Mars Reconnaissance Orbiter: Atmospheric Science Objectives

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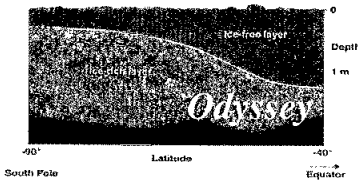
Mars Reconnaissance Orbiter (MRO)

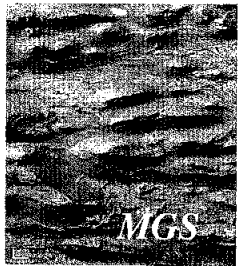
Salient Features

- 4 Earth years in Mars orbit (near polar, 3 p.m., 255 x 320 km)
  - 2 years science observations plus relay support
  - 2 years relay mode with capability to extend science operations
- International Science Payload:
  - Meter- scale and context (6 m/pixel) imaging
  - Hyperspectral (25 m, 10 nm) compositional mapping
  - Atmospheric profiling and weather monitoring
  - Radar probing of the near-subsurface; gravity science
- Relay Telecom Payload + Optical Navigation & Ka-Band Experiments
- Launch: August 2005; Arrive: March '06; Aerobrake: Mar.- Oct '06; Mission End: Dec., 2010

MRO



Science (Atmospheric Science & Present Climate Objectives highlighted in blue)



- Characterize Mars' seasonal cycles and daily variations of water, dust & carbon dioxide.
- Characterize Mars' global atmospheric structure, transport and surface changes.
- Search sites for evidence of aqueous and/or hydrothermal activity.
- Characterize in detail the stratigraphy, geology & composition of Mars surface features.
- Characterize the Martian ice caps and the polar layered terrains.
- Profile the upper crust while probing for subsurface water and ground ice.
- Characterize the Martian gravity field and upper atmosphere in greater detail.
- Identify and characterize many sites for future landed missions.

MRO Science Investigations (1 of 2)

Instrument	*Type*	*PI/TL, Institution*	*Science Goals*	*Attributes*
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars	*Scott Murchie. PI* **Johns Hopkins University Applied Physics Lab** ***Selected thru MRO -2005 AO***	Regional & Local Surface Composition; Atmospheric Properties	***Key: High Spectral & Spatial Resolution*** Targeted & Regional Survey ***Very High Data Rate***
CTX	Context Imager	*Michael Malin, TL* **Malin Space Science Systems (MSSS)** ***Facility Instrument*** ***Replaces MCO MARCI-MAC***	Regional Stratigraphy and Morphology	***Key: High Resolution with Coverage*** Targeted & Regional Survey ***High Data Rate***
HiRISE	High-Resolution Imaging Science Experiment	*Alfred McEwen, PI* **University of Arizona** ***Selected thru MRO-2005 AO***	Stratigraphy, Processes, Site Morphology	***Key: Very High Resolution*** Targeted Imaging ***Very High Data Rate***
SHARAD	Shallow Subsurface RADAR	*Roberto Seu, TL/PI* **University of Rome** *Roger Phillips, DTL (US)* ***NASA-ASI Selection***	Regional Near-Surface Ground Structure	***Key: Shallow Sounding*** Regional Profiling ***High Data Rate***

MRO Science Investigations (2 of 2)

Instrument	Type	PI/TL Institution	Science Goals	Attributes
MARCI	Mars Color Imager	*Michael Malin, PI* **Malin Space Science Systems** ***Recover MCO MARCI-WAC***	Global Weather and Surface Change	***Key: Daily Global Coverage*** Daily,Global Mapping ***Moderate Data Rate***
MCS	Mars Climate Sounder	*Daniel J. McCleese, PI* **Jet Propulsion Laboratory** **California Institute of Technology** ***Recover MCO PMIRR Science***	Atmospheric Fields, Transport & Polar Processes	***Key: Global Limb Sounding*** Daily,Global Limb & On-Planet Mapping; ***Low-Data Rate***
Gravity Science	Facility Science Team Investigation	*Maria Zuber, TL* **MIT / GSFC** ***Selected thru MRO-2005 AO***	Improved Gravity Field Model; transient Mass Change	***Key: Data from DSN tracking using Spacecraft X & Ka Band Telecom***
Atmospheric Structure	Facility Science Team Investigation	*Gerald Keating, TL* **GWU / LaRC** ***Selected thru MRO-2005 AO***	Upper Atmospheric Structure & Variability; A/B Support	***Key: Data from Spacecraft Accelerometers during Aerobraking***
Future	***Participating and Interdisciplinary Scientists may be selected and funded as part of a future Announcement of Opportunity or Research Announcement***			

MRO Science Instrument Requirements (1 of 2)

Instrument	Attributes	L1 Requirements	Baseline Capabilities
CRISM	Highest Ground Resoln.*	< 40 m/pixel	18 m/pixel
	Swath Width*	> 7 km	10.8 km
	Spectral Resolution Spectral Range	≤ 10 nm 0.4 - 3.6 μm	6.55 nm 0.4 - 4.05 μm
CTX	Highest Ground Resoln.*	≤ 10 m/pixel	6 m/pixel
	Swath Width*	≥ 20 km	30 km
	Spectral Bands	Single Bandpass	Panchromatic - blue
	SNR	≥ 20	> 20
HiRISE	Highest Ground Resolution*	Resolve 1-meter scale objects & structure	< 1 m resolution using ground sampling of 0.3 m/pixel
	Swath Width*	≥ 3.5 km	6 km
	Spectral Bands	Single Bandpass	Red (6 km swath*) Blue-Green & NIR (1.2 km swath*)
	SNR	≥ 50	≥ 150
	Stereo Capability	By Revisit	Revisit (within 17 days)

***Referenced to 300 km orbital altitude**

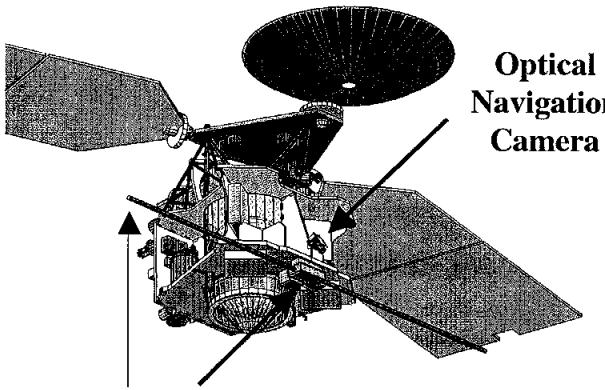
MRO Science Instrument Requirements (2 of 2)

