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

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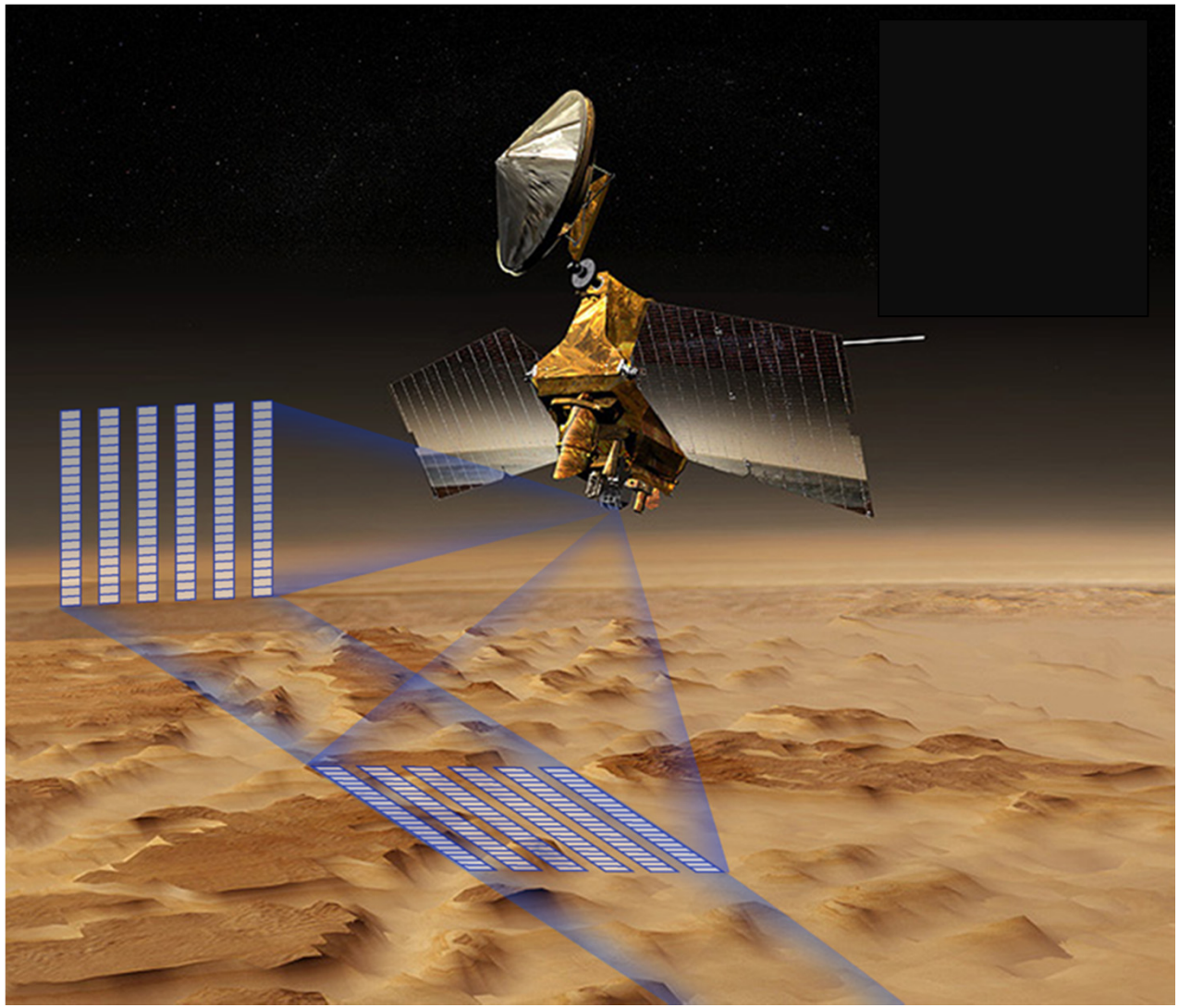
Outline

- 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)



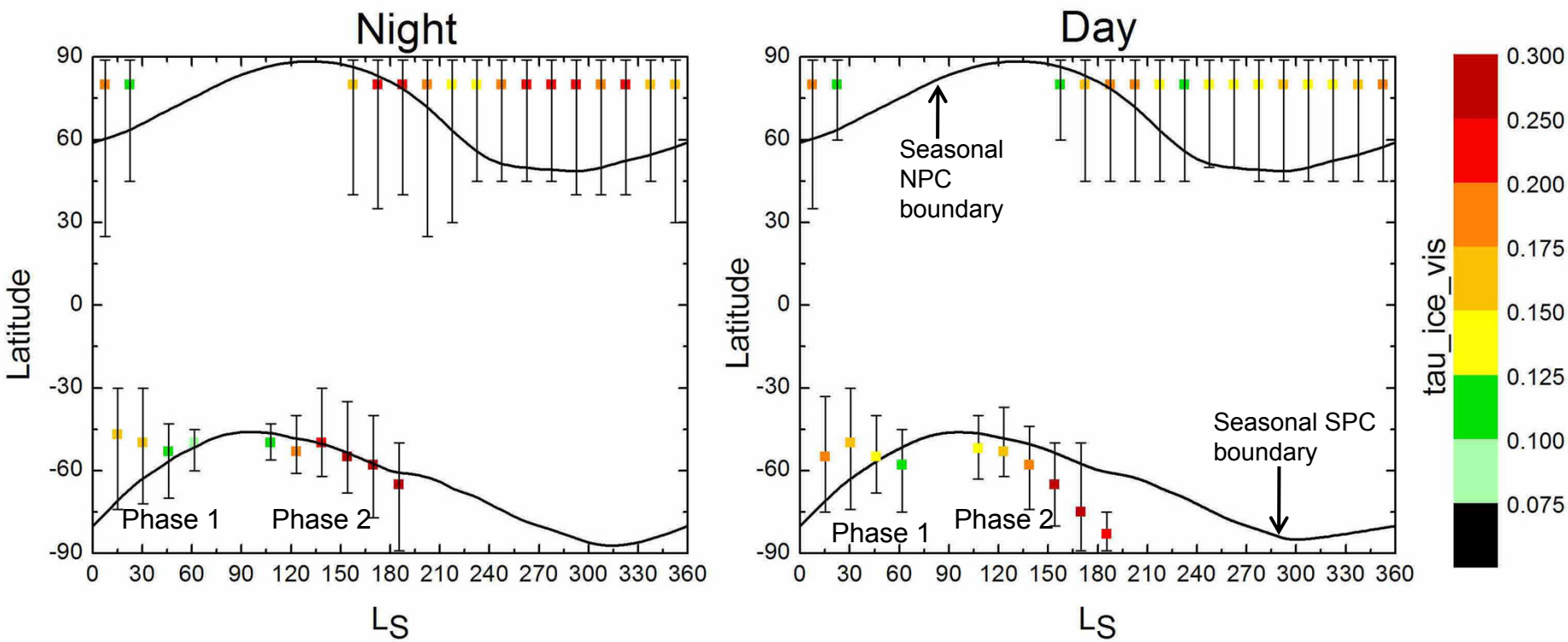
Polar Hood Introduction

- 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

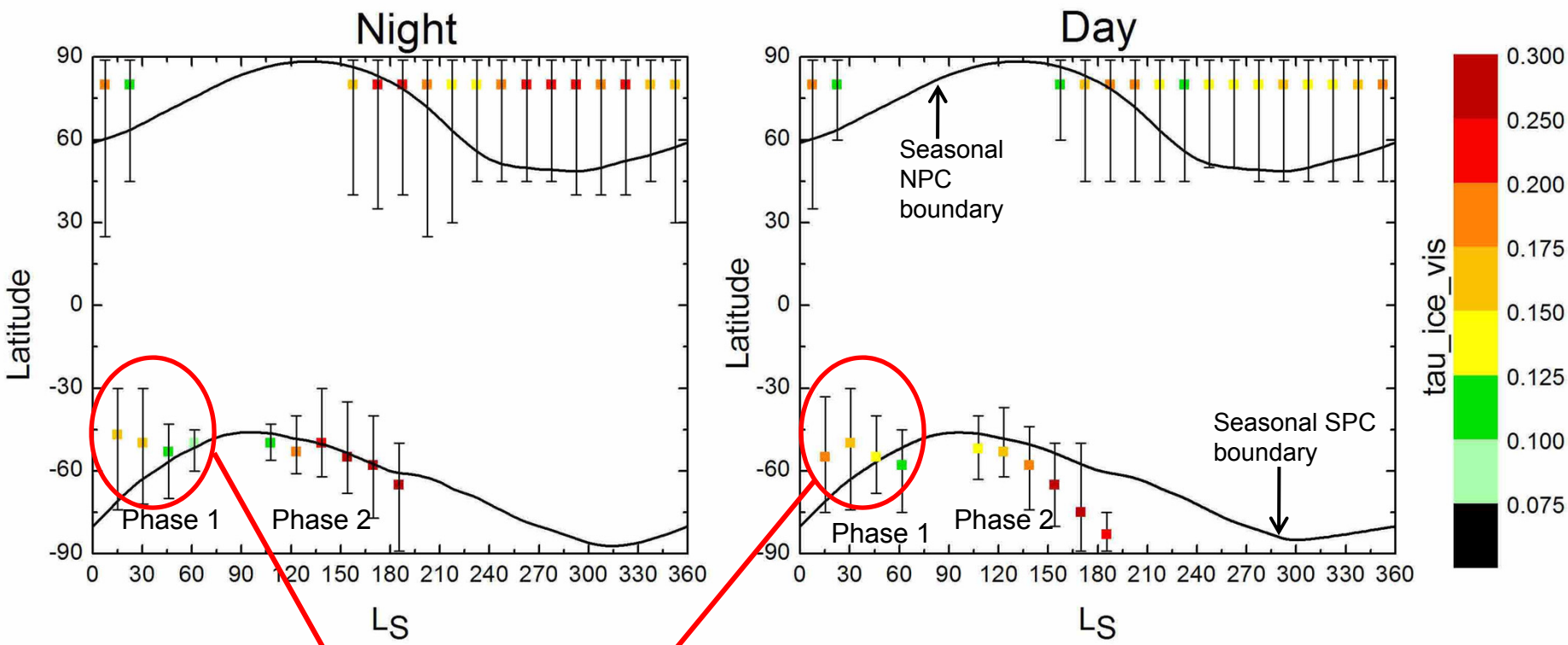
- Use water ice opacity retrievals (at 12 µm) to examine north and south polar hood clouds at night and day
  - Night – 3 am, Day – 3 pm
  - We integrated the water ice opacity profile to calculate a column opacity, which we converted to visible wavelength (600 nm)
  - Used bin sizes of 5° latitude, 5° longitude, and 15° L_S
  - 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…
  - Benson et al. 2010, Mars' south polar hood as observed by the Mars Climate Sounder, *JGR, 115*, E12015, doi:10.1029/2009JE003554.
  - Benson et al. 2011, Mars' north polar hood as observed by the Mars Climate Sounder, *JGR, 116*, E03008, doi:10.1029/2010JE003693.

Polar Hood Seasonal Cycles



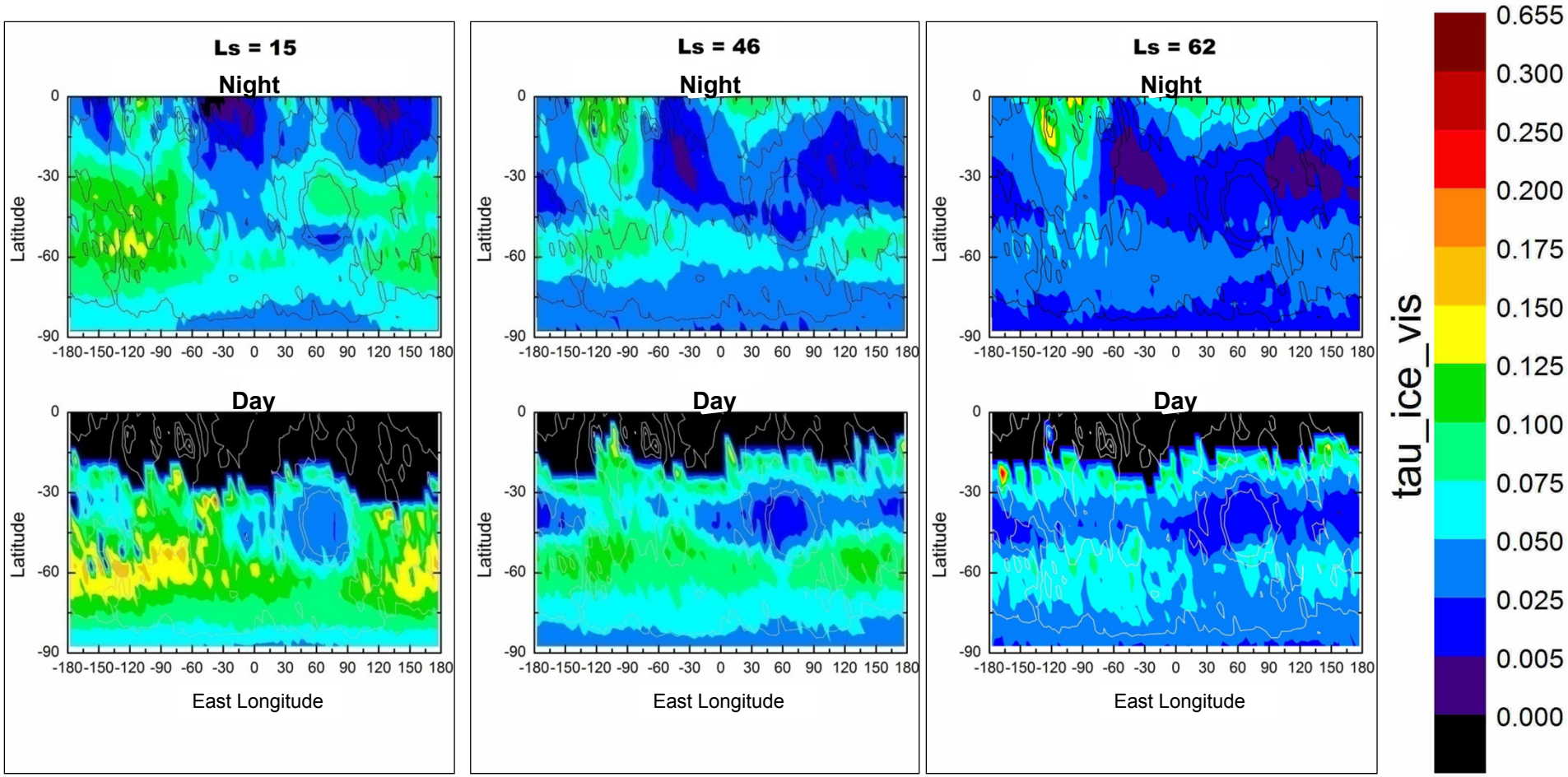
The SPH forms as a belt (or annular ring), that does not extend all the way to the pole, whereas the NPH always extends to the pole.

