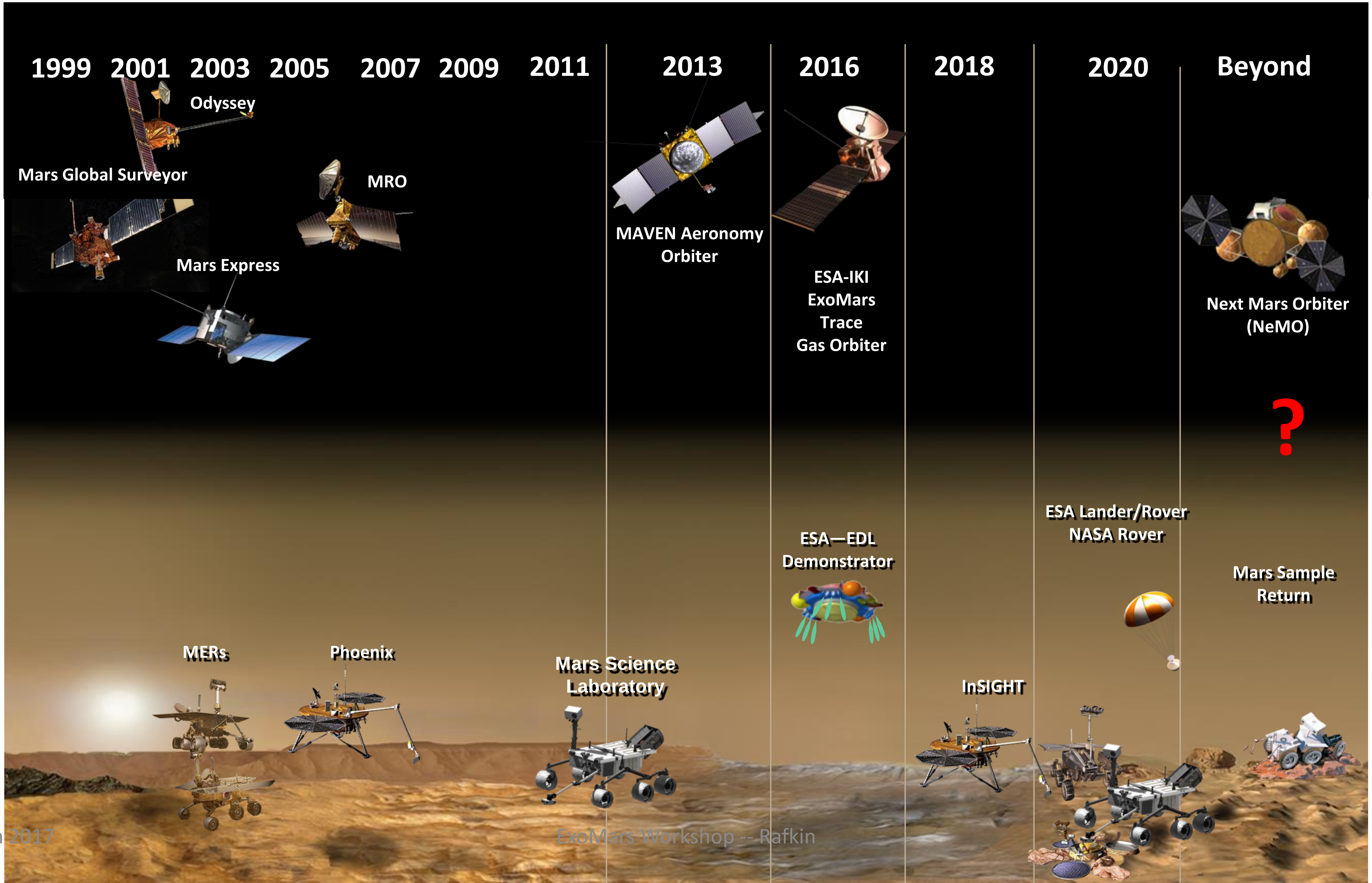
The Relevance of Current and Future Mars Missions to Mars Atmospheric Science

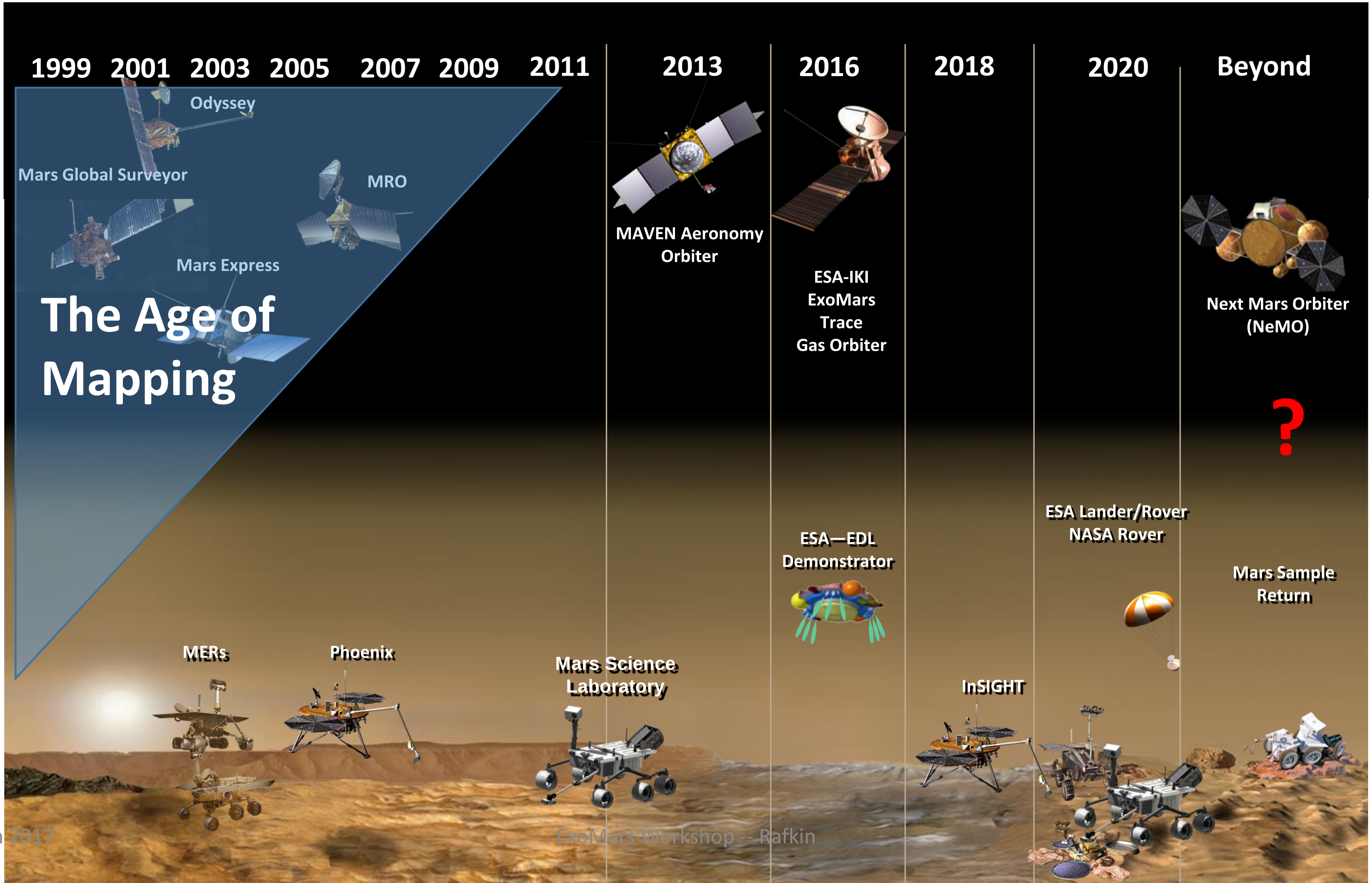
(An Admittedly Slight U.S.-Centric View)

Scot Rafkin
Southwest Research Institute
Boulder, Colorado, USA
rafkin.swri@gmail.com