Instrument	Attributes	L1 Requirements	Baseline Capabilities
MARCI	Re-flight of MCO MARCI Wide-Angle Camera	Re-build MARCI WAC (140° FOV)	New Electrical Interface & 180° FOV
	Spectral Bands	2 UV, 5 VIS/NIR	7 bands from 0.28-0.8 μm
	Observation Mode	Daily Global Mapping	Daily Global Mapping
MCS	Recover MCO PMIRR Science	Solar Channel & 8 Thermal IR Channels	Broadband Solar Channel & 8 Thermal IR Channels
	Vertical Range, Resoln.	0 - 80 km; $\leq$ 6 km	0 - 80 km; 5 km
	Observation Mode	Globally Distributed, Daily Atmospheric Limb & On-Planet Observations	Globally Distributed, Daily Atmospheric Limb & On-Planet Observations
SHARAD	Vertical Penetration & Resolution	Several hundred meters At many locations 15 m (free-space)	Several hundred meters At many locations 15 m (free-space)
	Horizontal Footprint (from 300 km)	< 7 km x 1 km (cross-track x down-track)	6 km x 1 km (SAR processing down-track)
	Operating Frequency	f_o > 10 MHz	20 MHz(f_o, central frequency)

MRO Payload

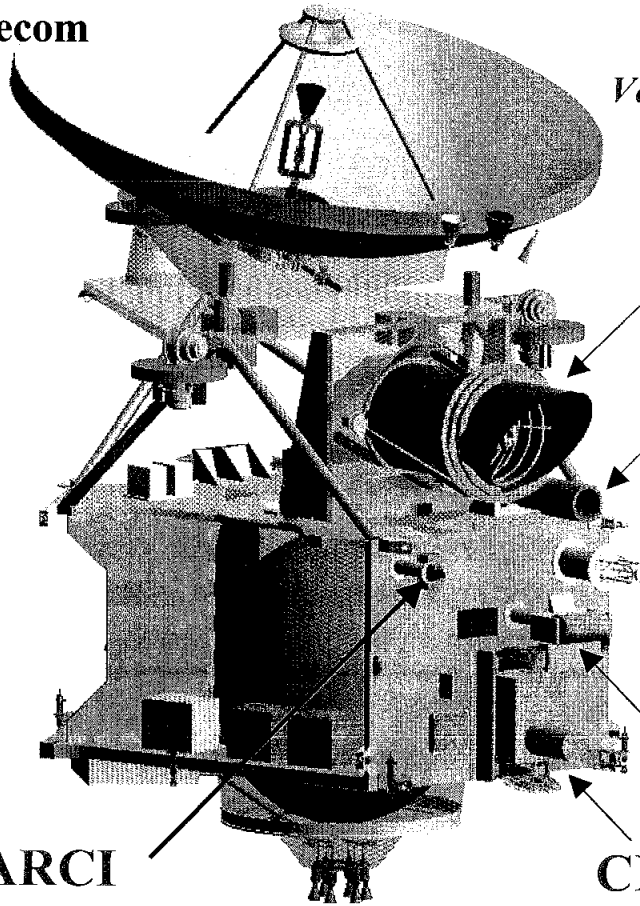
Gravity Science ← **X-Band & Ka-Band Telecom**
TL: M. Zuber
MIT/GSFC

Atmospheric Structure
(Accelerometer Data)
TL: G. Keating
GWU (LaRC)



Optical Navigation Camera

SHARAD
Shallow Subsurface Radar Profiler
TL/PI: R. Seu
U. Roma (Italy)
ASI/Alenia
DTL: R. Phillips
Wash. U. (USA)



HiRISE
Very High Resolution Camera
PI: A. McEwen
U. Arizona

CTX
Context Imager
TL: M. Malin
MSSS

Electra
UHF Relay Antenna

MCS
Atmospheric Profiler
PI: D. McCleese
JPL

MARCI
Daily Global Color Imager
PI: M. Malin
MSSS

CRISM
Hyperspectral Imaging Spectrometer
PI: S. Murchie
JHU/APL

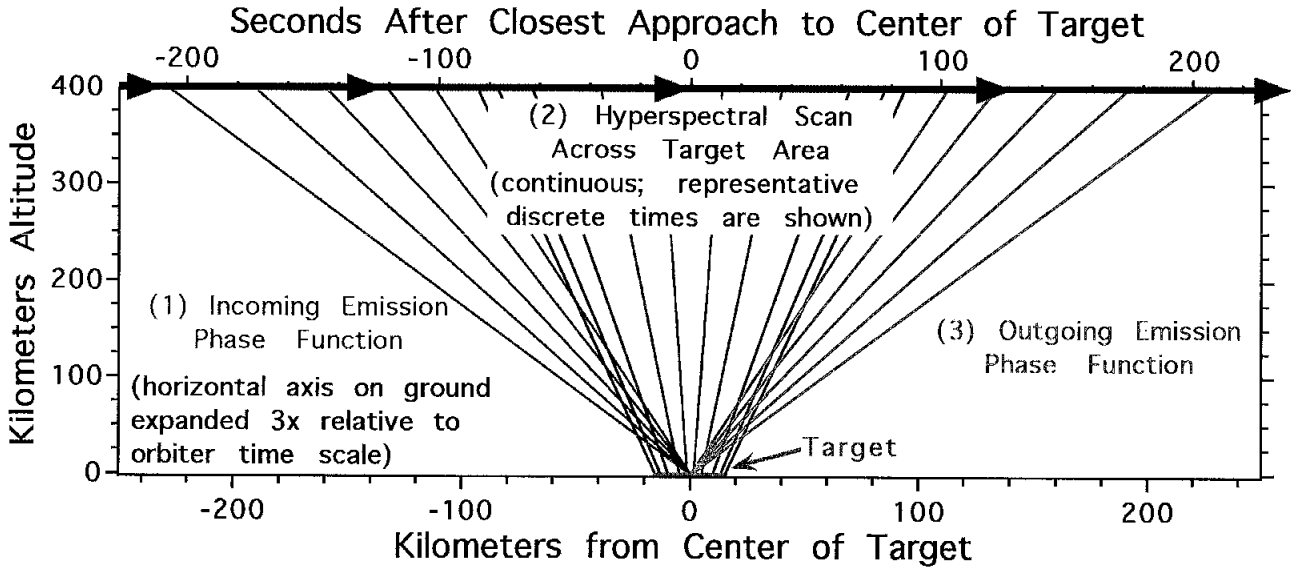
MRO Atmospheric Data Sets (1 of 2)

- **Aerobraking Phase: March-September 2006**
  - Accelerometer measurements yielding upper atmospheric density and scale heights (first aerobraking during solar minimum conditions)
- **Primary Science Phase: November 2006 - December 2008**
  - Near-circular polar orbit, 265-320 km, frozen over S. Pole, 3 p.m./a.m.
  - Mars Climate Sounder (MCS - PMIRR rebuild):
    - Daily, global limb sounding
      - Atmospheric temperature, dust, condensates and water vapor
      - Derived winds and diabatic circulation
    - Seasonal monitoring of polar radiative balance
  - Mars Color Imager (MARCI):
    - Daily, Global Monitoring in UV and VIS channels
      - Atmospheric hazes and storms; column ozone distribution
      - Derived winds
  - Context Imager (CTX)
    - Survey of regional and local storms; boundary layer phenomena

MRO Atmospheric Data Sets (2 of 2)