SPH Seasonal Cycles



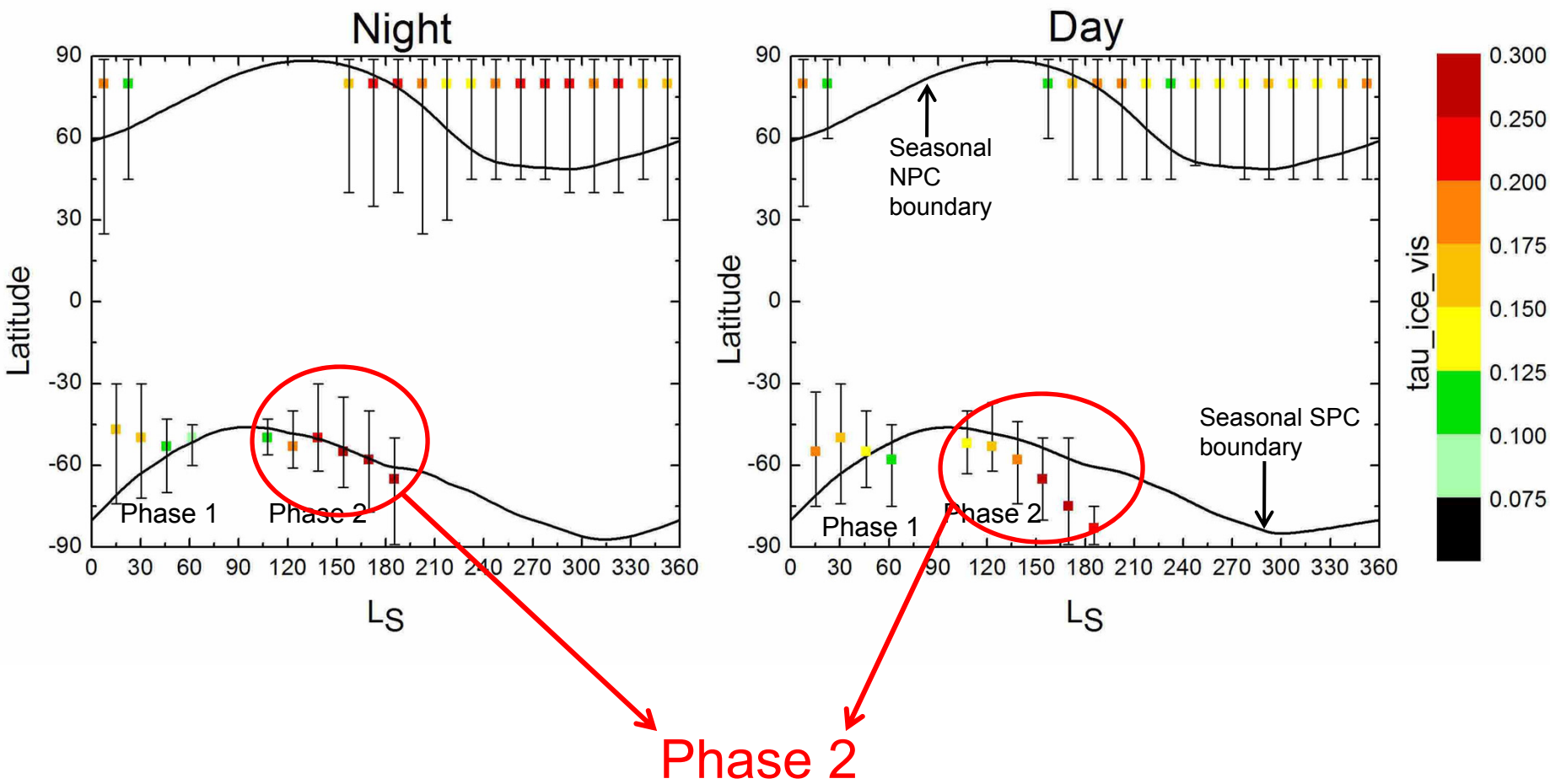
Phase 1

SPH Cloud Maps – Phase 1

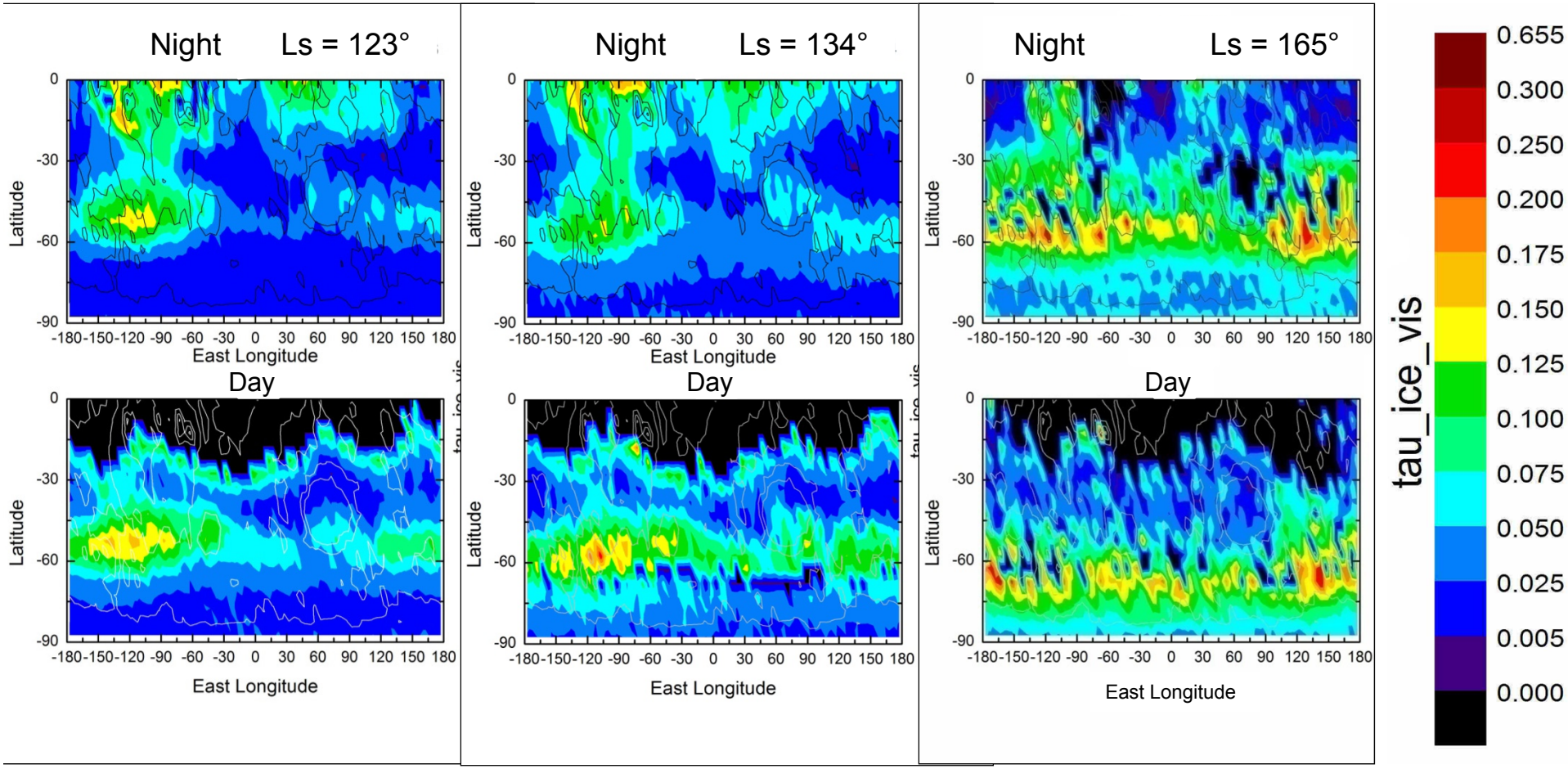


The occurrence of SPH water ice clouds fall into two phases.
The first is from L_S=10°-70° (Phase 1)

SPH Seasonal Cycles



SPH Cloud Maps – Phase 2

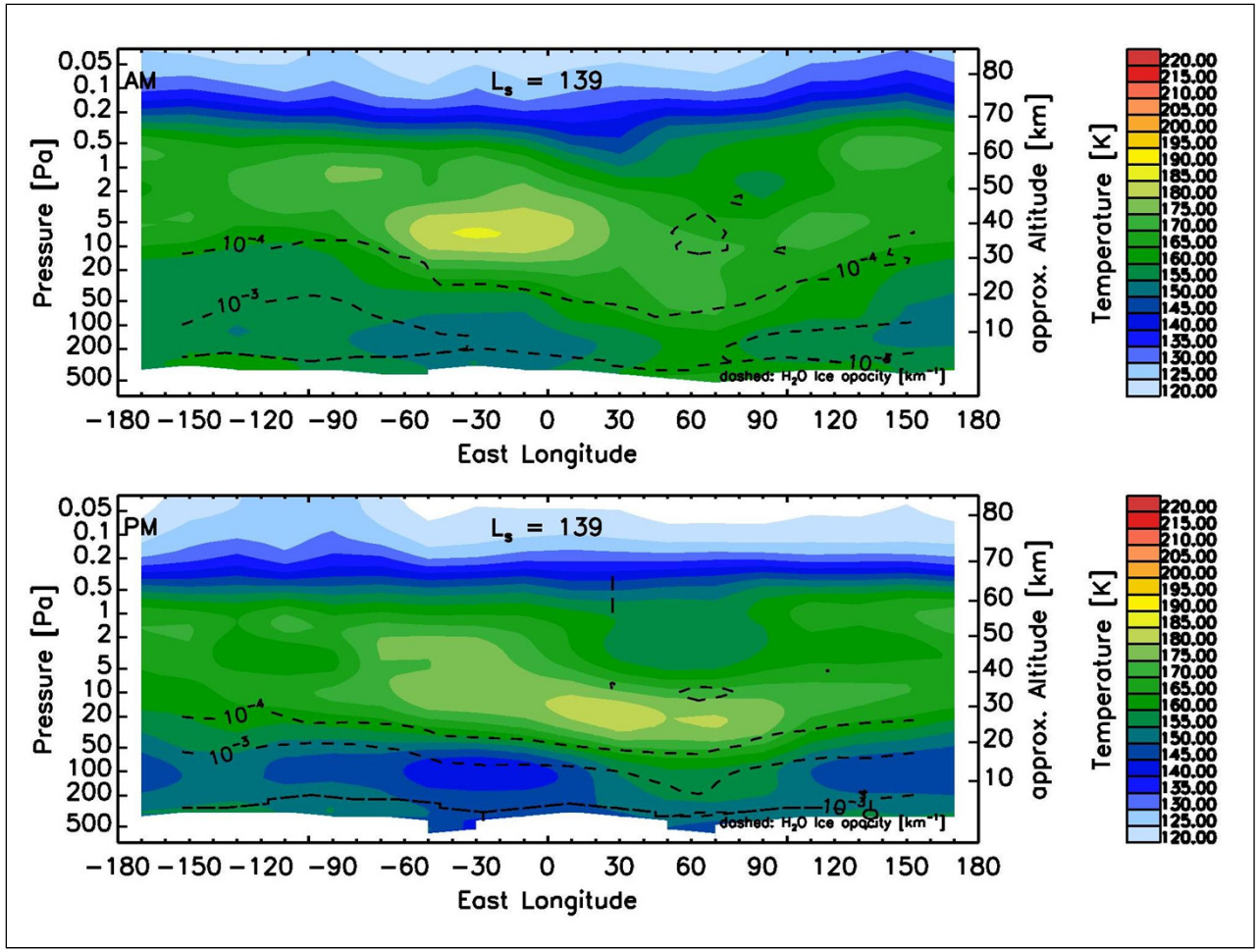


SPH clouds reform after 30° of L_S during Phase 2 (L_S=100°-200°)

SPH Longitudinal Temperature Structure

Nighttime

Daytime

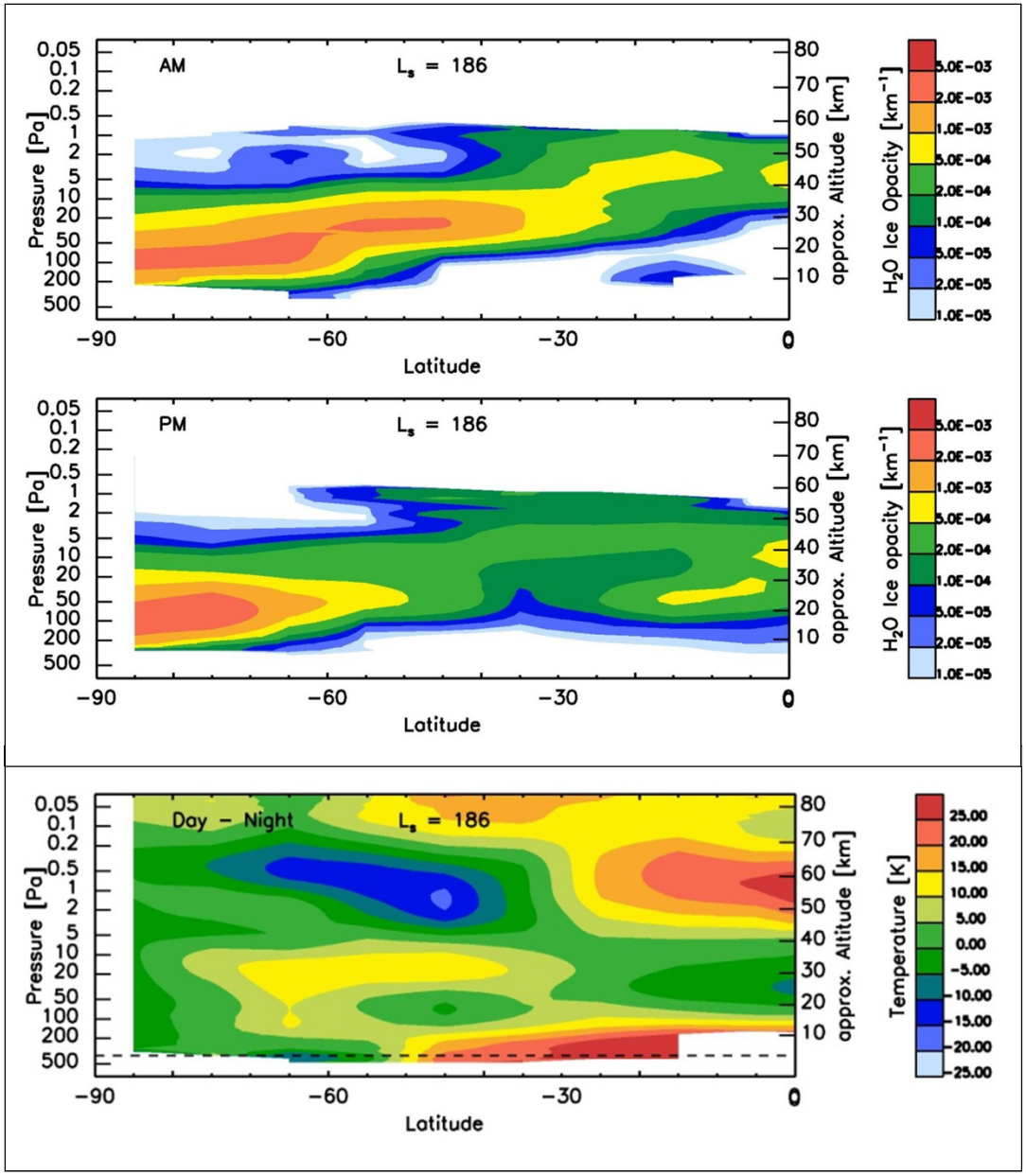


Meridional mean temperature cross-sections with water ice contours superimposed

SPH Ice Opacity and Temperature Correlation

Nighttime

Daytime



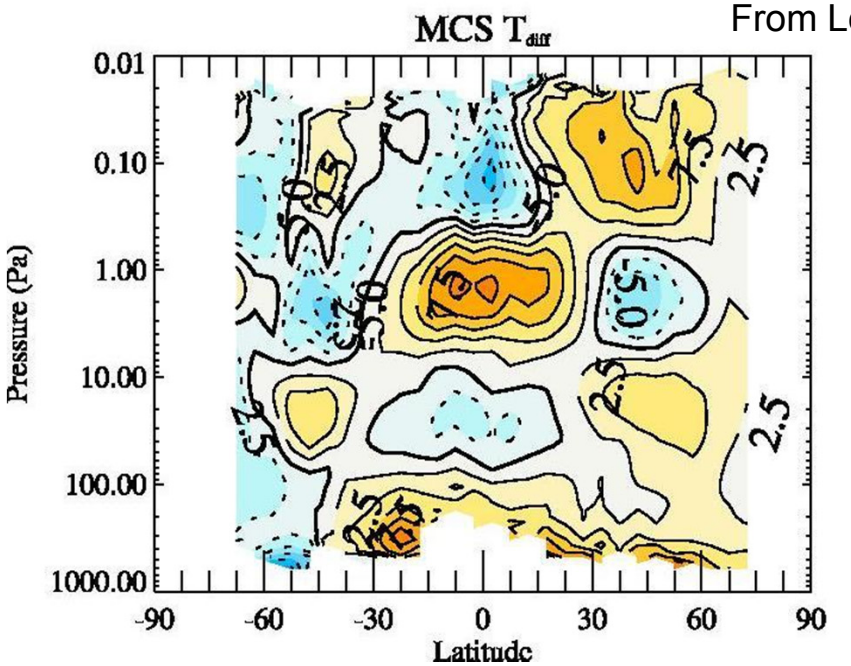
Night and Day zonal mean H_2O ice extinction

