Water Ice Clouds and Dust in the Martian Atmosphere Observed by Mars Climate Sounder

Jennifer L. Benson\(^1\)
David Kass\(^1\), Nicholas Heavens\(^2\), Armin Kleinböhl\(^1\) and the MCS Team

\(^1\)JPL/Caltech
\(^2\)Dept. of Earth and Atmospheric Sciences, Cornell University

April 5, 2011

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Outline

• MCS instrument
• Polar Hoods
  – Introduction to polar hoods and data analysis
  – Polar hood seasonal cycles
  – Cloud maps and temperature structure
  – Polar hood ice opacity profiles
• Water ice and dust layering
  – Three ways of looking at data
  – Seasonal differences
  – Day/Night differences
• Summary
MCS Instrument

- The Mars Climate Sounder (MCS) onboard Mars Reconnaissance Orbiter began observing Mars in Sept. 2006 and has now been operating for ~2 ½ Mars years.

- Each MCS channel has 21 detectors, covering an altitude range from the surface to ~80 km (50 miles)
Polar Hood Introduction

- Polar hoods are cloud zones that develop over the polar cap during late summer and persist through winter, sometimes into early spring.
- The north and south polar hoods (NPH & SPH) on Mars have been studied for a long time but the datasets have been limited.
  - Early spacecrafts (Mariner 9 and Viking orbiters) as well as Earth ground-based telescopes were limited in their observations of the polar hoods, especially the SPH.
  - Thermal Emission Spectrometer and Mars Orbiter Camera on MGS provided better observations of the polar hoods, but both data sets were limited to observations equatorward of about 60° latitude and 2:00pm local time.
- Mars Climate Sounder (MCS) data provide a more complete view.
  - Time of day variations
  - Vertical structure
- Investigated, the spatial and temporal extent of the north and south polar hoods on Mars and their formation mechanisms.
Data Analysis Approach

• Use water ice opacity retrievals (at 12 µm) to examine north and south polar hood clouds at night and day
  – Night – 3 am, Day – 3 pm
  – We integrated the water ice opacity profile to calculate a column opacity, which we converted to visible wavelength (600 nm)
  – Used bin sizes of 5° latitude, 5° longitude, and 15° Ls
  – Created maps of water ice visible optical depth in the night and day

• Use maps to define the edge of the hood and the peak opacity within the hood.

• Examine the entire Mars year to determine the seasonal cycle of polar clouds.

• Details described in papers...
The SPH forms as a belt (or annular ring), that does not extend all the way to the pole, whereas the NPH always extends to the pole.
SPH Seasonal Cycles

Night

Day

Seasonal NPC boundary

Seasonal SPC boundary

Phase 1

LS

Latitude

Phase 1

Phase 2

LS

Latitude

Phase 1

Phase 2

tau_ice_vis

0.300

0.250

0.200

0.175

0.150

0.125

0.100

0.075
The occurrence of SPH water ice clouds fall into two phases. The first is from $L_s=10^\circ-70^\circ$ (Phase 1).
SPH Seasonal Cycles

Night

Day

Seasonal NPC boundary

Seasonal SPC boundary

Phase 1

Phase 2

Phase 2
SPH Cloud Maps – Phase 2

SPH clouds reform after 30° of L_s during Phase 2 (L_s=100°-200°)
SPH Longitudinal Temperature Structure

Meridional mean temperature cross-sections with water ice contours superimposed
SPH Ice Opacity and Temperature Correlation

Nighttime

Daytime

Night and Day zonal mean $\text{H}_2\text{O}$ ice extinction

Day minus night temperature difference

Thermal tidal structure
Thermal Tide

From Lee et al. 2009

Day minus night temperature difference from MCS data

Schematic
SPH Thermal Tide

SPH Day minus night temperature difference

Schematic
SPH Seasonal Cycles

Night

Day

Seasonal NPC boundary

Seasonal SPC boundary

Cloud free gap
SPH Seasonal Temperature Structure

$L_s = 77^\circ – 45^\circ$ temperature difference  
(Cloud free gap minus Phase 1)

$L_s = 138^\circ – 92^\circ$ temperature difference  
(Phase 2 minus cloud free gap)
**NPH Seasonal Cycles**

![Diagram showing NPH Seasonal Cycles with Night and Day phases, seasonal SPC and NPC boundaries, and data points at different latitudes and LS values.]
NPH clouds start to form at $L_S = 150^\circ$ and by $L_S = 165^\circ$ clouds have increased in optical depth both at night and day.
NPH Cloud Maps
NPH Ice Opacity and Temperature Correlation

Night and Day zonal mean \( \text{H}_2\text{O} \) ice extinction

Day minus night temperature difference

Thermal tidal structure
NPH Thermal Tide

NPH Day minus night temperature difference

Schematic
NPH Ice Opacity and Temperature Correlation

Night and Day zonal mean temperature cross-sections with water ice contours superimposed

Day minus night temperature difference
NPH Ice Opacity and Temperature Correlation

Day minus night temperature difference

Similar ice opacity day and night because clouds are located where there is no day-night temperature difference
SPH Ice Extinction Profiles

Ls = 23 - 30

Night

Day

SPH clouds have 2 layers at both day and night.

