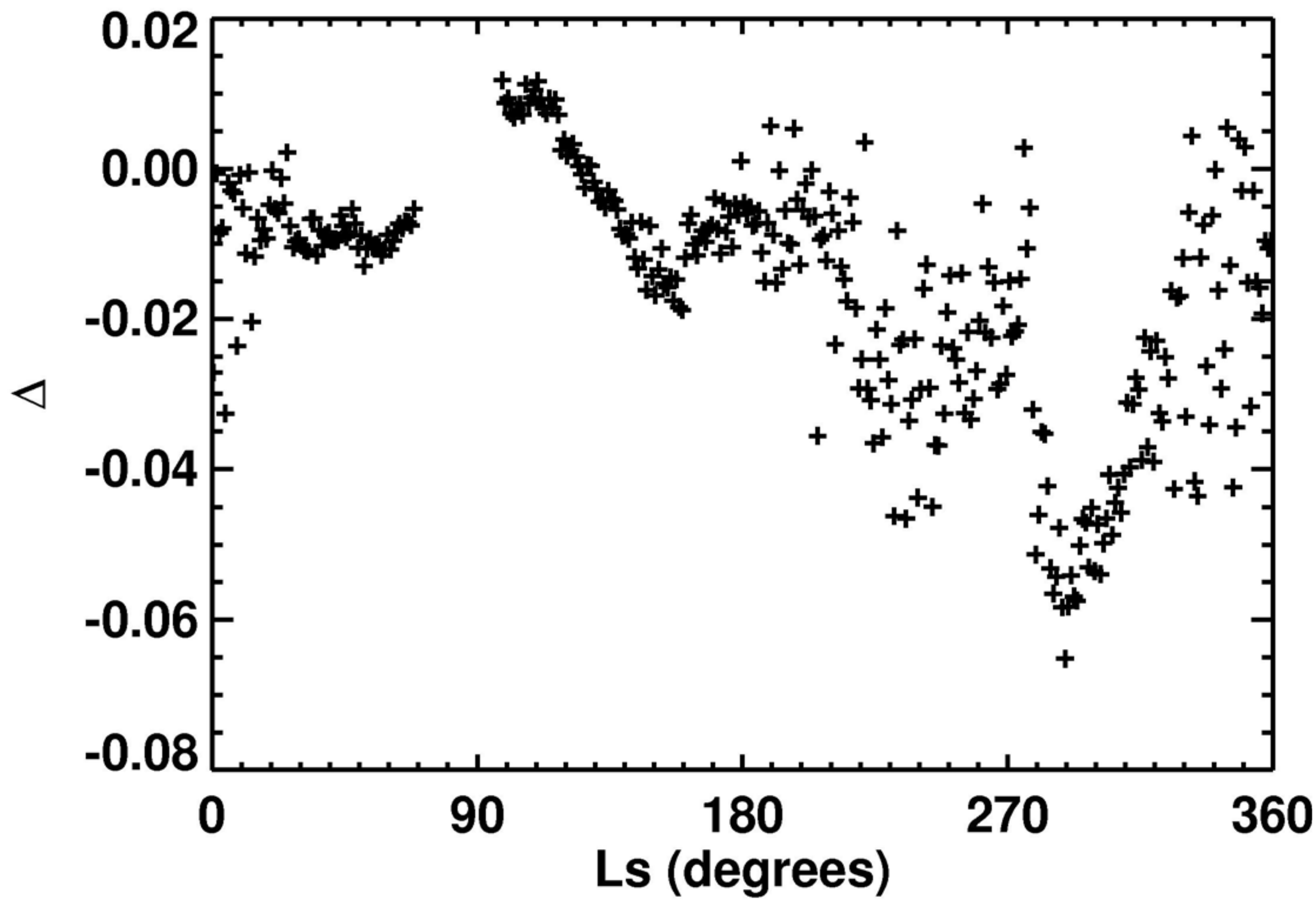
Poor predictions at Ls=255-340

OK at other seasons

Possible trend with Ls at Ls=120-175?

Only data from z<+1 km and 45S to 45N shown here

Delta vs Ls for VL2



Poor predictions at Ls=240-360

OK at other seasons

Trend with Ls at Ls=110-160, similar to MGS?

Going to wave-4 in f(Ls) fixes this trend in VL1 and VL2, but has no effect on trend in MGS

So retain wave-2 for f(Ls)

Accuracy of Predictions

Mission	$\overline{\Delta}$ (all L_s)	S. D. of Δ (all L_s)	$\overline{\Delta}$ ($L_s = 120°–180°$)	S. D. of Δ ($L_s = 120°–180°$)
VL1	2.5E-3%	0.6%	-0.4%	0.6%
VL2	6.7E-3%	1.1%	-0.4%	0.6%
MPF	2.2%	0.2%	2.2%	0.2%
PHX	-0.2%	3.0%	—	—
MGS	1.4%	3.2%	-1.7%	1.8%
MEX	0.2%	3.3%	-7.1%	7.0%