- **Primary Science Phase: November 2006 - December 2008**
  - Near-circular polar orbit, 265-320 km, frozen over S. Pole, 3 p.m./a.m.
  - Compact Reconnaissance Imaging Spectrometer for Mars (CRISM):
    - Seasonal, global monitoring with EPF-type profiles in visible and near IR atmospheric bands to derive column abundances of dust, water vapor
      - Note: EPF (emission phase function)-type monitoring includes a limb view
  - High Resolution Imaging Science Experiment (HiRISE):
    - High-resolution imaging of mesoscale phenomena, including dust storm onsets, frontal passages and planetary boundary layer activity (e.g., dust devils)
      - Note: Difficult to target time-dependent phenomena
  - Gravity & Radio Science:
    - Tracking seasonal & interannual (?) mass redistribution
    - Atmospheric temperature/pressure/height profiles (Participating Sci.?)
  - Shallow Radar (SHARAD):
    - Searching for near-surface water/water ice reservoirs
    - Characterizing polar (ice) cap structure, surface roughness

Observing Modes

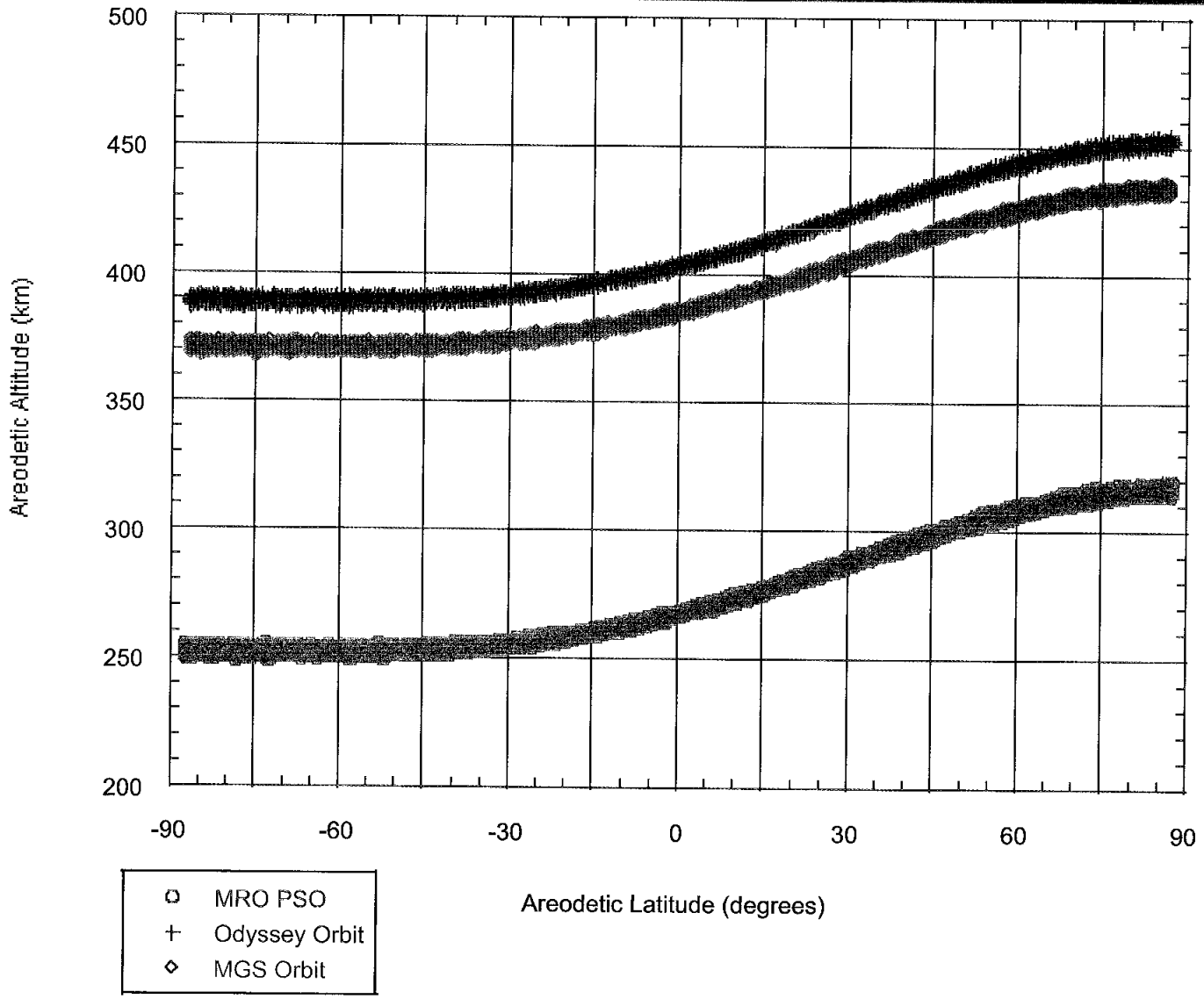


Mode	Description
Full Resolution	As shown, full spectral and spatial resolution (24 m/pixel @400 km, 12 m/pixel @200 km)
Half Resolution	As shown, spatial pixels 2x binned to provide longer swath at low altitude (48 m/pixel @400 km, 24 m/pixel @200 km)
Atmospheric	Only central point of target scanned, to probe atmosphere
Multispectral Survey	Nadir-pointed, 50 selected channels , spatial pixels 4x binned (96 m/pixel)
Calibration	No scanning, integrating sphere measured on-orbit
Standby	Detectors and associated electronics powered down