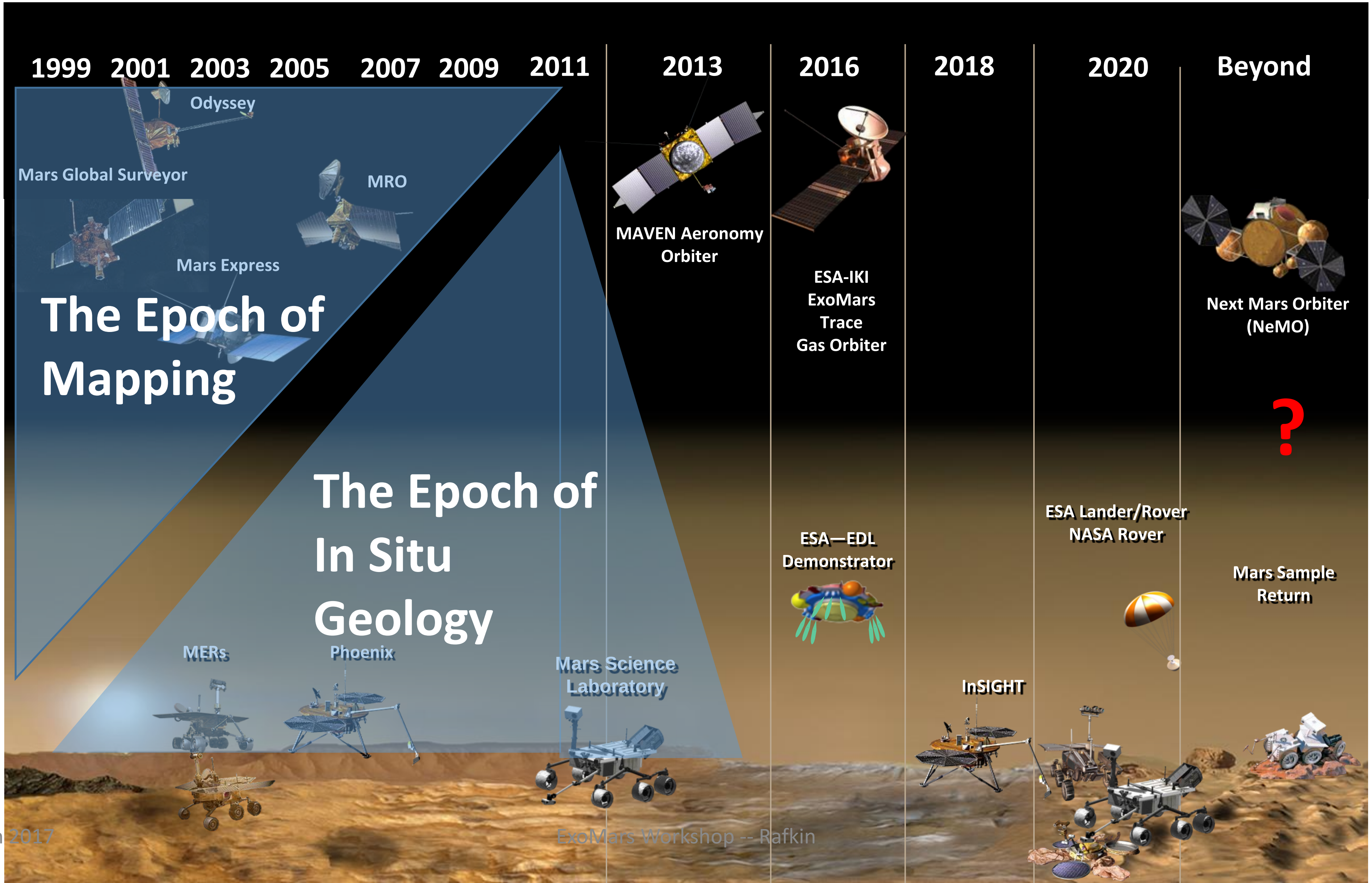
NASA and ESA Mars Mission Portfolio



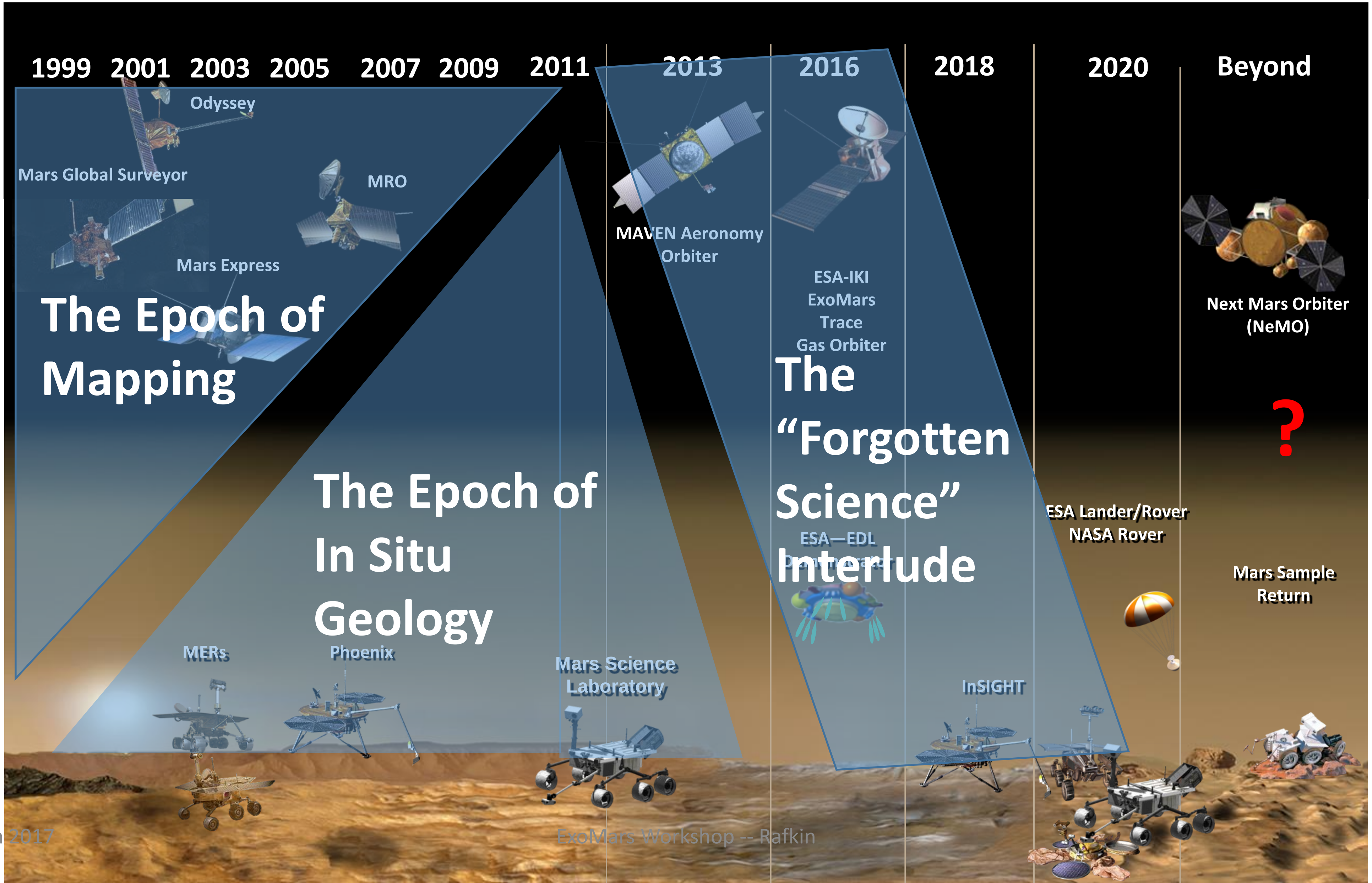
NASA and ESA Mars Mission Portfolio



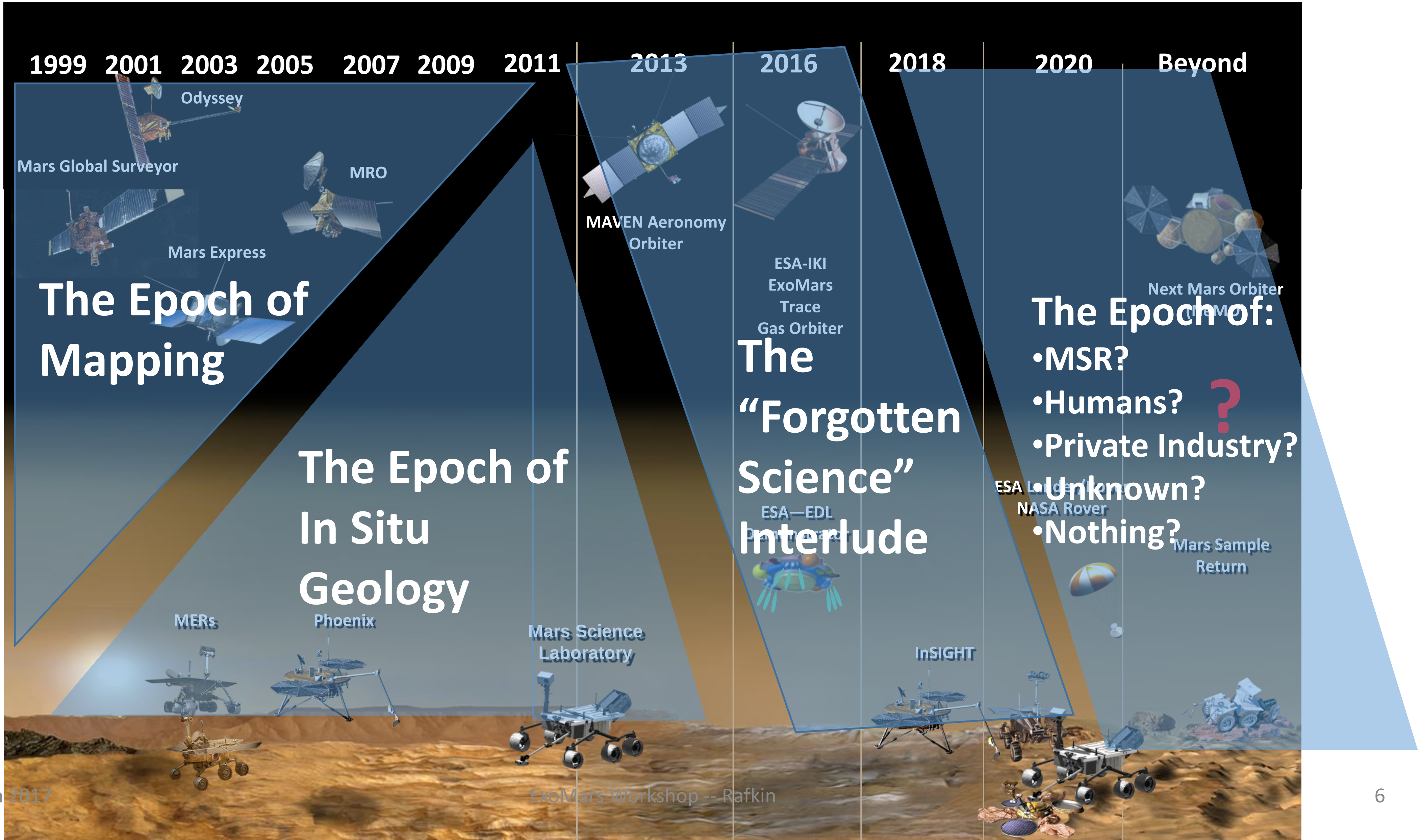
NASA and ESA Mars Mission Portfolio



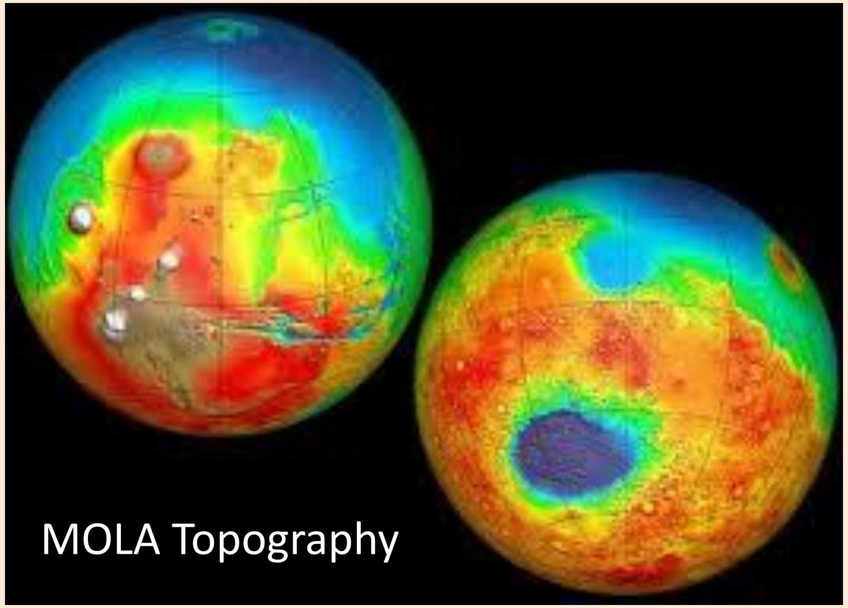
NASA and ESA Mars Mission Portfolio



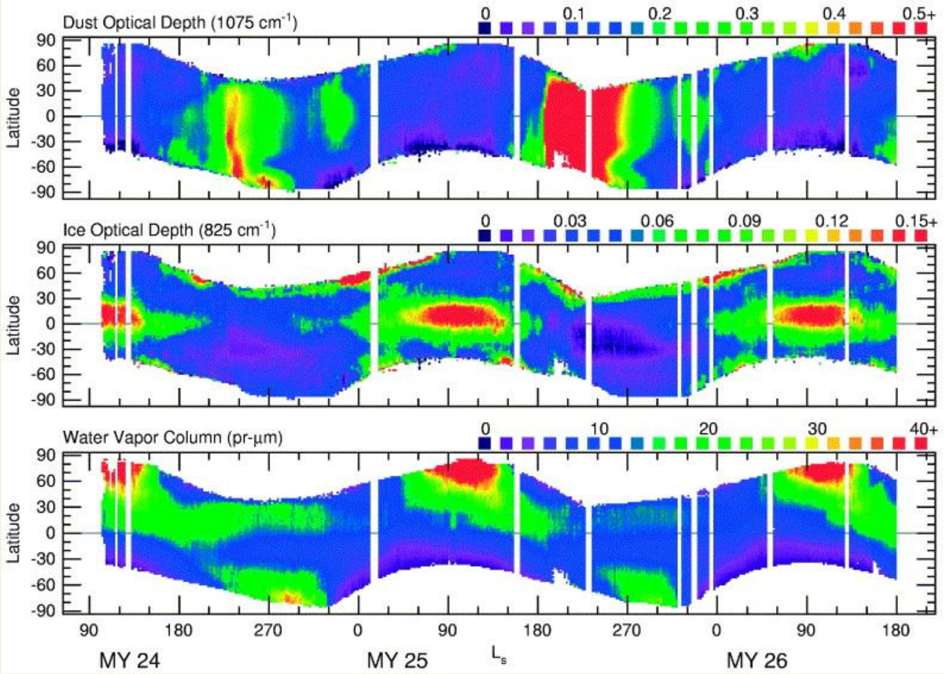
NASA and ESA Mars Mission Portfolio

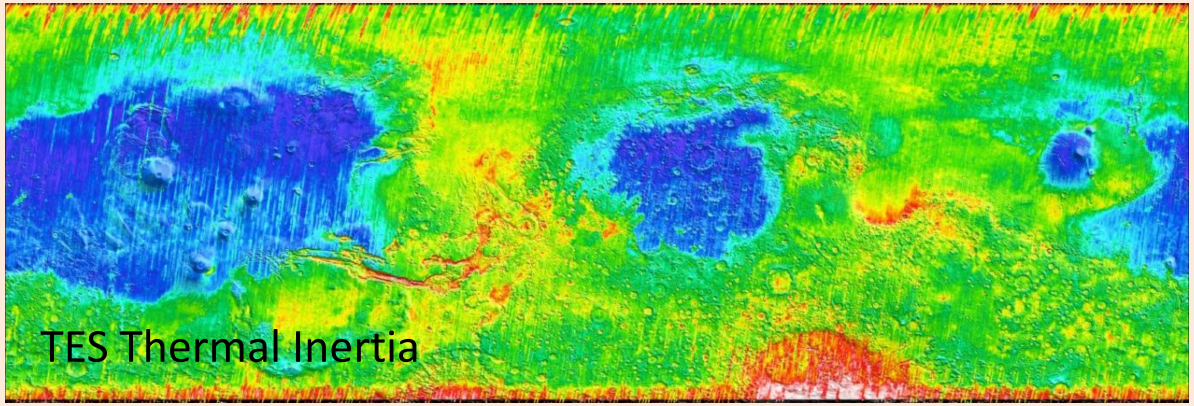


The Epoch of Mapping

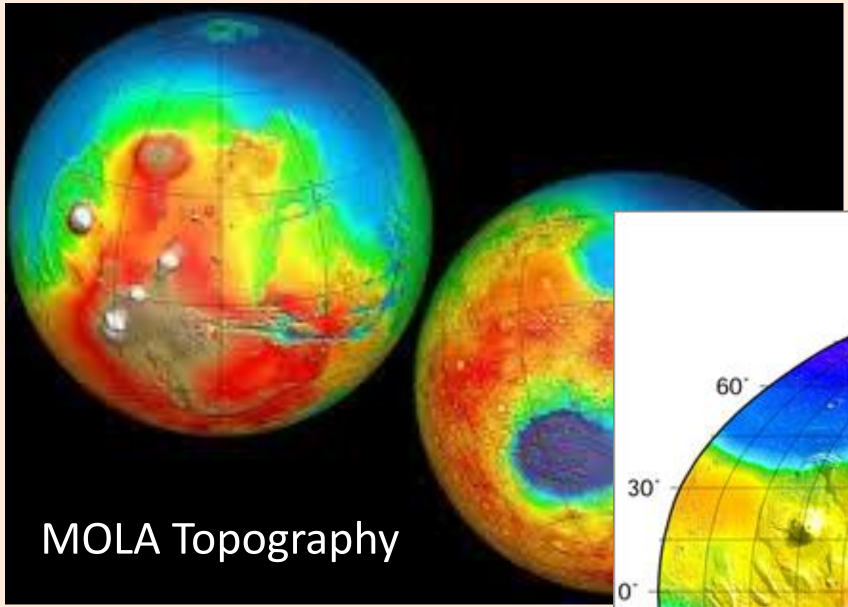


TES Dust, Clouds, Vapor

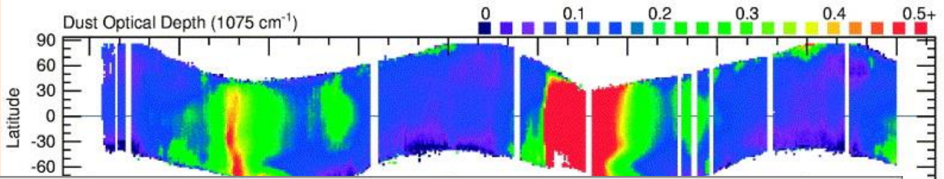


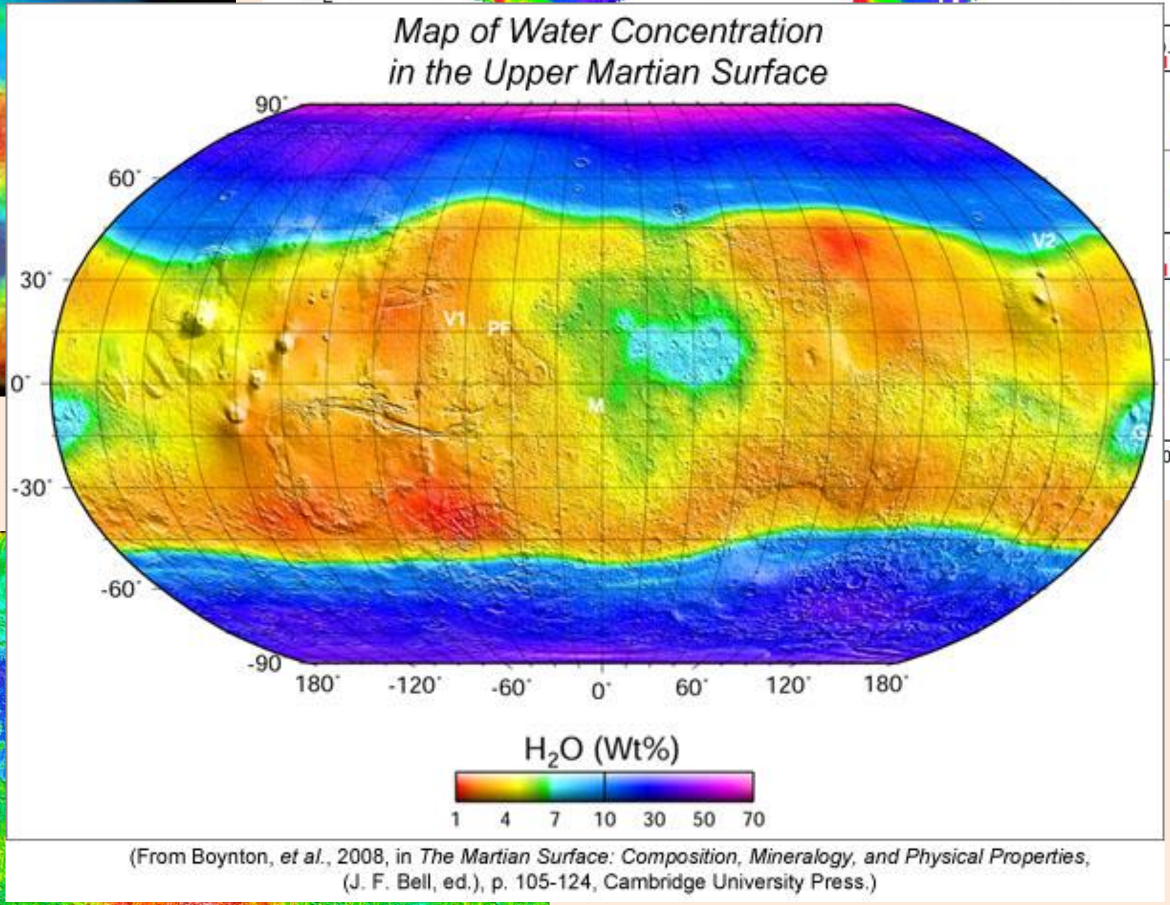


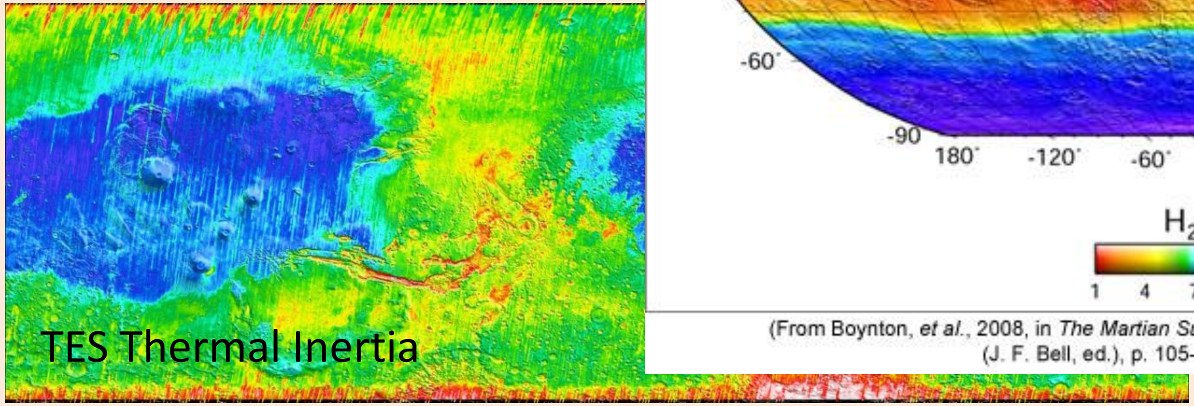
The Epoch of Mapping



TES Dust, Clouds, Vapor

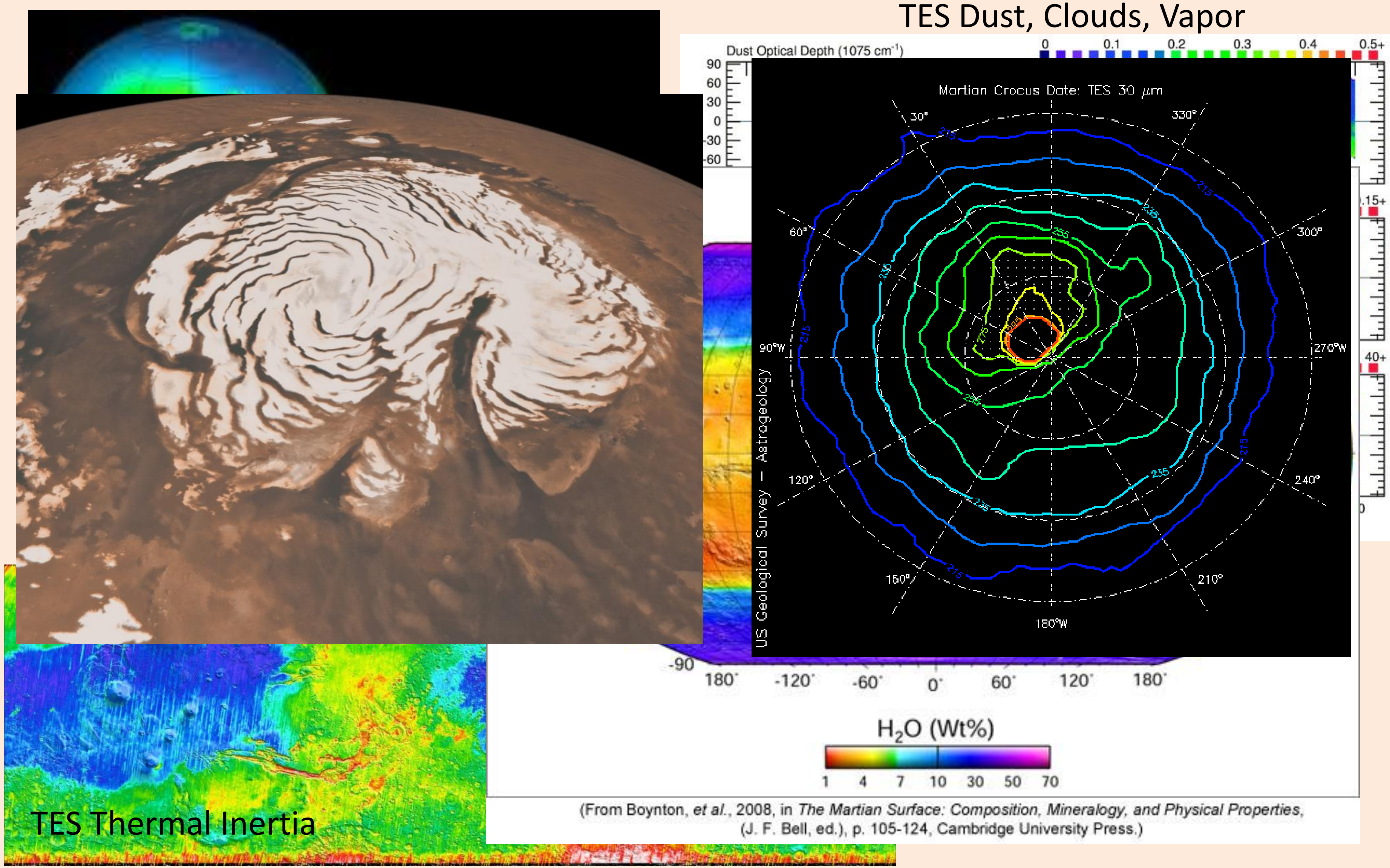




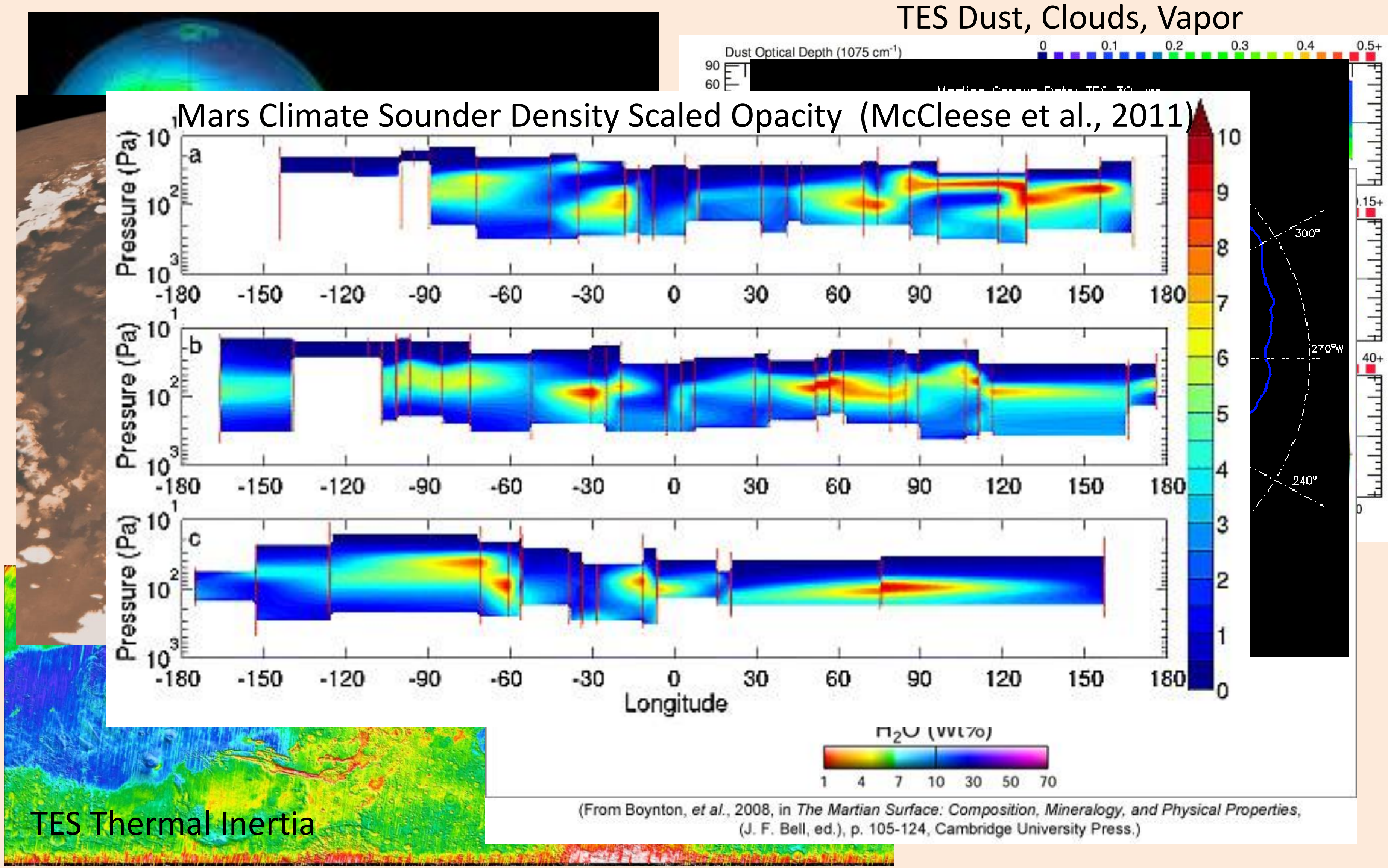


The Epoch of Mapping

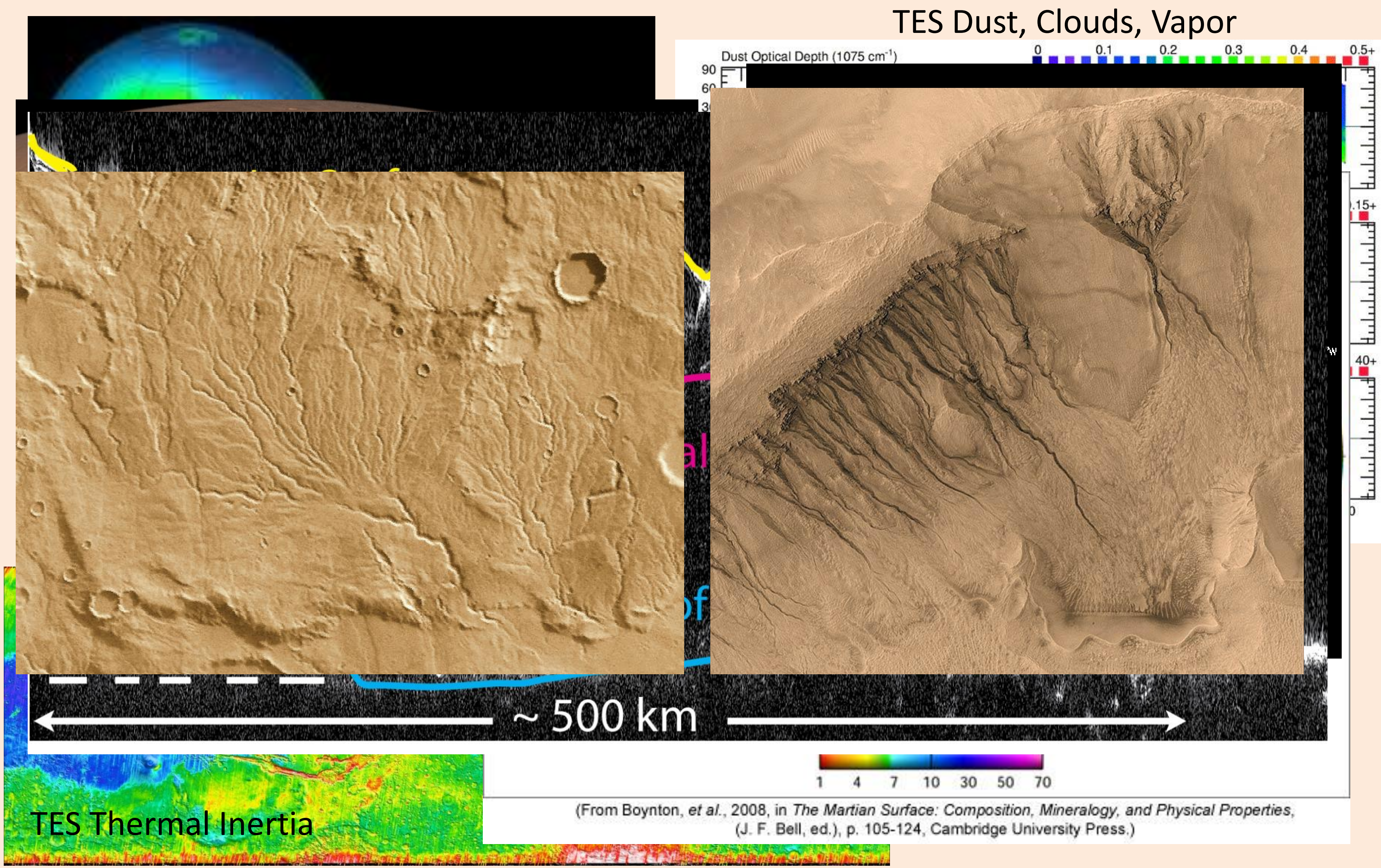
TES Dust, Clouds, Vapor



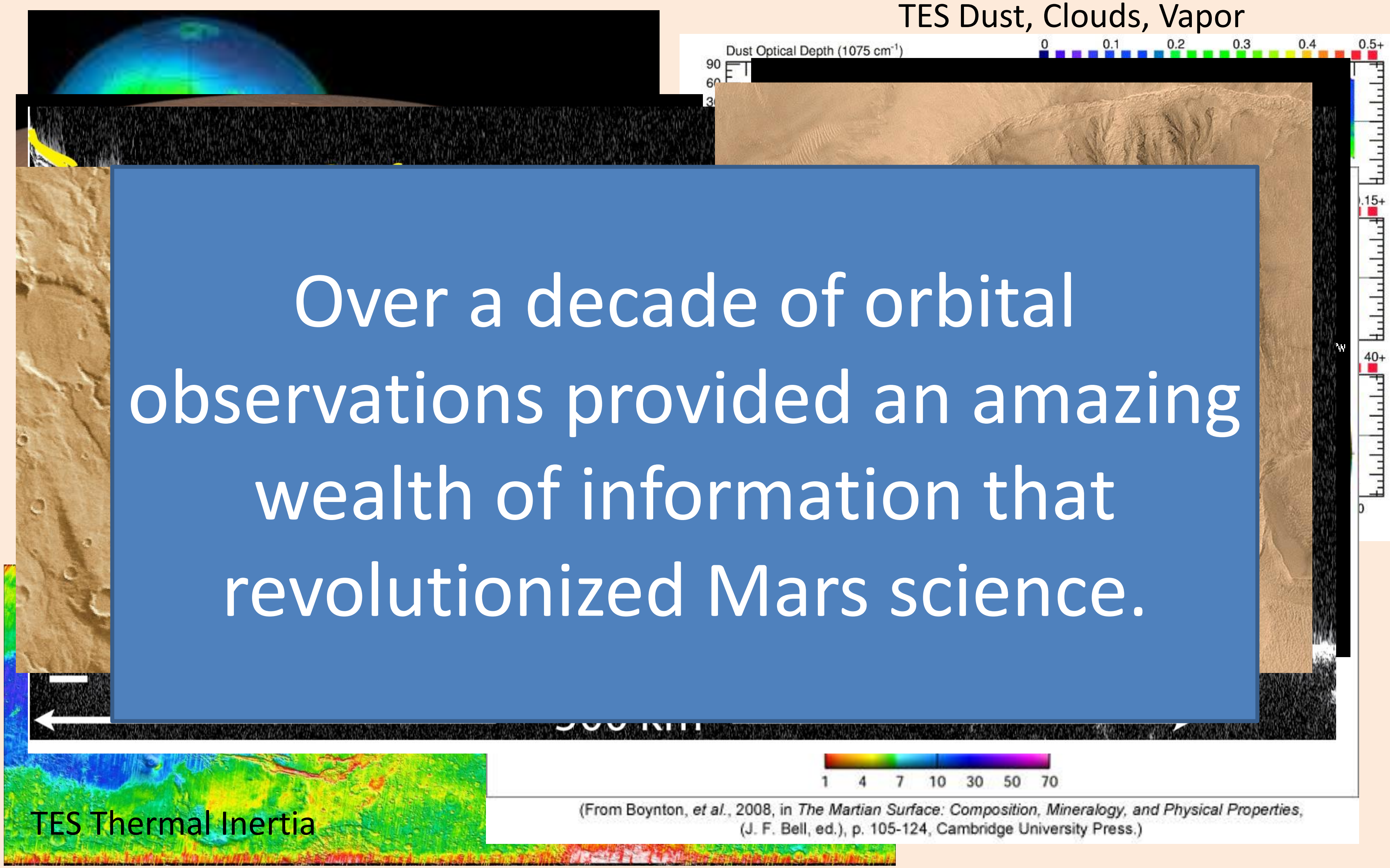
The Epoch of Mapping



The Epoch of Mapping



The Epoch of Mapping



Over a decade of orbital observations provided an amazing wealth of information that revolutionized Mars science.

