Scientific Knowledge Gaps in the Atmospheric Planetary Boundary Layer of Mars

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*No major involvement or conflict of interest with future Mars mission concepts. Minor contribution to Mars White Papers on surface-atmosphere interactions.

Why Mars Climate and Weather?

Mars is a portal from Earth to the climate system dynamics of other planets.

- ✓ Closest natural laboratory
- ✓ Most easily accessible
- ✓ Meteorologically diverse
- ✓ Process and phenomenologically rich

To what extent are the physics of Earth's climate system unique vs. universal?

Mars Climate Knowledge Gaps:

Processes and forcing in addition to characterization, mapping, and state

The Biology Analog: What is it vs. How does it work?

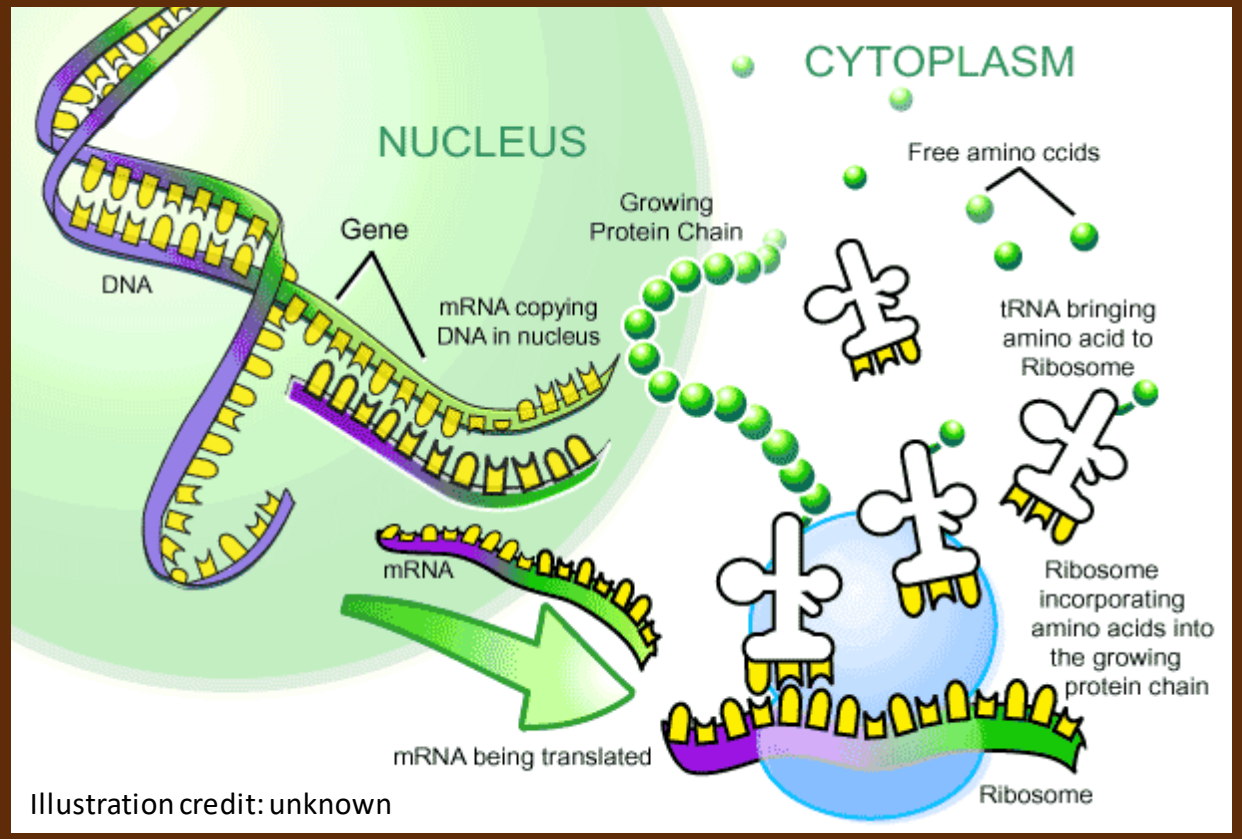

Illustration credit: unknown

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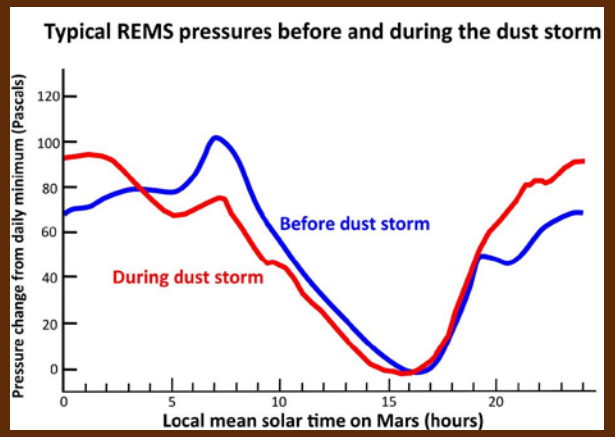
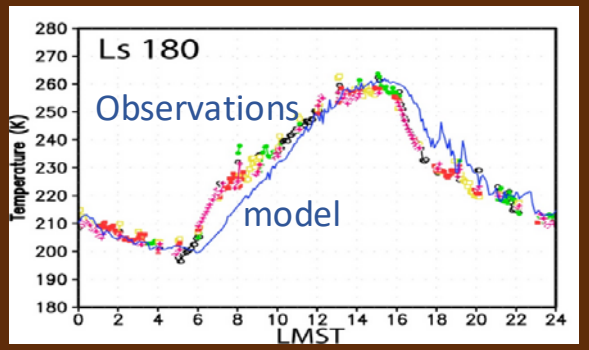
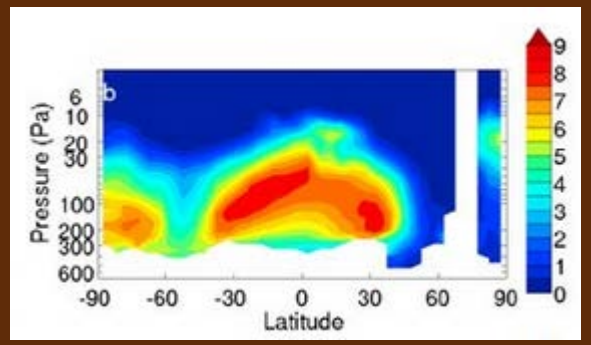
Mars: What is it vs. How does it work?



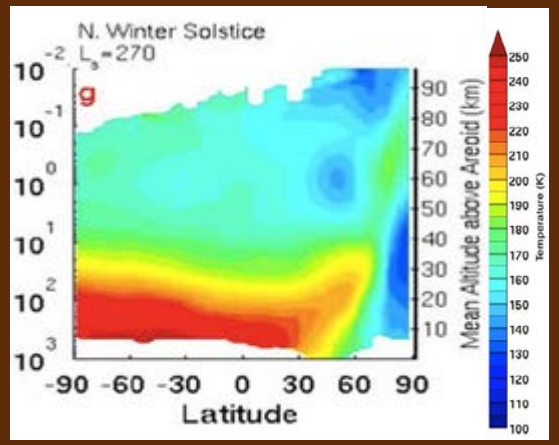
NASA/JPL-Caltech/
CAB(CSIC-INTA)/FMI/Ashima Research



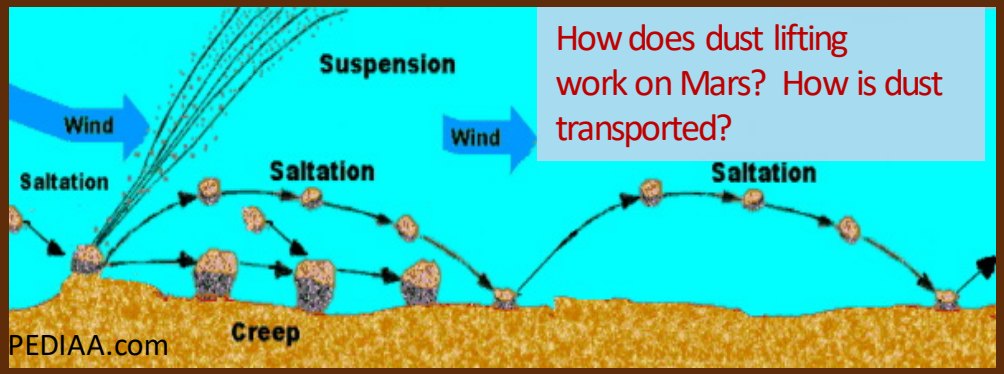
REMS temperature vs Model
Pla-Garcia et al (2016)