Day minus night temperature difference

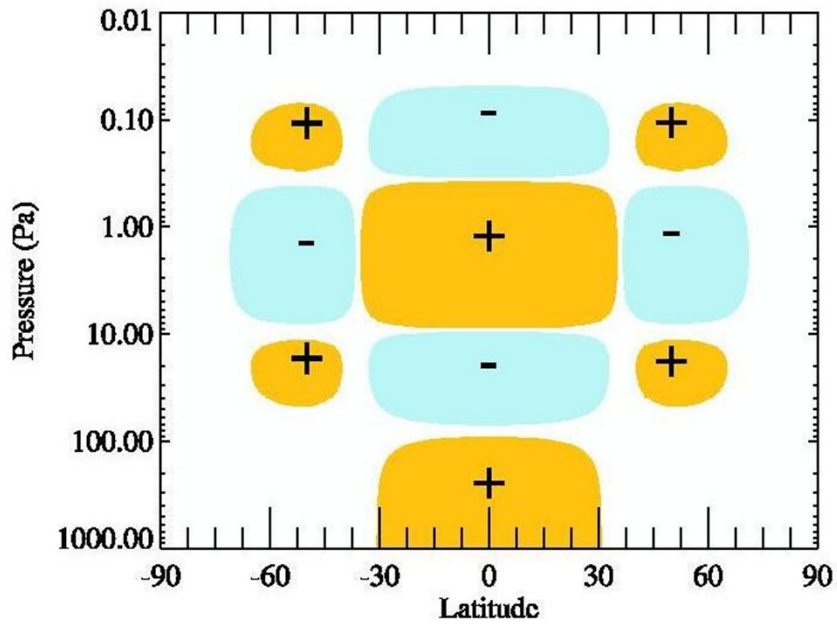
Thermal tidal structure

Thermal Tide

From Lee et al. 2009

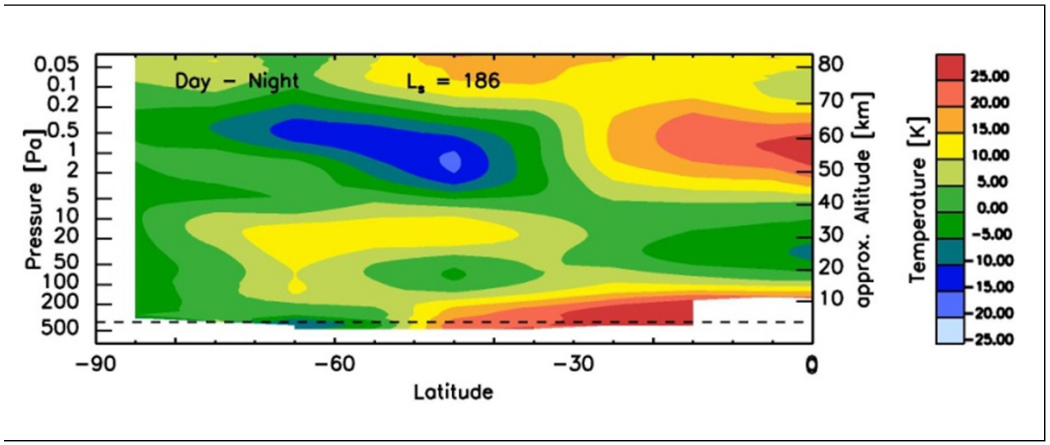


Day minus night temperature difference from MCS data

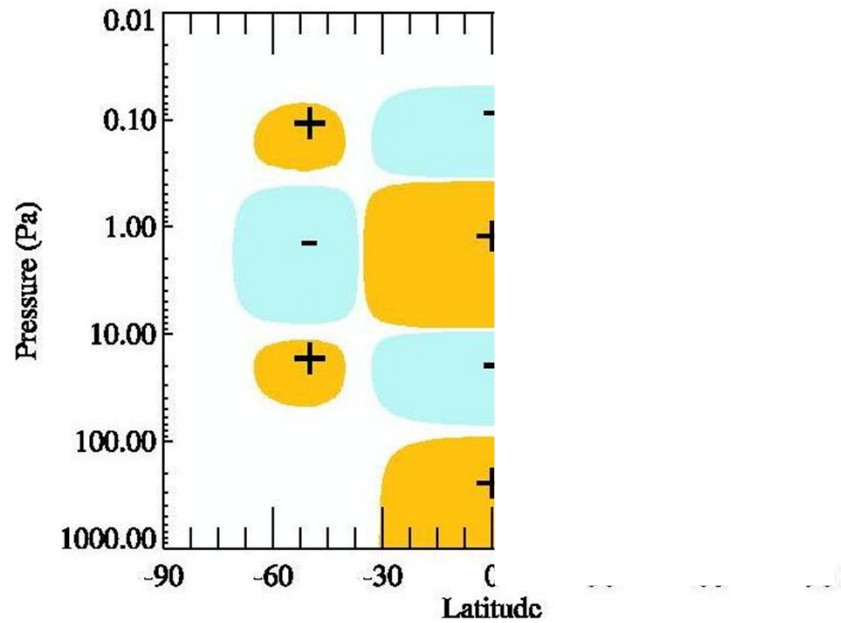


Schematic

SPH Thermal Tide

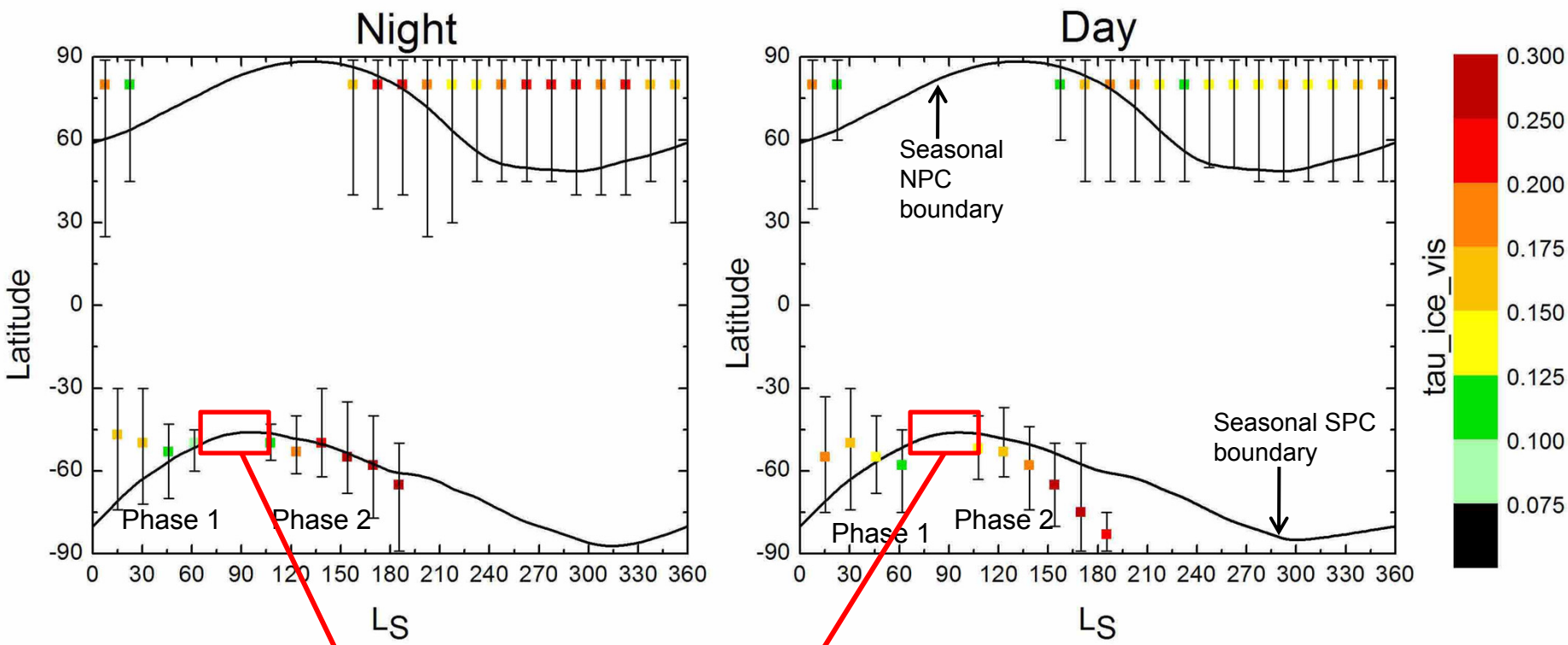


SPH Day minus night temperature difference



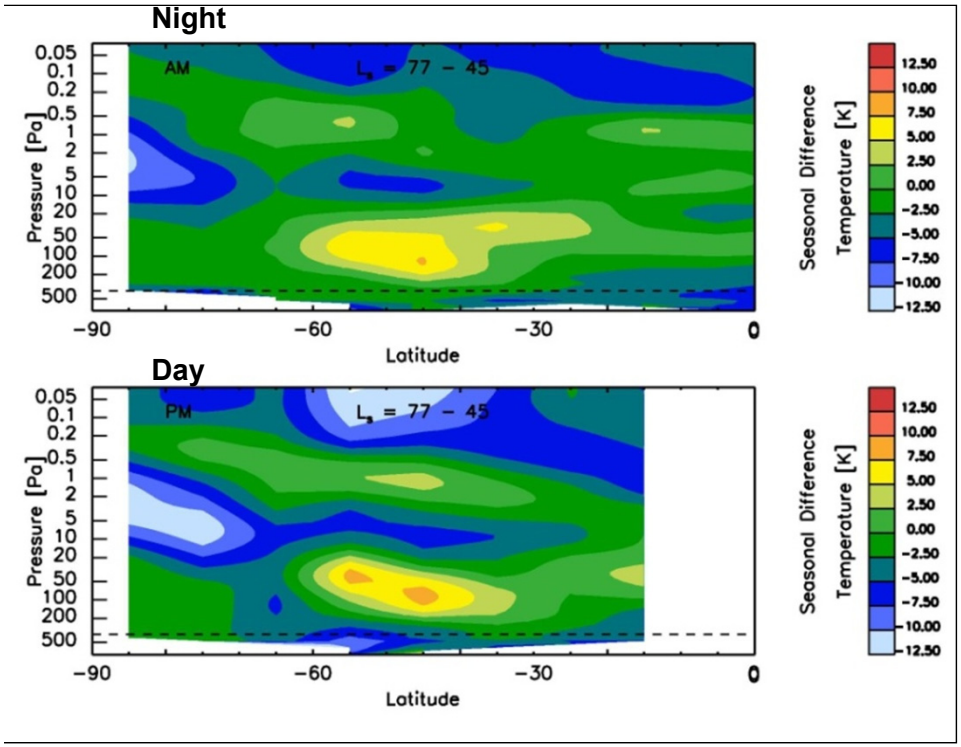
Schematic

SPH Seasonal Cycles

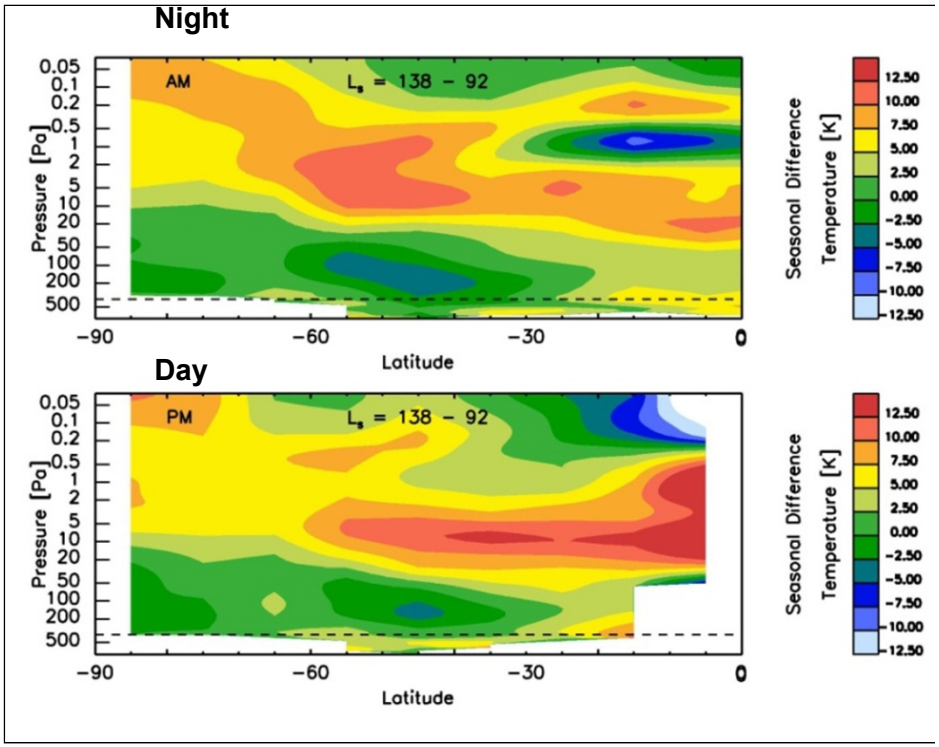


Cloud free gap

SPH Seasonal Temperature Structure

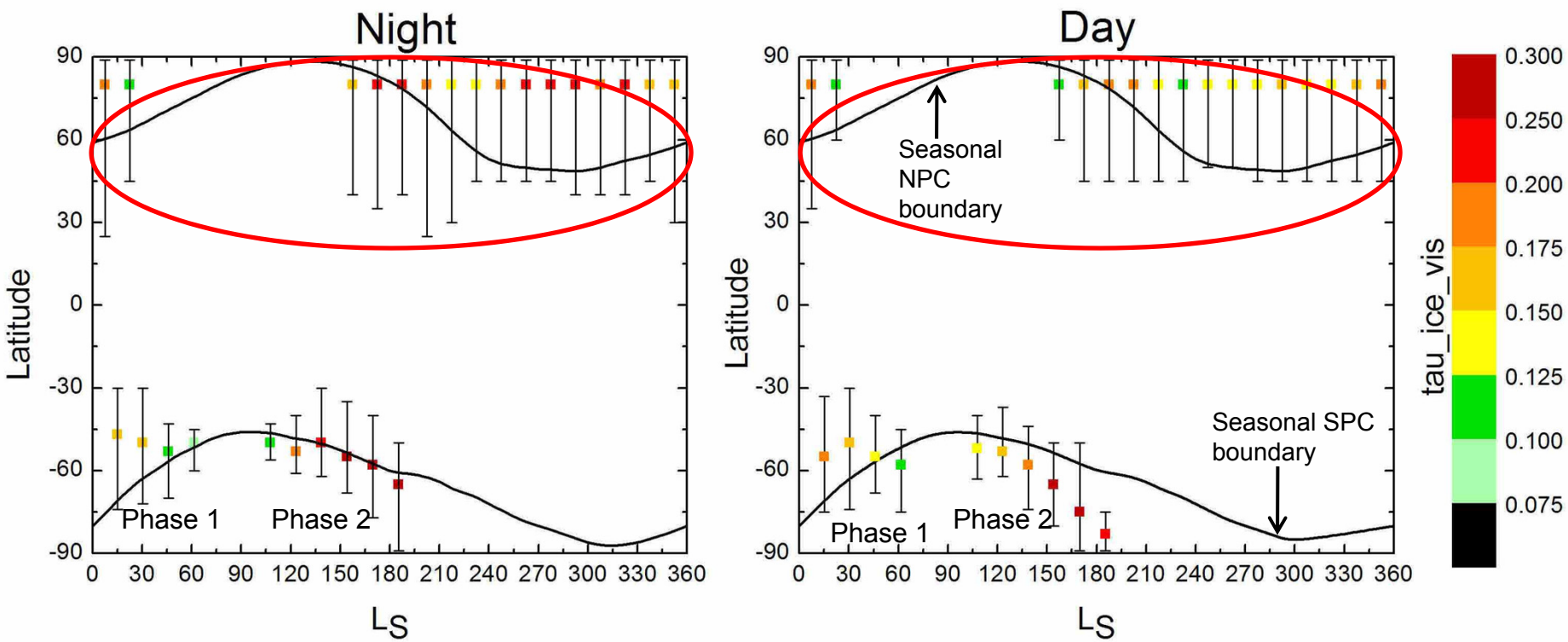


L_S = 77° – 45° temperature difference
(Cloud free gap minus Phase 1)