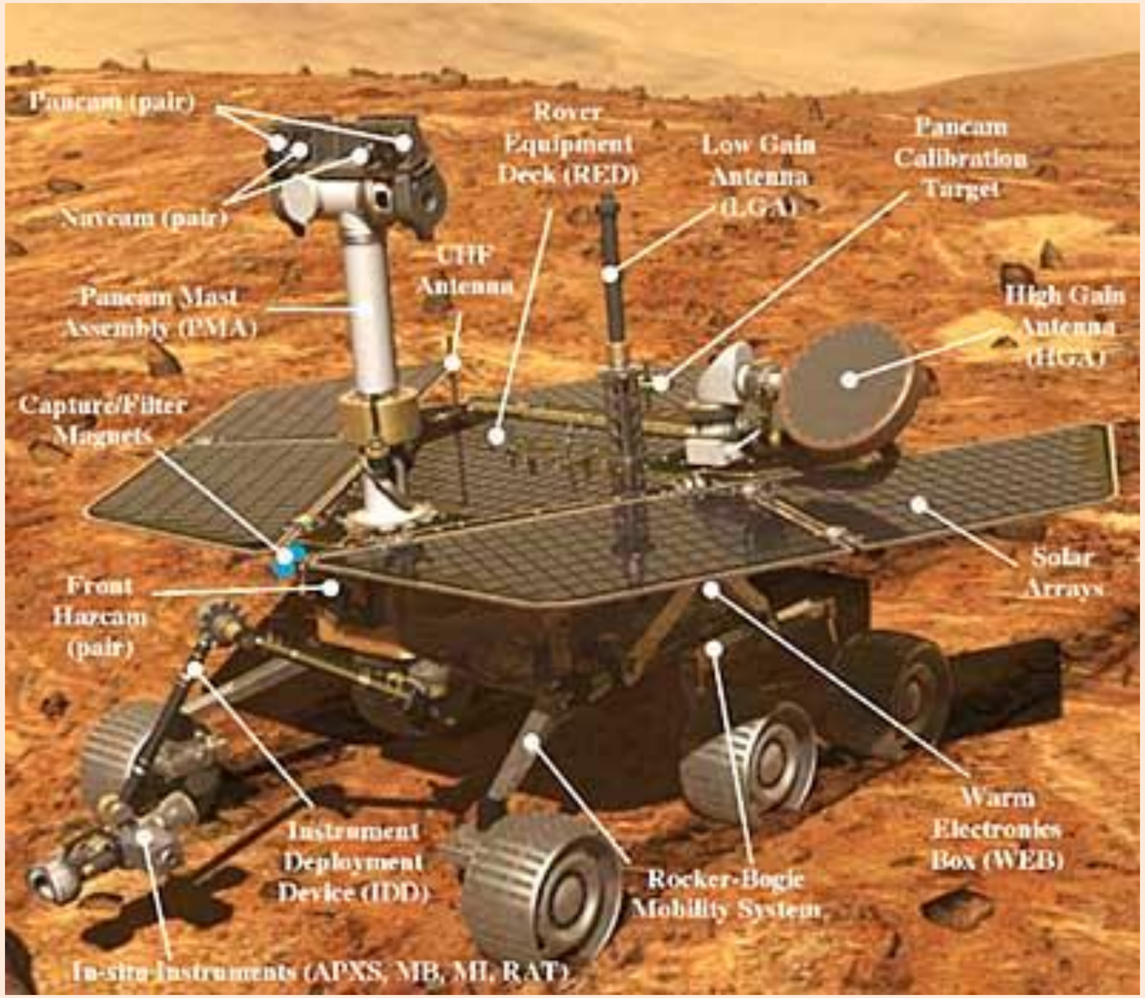
Epoch of Mapping: Climate Science

- Atmospheric thermal structure plus *derived* balanced wind
  - Thermal tides, waves
  - Effect of dust on temperatures
  - Inferred wind structure (zonal jets)
- Water vapor/cloud climatology
  - Column abundance
- Dust
  - Column abundance and limited vertical structure
- Surface boundary conditions for climate and mesoscale modeling
  - Topography
  - Thermal inertia
  - Albedo
- No surface measurements since Viking

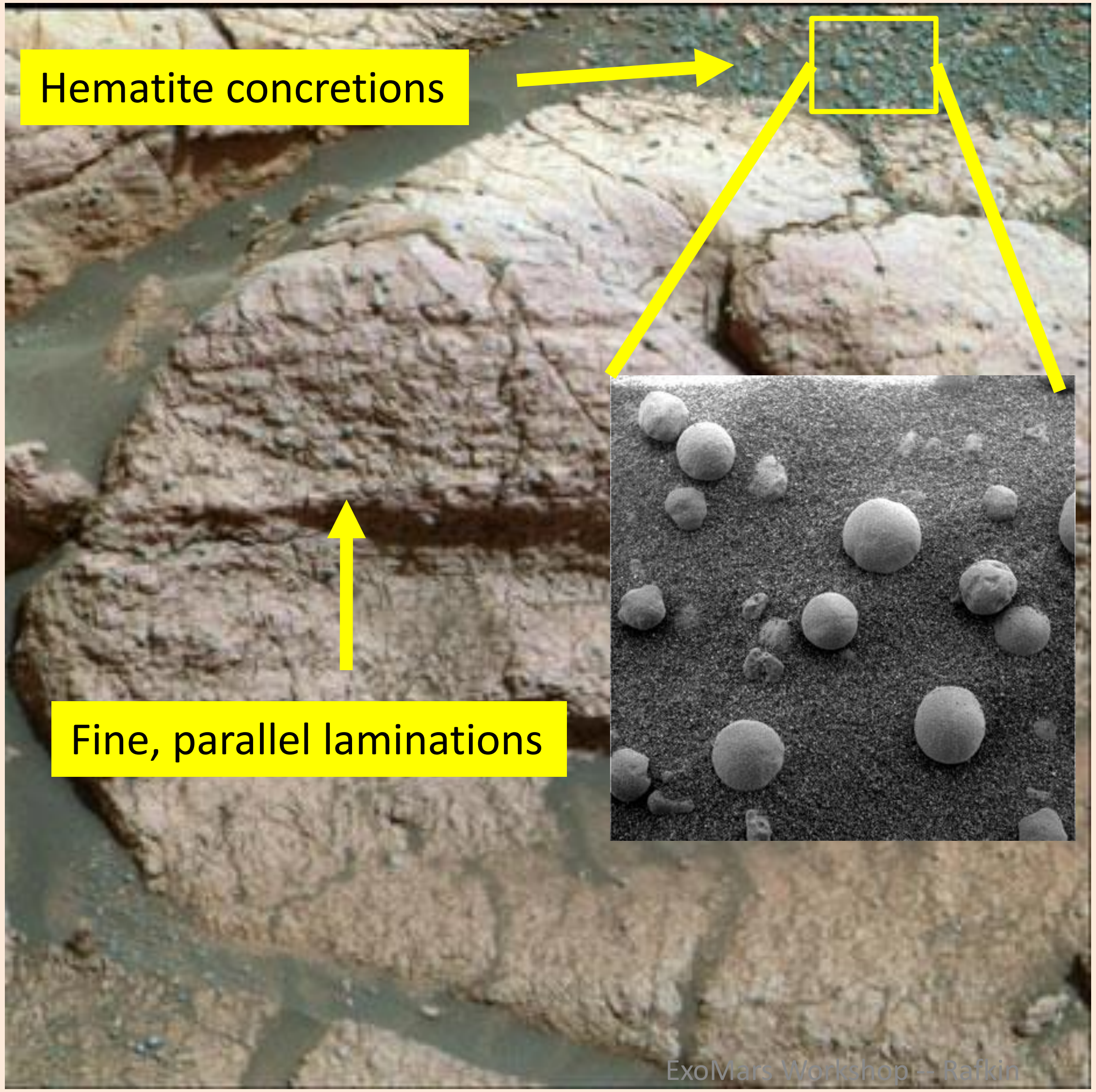
First steps: Characterization of what is there

The Epoch of In Situ Geology

The Mars Exploration Rovers represent the first robotic geologists on Mars that investigated interesting areas observed from orbit in the previous Epoch of Mapping.



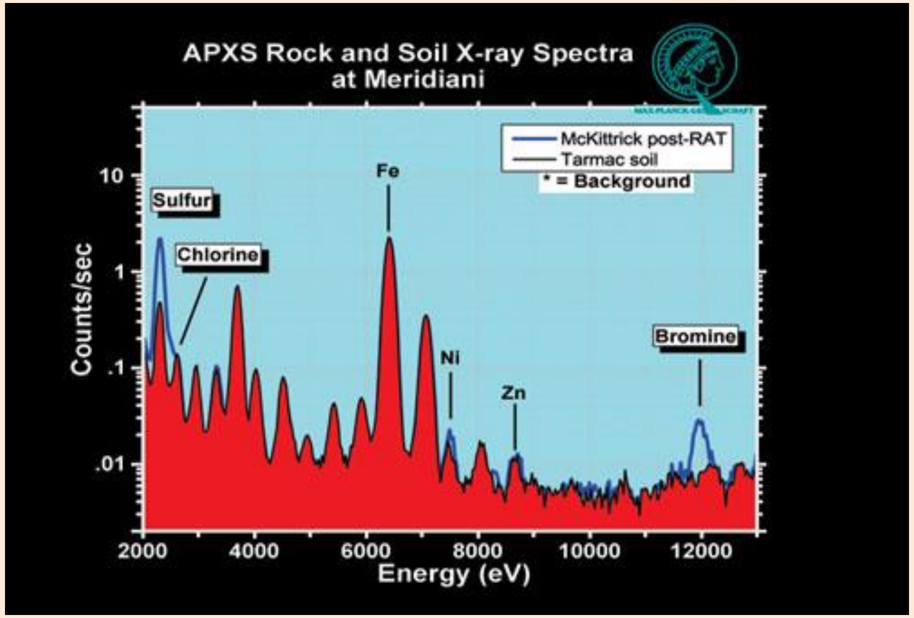
MERs: Evidence of Past Water

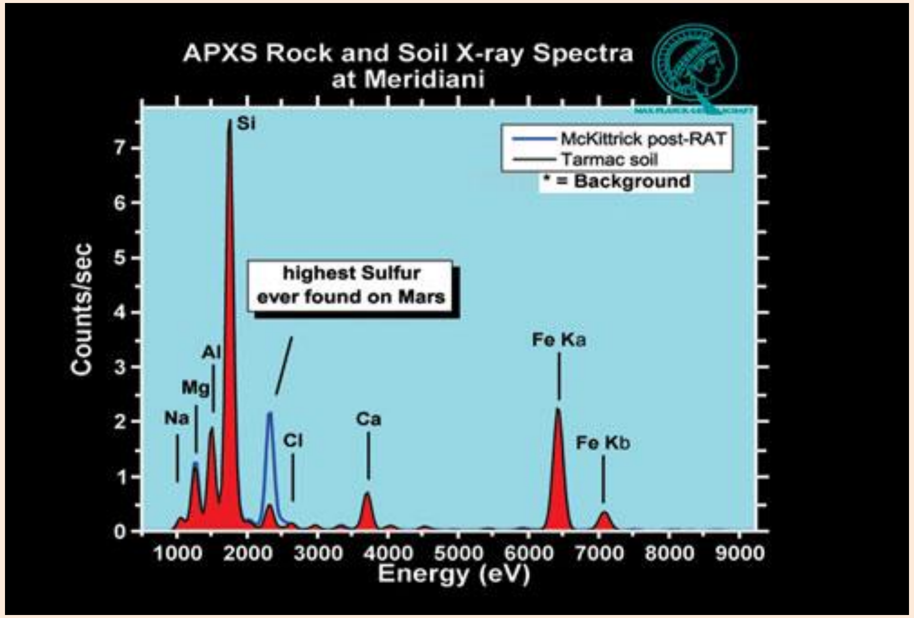


The Mini-Thermal Emission Spectromter found high amounts of sulfate.

The Mössbauer spectrometer identified the mineral jarosite that contains OH.

MERs: Evidence of Brines and Evaporites





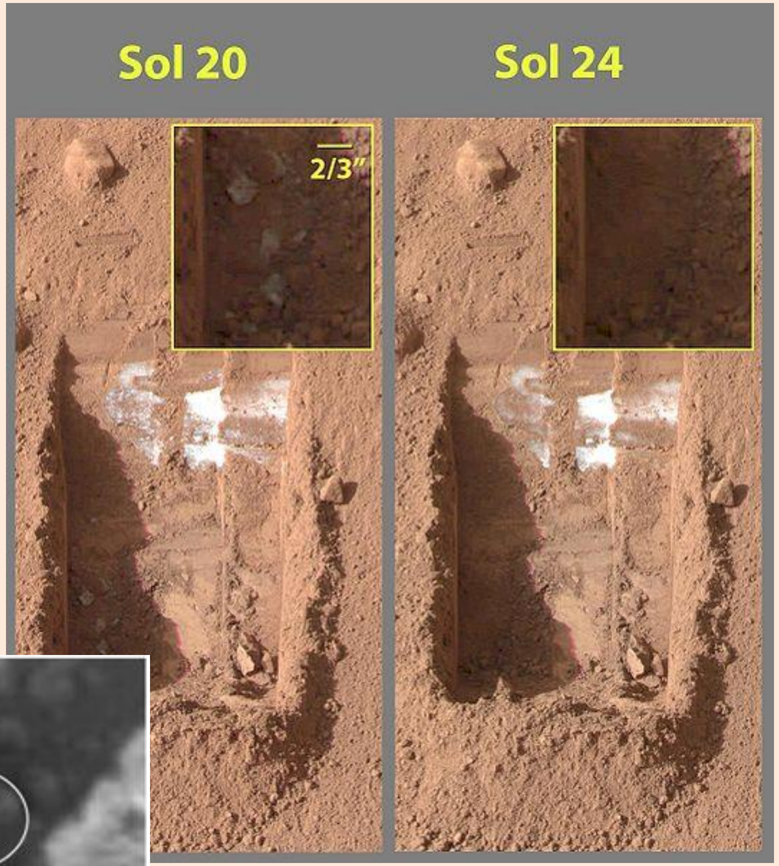
- Higher concentrations of sulfur and bromine than nearby patch of soil.
- A nearby rock similarly has extremely high concentrations of sulfur, but very little bromine.
- Element fractionation typically occurs when a brine slowly evaporates and various salt compounds are precipitated in sequence.

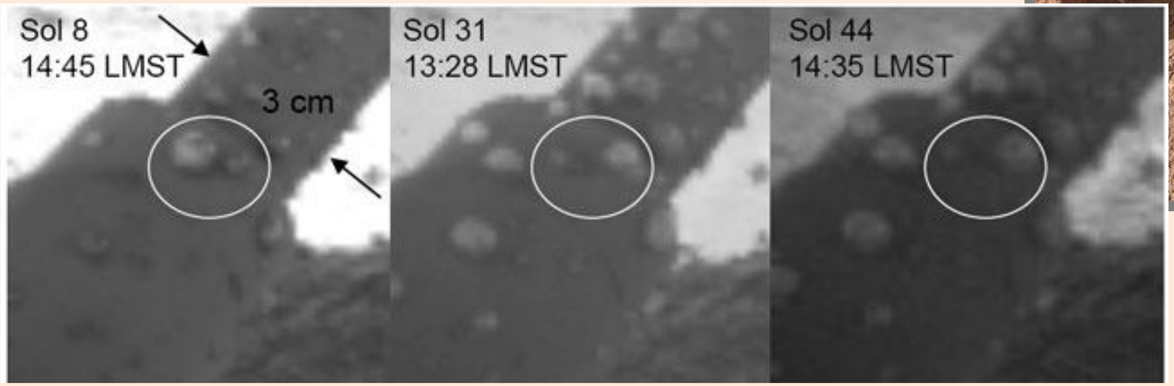
Lessons from MERs

- Liquid water was present on Mars over geological time scales.
- Consistent with subsurface infiltration of water and with surface evaporites.
- Crossbedding indicates presences of surface water.
- Mars likely had a habitable environment in the past.
  - How long ago and for how long?
  - How did the climate evolve to its current water-unstable state?
- **You really ought to carry a weather station on every mission to the surface.**

Phoenix – Polar Ice and Water

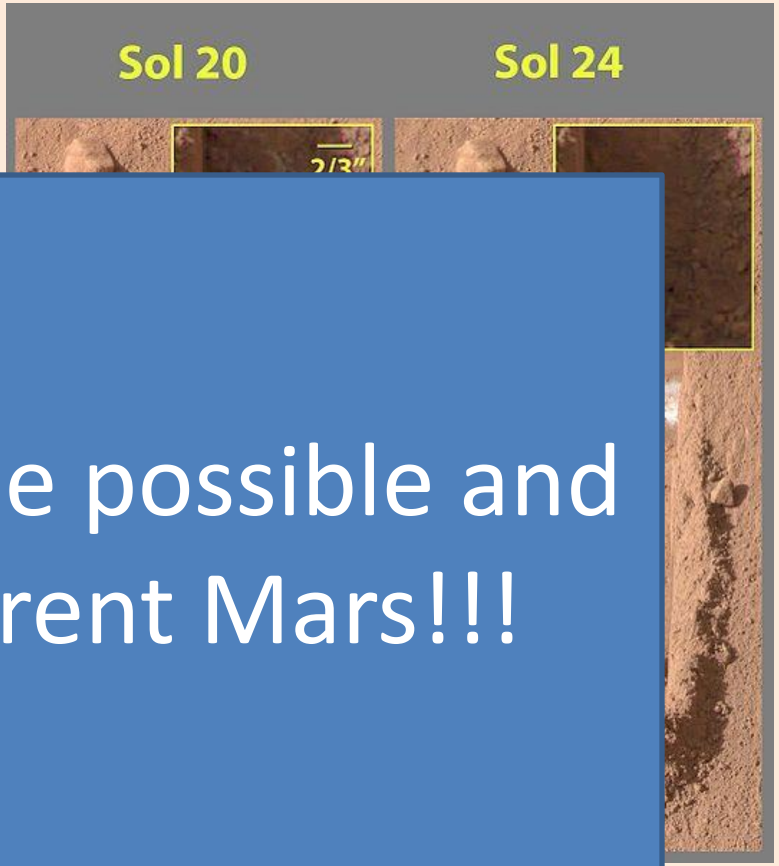
- Confirmed shallow surface ice.
- Perchlorates.
- Liquid water?
- Some evidence of water exchange with regolith and atmosphere over diurnal cycle.





Phoenix – Polar Ice and Water

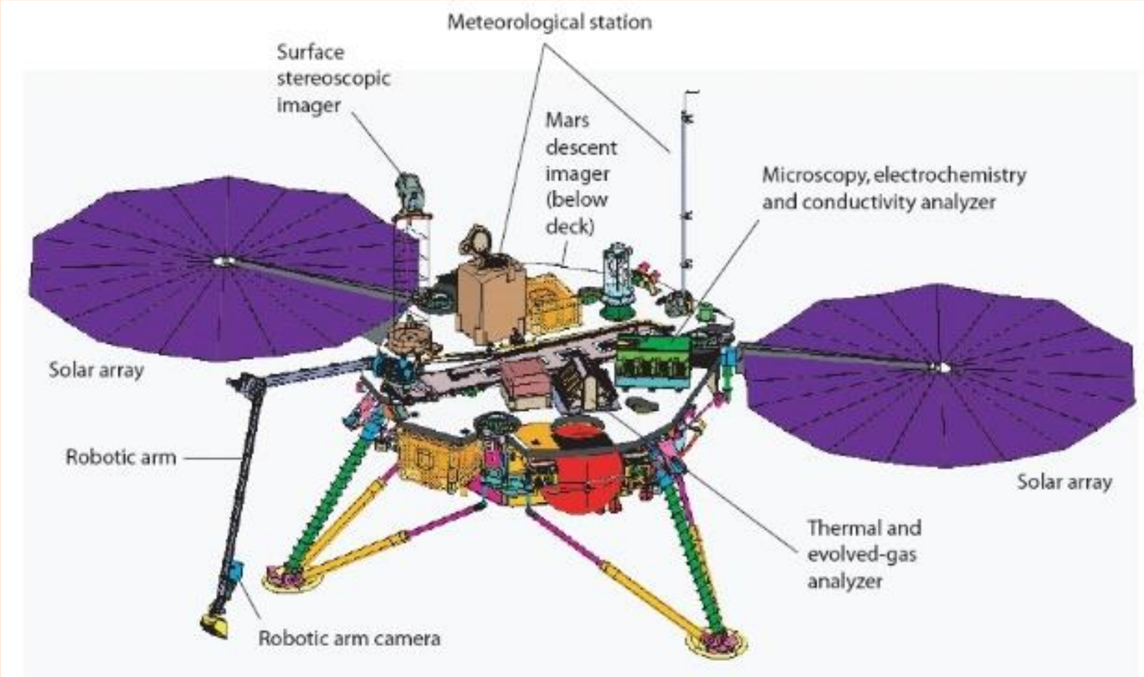
- Confirmed shallow surface ice.
- Pc
- Li
- Sc
ex
at
cy

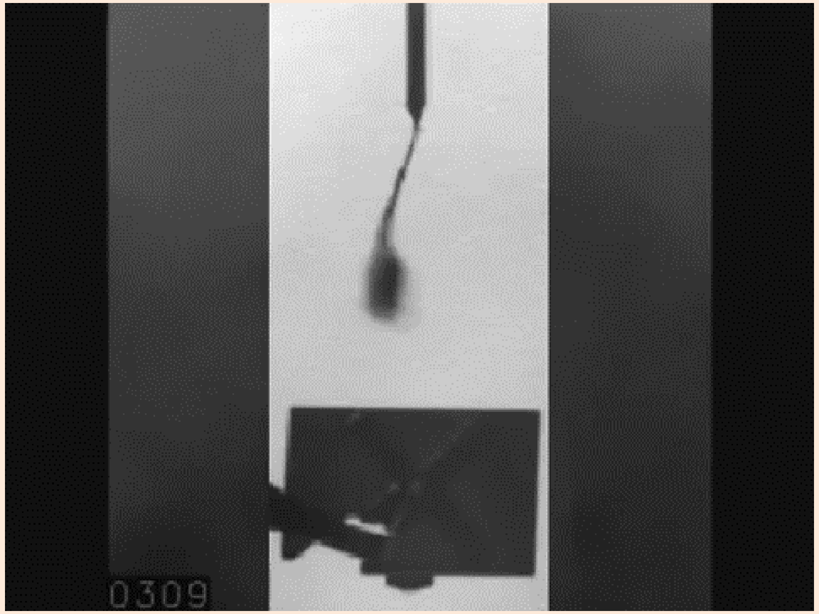


Liquid water may be possible and stable on current Mars!!!