MRO Atmospheric Science

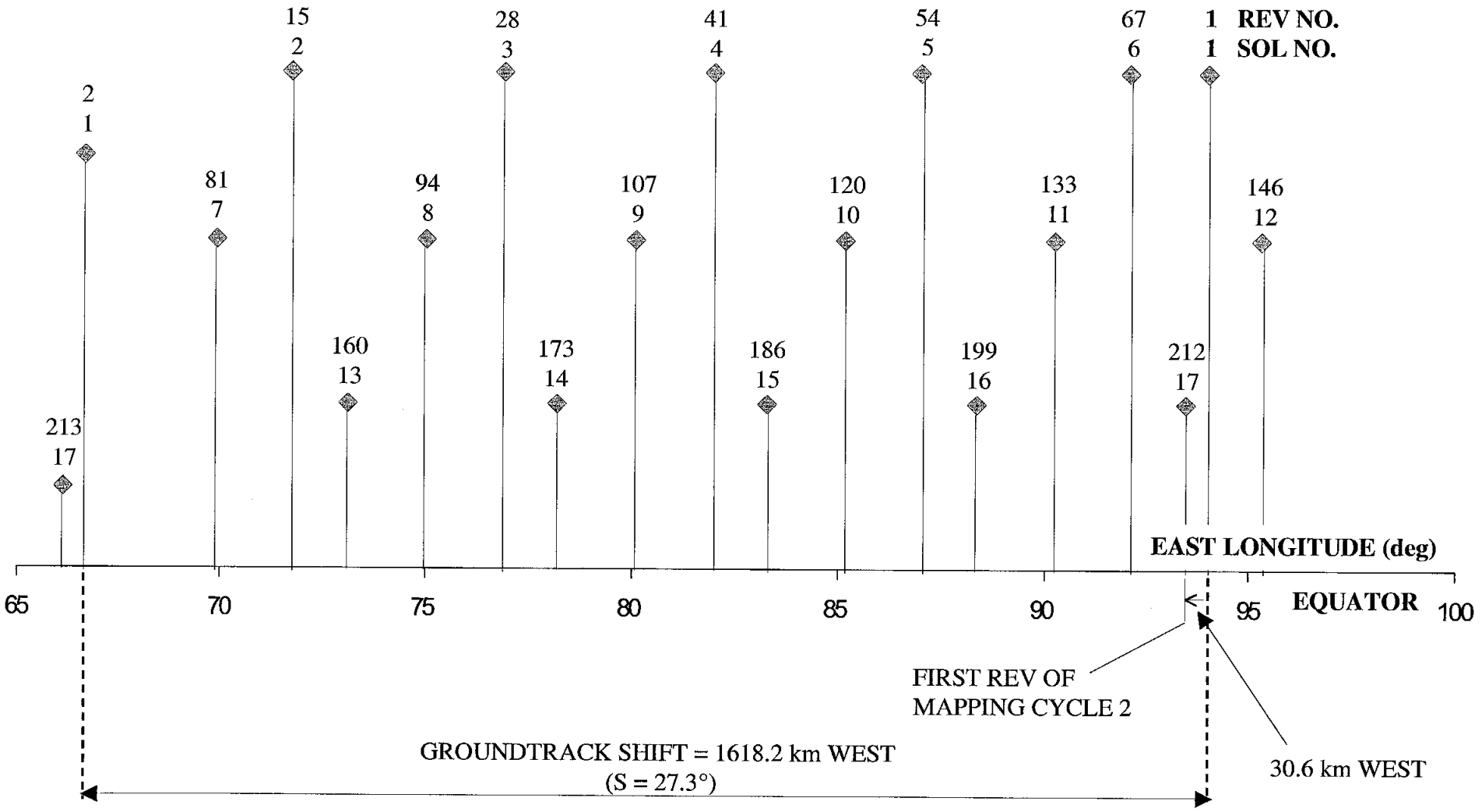
- **Strengths**
  - Near-circular polar orbit, 265-320 km, frozen over S. Pole, supports daily global observations at two primary local times, unaffected by altitude variations
  - MARCI & MCS devote more data coverage & time to atmospheric observations and surface transient behavior than their predecessors
  - MCS has higher resolution and somewhat extended range over previous (ongoing) IR sounders
- **Issues**
  - MRO will target (off-nadir roll) a few thousand sites, impacting atmospheric observational coverage
    - MARCI FOV broadened to 180 deg (from 140) to compensate rolls
    - Ground track chosen to enable targeting with small roll angle (< 10 deg)
      - Stereo imaging will require exceeding this limit many times
    - Global sounding patterns will have holes!
      - Emphasize need for dealing with irregular data coverage
  - Limited local time coverage (3 p.m. /a.m. equatorial crossing times)

MRO, MGS, and Odyssey Science Orbits

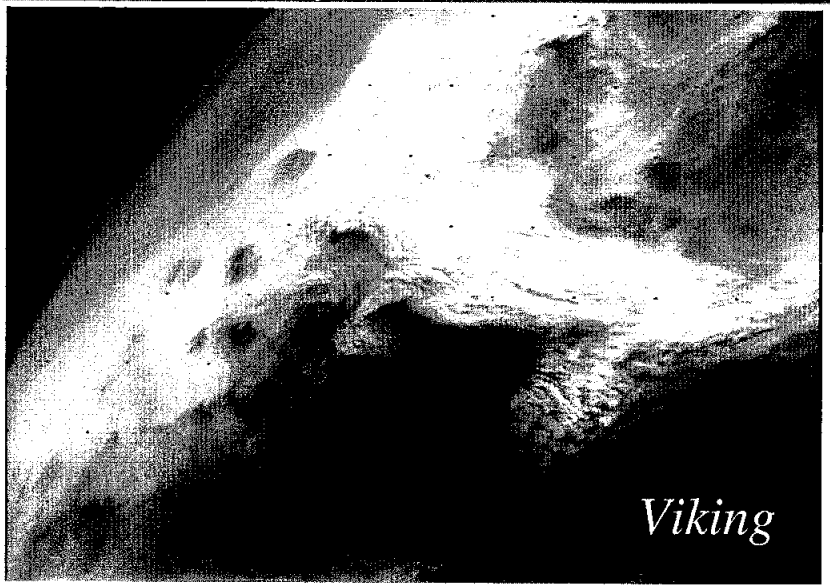


Orbit Nodal Orientations:
ODY: 5:00 PM DN LMST
MGS: 2:00 PM AN LMST
MRO: 3:00 PM AN LMST