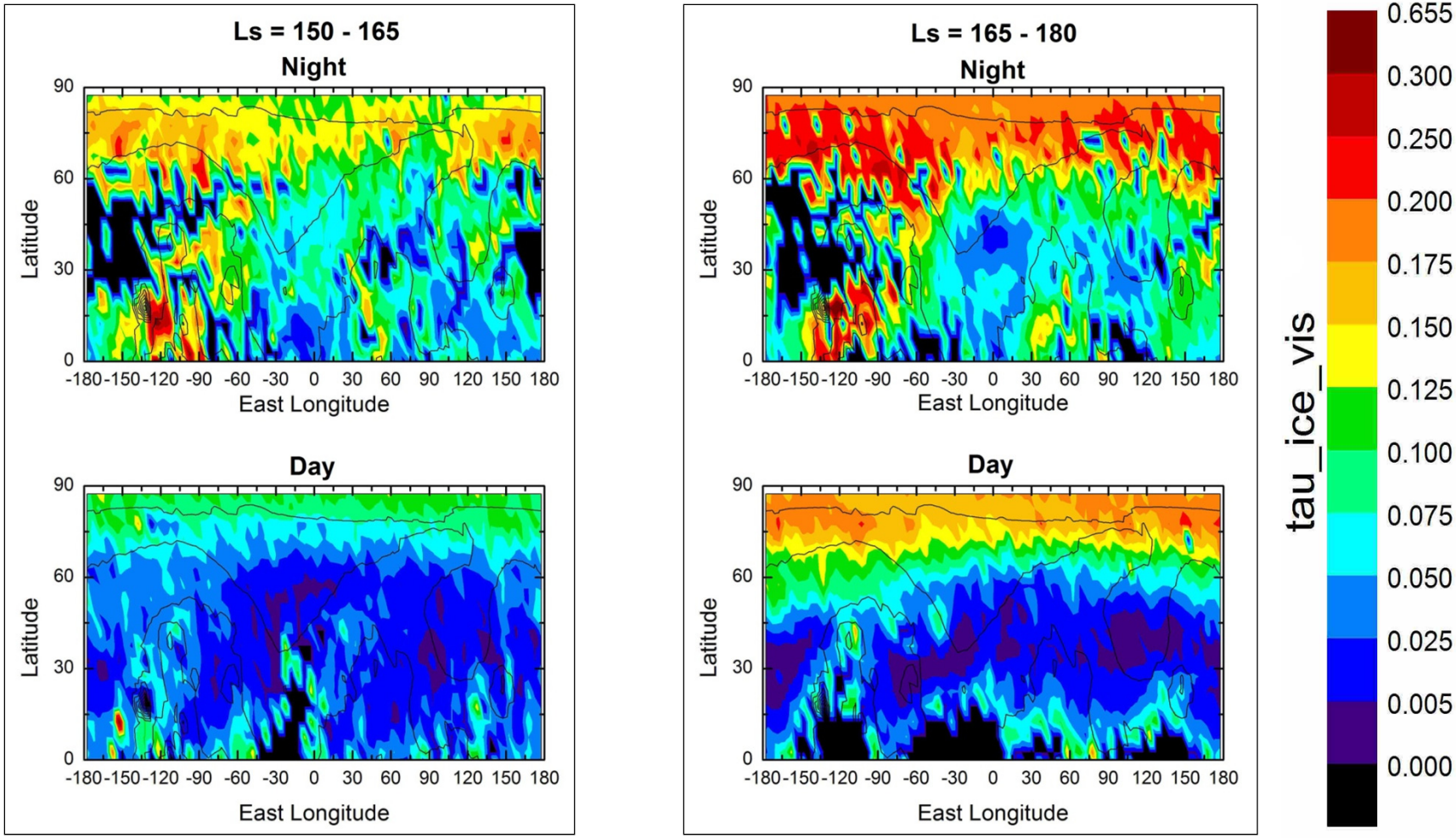


L_S = 138° – 92° temperature difference
(Phase 2 minus cloud free gap)

NPH Seasonal Cycles

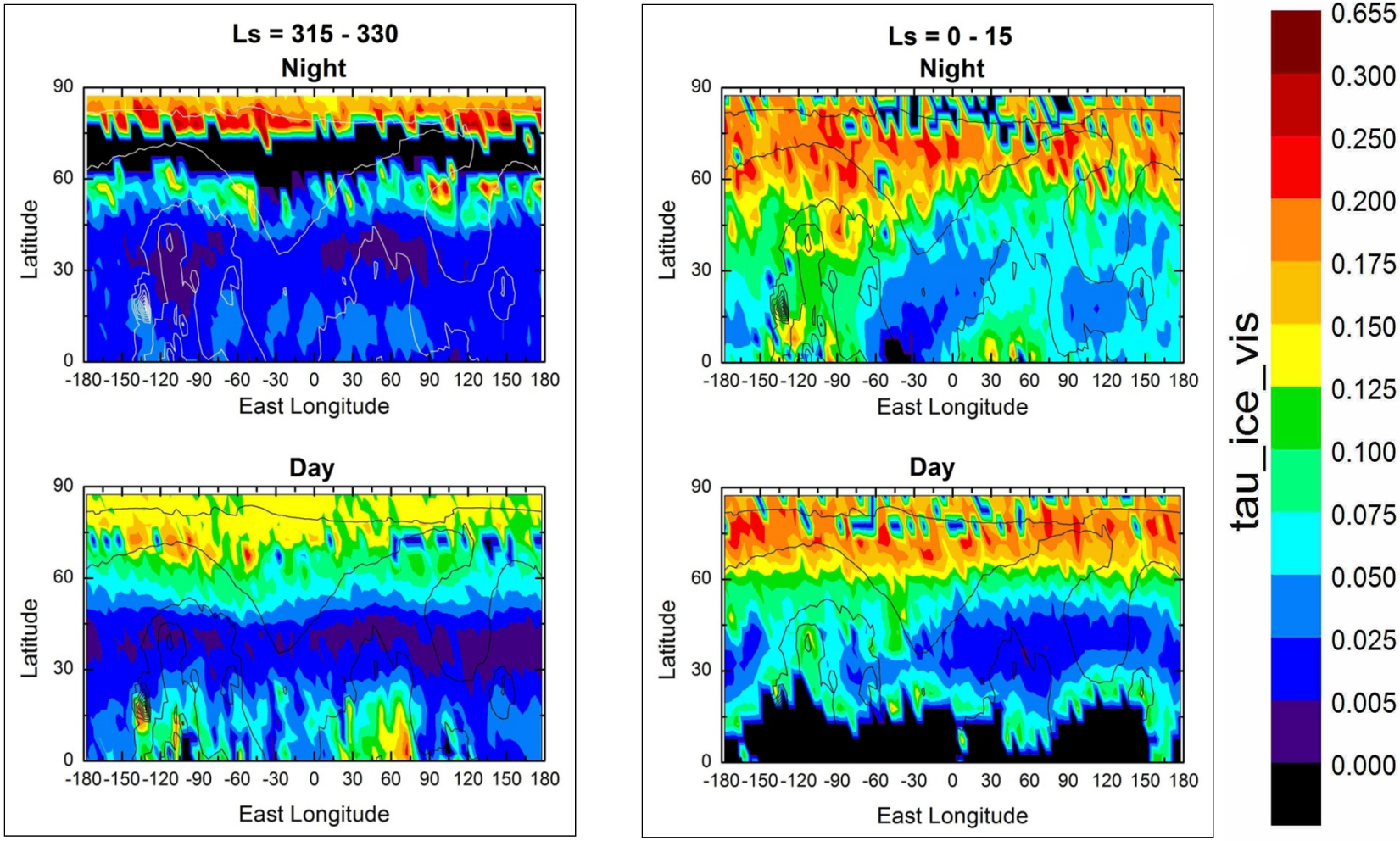


NPH Cloud Maps

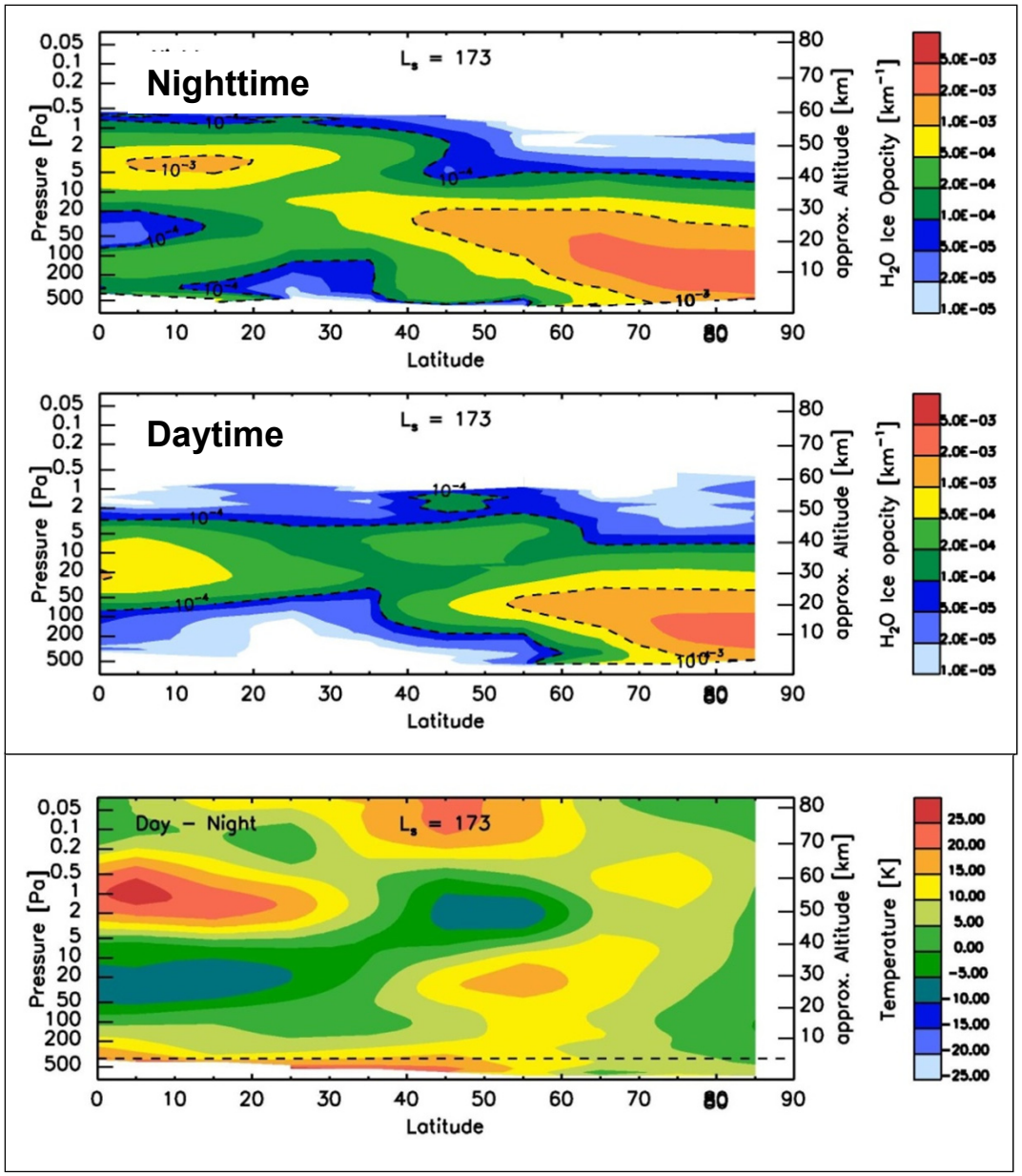


NPH clouds start to form at L_S =150° and by L_S =165° clouds have increased in optical depth both at night and day.