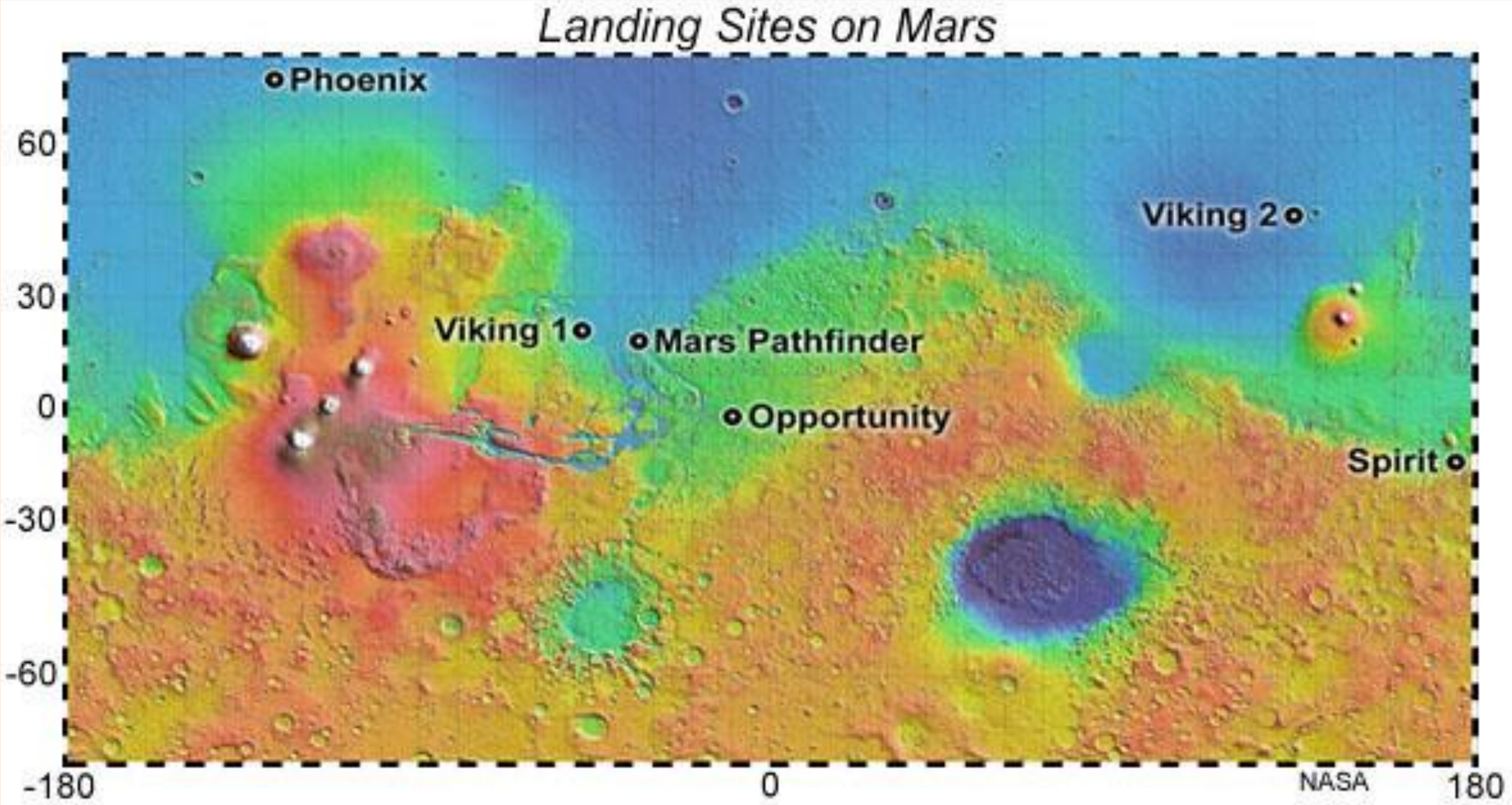
Lessons from Phoenix

- Really interesting polar weather.
- Liquid water?
- You really ought to carry a *complete* weather station on every surface mission