Short-Term Groundtrack Pattern

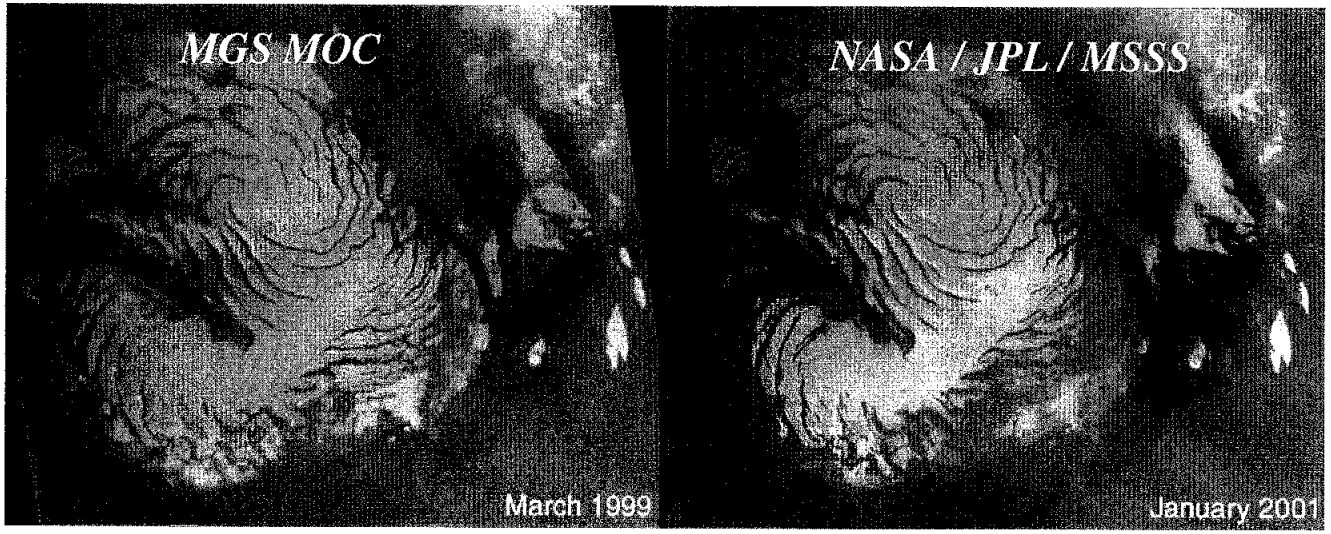


Mars Climate Objectives

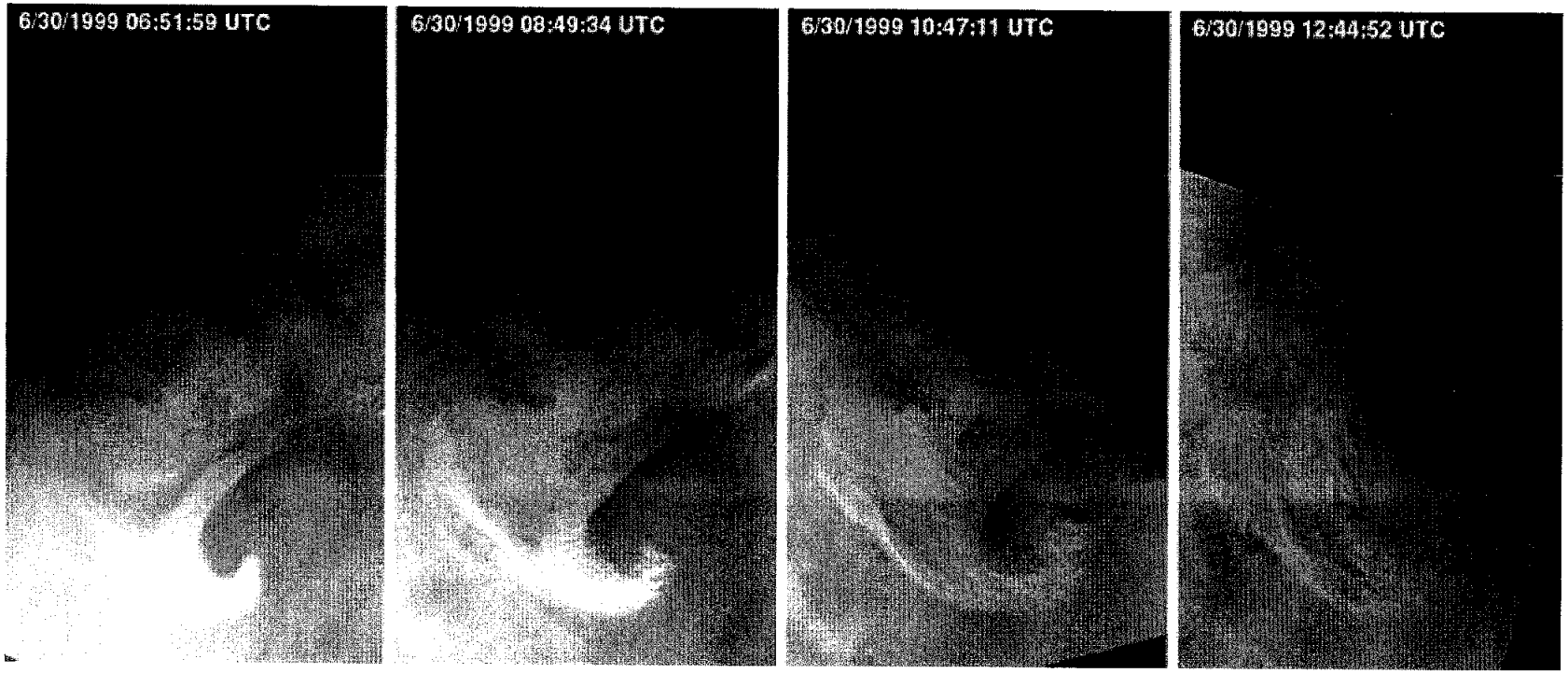


Dust Storms;
Atmospheric Transport:
MCS, MARCI, CRISM
Seasonal Cycles;
Water Sources & Sinks:
MCS, MARCI, CRISM
Polar Layering;
Structure & Seasonal Changes:
CTX, HiRISE, MARCI

Polar Monitoring:
Radiation Balance
& Morphology
MCS,
CTX, MARCI



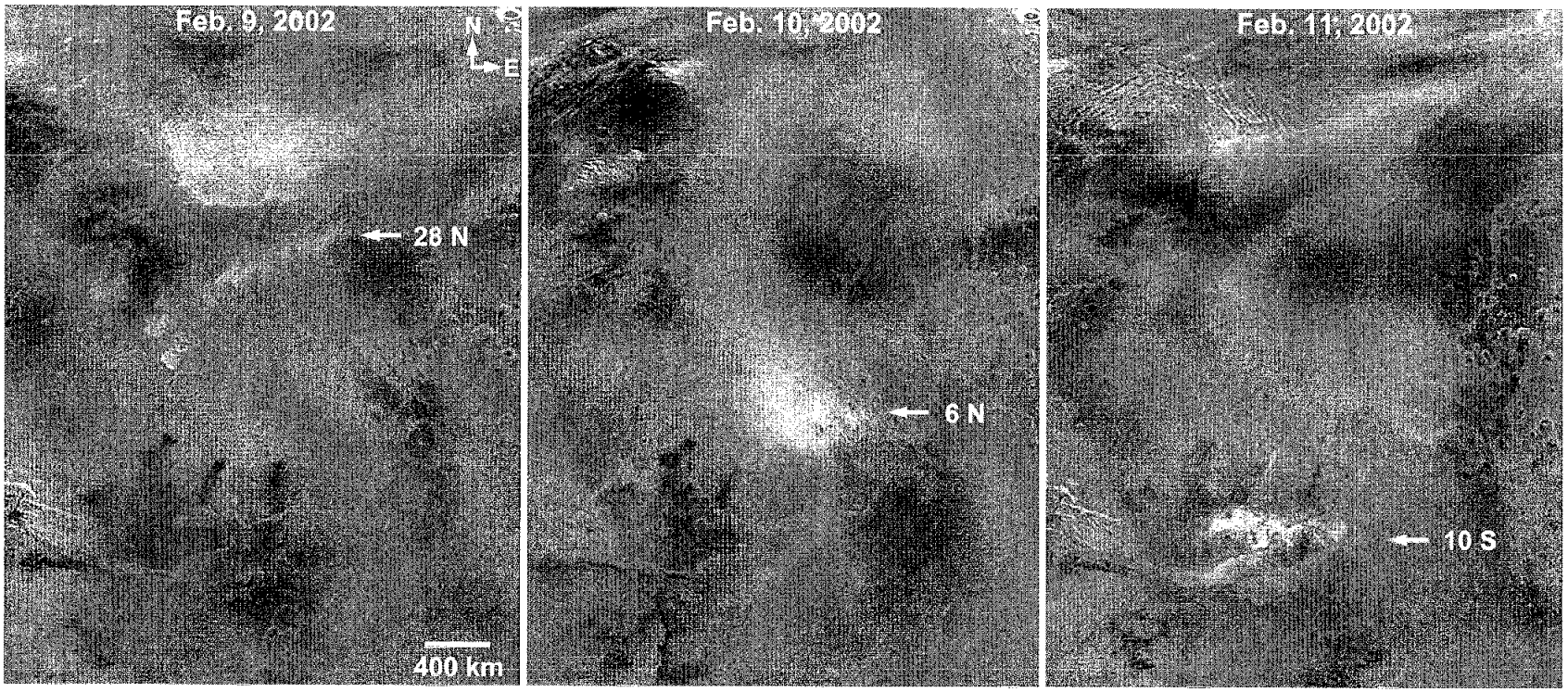
North Polar Dust Storm



Viewed on Consecutive MGS Orbits (~ 2 hrs apart)