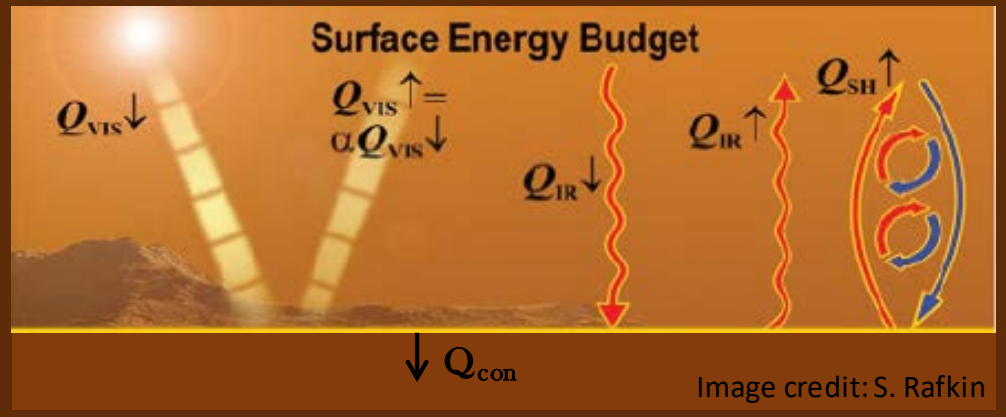
Nightside density scaled opacity
Heavens et al., JGR, (2011)



Zonal Temperature Ls 270
McCleese et al., JGR, (2010)

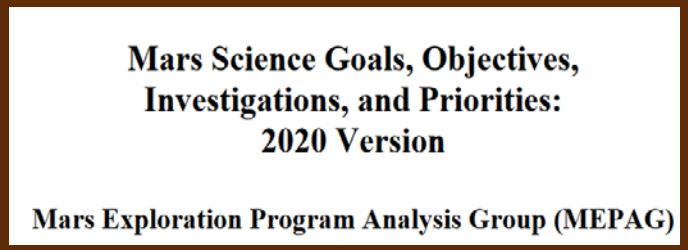


Gap: Quantitative measurements on dust lifting processes, surface dust fluxes, turbulent wind stress, dust/sand properties,…



Gap: Quantitative surface energy budget and how it drives atmosphere.

Lower/Near-Surface Atmosphere Knowledge Gaps: **An Abridged List**



Lower atmosphere objectives and investigations largely unchanged for 10+ years.

How can that be?

Key Investigation Properties to Close Lower Atmosphere Knowledge Gaps

- ✓ Measure all the appropriate parameters for closure.
- ✓ Simultaneity of measurements.
- ✓ Demonstration of adequate fidelity, accuracy, precision, cadence.
- ✓ Adequate time-of-day coverage.
- ✓ Appropriate accommodation.
- ✓ Meaningful model validation and improvement.

Failure to achieve any of the above hinders or prevents progress.

On Earth, the above are achieved through Field Experiments and Field Campaigns

Example Knowledge Gap Processes

- ❑ Surface energy balance: Energy drives the atmosphere.
- ❑ Aeolian processes: How are dust/sand mobilized?
- ❑ Dust transport: How is dust moved once lifted?
- ❑ Dust storms: How do they form and how do they impact other processes?
- ❑ Water and CO_2 surface exchange: Is it really just vapor pressure equilibrium?
- ❑ Methane and trace gases: Surface fluxes and transport.
- ❑ …

Some Example PBL Knowledge Gaps: Processes and Forcing

Surface Energy Balance

- ❑ Insolation (direct & diffuse)
- ❑ IR ↑↓
- ❑ Subsurface conduction
- ❑ Turbulent eddy heat flux
- ❑ Albedo, thermal inertia
- ❑ Total column opacity
- ❑ Forcing terms with sufficient accuracy (~1 Wm^{-2})
- ❑ Simultaneous measurements