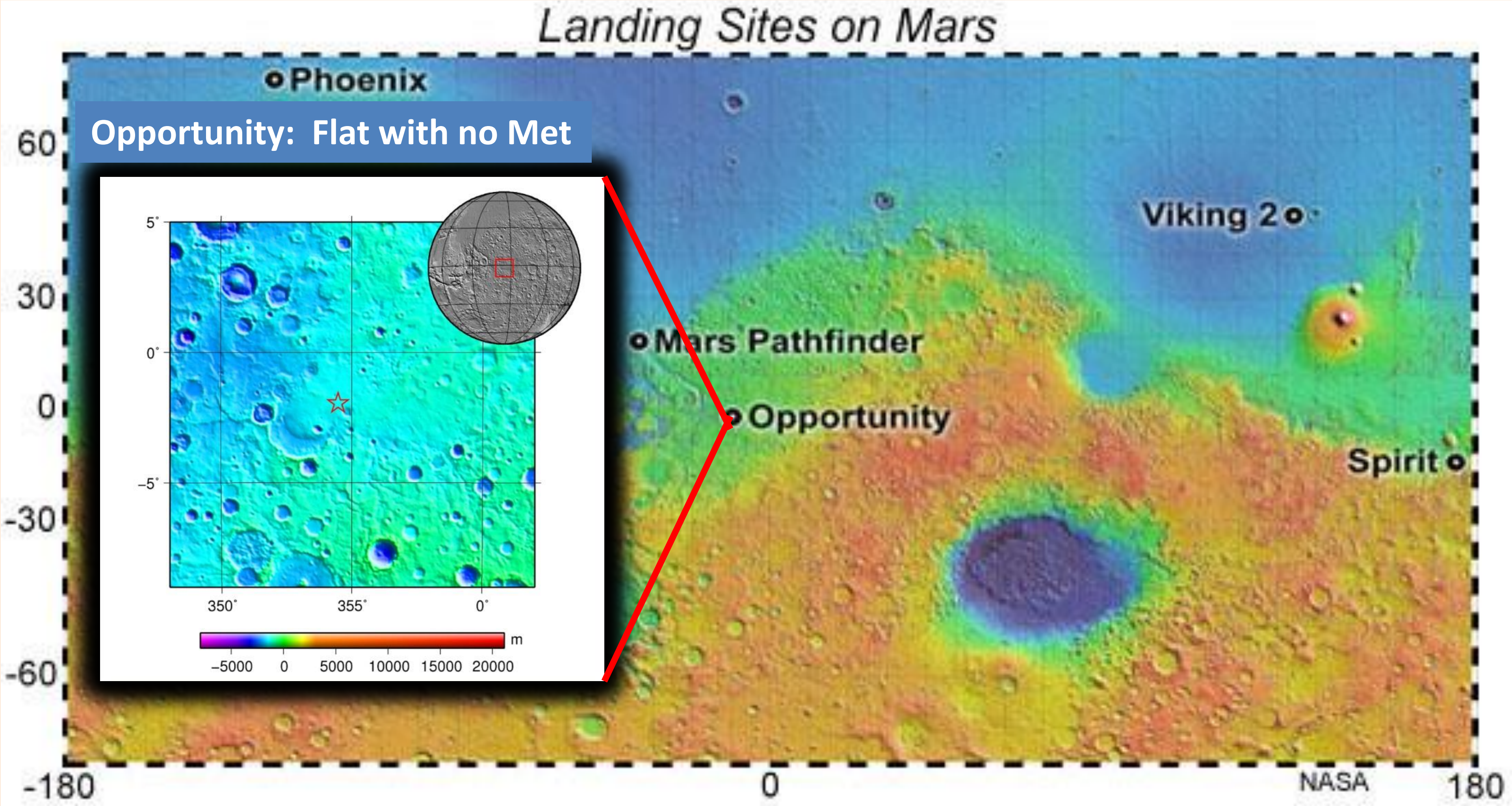




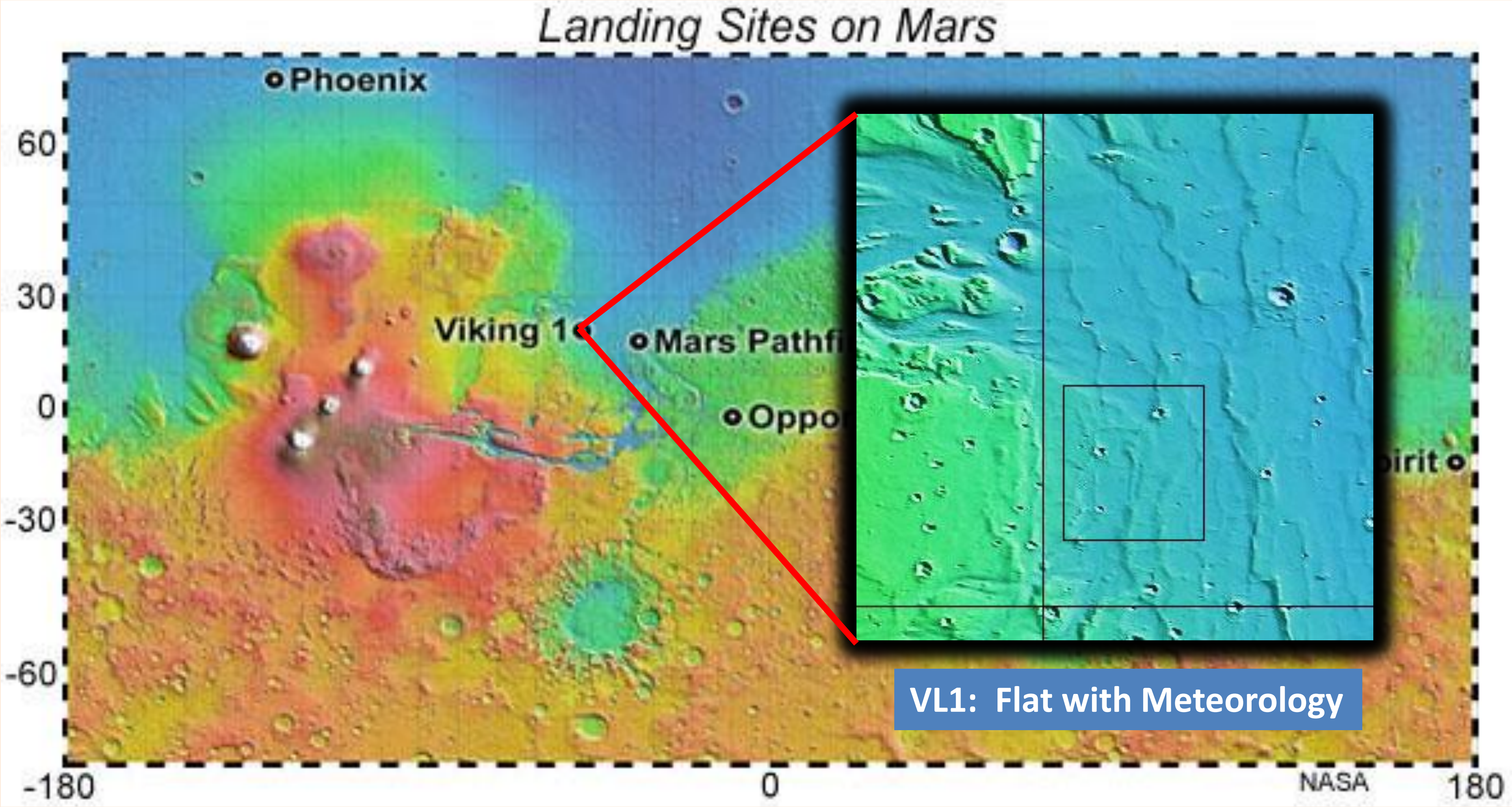
Topography and Mission Meteorology



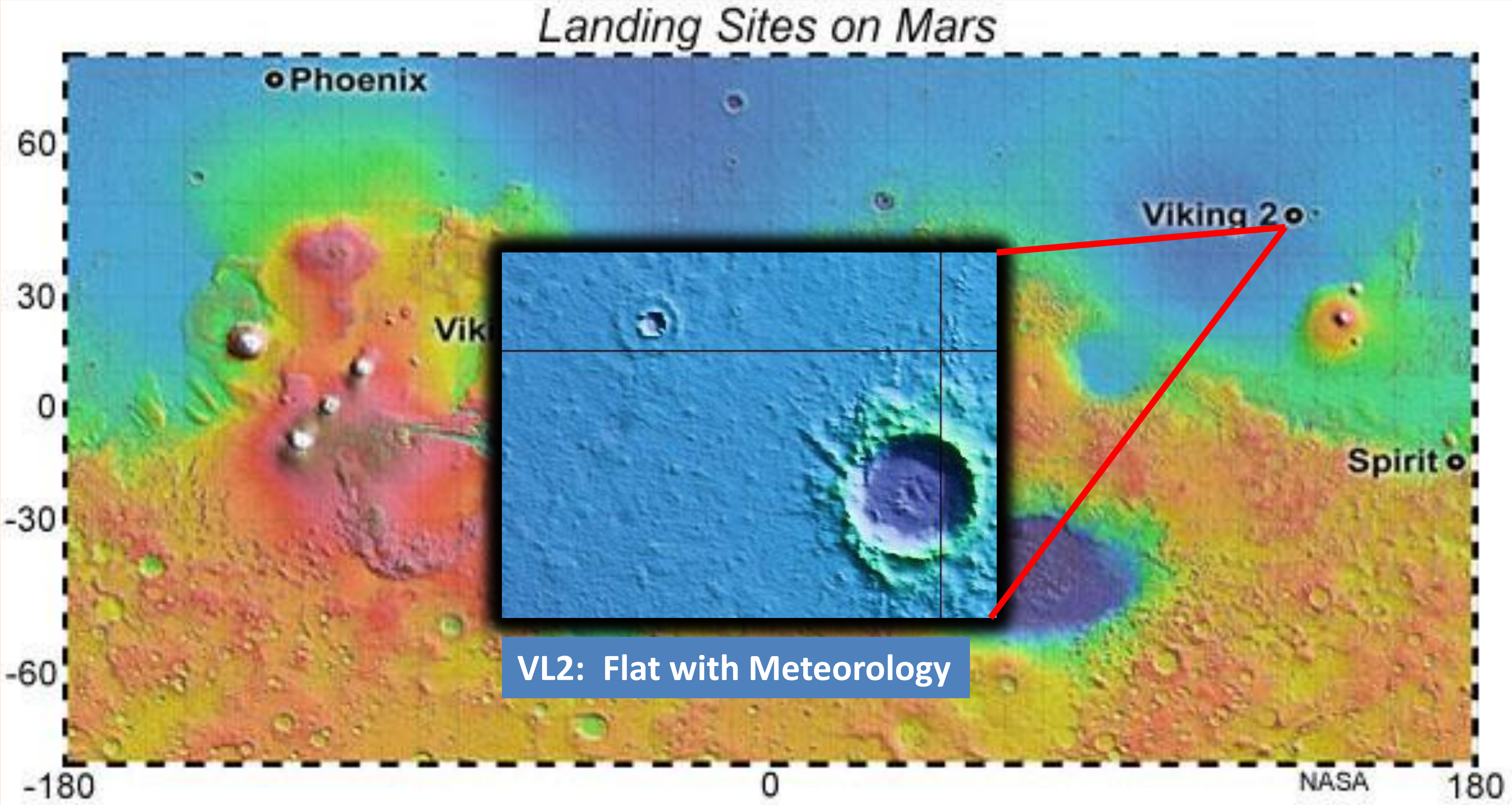
Topography and Mission Meteorology



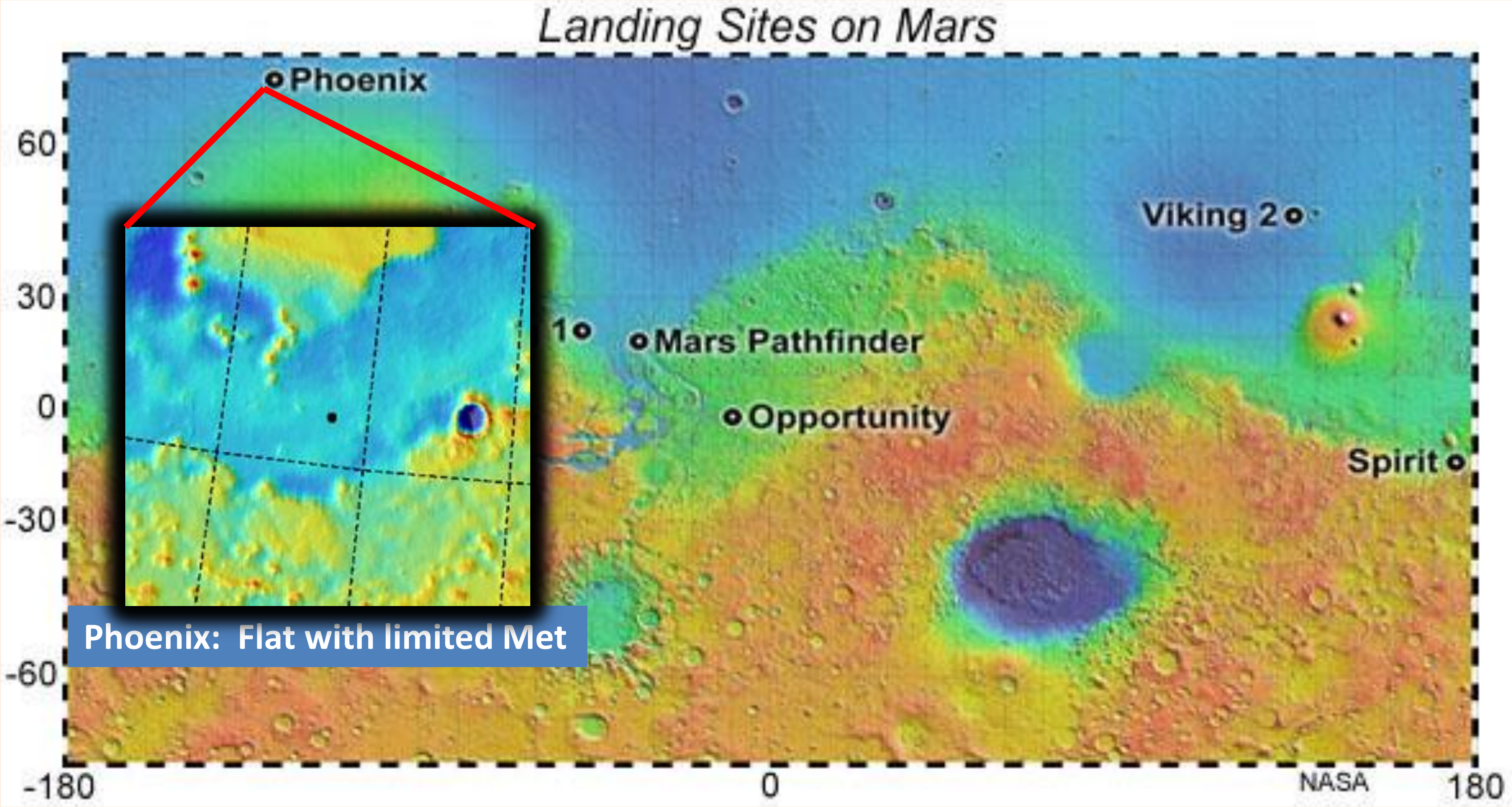
Topography and Mission Meteorology



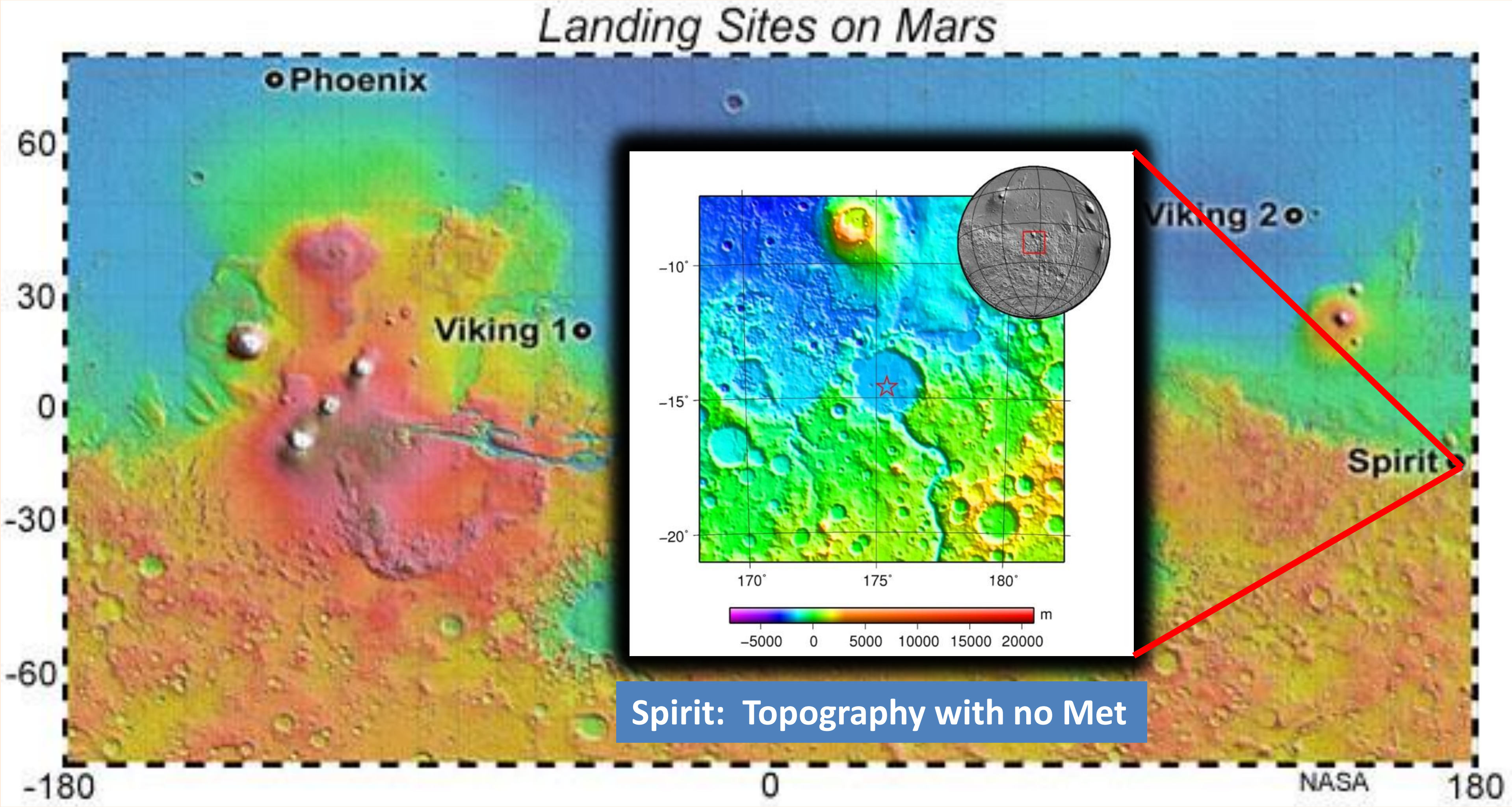
Topography and Mission Meteorology



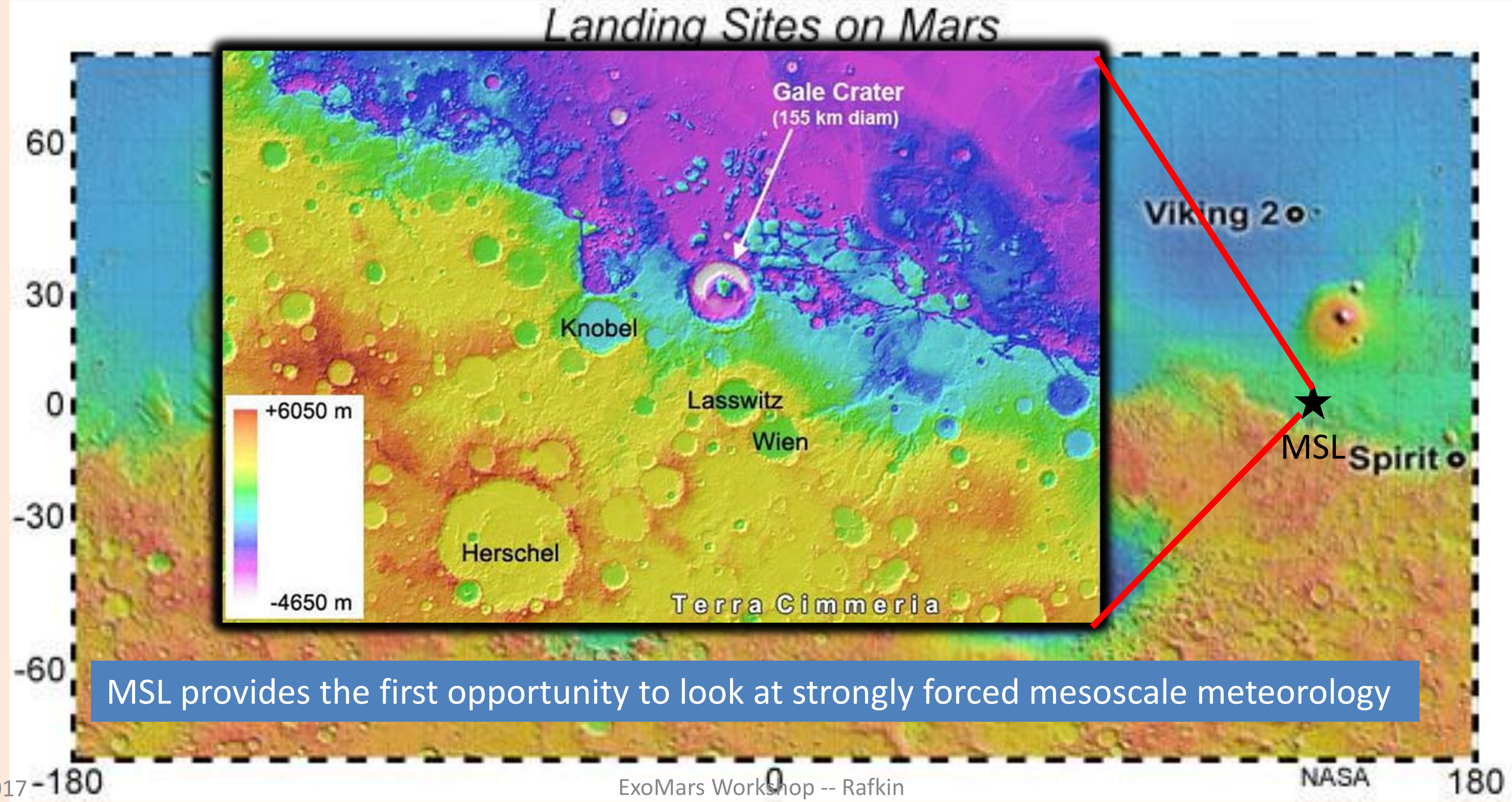
Topography and Mission Meteorology



Topography and Mission Meteorology

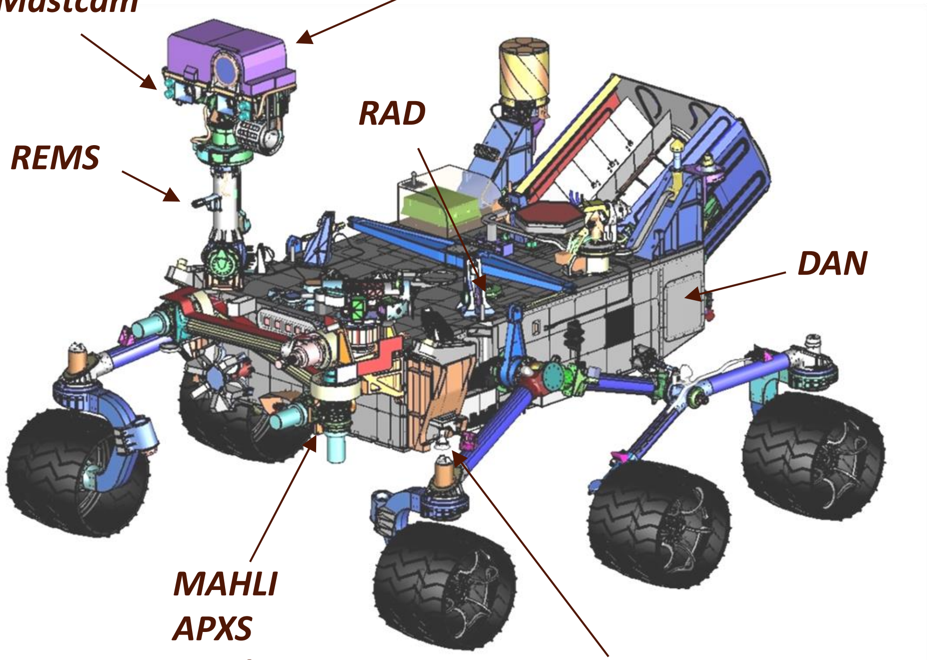


Gale: A Region of Complex Topography With Meteorological Instrumentation (REMS)



MSL provides the first opportunity to look at strongly forced mesoscale meteorology

MSL Science Payload



Wheel Base:	**2.8 m**
Height of Deck:	**1.1 m**
Ground Clearance:	**0.66 m**
Height of Mast:	**2.2 m**

REMOTE SENSING

Mastcam Color and telephoto imaging, video, atmospheric opacity

ChemCam Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)

MAHLI Hand-lens color imaging

APXS Chemical composition

ANALYTICAL LABORATORY (ROVER BODY)

SAM Chemical and isotopic composition, including organics

CheMin Mineralogy

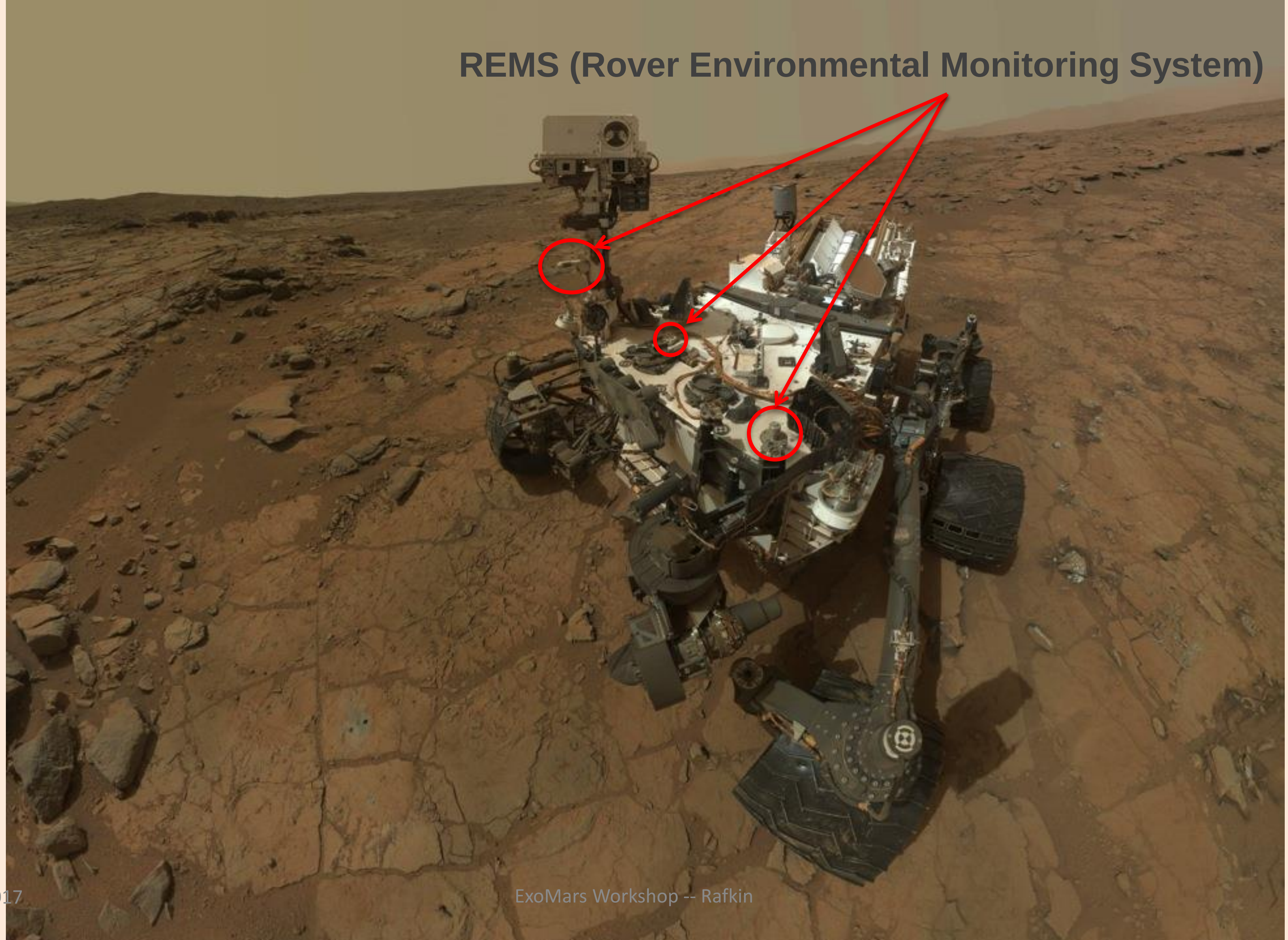
ENVIRONMENTAL CHARACTERIZATION

MARDI Descent imaging

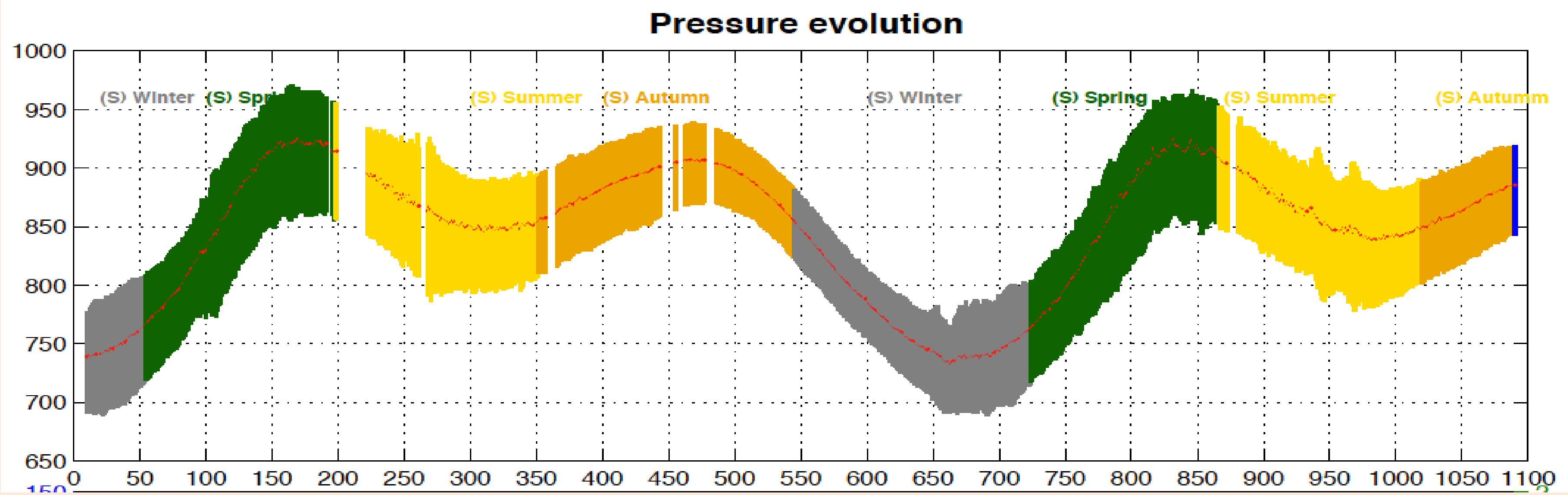
REMS Meteorology / UV

RAD High-energy radiation

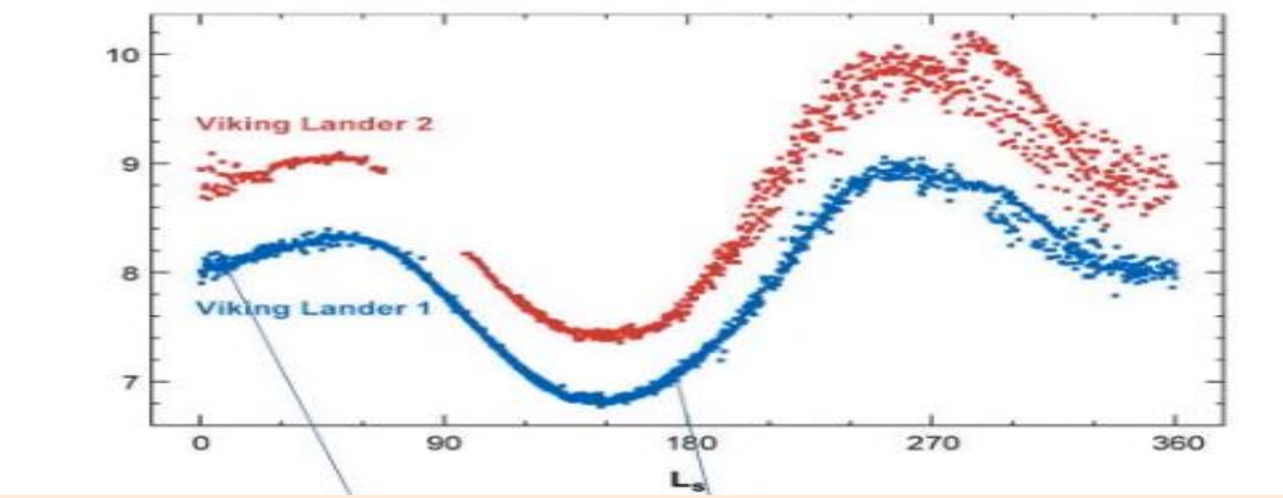
DAN Subsurface hydrogen


REMS (Rover Environmental Monitoring System)

Comparison of Gale to VL1 and VL2

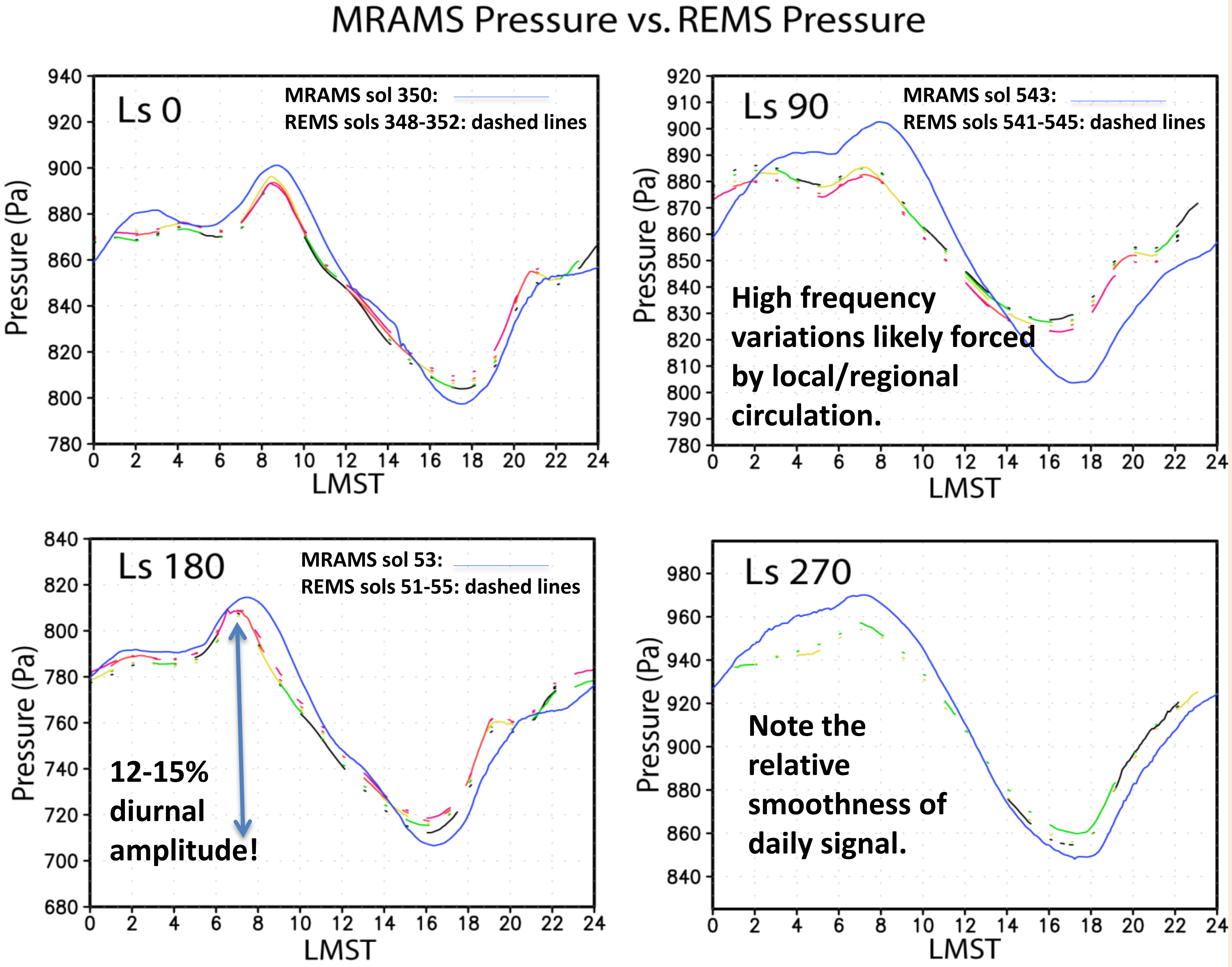


- Same overall cycle
- Storm systems largest at VL2 in winter
- Overall higher diurnal amplitude at Gale



Synthesis of Observations and Models

- Observations validate models.
  - Where do models do well and where do they do poorly?
  - Specific measurements needed to identify *cause* of errors in models.
- Models simulate complex physical connection between meteorological parameters.
  - Can populate incomplete observational records.
  - Can provide greater meaning/understanding/context.
- When properly validated, greater confidence may given to model results at times and places without observations.



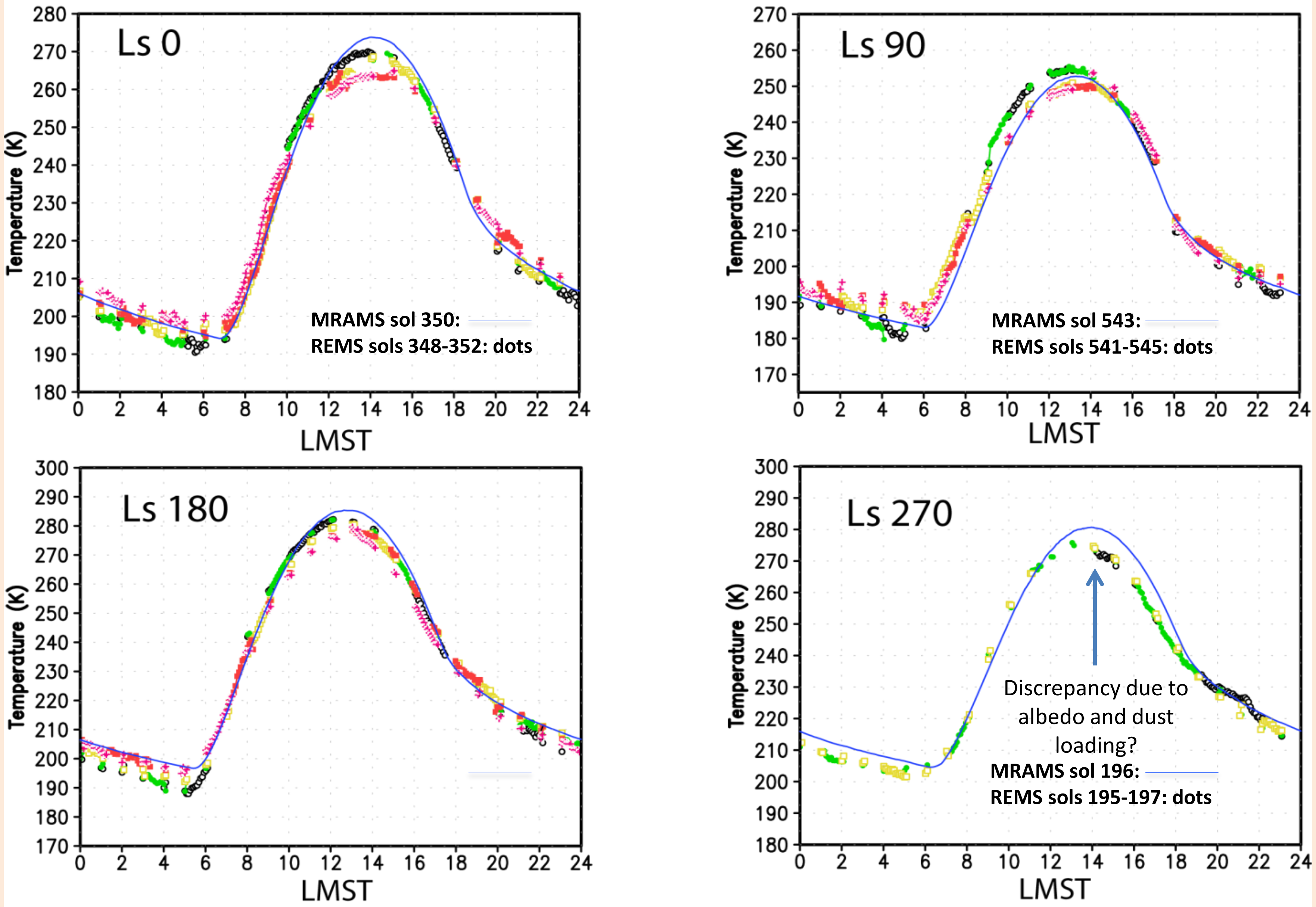
Why such a large discrepancy at Ls 90?