MGS MOC
CREDIT: NASA / JPL / MSSS

Northern Storm Paths



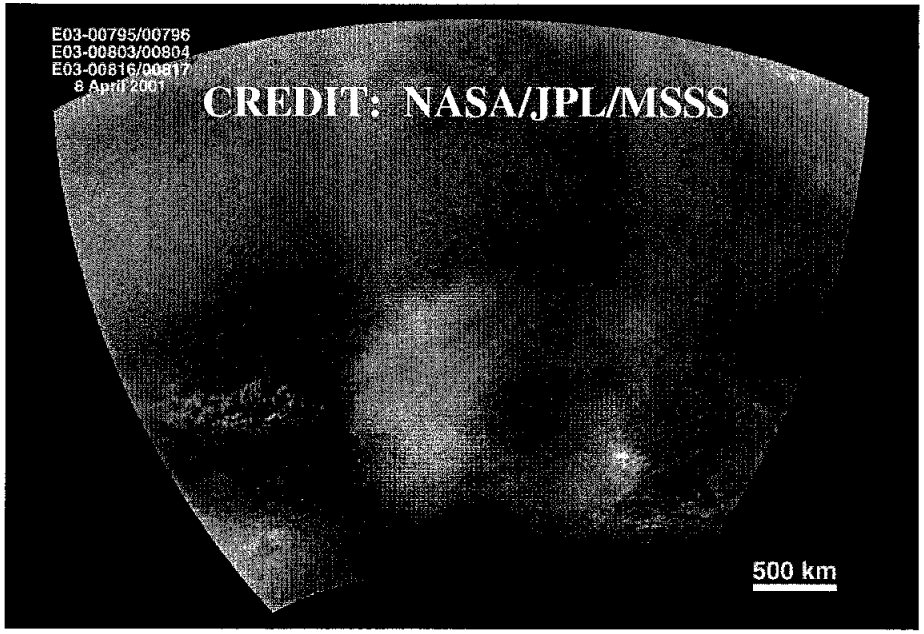
MGS MOC
CREDIT: NASA / JPL / MSSS

How to Raise Dust on Mars

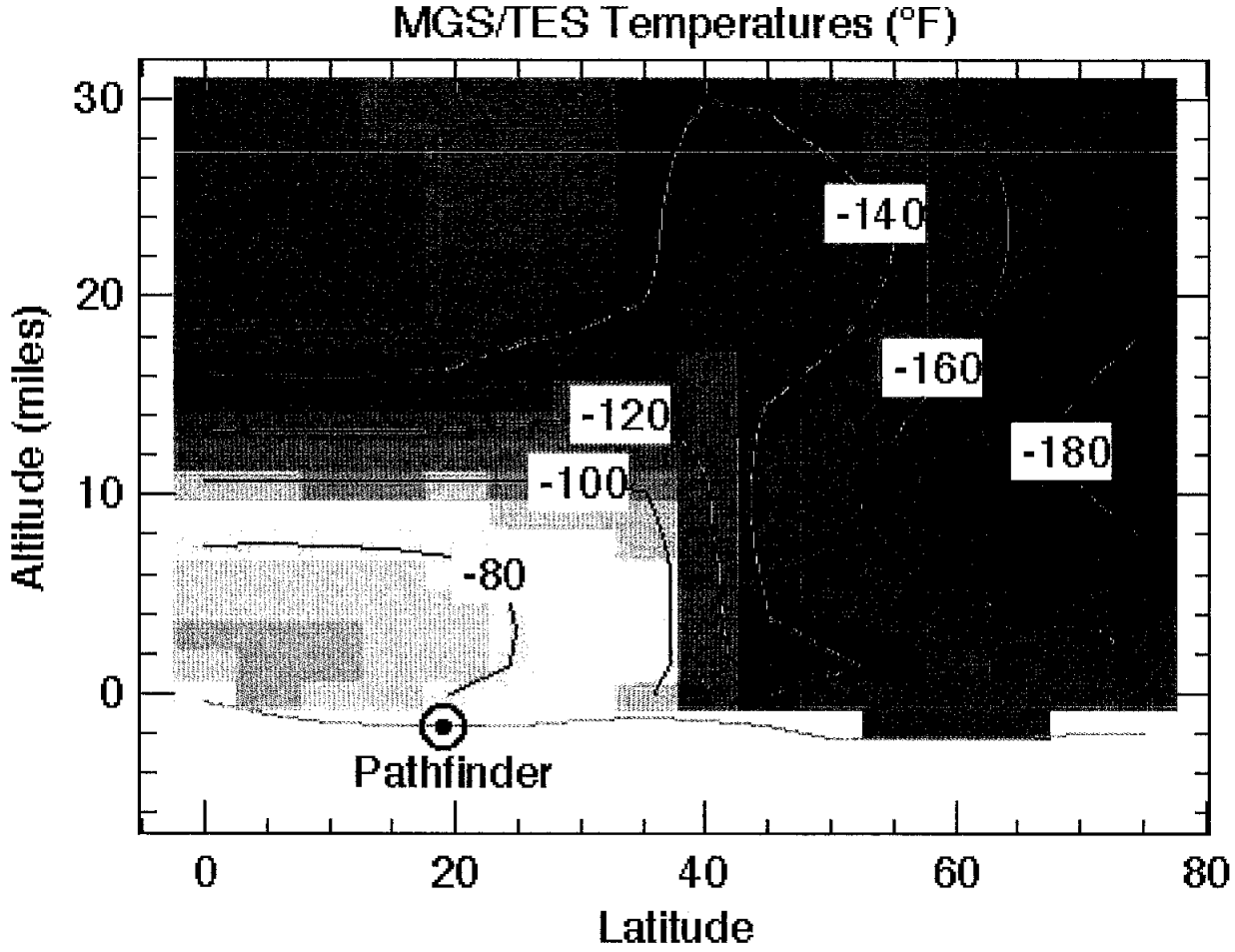
MGS Mars Orbiter Camera (MOC)
PI: M. Malin (MSSS)