NPH Cloud Maps



NPH Ice Opacity and Temperature Correlation

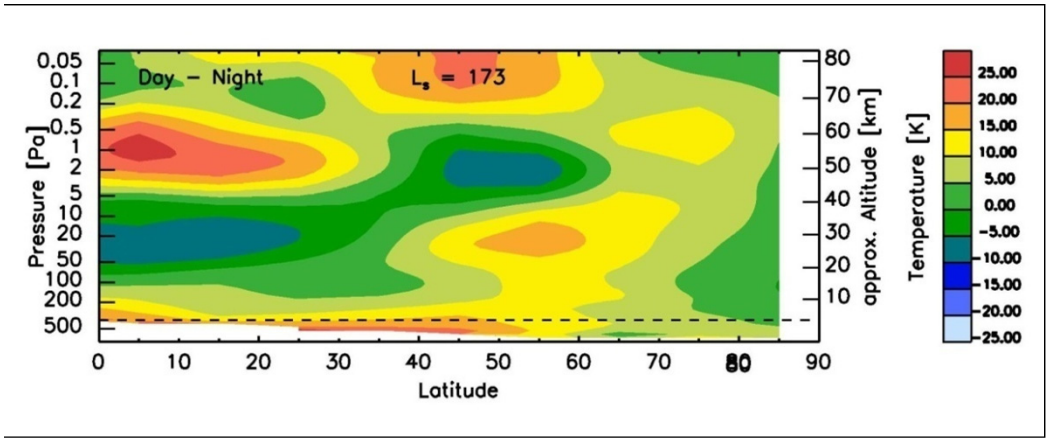


Night and Day zonal mean H_2O ice extinction

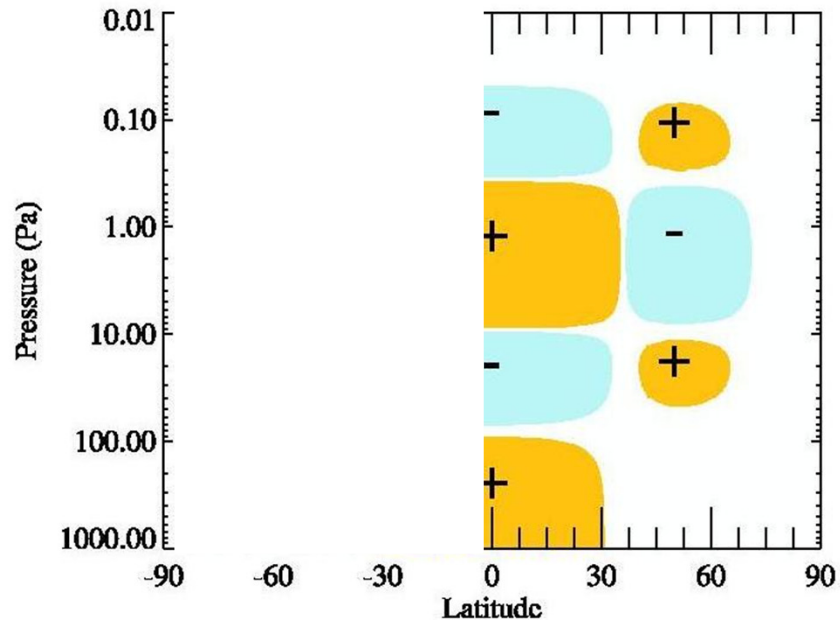
Day minus night temperature difference

Thermal tidal structure

NPH Thermal Tide



NPH Day minus night temperature difference

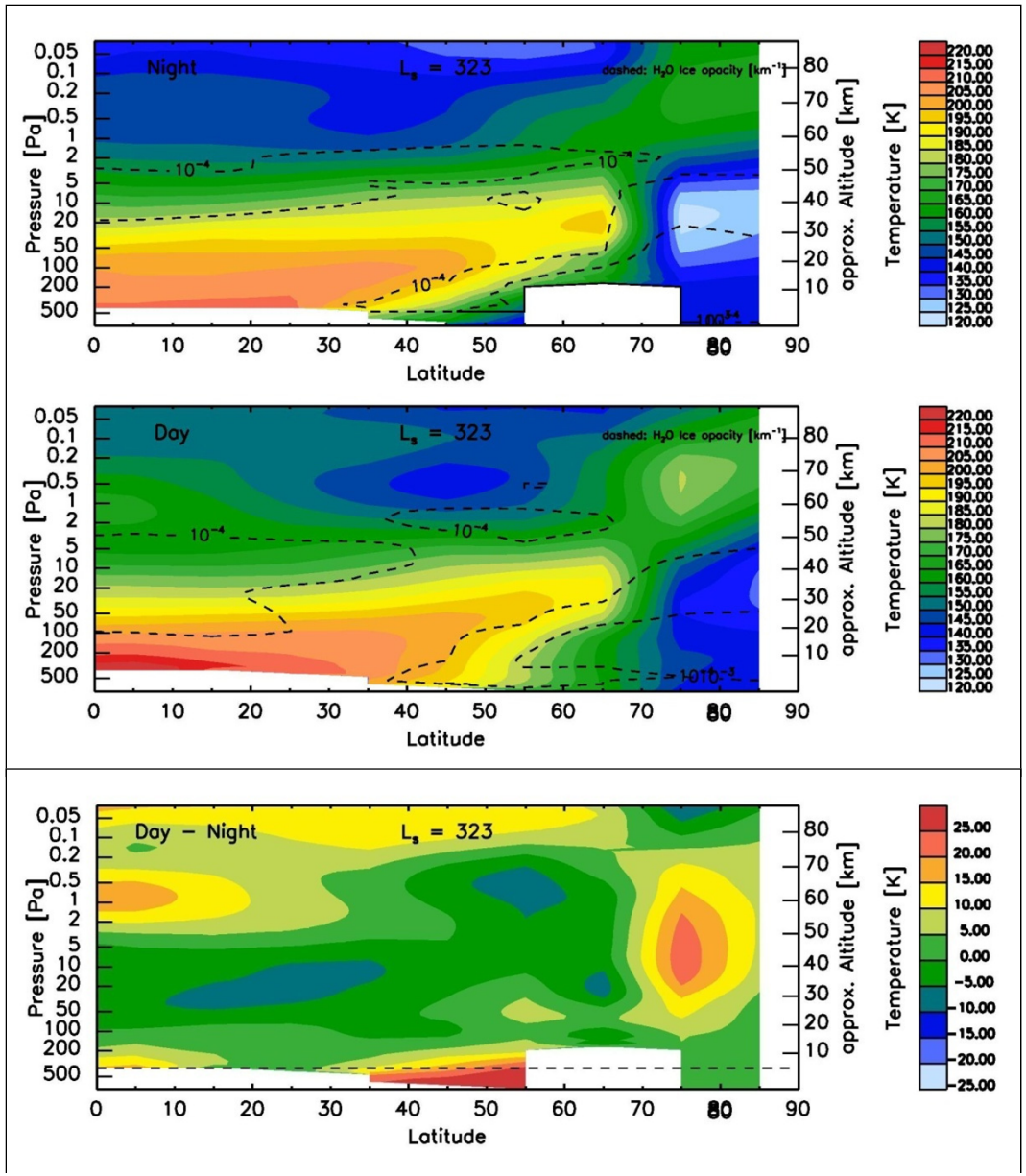


Schematic

NPH Ice Opacity and Temperature Correlation

Nighttime

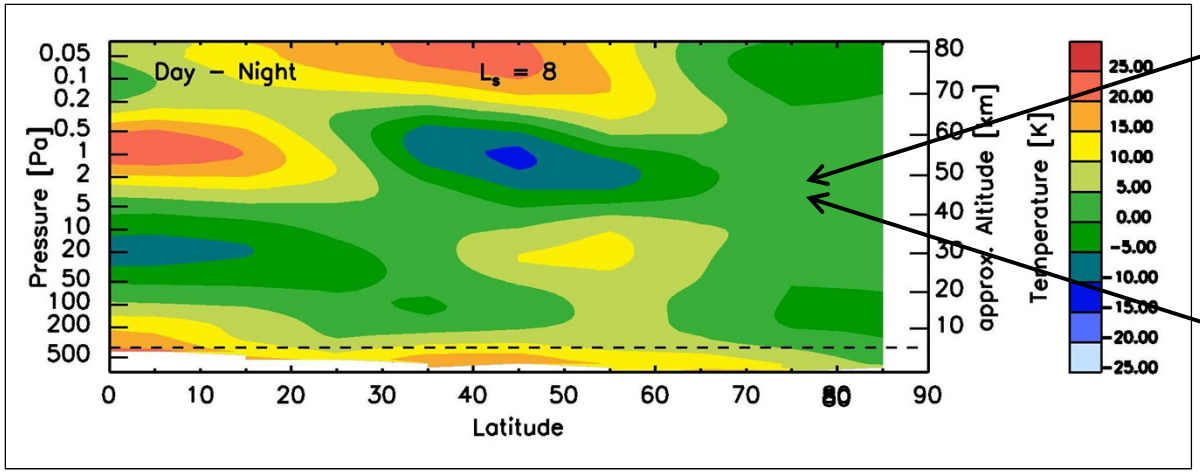
Daytime



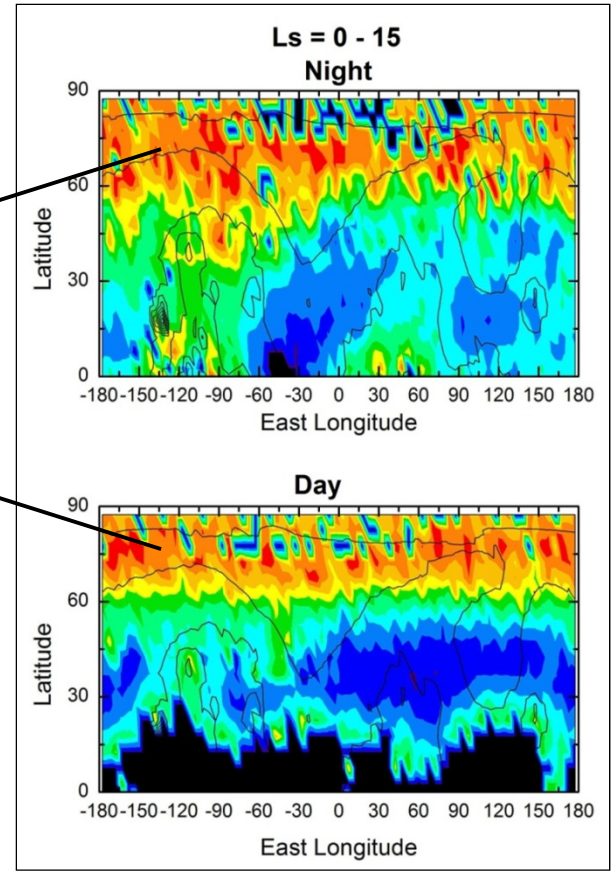
Night and Day zonal mean temperature cross-sections with water ice contours superimposed

Day minus night temperature difference

NPH Ice Opacity and Temperature Correlation



Day minus night temperature difference

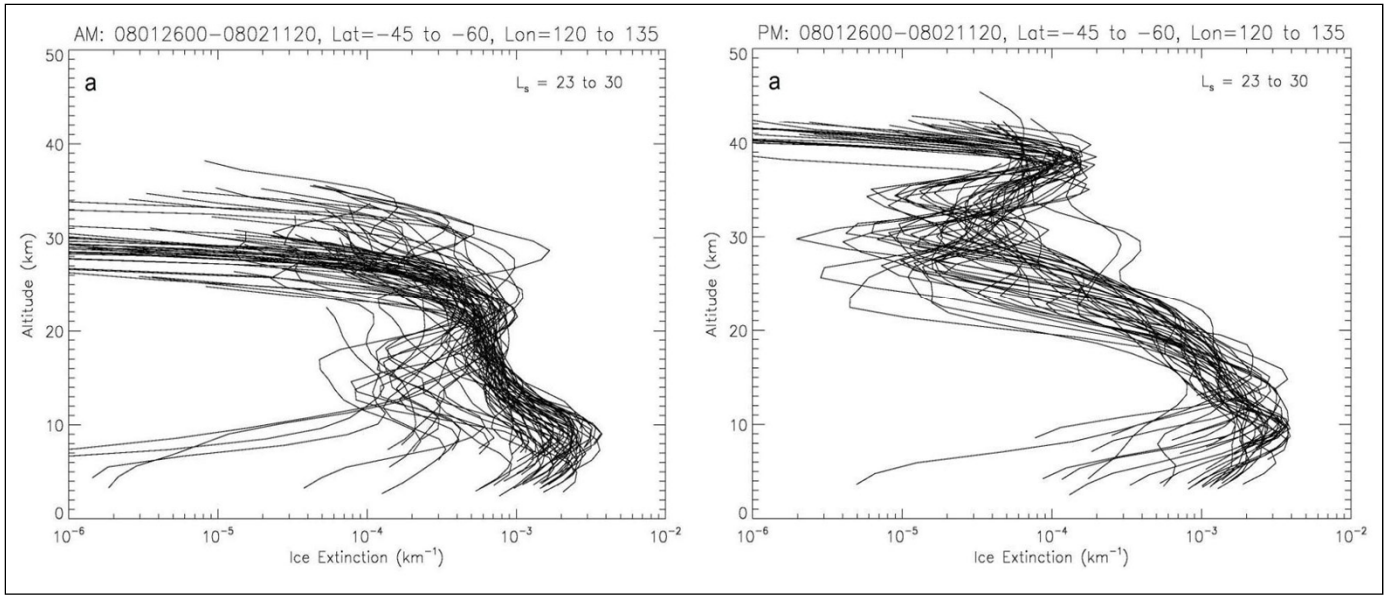


Similar ice opacity day and night because clouds are located where there is no day-night temperature difference

SPH Ice Extinction Profiles

Ls = 23 - 30

Night **Day**



SPH clouds have 2 layers at both day and night.

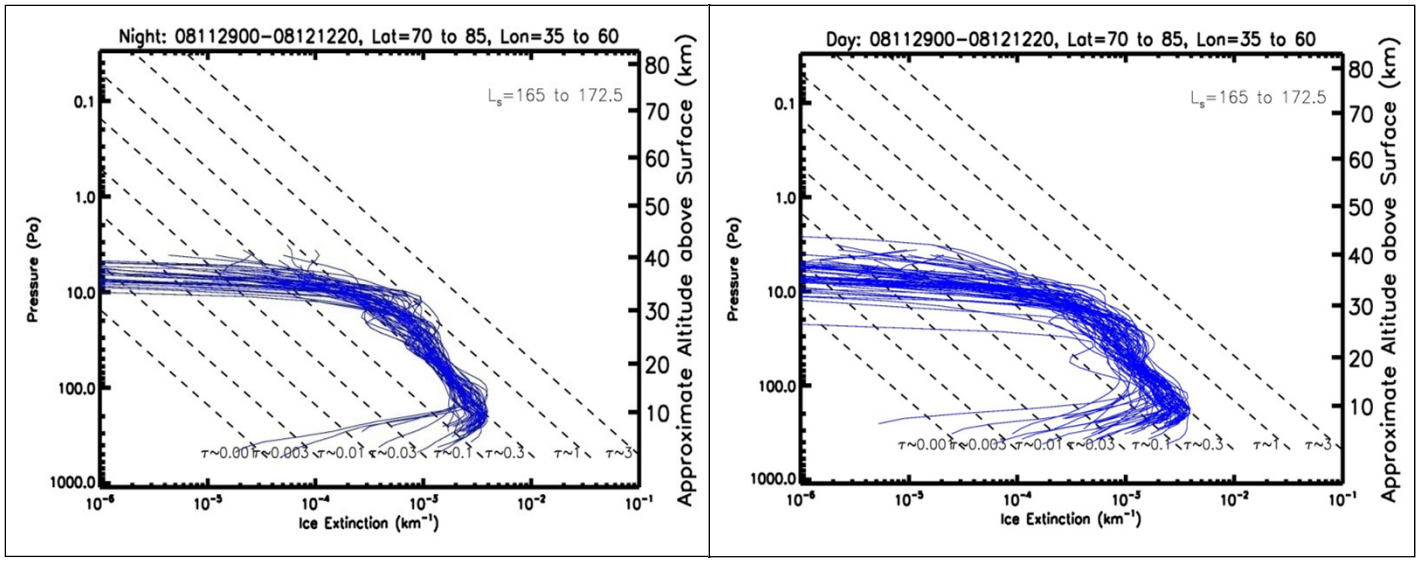
Daytime clouds extend ~10 km higher in the atmosphere than nighttime clouds

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.

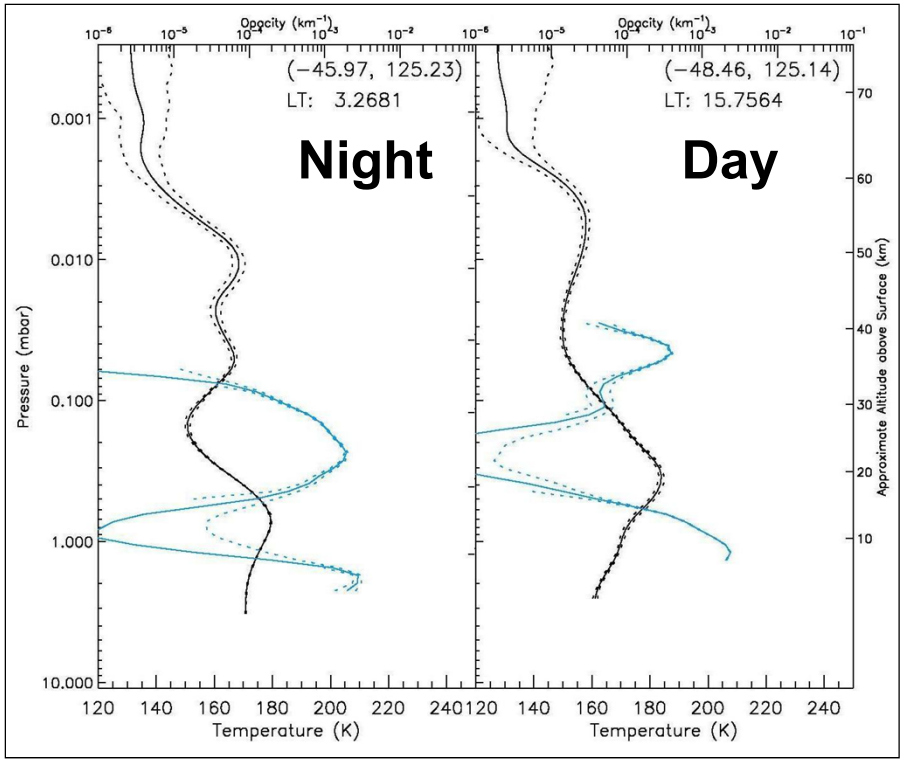
Cloud altitude structure is nearly identical across the NPH and throughout the season.

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

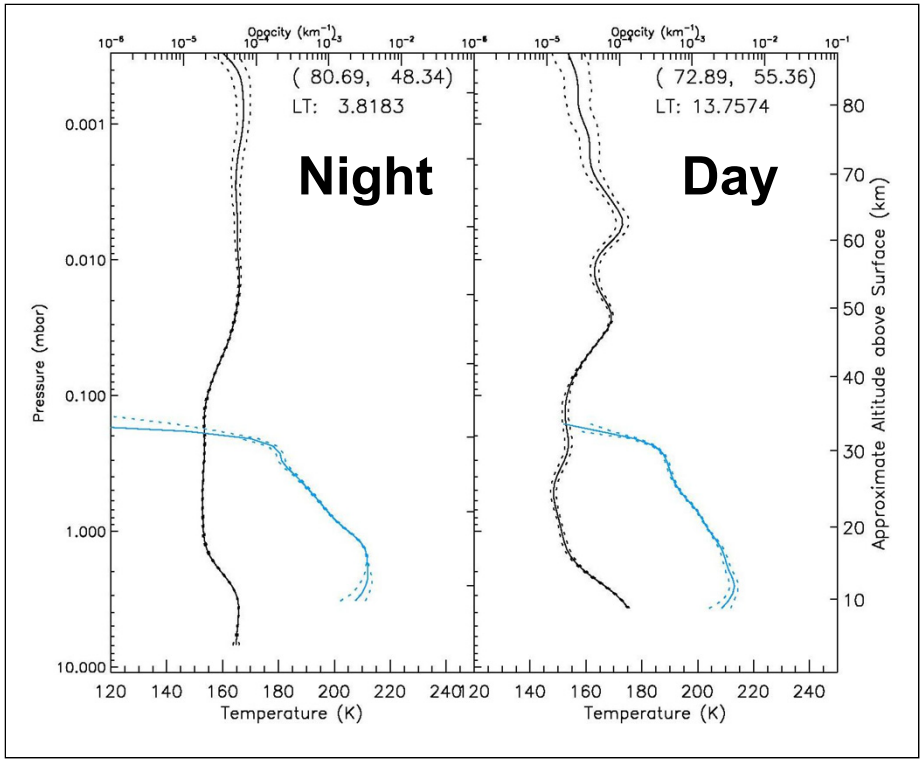
Dashed lines represent lines of constant ice mixing ratio