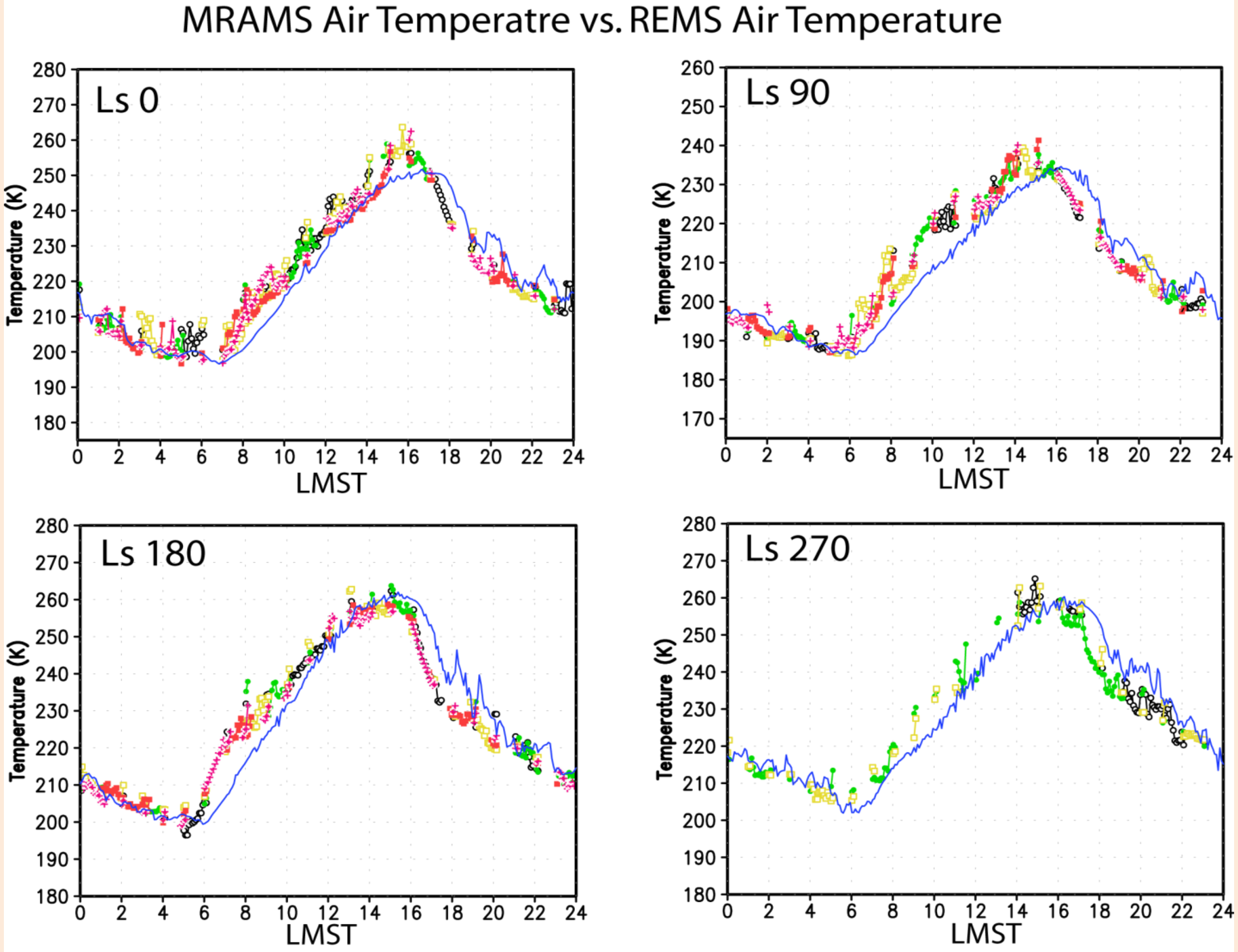
- Dust?
- Poor GCM input?
- Poor physical parameterizations?

Measurements from REMS are largely *unable* to answer this question.

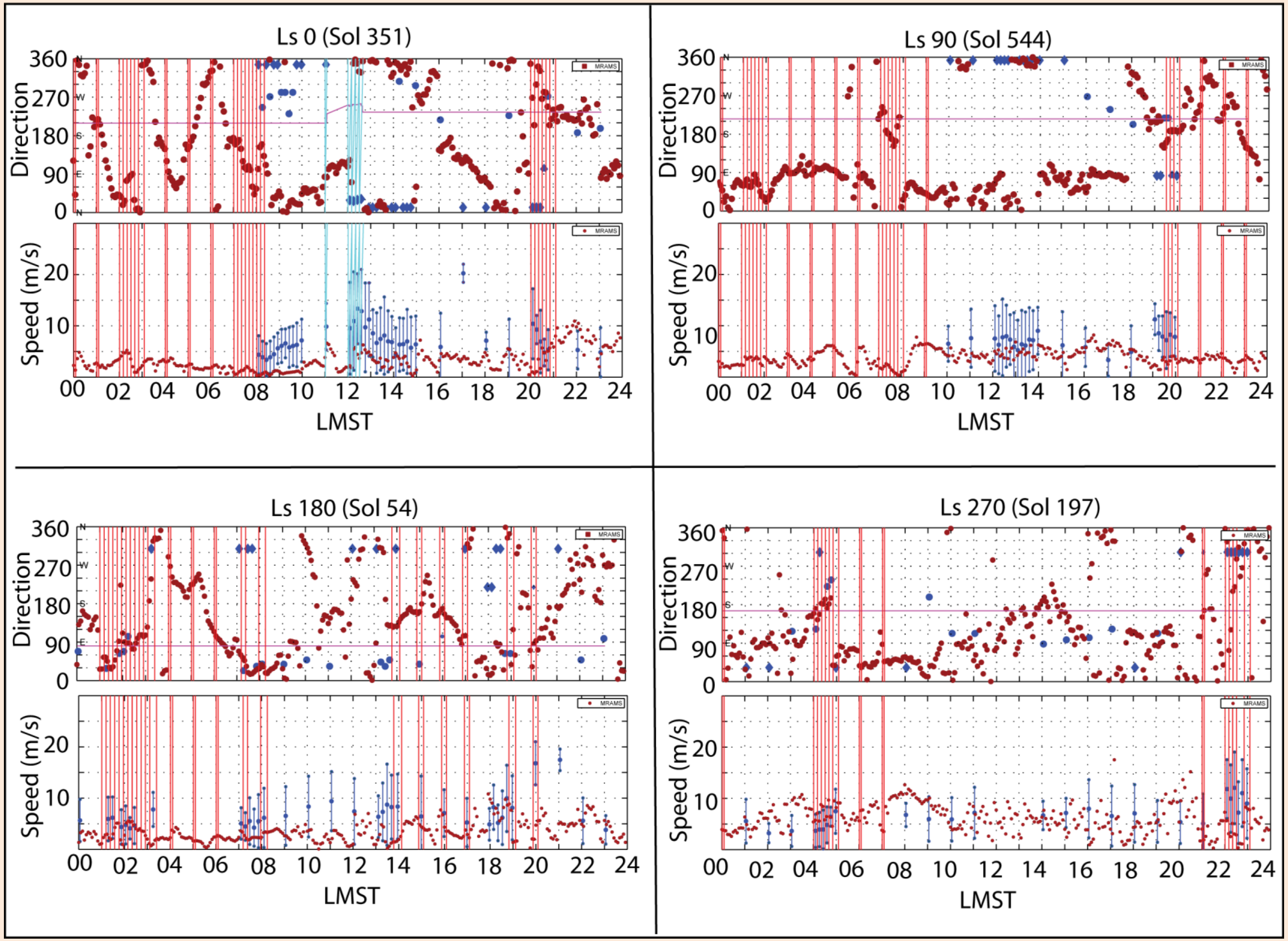
Need to measure atmospheric forcing in addition to atmospheric response.

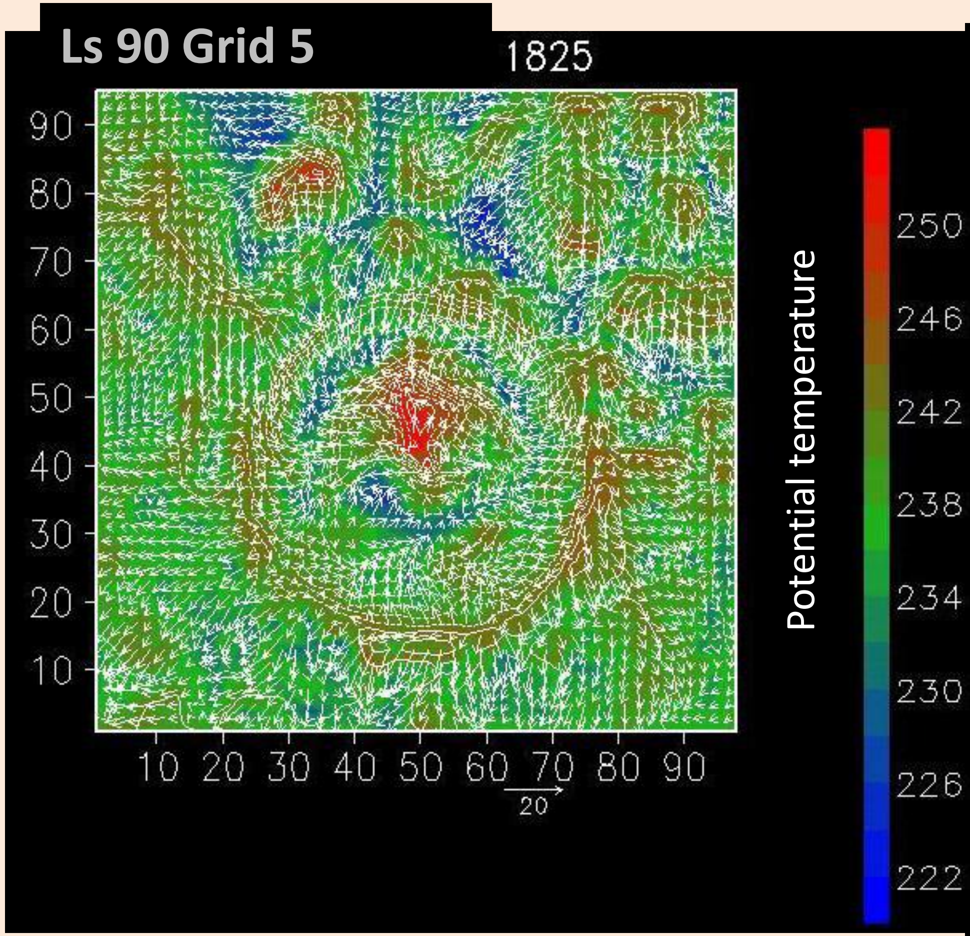
MRAMS Ground Temperature vs. REMS Ground Temperature



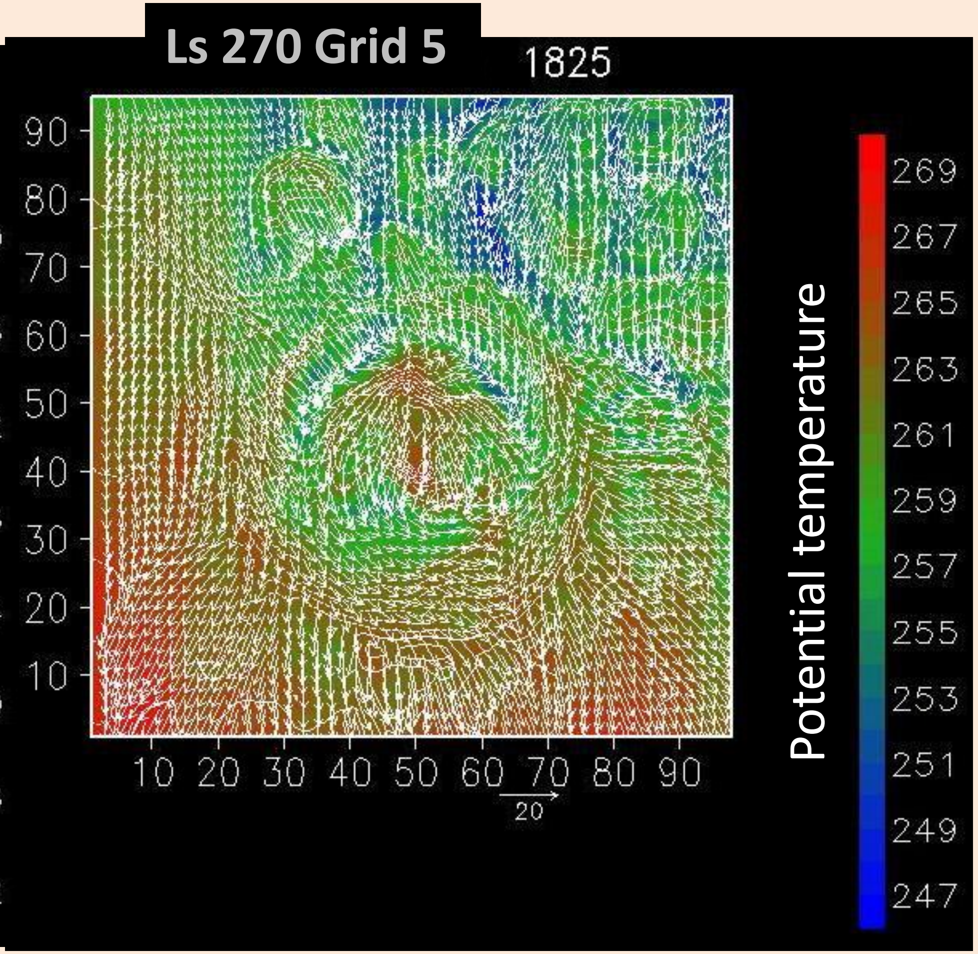

MRAMS Air Temperatre vs. REMS Air Temperature
Ls 0
Ls 90
Ls 180
Ls 270
Temperature (K)
LMST
280
270
260
250
240
230
220
210
200
190
180
170
0 2 4 6 8 10 12 14 16 18 20 22 24

MRAMS Wind vs. REMS Wind



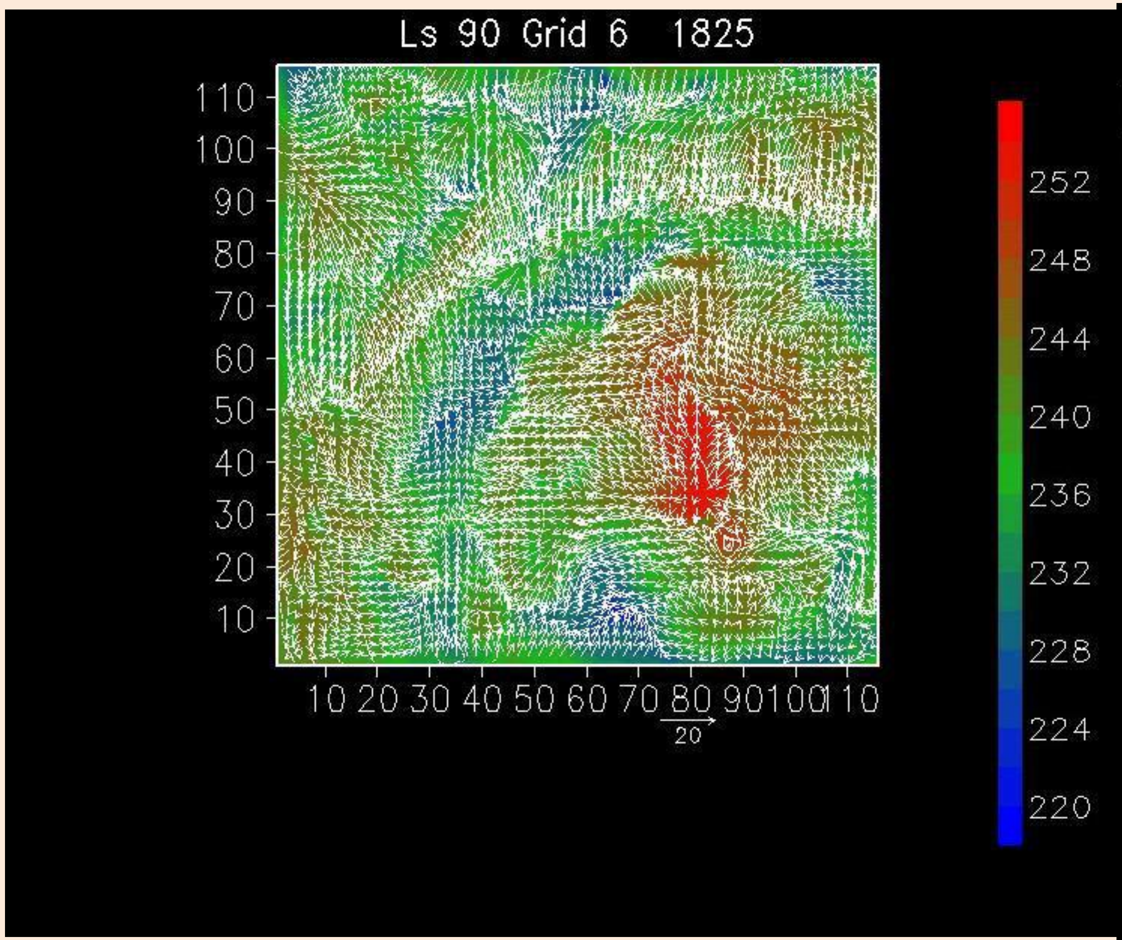


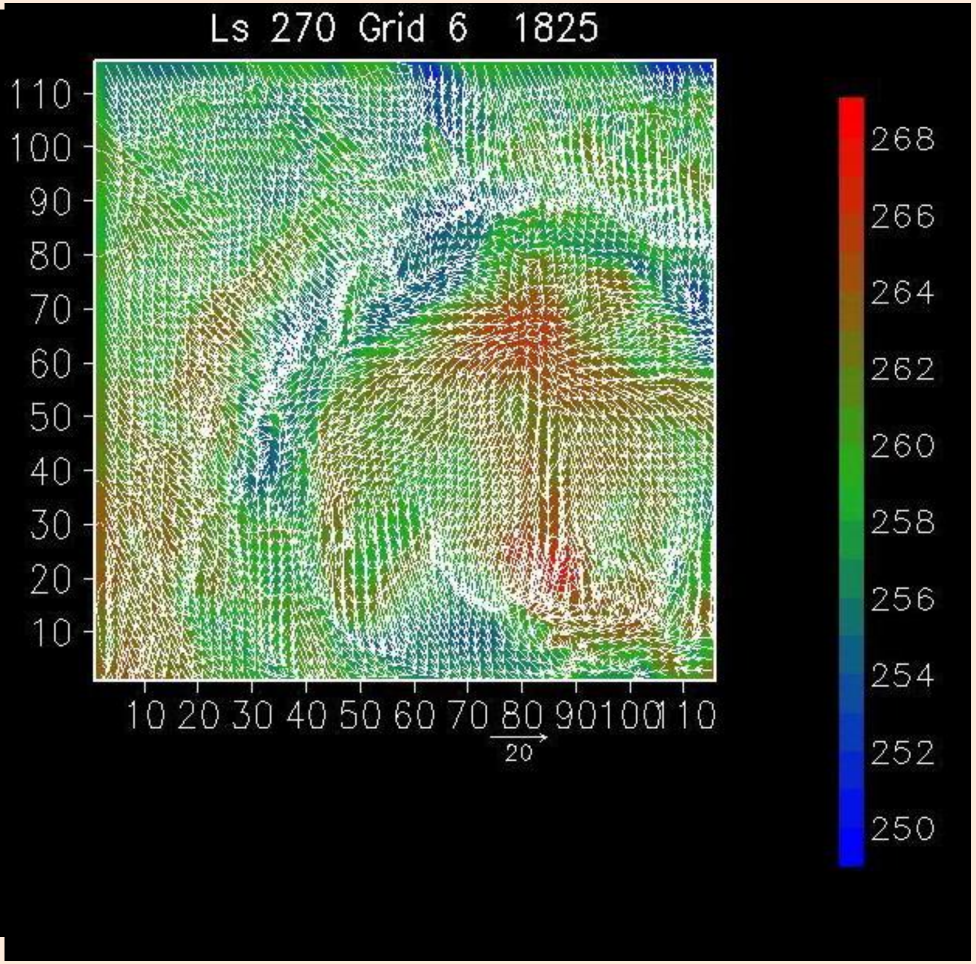
Crater air mass is generally much **colder** than outside the crater. External air hindered from entering crater.



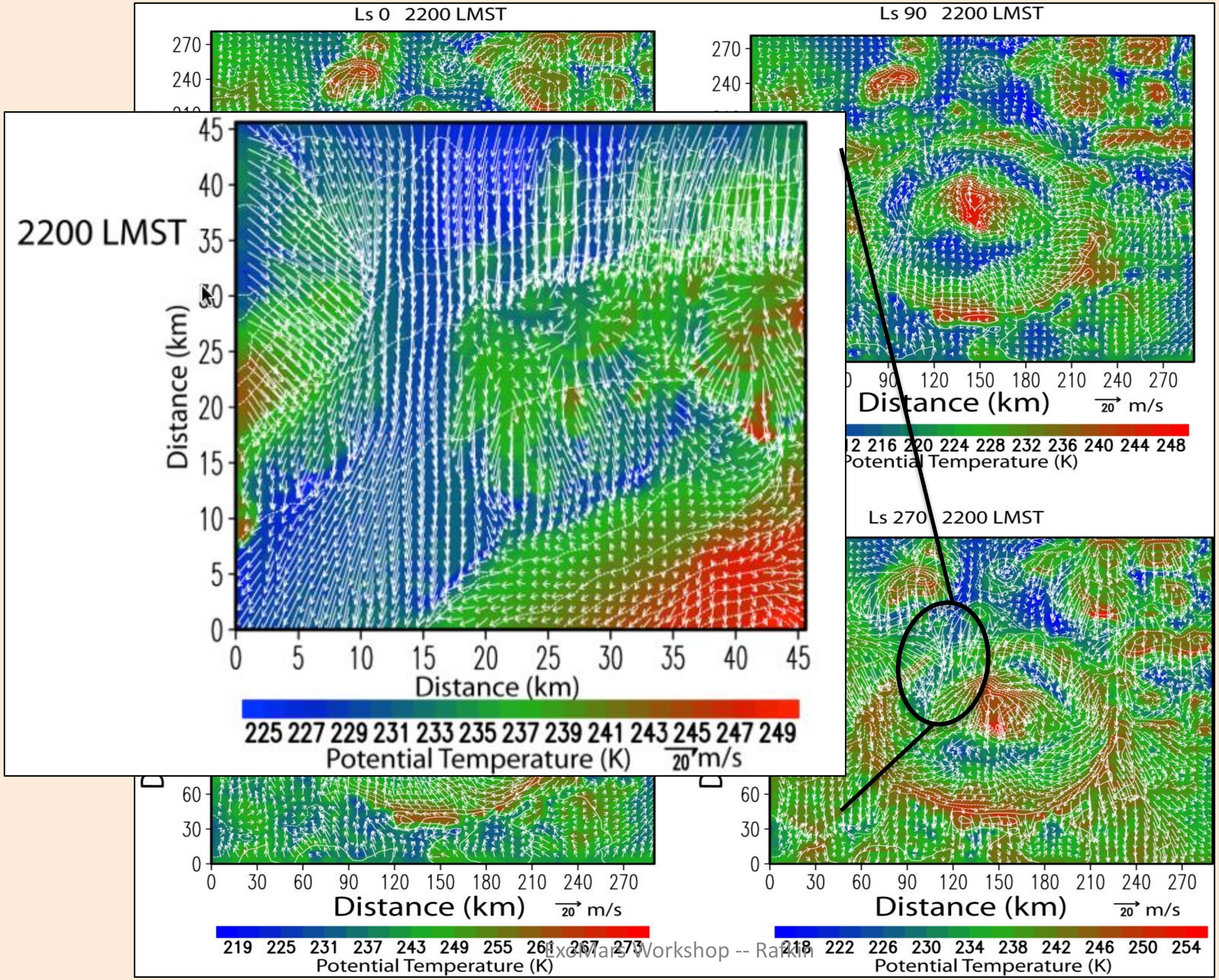
UNIQUE season at Gale. Air mass in crater mixes with the external atmosphere due to strong, cold, flushing, northerly flow and breaking mountain waves.