← ***Dust Devil Tracks***

Local Dust Storm at South Pole Cap Edge

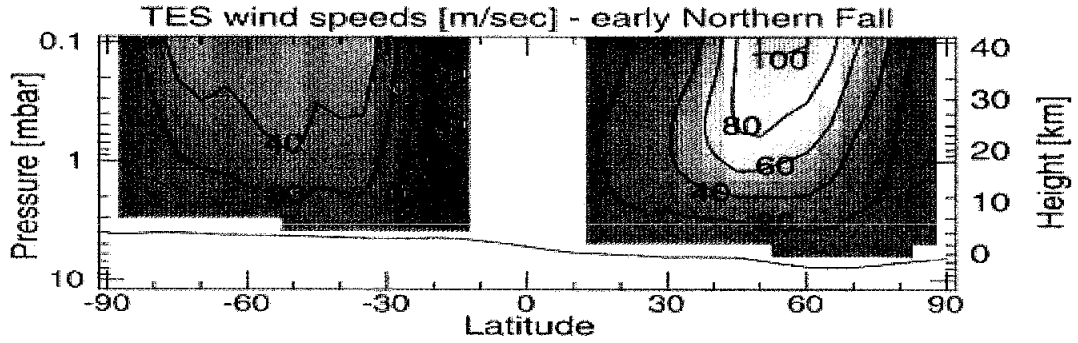


Zonal Temperatures in N. Winter

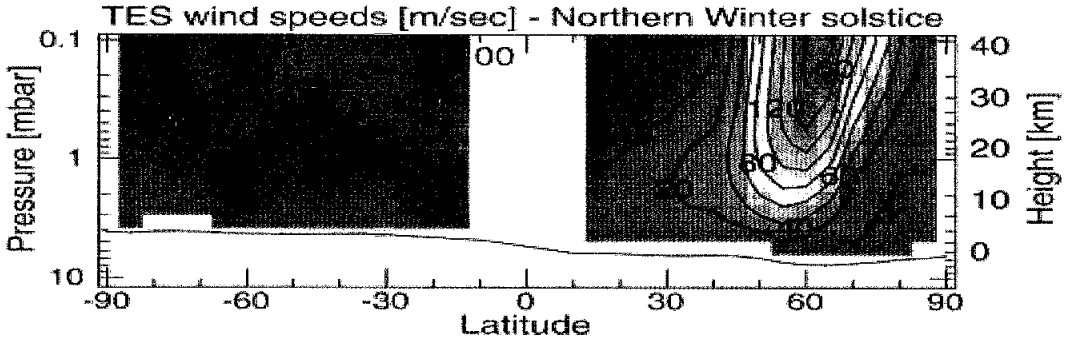


CREDIT: NASA / JPL / ASU

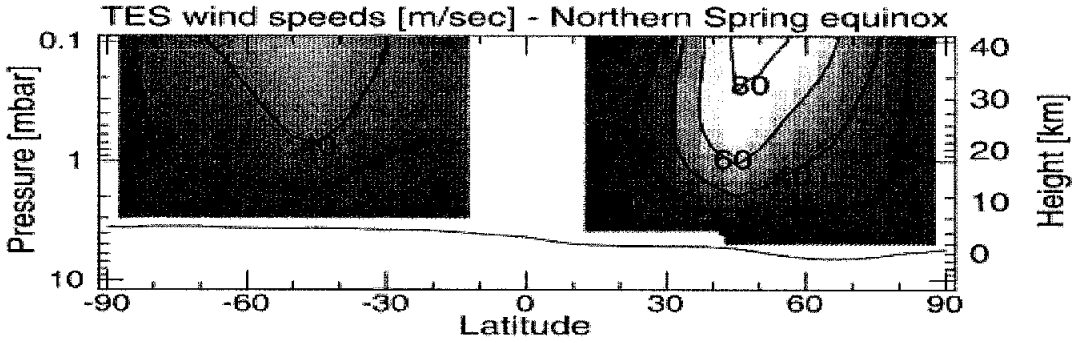
Geostrophic Winds



Early Southern Spring
Early Northern Fall



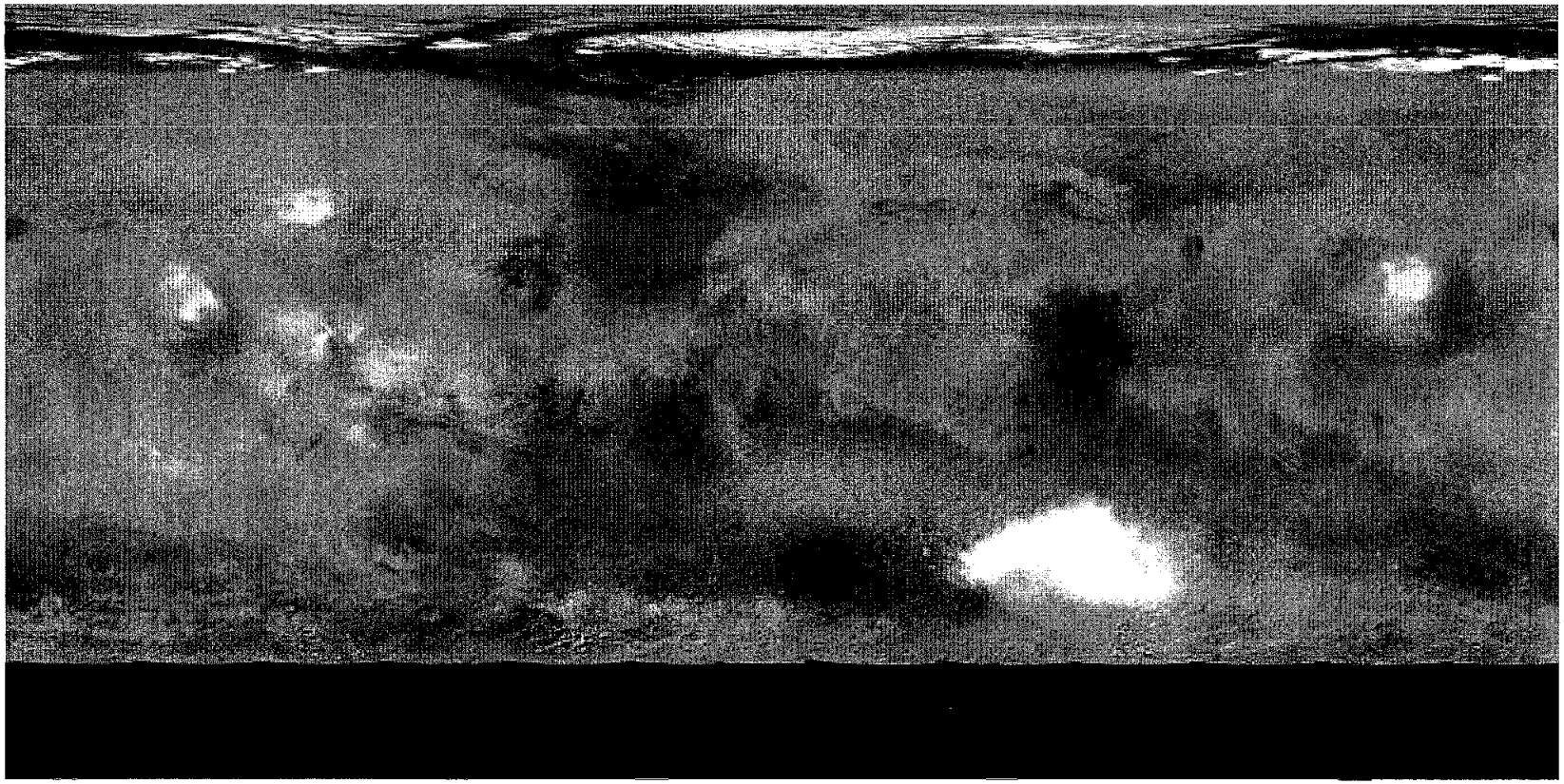
N. Winter Solstice S.
Summer Solstice
(near perihelion)



Vernal Equinox

CREDIT: NASA / JPL / ASU

Equatorial Cloud Belt (Mars ITCZ?)