SPH and NPH Profile Comparison

SPH

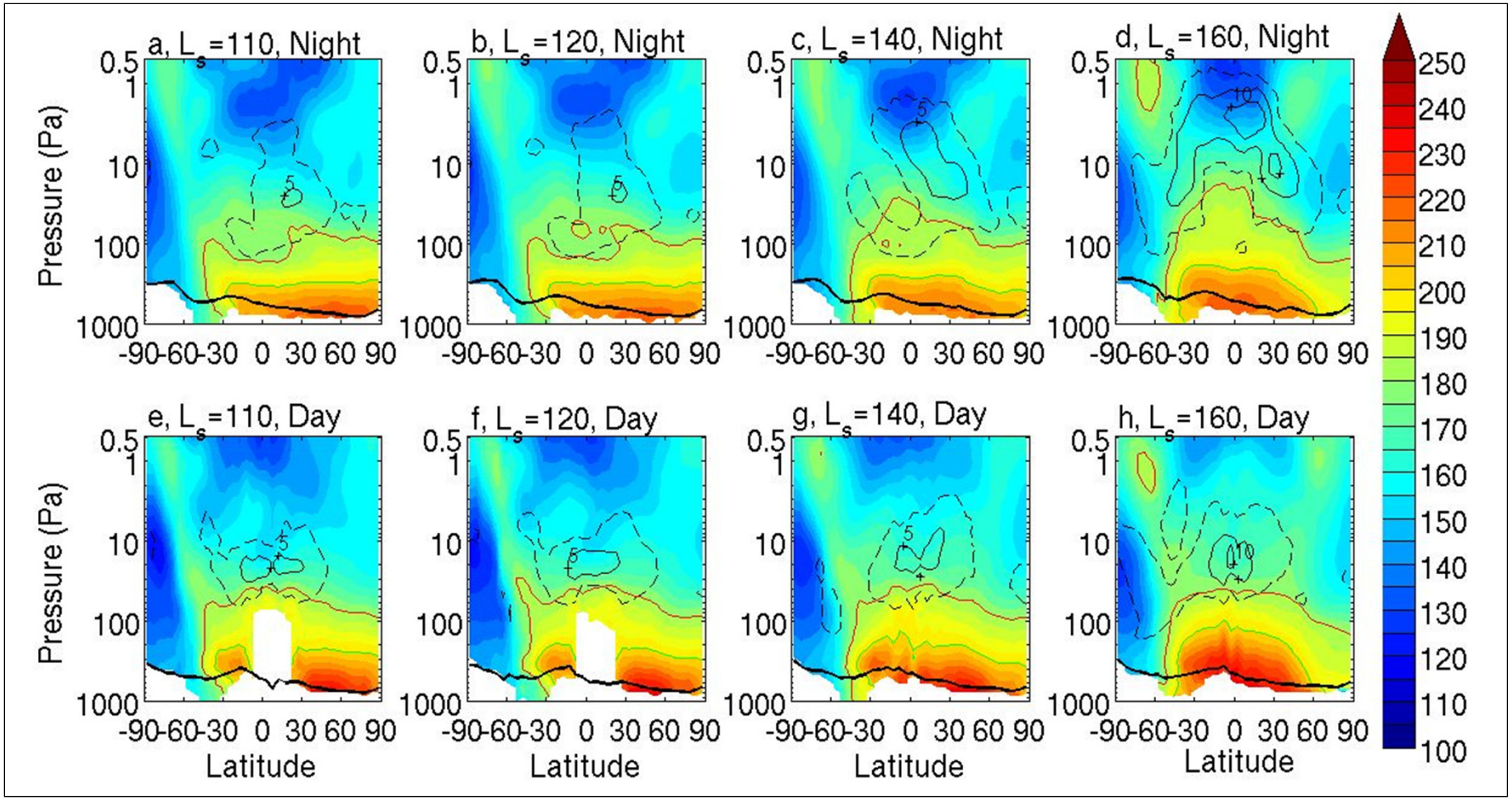


NPH



Temperature (black). Ice extinction (blue, 12 μm)

Tropical Water Ice Clouds



Heavens et al., 2010, GRL

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

Heavens et al., 2010, Water ice clouds over the Martian tropics during northern summer, *GRL, 37*, L18202, doi:10.1029/2010GL044610.

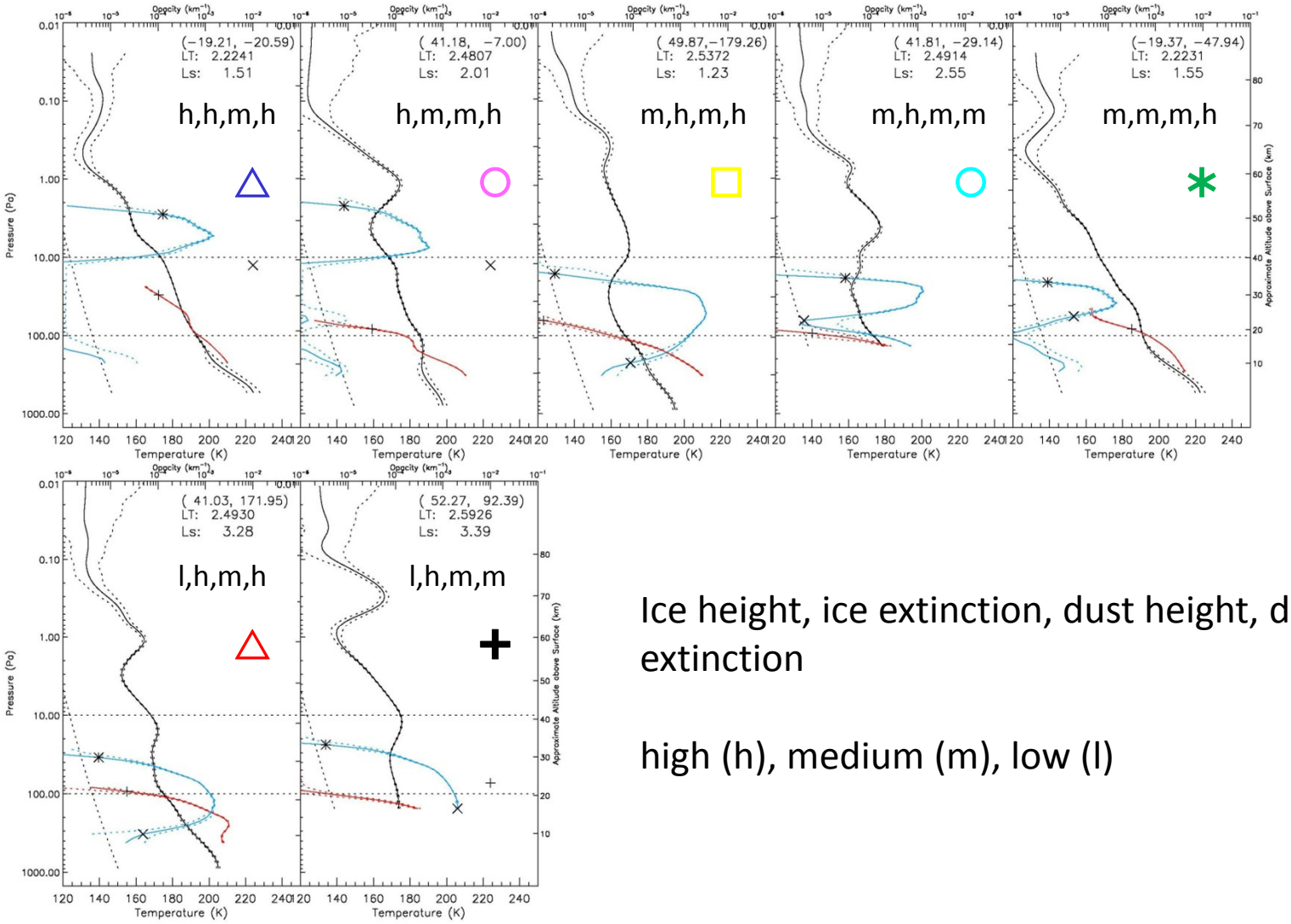
WATER ICE AND DUST LAYERING IN THE MARTIAN ATMOSPHERE

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
  - Ls=2, 72, 158, 213

Ice & Dust Height & Extinction

AM Ls = 2

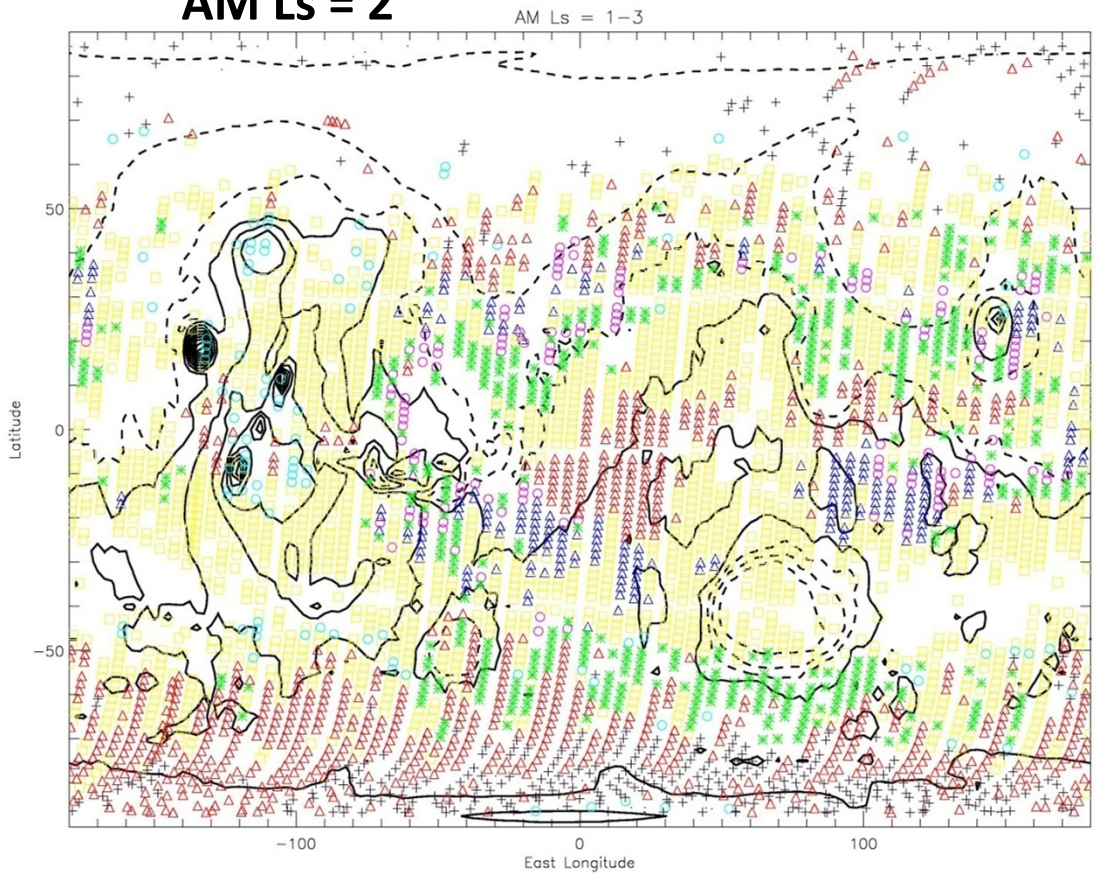


Ice height, ice extinction, dust height, dust extinction

high (h), medium (m), low (l)

Ice & Dust Height & Extinction

AM Ls = 2



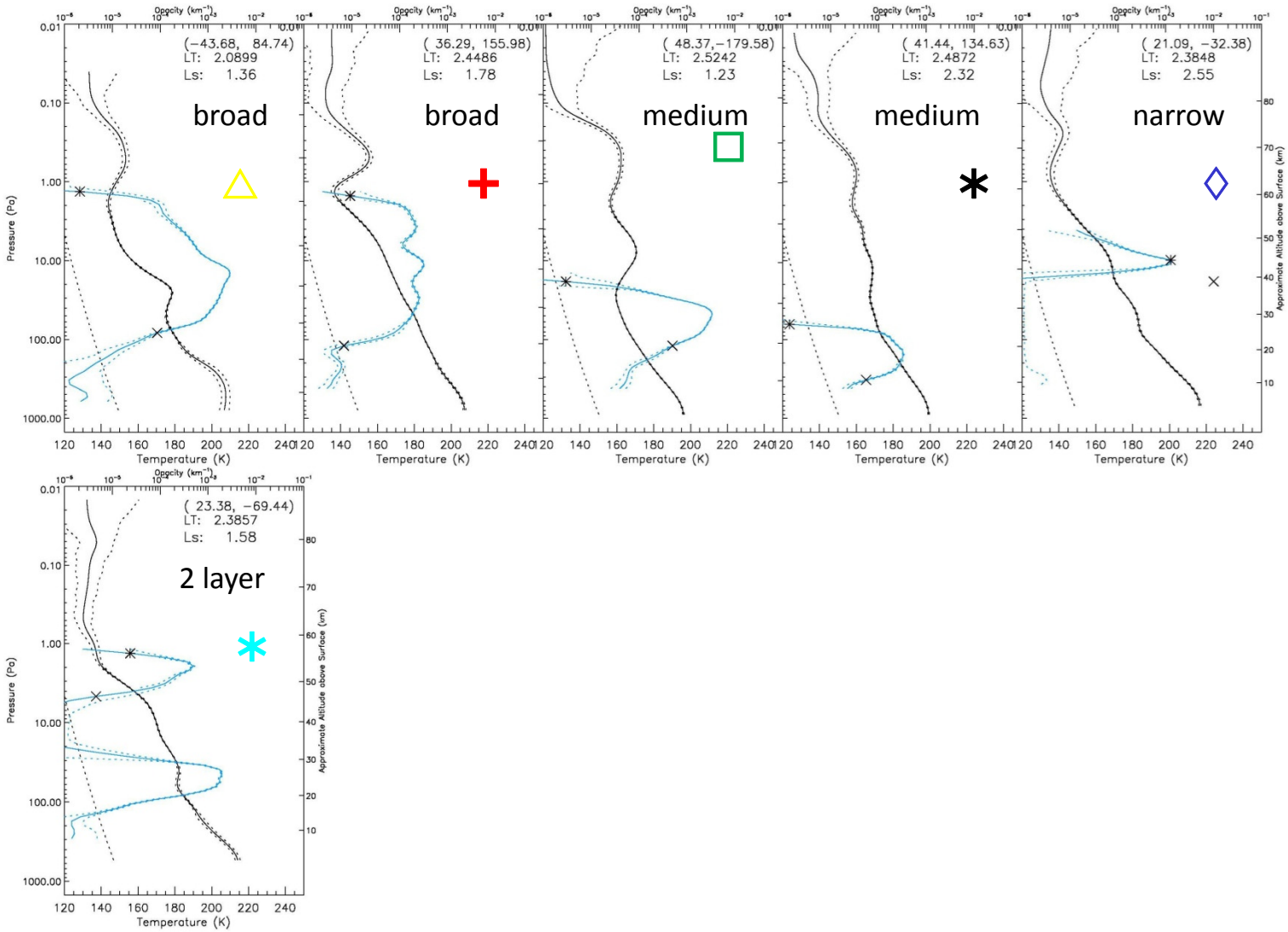
Color and Symbol	Ice Height	Ice Extinction	Dust Top Height	Dust Extinction
△	High	High	Medium	High
○	High	Medium	Medium	High
□	Medium	High	Medium	High
○	Medium	High	Medium	Medium
○	Medium	High	Medium and Low	Medium
*	Medium	High	Medium	Low
*	Medium	Medium	Medium	High
□	Medium	Medium	Medium and Low	Medium
□	Medium	Low	Medium	High
△	Low	High	Medium	High
+	Low	High	Medium and Low	Medium and Low
+	Low	Medium	Medium and Low	High
+	Low	Medium	Medium	Medium
X	Low	Medium	Low	High
+	Low	Medium	Low	Medium
◇	Low	Medium	Low	Low
X	Low	Low	Medium	High
X	Low	Low	Low	High