Complexities that Cannot be Captured by a Single Station

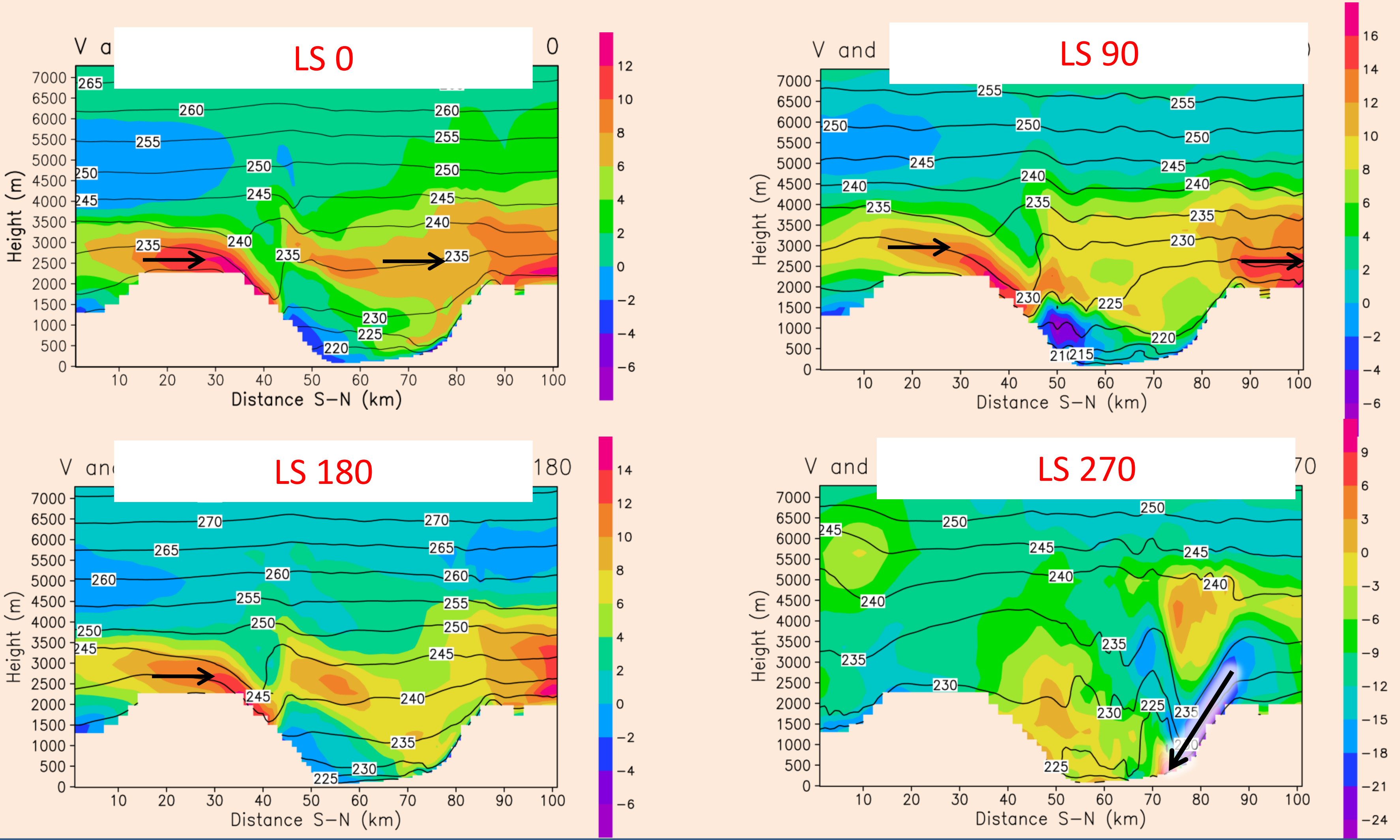




Night (2200 Local) Winds and Potential Temperature

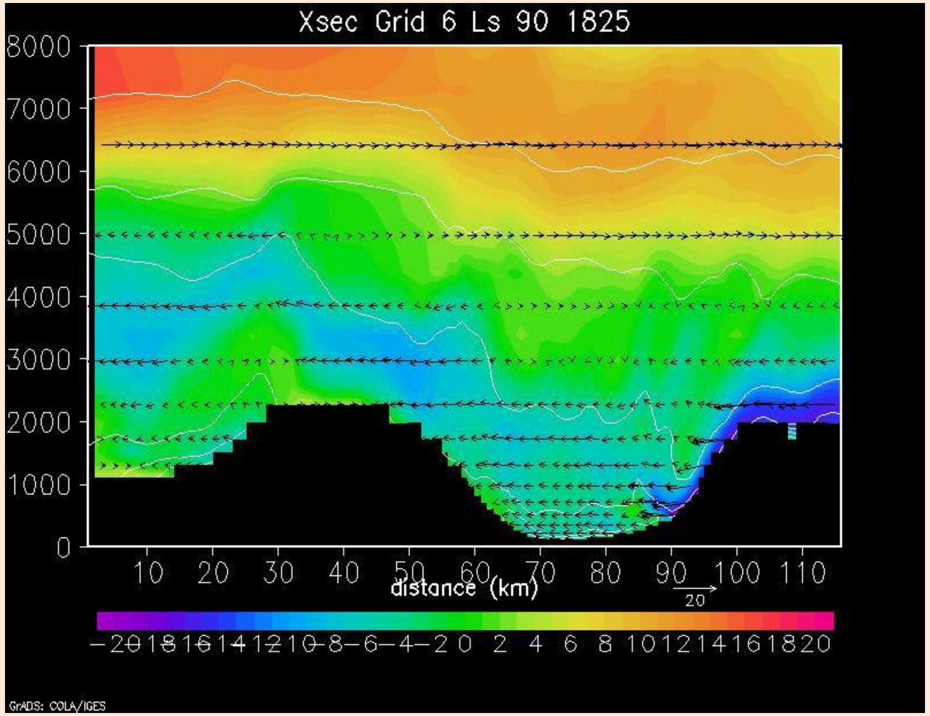


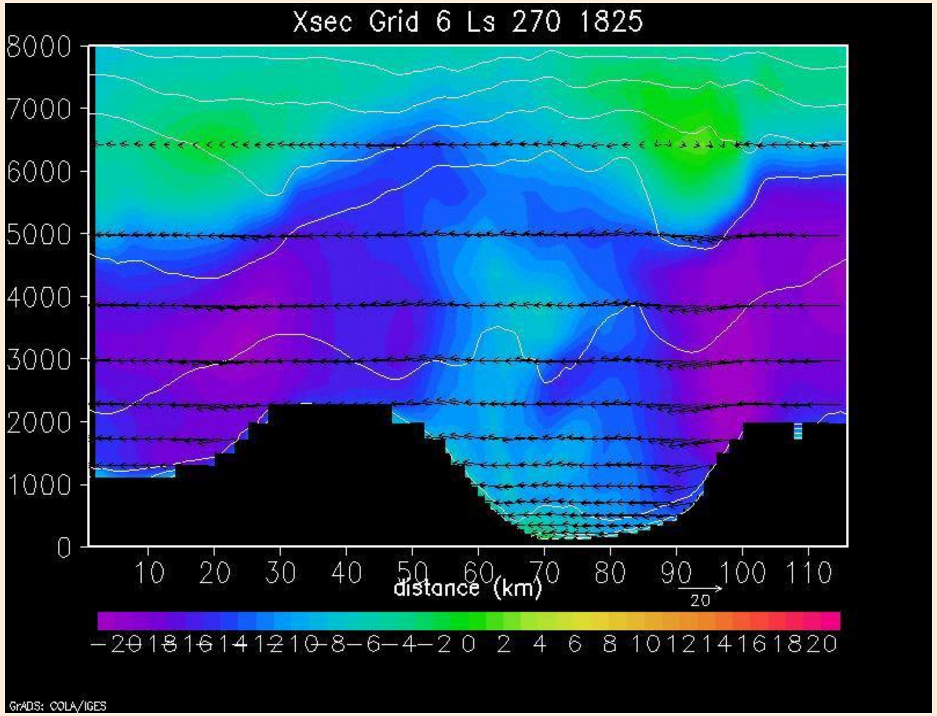
Cross-Sections: Wind and Potential Temperature (0410 Local)



Warm, capping inversion at all seasons but Ls 270.
Warm air tends to override crater air mass at other seasons.
Strong downslope winds and wave activity along north rim at Ls 270

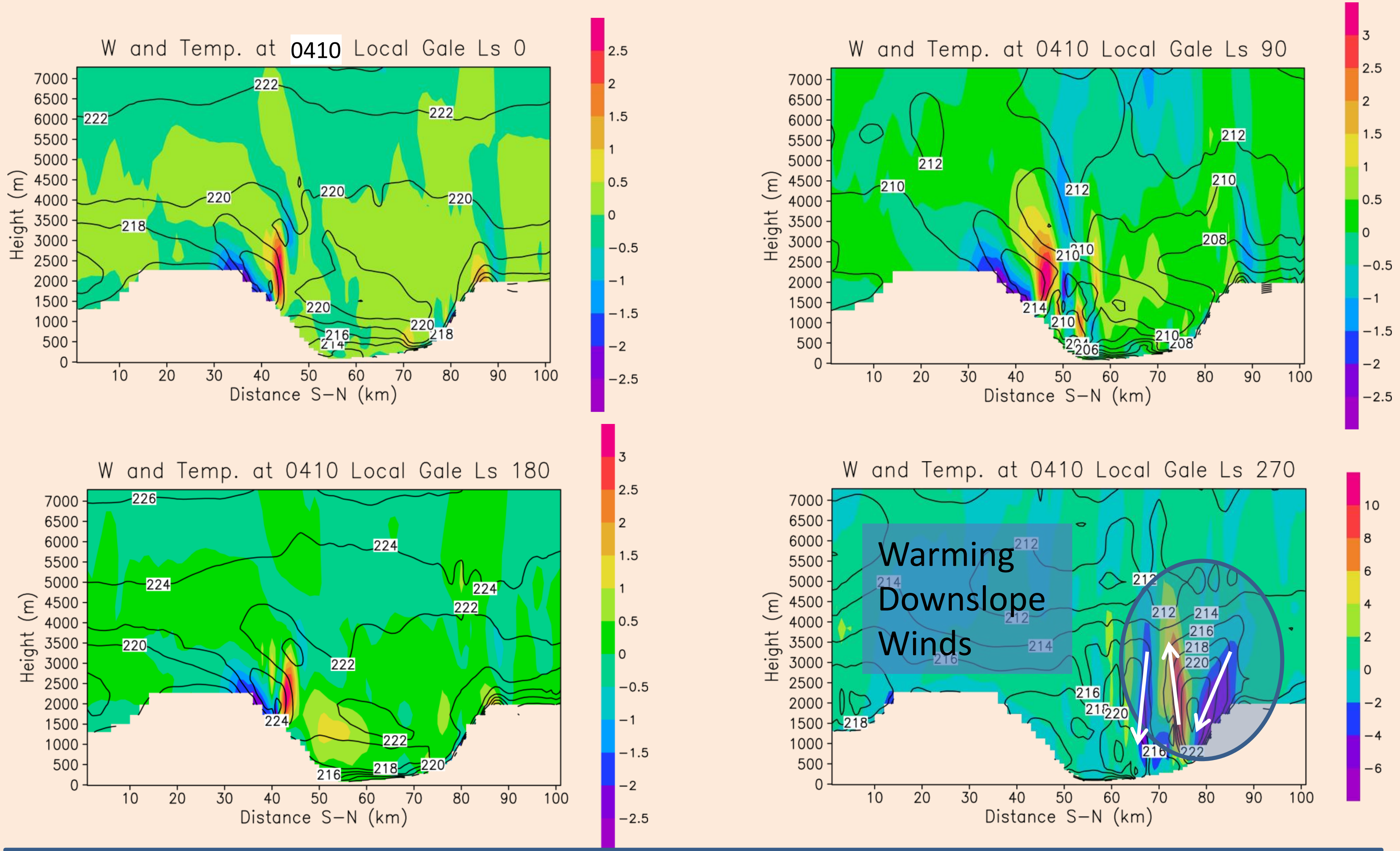
Ls 90 vs Ls 270





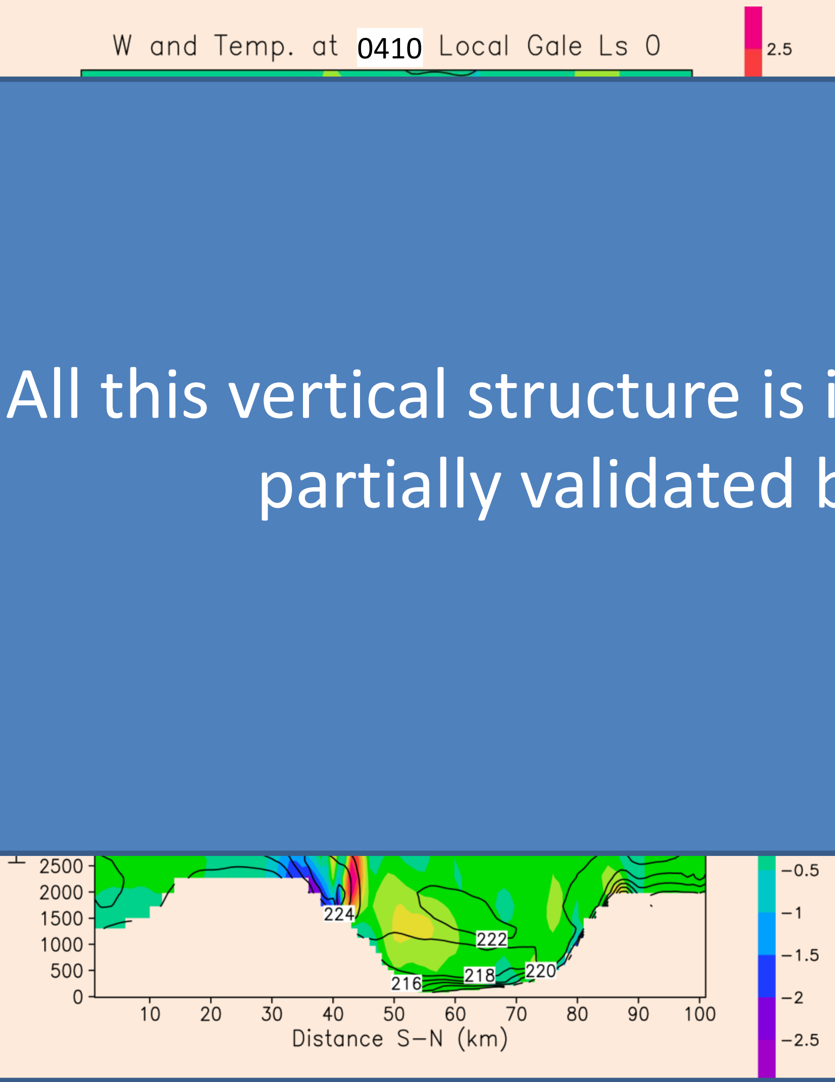
Wind speed (shaded)

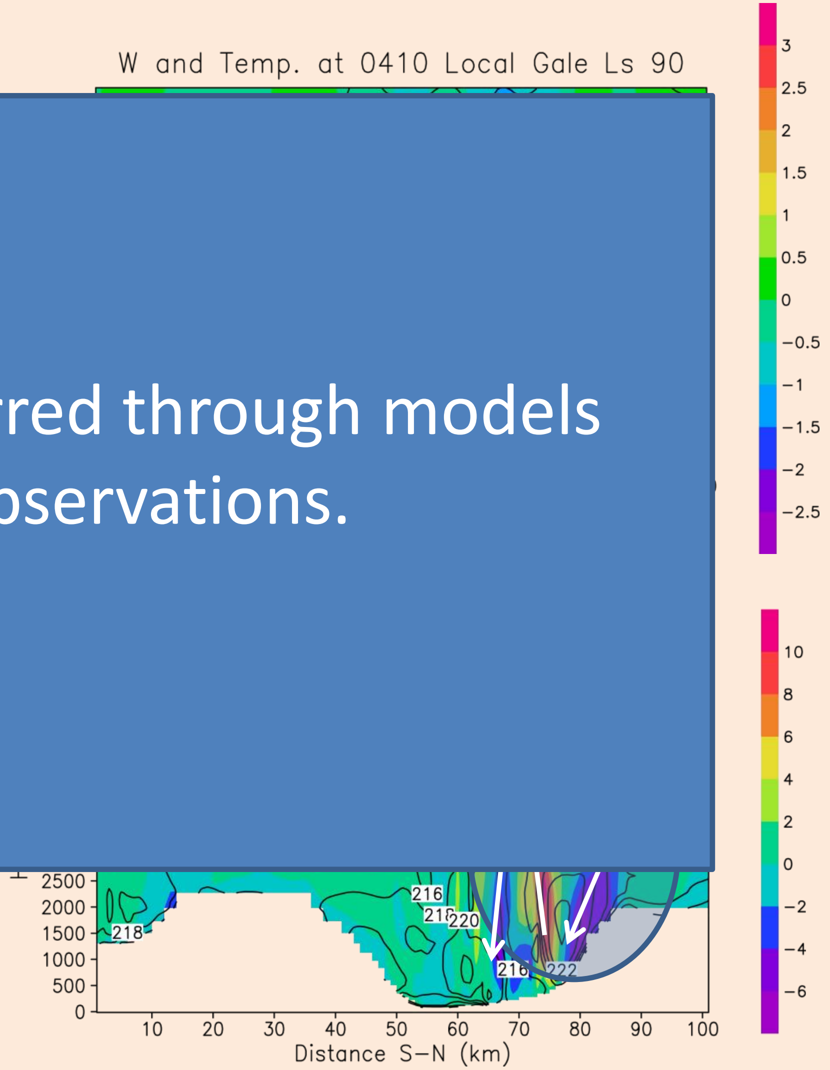
Cross-Sections: Vertical Wind



Wave activity clearly marked in vertical wind.

Cross-Sections: Vertical Wind

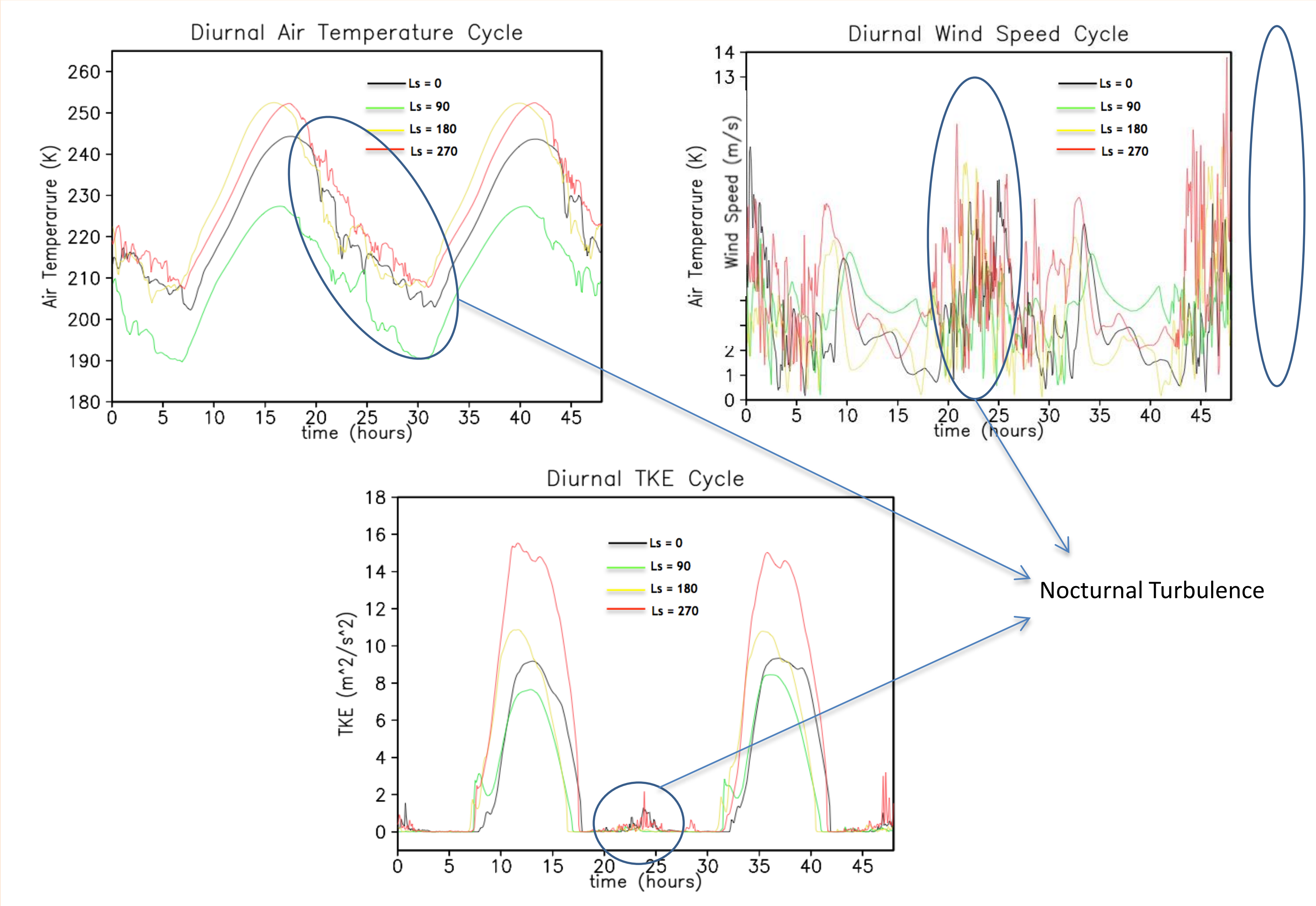




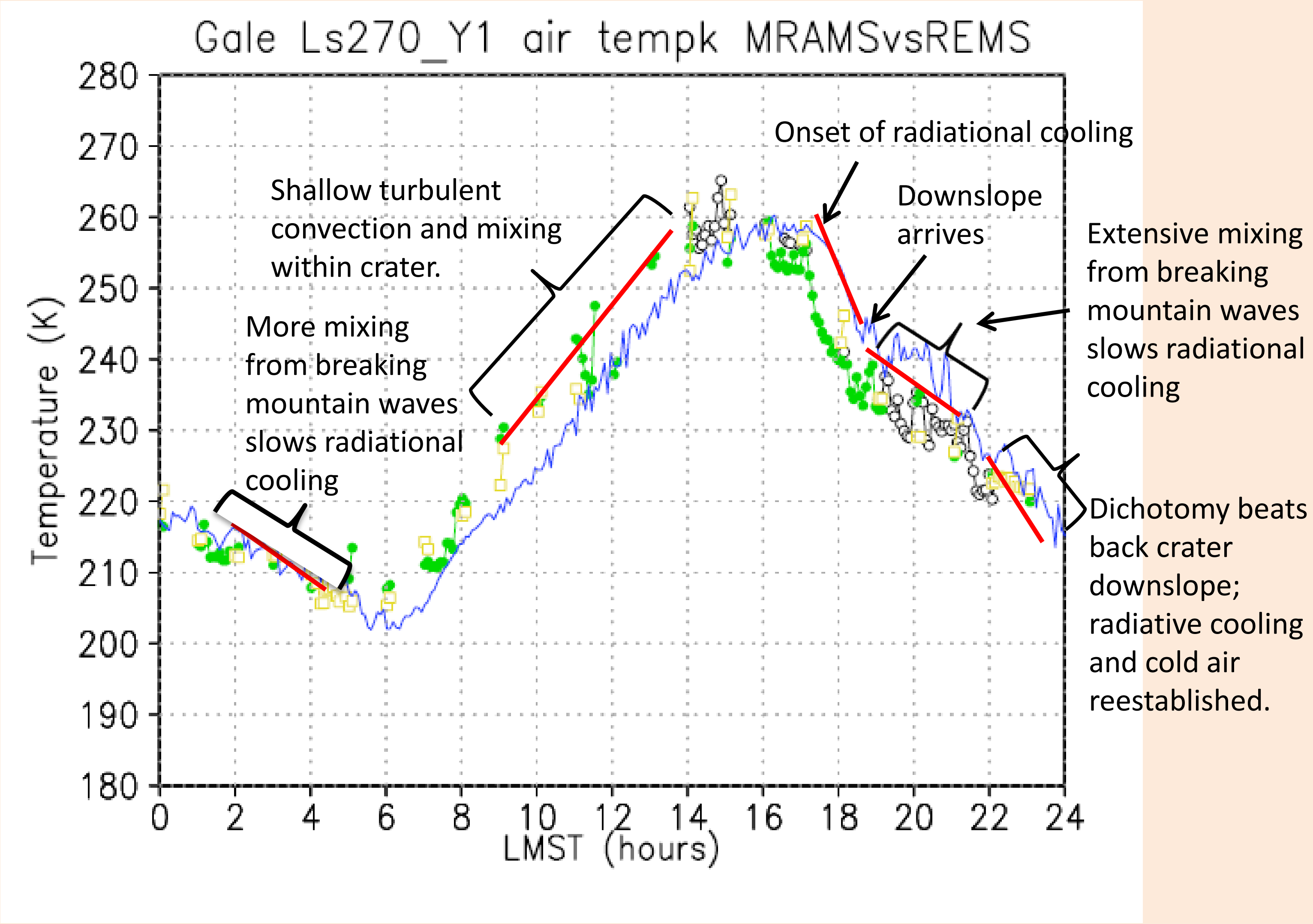
All this vertical structure is inferred through models partially validated by observations.