MGS MOC (PI: M. Malin)
CREDIT: NASA / JPL / MSSS

Mission Summary by Phase

LAUNCH	Launch Period:	8/10/2005 - 8/31/2005 (Atlas IIIB DEC) -- 22-days
	Launch Window:	minimum 30-minute windows
	Injection Requirements:	large C3 (> 16 km2/s2) and high DLA (> 40 deg) -- fixed daily injection targets planned
	DSN Initial Acquisition:	strategy to be worked - southerly and eastern launch azimuths
INTERPLANETARY CRUISE	Flight Time:	7 months (Type 1 trajectory)
	TCMs:	5 planned (4 nominal + 1 emergency)
	Navigation:	Doppler and ranging
APPROACH and MOI	Arrival Period:	3/8/2006 - 3/16/2006
	MOI DV:	1000 m/s max (3/8/2006) - varies as a function of launch date
	Capture Orbit:	35-hr orbit period, 93 deg inclination, 8:30 pm LMST ascending Node (same capture orbit for the entire arrival period)
	Navigation:	Doppler, Ranging, and Delta-DOR (complementary navigation)
AEROBRAKING	Initiation:	1 week after MOI from initial 35-hr capture orbit, ONE aerobraking strategy
	Duration:	less than 6 months, 550 orbits, robust thermal margins, 48-hr orbit lifetime requirement
	Termination:	propulsive termination at 450 km
	Transition to Primary Science:	~40-day transition orbit - propulsive establishment of primary science orbit
	Navigation:	similar to MGS and Odyssey aerobraking operations - predict periapsis times
PRIMARY SCIENCE	Orbit Design:	255 x 320 km "frozen" periapsis orbit, repeating groundtrack 3:00 pm LMST ascending node orientation, sun-synchronous
	Duration:	1 Mars year
	Navigation:	ephemeris predict: 1.5 km downtack, 0.04 km radial, 0.05 km crosstrack
	Science Data Acquistion:	global mapping and profiling, regional survey, and globally distributed targeting
	Data Return/Data Volume:	X-band via 2 DSN passes/day (16 hrs/day) - 34m subnet -- PSO data volume > 26 Tb
RELAY	Orbit Design:	same as primary science orbit
	Duration:	1 Mars Year
	Operations Activities:	Electra telecom and navigation
	End of Mission:	12/31/2010 - orbit raise option (DV budget to reach 450 km circular)
	2011 - 2015:	ACS propellant for extended relay operations

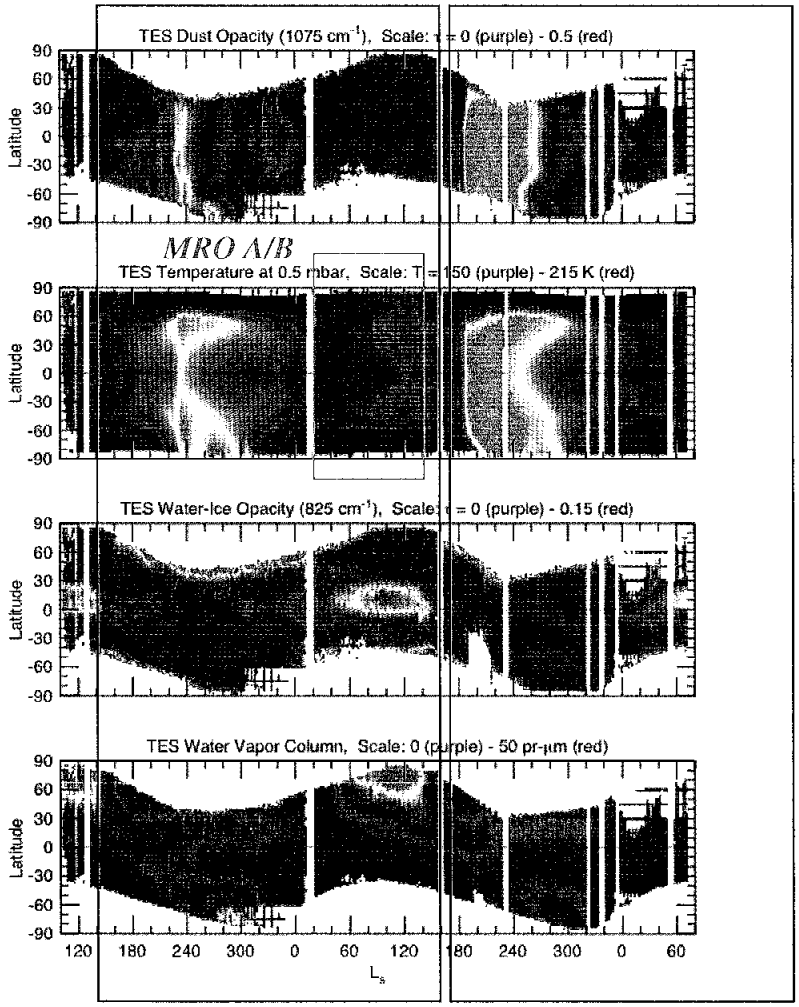
MGS TES Climatology

Dust

T(K)

ICE

Water Vapor



MRO
Primary Science Phase

Zonally Averaged Fields during Two Mars Years

Courtesy of
M. Smith
TES Team

(TES PI: P. Christensen)
NASA/JPL/ASU/GSFC

Summary: Prospects for Atmospheric Science

- **Build on MGS, Odyssey, & Mars Express data**
  - All 3 spacecraft may be observing during early MRO science phase
  - MGS + MRO could provide a full decade of observation of the Mars atmosphere and transient surface phenomena
- **MRO can make a substantial contribution to understanding the present Martian climate**
  - Profiling at higher spatial resolution and more frequently
  - Mapping globally in more spectral bands
  - Observing new properties (e.g., water vapor vertical distribution, column ozone)
- **Atmospheric models will continue to play a key role**
  - Use available data as broad constraints
  - Use models to fill in unobserved domains and to extend to different times (especially other times of day, solar cycle)
  - Use models to estimate unobserved, or loosely constrained, fields (e.g., near-surface winds)