Aeolian processes

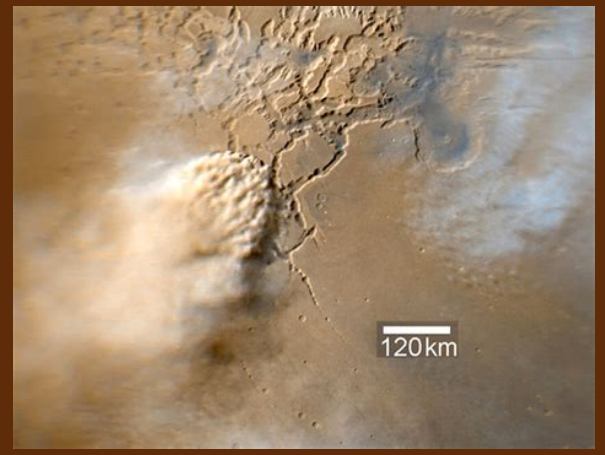
- ❑ Mean and turbulent wind stresses
- ❑ Pressure
- ❑ Surface dust/sand properties
- ❑ Saltation and particle flux
- ❑ Electrical environment, particle charge
- ❑ Movement/change detection

Turbulence Closure

- ❑ Mean wind and turbulent fluxes
- ❑ Wind shear
- ❑ Temperature lapse rate
- ❑ Surface roughness
- ❑ Ground temperature

Dust transport

- ❑ Direct measurement of circulations (3-D wind)
- ❑ Turbulent fluxes
- ❑ Dust devils
- ❑ Mesoscale/regional & global circulations
- ❑ Dust plumes?
- ❑ Dust storms



Instrumentation

Many mature instrument/sensor suites are ready for flight and could make substantial scientific advances.

Some science closure is achievable with modest instrument suites and modest mission concepts. Others will require significant additional investment and/or mission architectures.

- ❑ Surface Meteorology In Situ: Sensors and instrumentation for fundamental meteorological measurements (T, p, 3-D wind, H_2O, radiative fluxes) are mature.
- ❑ Surface Aeolian In Situ: A mixture of mature and needed development.
- ❑ Surface Remote Sensing: Development needed.
  - IR sounders – too broad of weighting functions.
  - LIDARS – Need development/demonstration of doppler capability.
  - Other?
- ❑ Orbital Remote Sensing: A mix of mature and needed development.
  - IR sounders/radio science are mature.
  - Microwave/Sub-mm/LIDAR are maturing but need more development: *exercise caution matching capabilities to need.*
  - Other?

All claims of instrument performance and science value should be justified and scrupulously verified.

Summary: PBL /Near-Surface Knowledge Gaps

- Major advances will come from a focus on processes and forcing in conjunction with ongoing mapping and monitoring.
- Current MEPAG Goals Document provides an accurate description of knowledge gaps: Emphasis on forcing and processes.
- Must measure all relevant parameters simultaneously and with sufficient accuracy, frequency, and diurnal coverage.
- Instrumentation is mature for many, but not all, process investigations.
- Accommodation is just as important as instrument performance.
- Mature and validated numerical models are necessary to provide context and extrapolate results to all of Mars—just like on Earth.

BACKUP

Wind: One of the last critical parameters needing measurement

- At Surface
  - Better than 2 m/s horizontal with better than 5° direction.
  - Ideally 3-D, with better than 1 cm/s vertical.
  - Turbulent fluctuations (> 20 Hz).
  - ACCOMMODATION IS CRITICAL!
- In PBL
  - Vertical shear of horizontal wind in lowest few km.
  - Vertical winds (thermal updrafts/downdrafts) with horizontal scale < 1 km.
  - Thermal/topographic circulations (direct and return flows). Horizontal scales from 1 – 100 km.
- In Free Atmosphere
  - Orbital IR sounding already provides reasonable estimates of balanced zonal flow.
  - Must provide more than minor updates/corrections to models.
  - Need to measure ageostrophic horizontal circulations (<10 m/s).
  - Need to disambiguate zonal and meridional: **Be very cautious of line of site**.
  - Better than 5 km vertical resolution (~1/2 scale height).
  - key information can be lost if measurements require substantial averaging in space or time.

Quantitative value of any proposed wind measurement should be carefully evaluated.
Something is NOT always better than nothing.

The Importance of Models

Lessons from Earth

- Not possible to measure atmosphere everywhere at all times.
  - Observations alone are not sufficient to close knowledge gaps everywhere at all times.
  - Numerical models are necessary to interpolate and extrapolate observations.
- Interpolation and extrapolation require models adequately representing reality of processes.
  - Observations are needed to validate models.
  - Validation includes model-predicted state AND processes/forcing.

Model Infrastructure

Investment in models must be made in concert with meteorological investigations and missions.

Current NASA R&A programs primarily support model application not development.

Without models, observations become site and time specific.