Wave activity clearly marked in vertical wind.

Nocturnal Turbulence



Daily Meteorological Regimes Recorded in Temperature



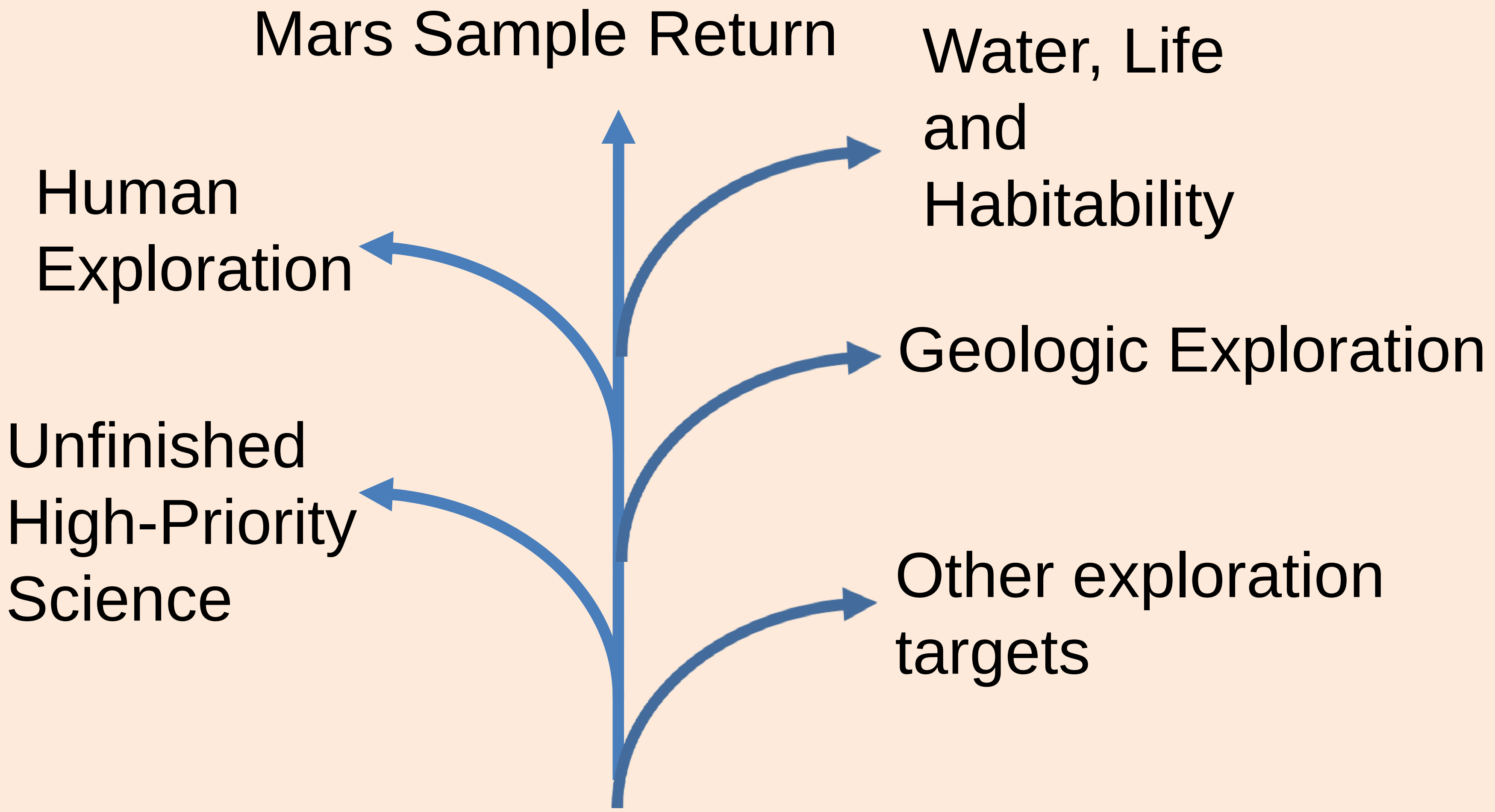
Lessons from REMS

- First opportunity since Viking with met station! Keep it coming.
- Complex topography drives interesting circulations.
- First wind sensor failure problematic.
- Second wind sensor failure extremely painful.
- Accommodation
  - Spacecraft perturbs environment. Accommodation matters.
  - Complications with calibration.
  - Need to design s/c with Met in mind, not as an afterthought. Met stations are difference than most other instruments.
- Sensor accuracy
  - RH sensor response at cold temperatures
  - Ground temperature sensor +/- 5K leads to larger uncertainty in upward IR flux.
  - Uncertainties in retrieving winds/temp from thermal/dynamic modeling. More direct measurement techniques?
- Still largely in “characterization” mode. Need better/additional data to answer “why” and “how”.
  - Need to measure forcing *and* response.

The “Forgotten Science” Intermission

- Focus on water/habitability led to neglect by NASA of other important science:
  - Atmospheric evolution and upper atmosphere Nothing until Maven)
  - Interior structure (Nothing until InSIGHT)
  - Photochemistry (Mission interruptus on TGO)
  - Present-day weather and climate cycles (No full surface Met until MSL)
  - Aeolian processes (No dedicated investigations)
  - Moons (No dedicated investigations)
- Limited preparation for future human exploration
  - Dust properties (Nothing)
  - Electrification (ESA DREAMS ExoMars Lander)
  - Radiation (MSL-RAD)
  - Resource utilization (MOXIE: 2020 Rover)
  - Atmospheric environment (MSL REMS, 2020 Rover MEDA)

The Future: The Epoch of ________?



Where do we go from here?

The NASA Mars Program: Mars Sample Return

Mars Sample Return

- Required by Decadal Survey.
  - NASA can ignore and does so when it wants to, but not this time.
- Congress and administration will not commit funding.
- Current cost estimates of MSR are almost certainly wrong by a large margin.
- MSR requires multiple new and major technological developments.
- Highly vulnerable to single mission element failure.
- High cost comes at expense of other Mars and planetary science activities.

Lessons from Mars Sample Return

- Mars Program had been on unsustainable trajectory for over a decade.
  - No planning for the eventual crash (and burn).
  - Don't put all your eggs in one basket.
  - Ocean Worlds beware!
- Should not commit to an expensive multi-decadal program until there is strong government commitment to fund.
- Decadal survey doesn't take into account politics.
  - Desired science can conflict with rapidly changing funding and political realities.
  - Need to have a clear escape hatch from Decadal Survey when the basis of recommendations is broken.
- The idea that Mars could only be sold on the story of life and water became a self-fulfilling prophecy.
  - There *is* other compelling science.
  - If you tell a lie long enough, people start to believe it.
  - Cassini, New Horizons, Lucy,….none of these were sold using the life story!
- MSR is <u>not</u> a science mission until samples are returned.
- If you see a cliff coming, don't close your eyes and accelerate. TURN.THE.WHEEL!

Future Missions on the Books

- 2018 InSight with TWINS
- 2018 TGO Science Phase
  - Should provide major advance in photochemistry.
  - Should nail methane abundance and variability.
- 2020 Rover with MEDA
  - Many improvements over REMS.
  - Some measurement of the “forcings”. (Primarily IR)
  - Some of same uncertainty, accommodation, retrieval issues remain.
- 2020 ExoMars lander
- 2020 UAE areostationary orbiter (first true synoptic view of Mars)
- 2020 SpaceX Dragon…NASA may solicit payload!
- 2020 China TBD
- 2022, 2024,….200(2*N): NOTHING!
  - NASA 2022 NeMO looks unlikely or with minimal to no atmospheric science
  - Best atmos instrument for NeMO is sub-mm: overlap with TGO, mediocre wind measurements.

Advancing Climate Science

Objectives	Sub-objectives
A. Characterize the state of the present climate of Mars' atmosphere and surrounding plasma environment, and the underlying processes, under the current orbital configuration.	**A1.** Constrain the processes that control the present distributions of dust, water, and carbon dioxide in the lower atmosphere, at daily, seasonal and multi-annual timescales.
	A2. Constrain the processes that control the dynamics and thermal structure of the upper atmosphere and surrounding plasma environment.
	A3. Constrain the processes that control the chemical composition of the atmosphere and surrounding plasma environment.
	A4. Constrain the processes by which volatiles and dust exchange between surface and atmospheric reservoirs.
B. Characterize the history of Mars' climate in the recent past, and the underlying processes, under different orbital configurations.	**B1.** Determine how the chemical composition and mass of the atmosphere has changed in the recent past.
	B2. Determine the record of the recent past that is expressed in geological and mineralogical features of the polar regions.
	B3. Determine the record of the climate of the recent past that is expressed in geological and mineralogical features of low- and mid-latitudes.
C. Characterize Mars' ancient climate and underlying processes.	**C1.** Determine how the chemical composition and mass of the atmosphere have evolved from the ancient past to the present.
	C2. Find physical and chemical records of past climates and factors that affect climate.
	C3. Determine present escape rates of key species and constrain the processes that control them.

Relationship of Human Exploration Strategic Knowledge Gaps to Science(MEPAG/OPAG June 2012)

SKGs

Scientific Objectives, Martian System

Objective		#	Investigation (from 2010 MEPAG Goals Document)	A1 Upper Atmosphere	A2 Atm. Modeling	A3 Orbital Particulates	A4 Technology: To/from Mars System	B1 Lower Atmosphere	B2 Back PP	B3 Crew Health and Performance	B4 Dust Effects	B5 Forward PP	B6 Atmospheric ISRU	B7 Landing Site and Surface Hazards	B8 Technology: Mars Surface	C1 Phobos/Deimos Science	C2 Phobos/Deimos surface Ops	C3 Technology: Phobo/Deimos	D1 Water Resources	D2 Technology: Sustained Presence
I. Life	A. Past habitability /life	1	PRIOR HABITABILITY OF SURFACE ENVIRONMENTS																S	
		2	PRESERVATION POTENTIAL																	
		3	EVIDENCE OF PRIOR HABITABILITY OR BIOSIGNATURES																	
	B. Present habitability/life	1	PRESENTLY HABITABLE ENVIRONMENTS						E			E							S	
		2	DEGRADATION OF LIFE SIGNATURES						S			E								
		3	SEARCH FOR EXTANT LIFE						E			S								
	C. Evolution of habitability	1	CHARACTERIZE HYDROLOGICAL CYCLE																S	
		2	BIOESSENTIAL ELEMENTS																	
		3	POTENTIAL ENERGY SOURCES																	
		4	OXIDATIVE / RADIATION HAZARDS						E	E	S			S						
II. Climate	A. Present	1	WATER, CO2, AND DUST PROCESSES	E	E			E		S	S		E	S					S	
		2	PHOTOCHEMICAL SPECIES	S	S			S	E		S		E							
		3	VOLATILE AND DUST EXCHANGE	S	S			S			S		E							
		4	SEARCH FOR MICROCLIMATES						S		S	S	S							
	B. Recent	1	ISOTOPIC, NOBLE, & TRACE GAS CHANGES W/ OBLIQUITY																	
		2	STRATIGRAPHIC RECORD--PLD																	
		3	PERIGLACIAL PROCESSES																	
	C. Ancient	1	RATES OF ESCAPE OF KEY SPECIES				Not addressed.								Not addressed.			Not addressed.		Not addressed.
		2	PHYS AND CHEM RECORDS																S	
		3	ISOTOPIC, NOBLE, AND TRACE GAS EVOLUTION																	
III. Geology/ Geophysics	A. Crust	1	MINERALOGY OF GEOLOGIC UNITS							S	E			E					E	
		2	SEDIMENTARY PROCESSES AND EVOLUTION							S	S			S					S	
		3	ABSOLUTE AGES																	
		4	HYDROTHERMAL ENVIRONMENTS						E										S	
		5	IGNEOUS PROCESSES AND EVOLUTION																	
		6	SURFACE-ATM INTERACTIONS								S			S					S	
		7	TECTONIC HISTORY OF CRUST																	
		8	PRESENT STATE AND CYCLING OF WATER																E	
		9	CRUSTAL MAGNETIZATION																	
		10	EFFECTS OF IMPACTS																	
	B. Interior	1	STRUCTURE AND DYNAMICS OF INTERIOR																	
		2	ORIGIN AND HISTORY OF MAGNETIC FIELD																	
		3	CHEMICAL AND THERMAL EVOLUTION																	
	C. Phobos / Deimos	1	ORIGIN													E	S			
		2	COMPOSITION													E	E			
		3	INTERNAL STRUCTURE													E	E			

NO OVERLAP | EXCELLENT OVERLAP | SOME OVERLAP

Relationship of Human Exploration Strategic Knowledge Gaps to Science(MEPAG/OPAG June 2012)

SKGs

Scientific Objectives, Martian System

Objective		#	Investigation (from 2010 MEPAG Goals Document)	A1 Upper Atmosphere	A2 Atm. Modeling	A3 Orbital Particulates	A4 Technology: To/from Mars System	B1 Lower Atmosphere	B2 Back PP	B3 Crew Health and Performance	B4 Dust Effects	B5 Forward PP	B6 Atmospheric ISRU	B7 Landing Site and Surface Hazards	B8 Technology: Mars Surface	C1 Phobos/Deimos Science	C2 Phobos/Deimos surface Ops	C3 Technology: Phobo/Deimos	D1 Water Resources	D2 Technology: Sustained Presence
I. Life	A. Past habitability/life	1	PRIOR HABITABILITY OF SURFACE ENVIRONMENTS																S	
		2	PRESERVATION POTENTIAL																	
		3	EVIDENCE OF PRIOR HABITABILITY OR BIOSIGNATURES																	
	B. Present habitability/life	1	PRESENTLY HABITABLE ENVIRONMENTS						E			E							S	
		2	DEGRADATION OF LIFE SIGNATURES						S			E								
		3	SEARCH FOR EXTANT LIFE						E			S								
	C. Evolution of habitability	1	CHARACTERIZE HYDROLOGICAL CYCLE																S	
		2	BIOESSENTIAL ELEMENTS																	
		3	POTENTIAL ENERGY SOURCES																	
		4	OXIDATIVE / RADIATION HAZARDS						E	E	S			S						
II. Climate	A. Present	1	WATER, CO2, AND DUST PROCESSES	E	E			E		S	S		E	S					S	
		2	PHOTOCHEMICAL SPECIES	S	S			S	E		S		E							
		3	VOLATILE AND DUST EXCHANGE	S	S			S			S		E							
		4	SEARCH FOR MICROCLIMATES						S		S	S	S							
	B. Recent	1	ISOTOPIC, NOBLE, & TRACE GAS CHANGES W/ OBLIQUITY																	
		2	STRATIGRAPHIC RECORD--PLD																	
		3	PERIGLACIAL PROCESSES																	
	C. Ancient	1	RATES OF ESCAPE OF KEY SPECIES				Not addressed.								Not addressed.			Not addressed.		Not addressed.
		2	PHYS AND CHEM RECORDS																[illegible]	
		3	ISOTOPIC, NOBLE, AND TRACE GAS EVOLUTION																	
III. Geology/ Geophysics	A. Crust	1	MINERALOGY OF GEOLOGIC UNITS							S	E			E					E	
		2	SEDIMENTARY PROCESSES AND EVOLUTION							S	S			S					S	
		3	ABSOLUTE AGES																	
		4	HYDROTHERMAL ENVIRONMENTS						E										S	
		5	IGNEOUS PROCESSES AND EVOLUTION																	
		6	SURFACE-ATM INTERACTIONS								S			S					S	
		7	TECTONIC HISTORY OF CRUST																	
		8	PRESENT STATE AND CYCLING OF WATER																E	
		9	CRUSTAL MAGNETIZATION																	
		10	EFFECTS OF IMPACTS																	
	B. Interior	1	STRUCTURE AND DYNAMICS OF INTERIOR																	
		2	ORIGIN AND HISTORY OF MAGNETIC FIELD																	
		3	CHEMICAL AND THERMAL EVOLUTION																	
	C. Phobos / Deimos	1	ORIGIN													E	S			
		2	COMPOSITION													E	E			
		3	INTERNAL STRUCTURE													E	E			

NO OVERLAP | EXCELLENT OVERLAP | SOME OVERLAP

Relationship of Human Exploration Strategic Knowledge Gaps to Science(MEPAG/OPAG June 2012)

SKGs

Scientific Objectives, Martian System

Objective		#	Investigation (from 2010 MEPAG Goals Document)	A1 Upper Atmosphere	A2 Atm. Modeling	A3 Orbital Particulates	A4 Technology: To/from Mars System	B1 Lower Atmosphere	B2 Back PP	B3 Crew Health and Performance	B4 Dust Effects	B5 Forward PP	B6 Atmospheric ISRU	B7 Landing Site and Surface Hazards	B8 Technology: Mars Surface	C1 Phobos/Deimos Science	C2 Phobos/Deimos surface Ops	C3 Technology: Phobo/Deimos	D1 Water Resources	D2 Technology: Sustained Presence
I. Life	A. Past habitability /life	1	PRIOR HABITABILITY OF SURFACE ENVIRONMENTS				Not addressed								Not addressed			Not addressed.	S	Not addressed.
		2	PRESERVATION POTENTIAL																	
		3	EVIDENCE OF PRIOR HABITABILITY OR BIOSIGNATURES																	
	B. Present habitability/life	1	PRESENTLY HABITABLE ENVIRONMENTS						E			E							S	
		2	DEGRADATION OF LIFE SIGNATURES						S			E								
		3	SEARCH FOR EXTANT LIFE						E			S								
	C. Evolution of habitability	1	CHARACTERIZE HYDROLOGICAL CYCLE																S	
		2	BIOESSENTIAL ELEMENTS																	
		3	POTENTIAL ENERGY SOURCES																	
		4	OXIDATIVE / RADIATION HAZARDS						E	E	S			S						
II. Climate	A. Present	1	WATER, CO2, AND DUST PROCESSES	E	E			E		S	S		E	S					S	
		2	PHOTOCHEMICAL SPECIES	S	S			S	E		S		E							
		3	VOLATILE AND DUST EXCHANGE	S	S			S			S		E							
		4	SEARCH FOR MICROCLIMATES						S		S	S	S							
	B. Recent	1	ISOTOPIC, NOBLE, & TRACE GAS CHANGES W/ OBLIQUITY																	
		2	STRATIGRAPHIC RECORD (PLD)																	
		3	PERIGLACIAL PROCESSES																	
	C. Ancient	1	RATES OF ESCAPE OF KEY SPECIES																	
		2	PHYS AND CHEM RECORDS																S	
		3	ISOTOPIC, NOBLE, AND TRACE GAS EVOLUTION																	
III. Geology/ Geophysics	A. Crust	1	MINERALOGY OF GEOLOGIC UNITS							S	E			E					E	
		2	SEDIMENTARY PROCESSES AND EVOLUTION							S	S			S					S	
		3	ABSOLUTE AGES																	
		4	HYDROTHERMAL ENVIRONMENTS						E										S	
		5	IGNEOUS PROCESSES AND EVOLUTION																	
		6	SURFACE-ATM INTERACTIONS								S			S					S	
		7	TECTONIC HISTORY OF CRUST																	
		8	PRESENT STATE AND CYCLING OF WATER																E	
		9	CRUSTAL MAGNETIZATION																	
		10	EFFECTS OF IMPACTS																	
	B. Interior	1	STRUCTURE AND DYNAMICS OF INTERIOR																	
		2	ORIGIN AND HISTORY OF MAGNETIC FIELD																	
		3	CHEMICAL AND THERMAL EVOLUTION																	
	C. Phobos / Deimos	1	ORIGIN													E	S			
		2	COMPOSITION													E	E			
		3	INTERNAL STRUCTURE													E	E			

NO OVERLAP | EXCELLENT OVERLAP | SOME OVERLAP

A Closer Look Shows Many Missed Overlaps

Future European Missions

- Not directly bound by Decadal Survey or U.S. politics.
- Is indirectly bound to U.S. in a cooperative Mars program.

Can and is ESA willing to go it alone?

Can and is ESA willing to take the lead?

Some Parting Thoughts

- The international Mars exploration program has been a <u>phenomenal success</u>.
- Some forgotten science is now in progress or planned.
- Future progress on Mars atmosphere goals will require investigations that:
  - Measure forcing and response to that forcing.
  - Are accommodated on a s/c designed with forethought
  - Have instruments with improved sensitivity and response
  - Make missing measurements (wind!!!!)
- NASA continues to push towards a (failed) Mars Sample Return Program
  - The current NASA Mars Program is imploding.
  - Even if it moves forward, fundamental deviation from the previous exploration pathways.
  - Science will suffer either way.
- NASA-ESA Mars missions will suffer from NASA MEP collapse.
- Where do we go from here?
  - NASA needs to come to grips with reality and make massive course correction: MSR is DEAD.
  - International science community needs to:
    - Reimagine a <u>broad</u> science and exploration pathway not solely dependent on life and water.
    - Europe can help lead the way since it is unencumbered by the Decadal Survey.
  - More of the same measurements are helpful, but getting to the point of diminishing returns.
    - Atmospheric community would benefit from a consensus agreement on needed measurements, accuracy, etc. => **Future workshop on measurement and strategy**?
    - Winds at the surface and aloft remain a nagging problem.
    - Consider surface and from orbit.
    - What is the ideal surface/orbital experiment that might be achievable as a long term goal?