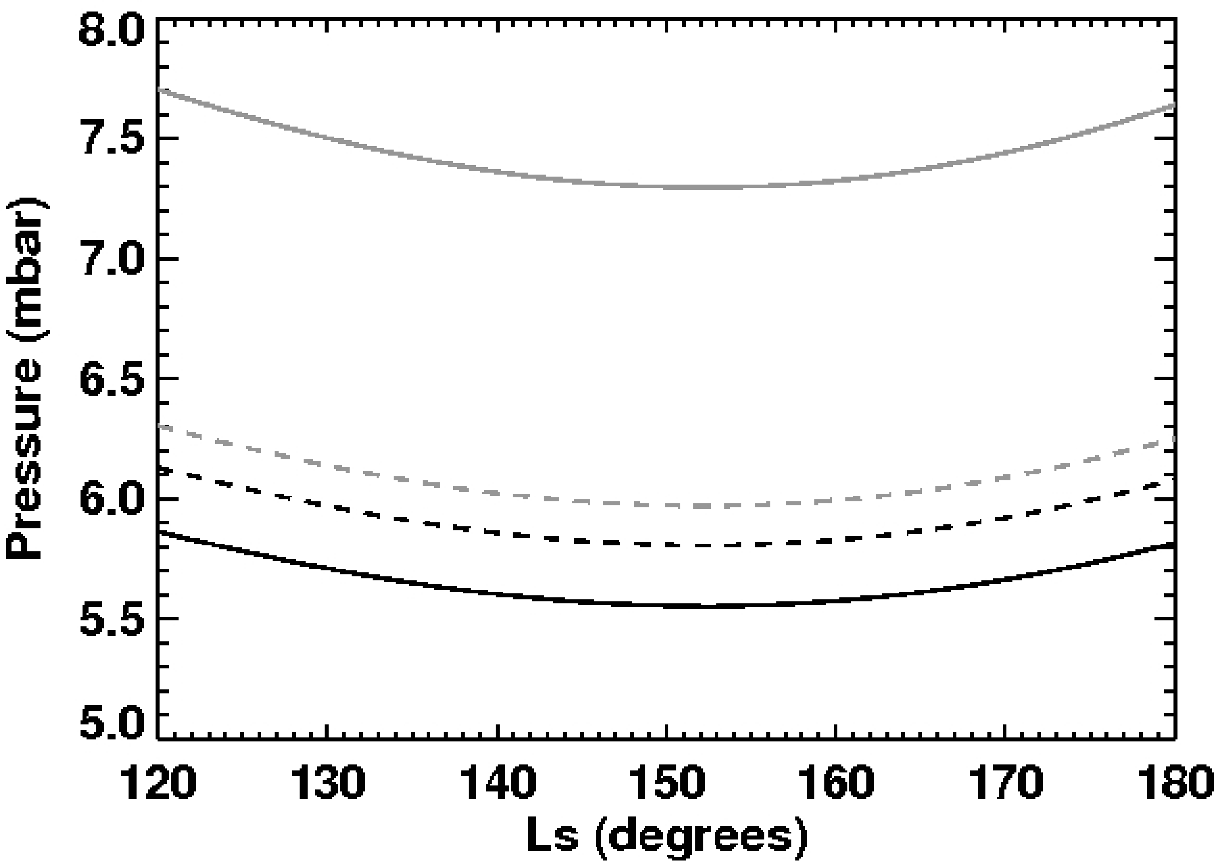
Expect 3% accuracy for MSL landing with 1-sigma confidence level

Overbar = Mean
S. D. = Standard deviation
Only data from z<+1 km and 45S to 45N used for orbital datasets

Evaluation

- Data from VL1 and MGS were used to obtain predictive expression, so good predictions for these data should not be over-interpreted
- However, MGS data do span a very wide range of altitudes, latitudes, and longitudes
- VL2 results are encouraging
- MPF surface pressures are systematically too small by ~0.1 mbar, as noted by previous workers (Haberle et al., 1999) due to problems in pre-flight testing. Standard deviation of Delta is reassuringly small.
- PHX results are encouraging, especially coming from 68N, which is far north of the VL1 site at 22N
- MEX results at Ls=120 to 180 are influenced by “small number statistics” (5 profiles). Also, preliminary versions of MEX profiles were used here. Results improve when final versions are used.

Predictions for MSL



Eberswalde (-1.450 km)
Solid black line
23.86S, 326.73E

Gale (-4.451 km)
Solid grey line
4.49S, 137.42E

Holden (-1.940 km)
Dashed black line
26.37S, 325.10E

Mawrth (-2.246 km)
Dashed grey line
24.01N, 341.03E

Potential Applications

- First-order surface pressure estimates for landing site selection
- Reality-check on predictions from more complex, physics-based models
- Total atmospheric mass from Eqn 1 is about 10 $p_0 R^2$ f(Ls) / g. Annual mean value is 2.4E16 kg and difference between maximum and minimum values is 6.6E15 kg, consistent with previous results.
- Correct orbital gamma ray and neutron spectrometer for atmospheric absorption effects
- Absolute altitude scales for T(p) profiles measured from orbit, such as MGS TES or Mariner 9 IRIS profiles
- Theoretical simulations of dust lifting and aeolian modification of surface features, the thermodynamic stability of near-surface liquids, and the surface radiation environment

Conclusions

- A simple expression with 7 free parameters provides surprisingly accurate predictions for surface pressure
- Expected accuracy of prediction for MSL landing is 3% (1-sigma confidence level)
- Predictions are least accurate at Ls=240 to 360 when interannual variability (large dust storms) is greatest
- There are many potential applications for accurate surface pressure predictions