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



Ice Layer Vertical Thickness & Ice Extinction

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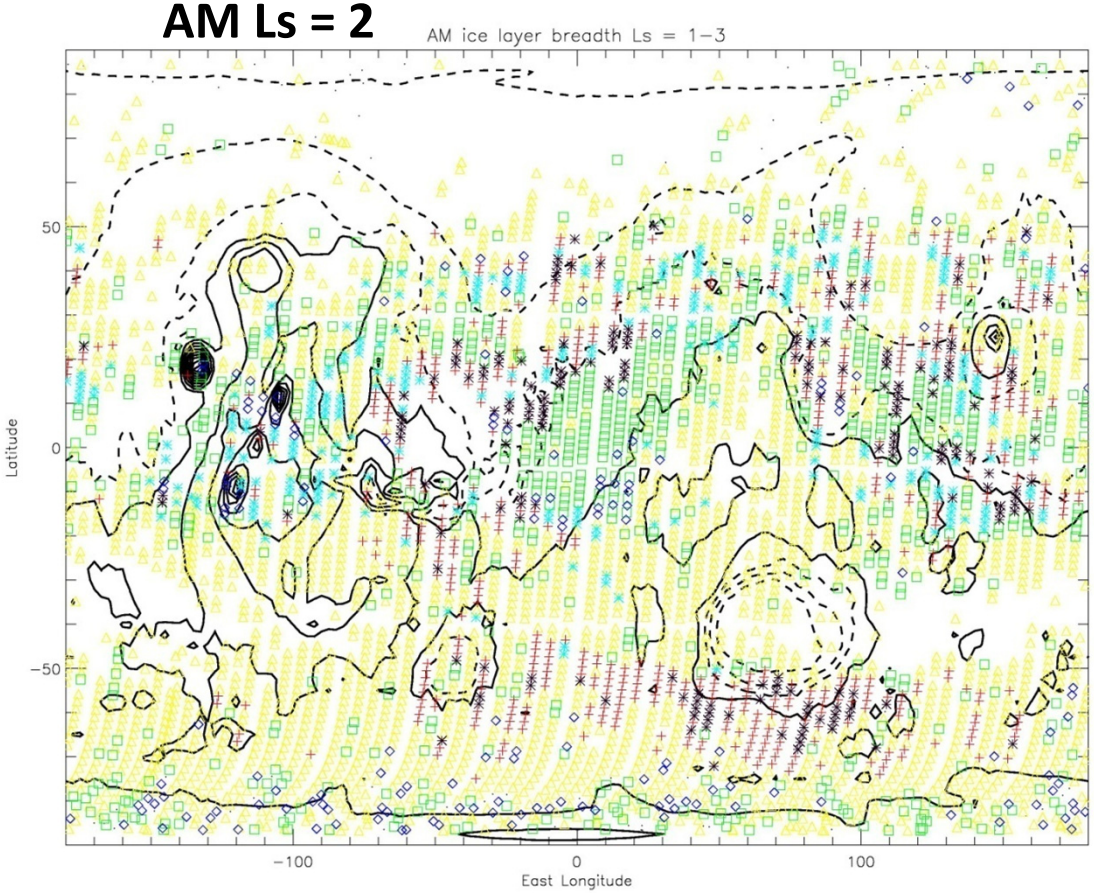
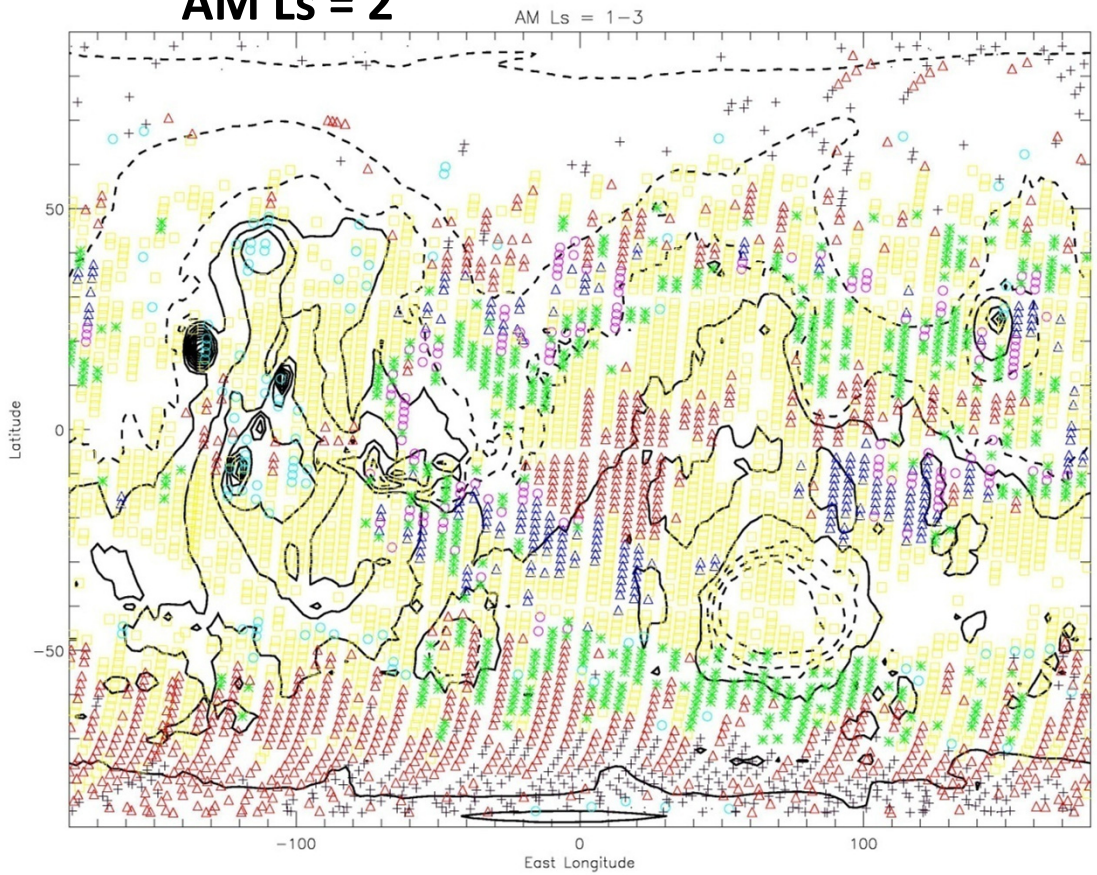


Color and Symbol	Ice Layer Vertical Thickness	Ice Extinction
△	Broad	High
+	Broad	Medium
□	Medium	High
*	Medium	Medium
○	Medium	Low
◇	Narrow	High
□	Narrow	Medium
○	Narrow	Low
*	Multilayer	----------

Clusters of longitudinal structure with varying ice layer breadth and ice extinction

Ice & Dust Height & Extinction

AM Ls = 2



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○	High	Medium	Medium	High
□	Medium	High	Medium	High
○	Medium	High	Medium	Medium
○	Medium	High	Medium and Low	Medium
*	Medium	High	Medium	Low
*	Medium	Medium	Medium	High
□	Medium	Medium	Medium and Low	Medium
□	Medium	Low	Medium	High
△	Low	High	Medium	High
+	Low	High	Medium and Low	Medium and Low
+	Low	Medium	Medium and Low	High
+	Low	Medium	Medium	Medium
X	Low	Medium	Low	High
+	Low	Medium	Low	Medium
◇	Low	Medium	Low	Low
X	Low	Low	Medium	High
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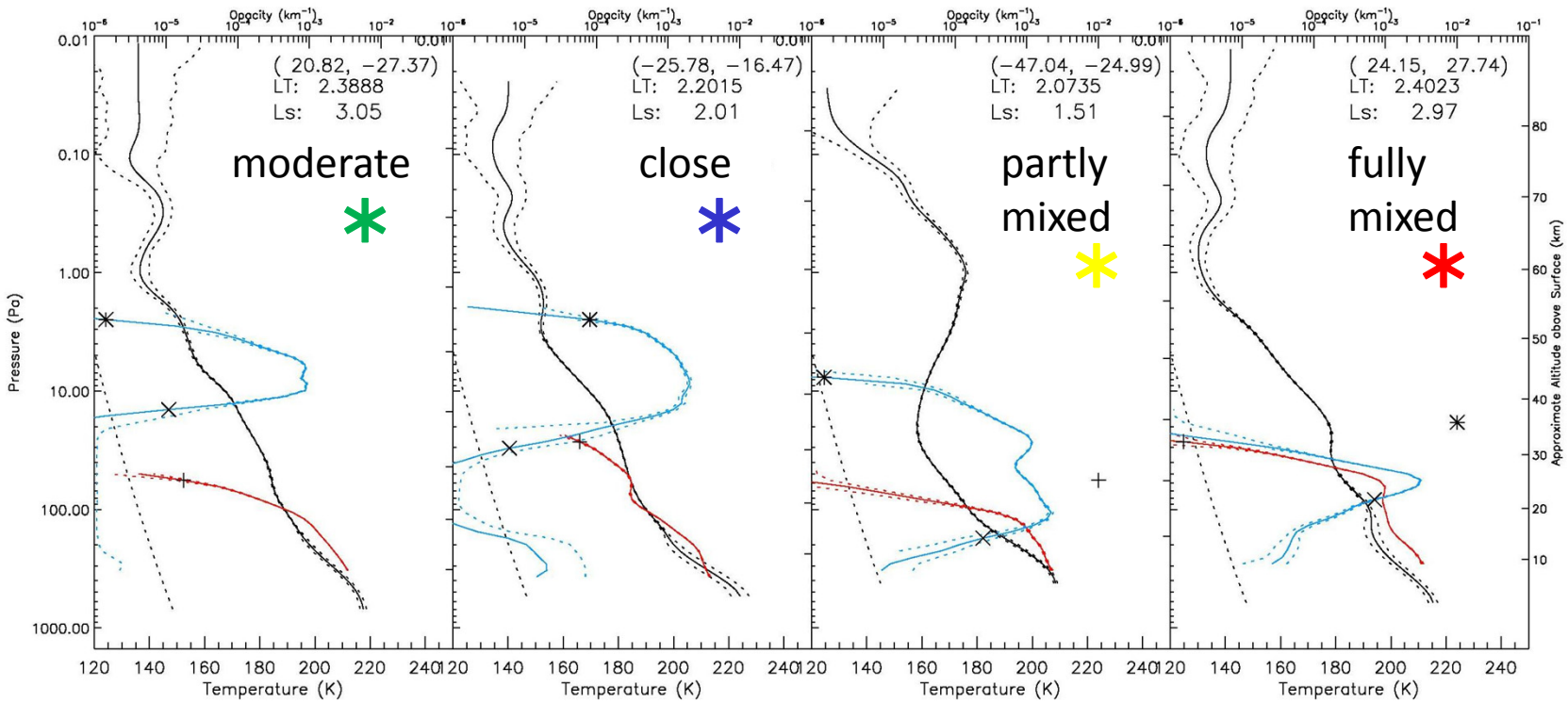
Ice & Dust Vertical Separation

AM Ls = 2



Ice & Dust Vertical Separation

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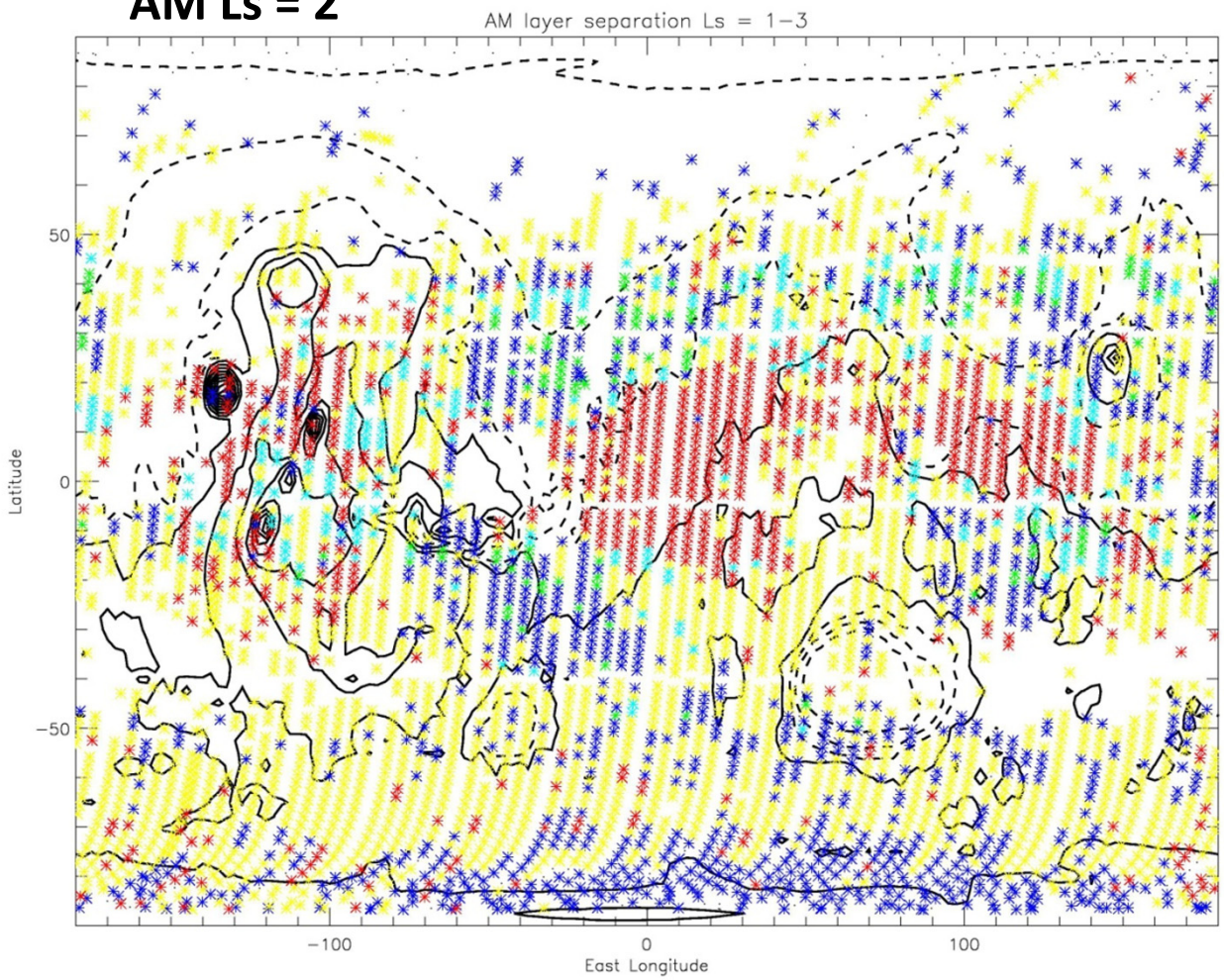


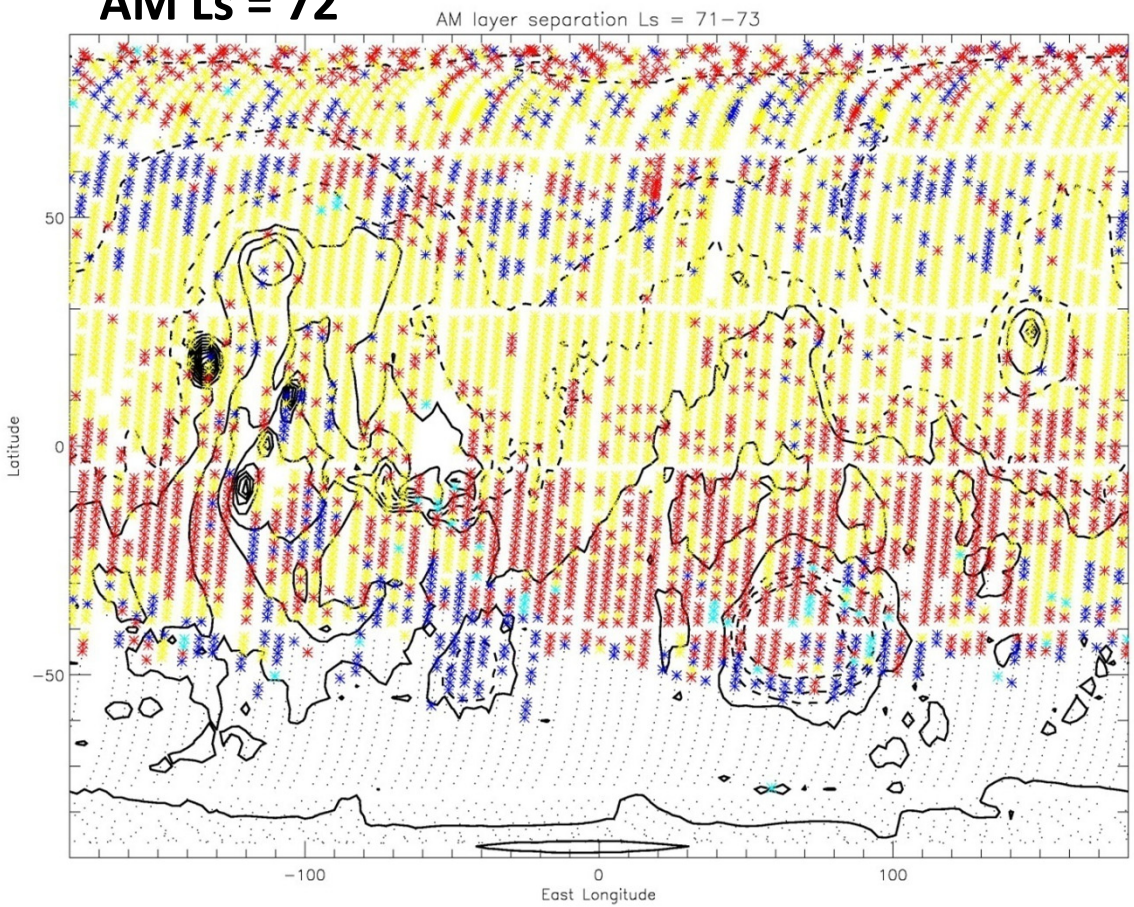
Color and Symbol	Vertical Separation
*	Moderate
*	Close
*	Partly Mixed
*	Fully Mixed
*	Multilayer

Clusters of longitudinal structure. Majority of planet shows some ice and dust mixing.