Daytime clouds extend ~10 km higher in the atmosphere than nighttime clouds.

MCS ice aerosol vertical extinction profiles (at 12 µm)
NPH Ice Extinction Profiles

Ls = 165 - 172

Night

Day

NPH clouds have 1 layer at both day and night.

Cloud altitude structure is nearly identical across the NPH and throughout the season.

MCS ice aerosol vertical extinction profiles (blue, at 12 µm).

Dashed lines represent lines of constant ice mixing ratio
SPH and NPH Profile Comparison

Temperature (black). Ice extinction (blue, 12 µm)
Tropical Water Ice Clouds

Zonal average temperature (K, shaded contours) and the mass mixing ratio of water ice, $q_{\text{ice}}$ (ppm, black contours)

WATER ICE AND DUST LAYERING IN THE MARTIAN ATMOSPHERE
Motivations for Approach

• MCS has retrieved global aerosol amounts over 2 ½ MY
  – ~ 2.5 million individual profiles of aerosols
• Spatial and temporal aerosol patterns are diagnostic of the weather and climate
  – Local profile variability obscures regional & global patterns
• We classified aerosol profiles into families with common characteristics
  – Aerosol peak height and extinction
  – Ice vertical thickness
  – Ice & dust vertical separation
  – Map families in order to reveal the spatial and temporal trends
• Analyzed day & night of 4 seasons
  – $L_s=2, 72, 158, 213$
Ice & Dust Height & Extinction

AM Ls = 2

Ice height, ice extinction, dust height, dust extinction

high (h), medium (m), low (l)
Ice & Dust Height & Extinction

**AM Ls = 2**

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<th>Ice Extinction</th>
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Shaded orange rows are in the map.

Zonal bands in the south and clusters of longitudinal structure (zonal asymmetries) elsewhere.
Ice Layer Vertical Thickness & Ice Extinction

AM Ls = 2

- broad
- medium
- narrow

2 layer
Ice Layer Vertical Thickness & Ice Extinction

AM Ls = 2

Clusters of longitudinal structure with varying ice layer breadth and ice extinction
Ice & Dust Height & Extinction

Zonal bands in the south and clusters of longitudinal structure (zonal asymmetries) elsewhere.

Shaded orange rows are in the map.
Ice & Dust Vertical Separation

AM Ls = 2

- Moderate
- Close
- Partly Mixed
- Fully Mixed
Ice & Dust Vertical Separation

AM Ls = 2

Clusters of longitudinal structure. Majority of planet shows some ice and dust mixing.
Ice & Dust Mixture
Vertical Separation

Majority of planet shows some ice and dust mixing.
The majority of ice and dust configurations separate into zonal bands. This is likely influenced by tidal control of ice. Some configurations cluster near topographic features.
Variability
Ice Layer Vertical Thickness & Ice Extinction

PM Ls = 158

AM Ls = 213

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Ice & Dust Height & Extinction

AM Ls = 158
Night

PM Ls = 158
Day

AM/PM difference in ice height in the tropics. AM has high ice height and PM has medium to low ice height.
Tropical Water Ice Clouds

Zonal average temperature (K, shaded contours) and the mass mixing ratio of water ice, $q_{ice}$ (ppm, black contours)

Heavens et al., 2010, GRL
Summary

• The water ice clouds are primarily controlled by the temperature structure and form at the water condensation level
• Clouds in all regions presented show day/night differences
  – Cloud altitude varies between night and day in the SPH and tropics
  – NPH water ice opacity is greater at night than day at some seasons
  – The diurnal thermal tide controls the daily variability.
  – Strong day/night changes indicate that the amount of gas in the atmosphere varies significantly
• See significant mixtures of dust and ice at the same altitude planet-wide
  – Points to a complex radiative and thermal balance between dust heating (in the visible) and ice heating or cooling in the infrared
• Aerosol layering
  – Early seasons reveal a zonally banded spatial distribution
  – Some localized longitudinal structure of aerosol layers
  – Later seasons show no consistent large scale organization