Ice & Dust Mixture

Vertical Separation

AM Ls = 72



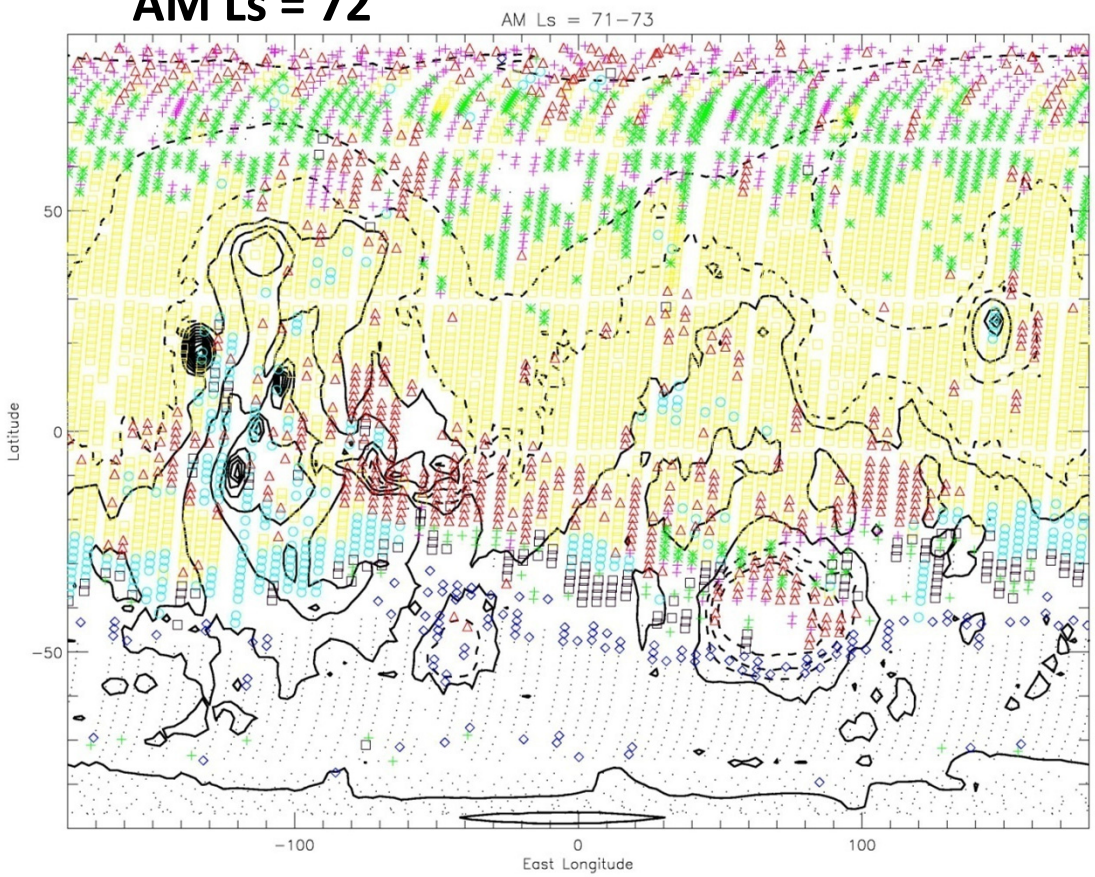
Color and Symbol	Vertical Separation
*	Moderate
*	Close
*	Partly Mixed
*	Fully Mixed
*	Multilayer

Majority of planet shows some ice and dust mixing.

Zonal Banding

Ice & Dust Height & Extinction

AM Ls = 72



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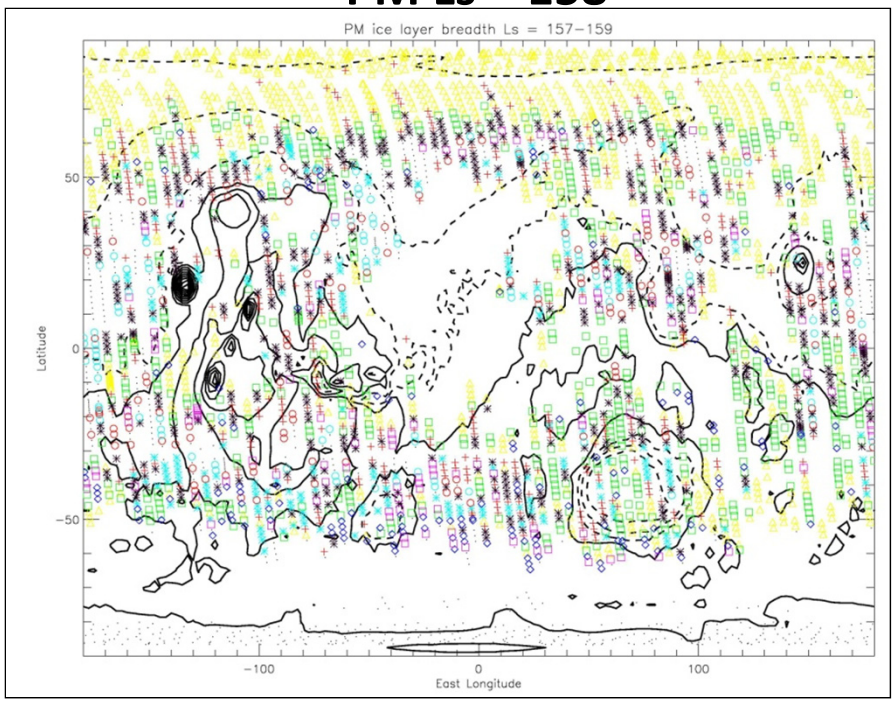
○	High	Medium	Medium	High
□	Medium	High	Medium	High
○	Medium	High	Medium	Medium
○	Medium	High	Medium and Low	Medium
✳	Medium	High	Medium	Low
✳	Medium	Medium	Medium	High
□	Medium	Medium	Medium and Low	Medium
□	Medium	Low	Medium	High
△	Low	High	Medium	High
+	Low	High	Medium and Low	Medium and Low
+	Low	Medium	Medium and Low	High
+	Low	Medium	Medium	Medium
x	Low	Medium	Low	High
+	Low	Medium	Low	Medium
◇	Low	Medium	Low	Low
x	Low	Low	Medium	High
x	Low	Low	Low	High

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.

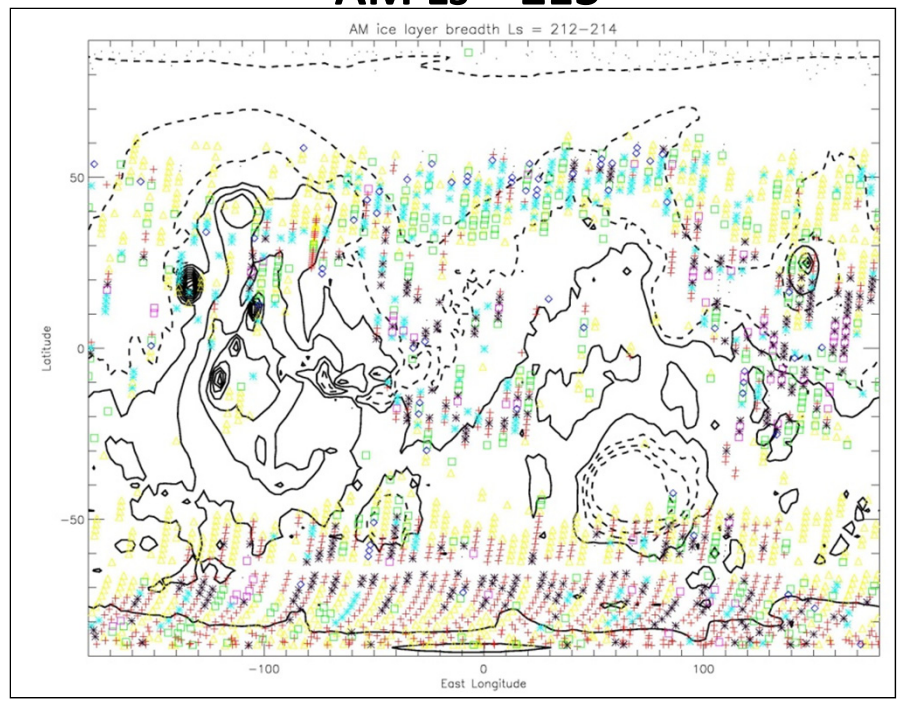
Variability

Ice Layer Vertical Thickness & Ice Extinction

PM Ls = 158



AM Ls = 213



Color and Symbol	Ice Layer Vertical Thickness	Ice Extinction
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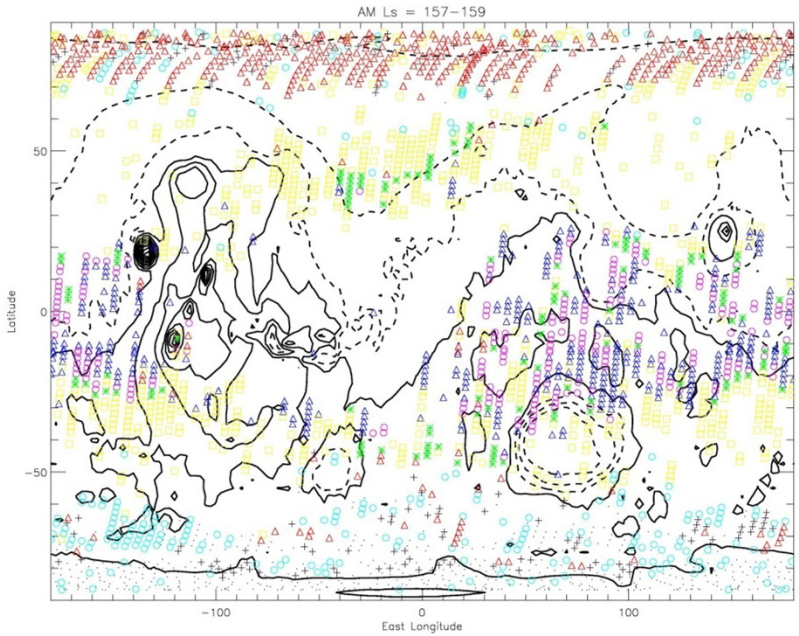
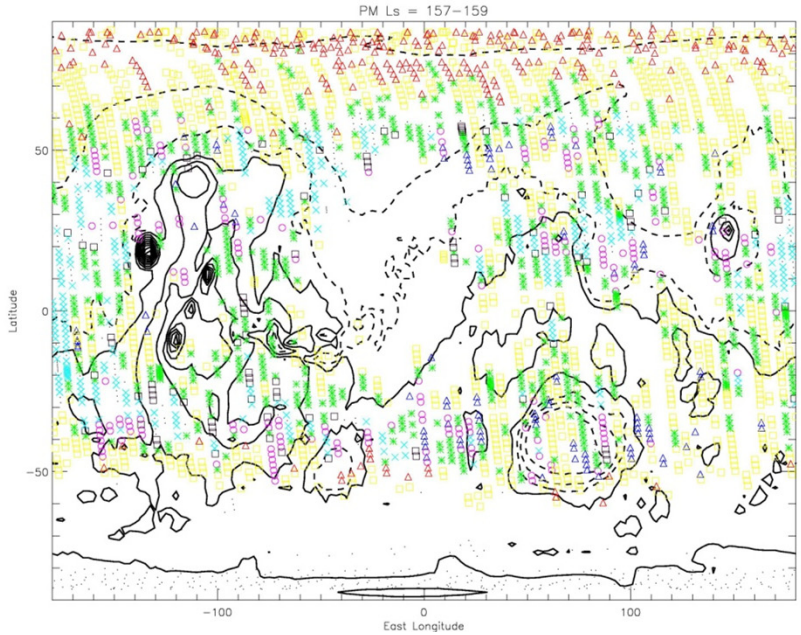
□	Medium	High
✱	Medium	Medium
○	Medium	Low
◊	Narrow	High
□	Narrow	Medium
○	Narrow	Low
✱	Multilayer	----------

Ice & Dust Height & Extinction

AM Ls = 158
Night



PM Ls = 158
Day

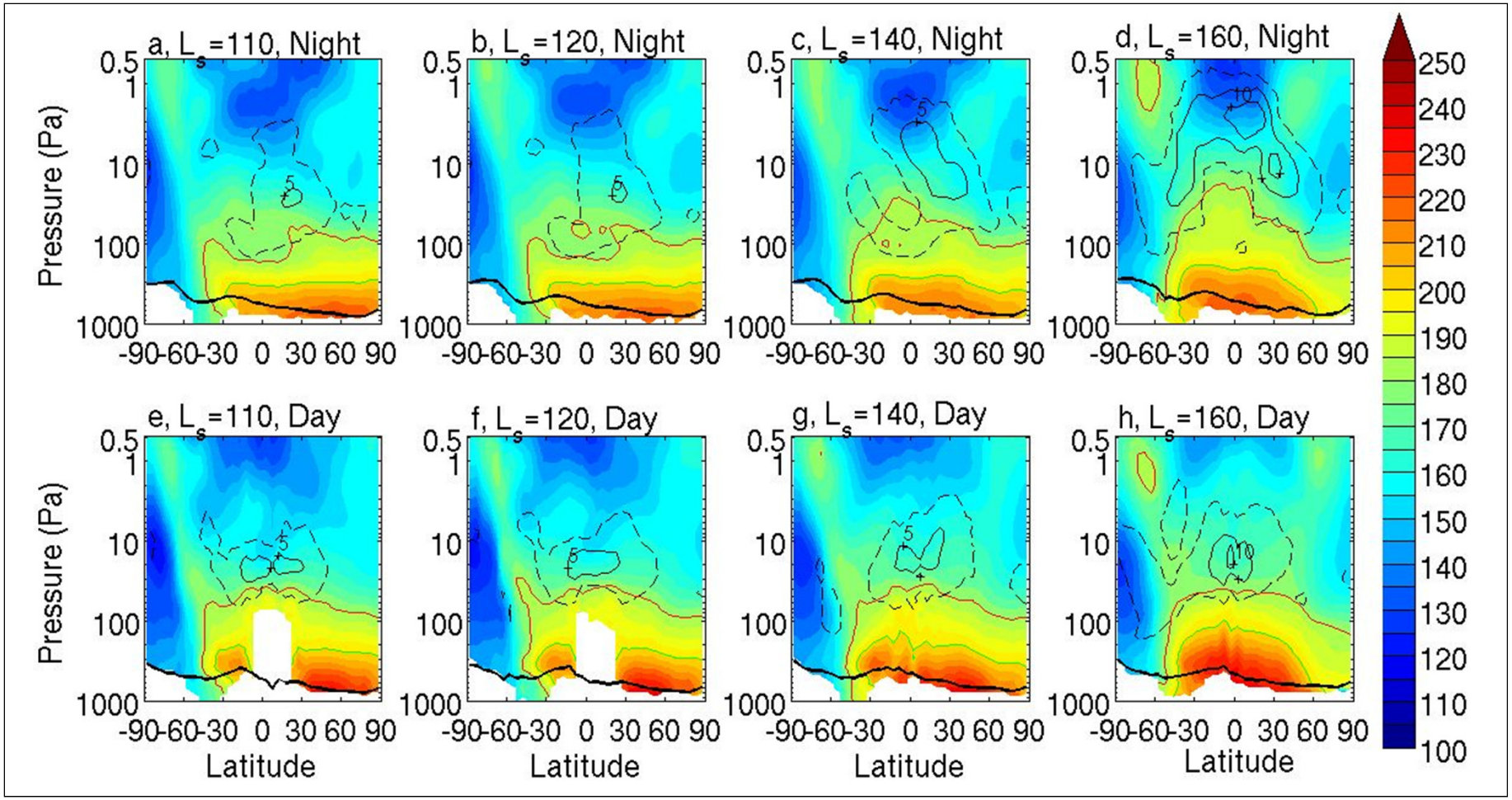


Color and Symbol	Ice Height	Ice Extinction	Dust Top Height	Dust Extinction
△	High	High	Medium	High
○	High	Medium	Medium	High
□	Medium	High	Medium	High
○	Medium	High	Medium	Medium
○	Medium	High	Medium and Low	Medium
*	Medium	High	Medium	Low
*	Medium	Medium	Medium	High
□	Medium	Medium	Medium and Low	Medium
□	Medium	Low	Medium	High
△	Low	High	Medium	High
+	Low	High	Medium and Low	Medium and Low
+	Low	Medium	Medium and Low	High
+	Low	Medium	Medium	Medium
X	Low	Medium	Low	High
+	Low	Medium	Low	Medium
◇	Low	Medium	Low	Low
X	Low	Low	Medium	High
X	Low	Low	Low	High

Shaded orange rows are in the maps.

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



Heavens et al., 2010, GRL

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

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