STUDIES OF THE MARTIAN ATMOSPHERE WITH PFS:

THERMAL PROFILES AND MINOR CONSTITUENTS

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Workshop Mars III – Les Houches – 28 March - 2 April 2010

The Planetary Fourier Spectrometer

- PFS is an infrared FT spectrometer optimized for atmospheric studies.
- Spectral range: 1.2 to 45 μm.
- Two spectral channels, **SWC** (1.2÷5.5 μm or 1700÷8200 cm^{-1}) and **LWC** (5.5÷45 μm or 250÷1700 cm^{-1}).
- Spectral resolution: 1.3 cm^{-1}. Sampling step: 1 cm^{-1}
- **IFOV** (FWHM): 1.6° for the SWC; 2.8° for the LWC corresponding to a spatial resolution of 7 and 12 km respectively, when Mars is observed from an height of 250 km (nominal height of the pericentre).

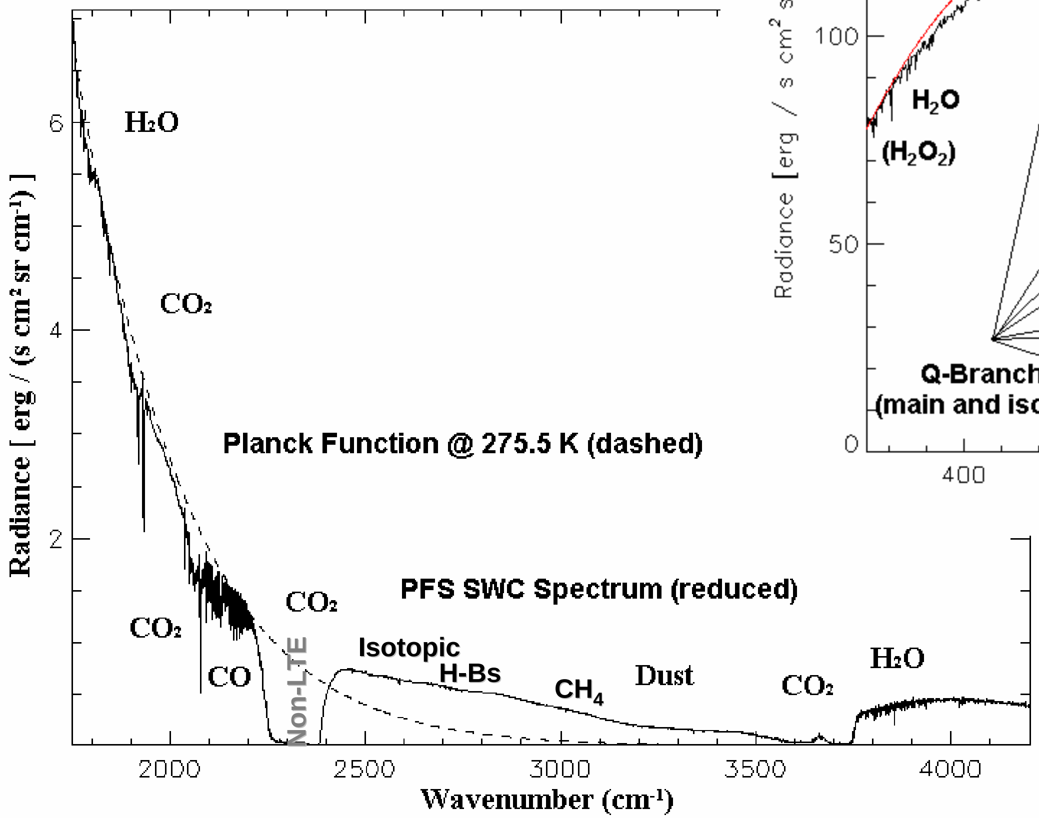
No Fourier spectrometer has ever been flown around Mars covering the wavelength range 1 ÷ 5 μm.

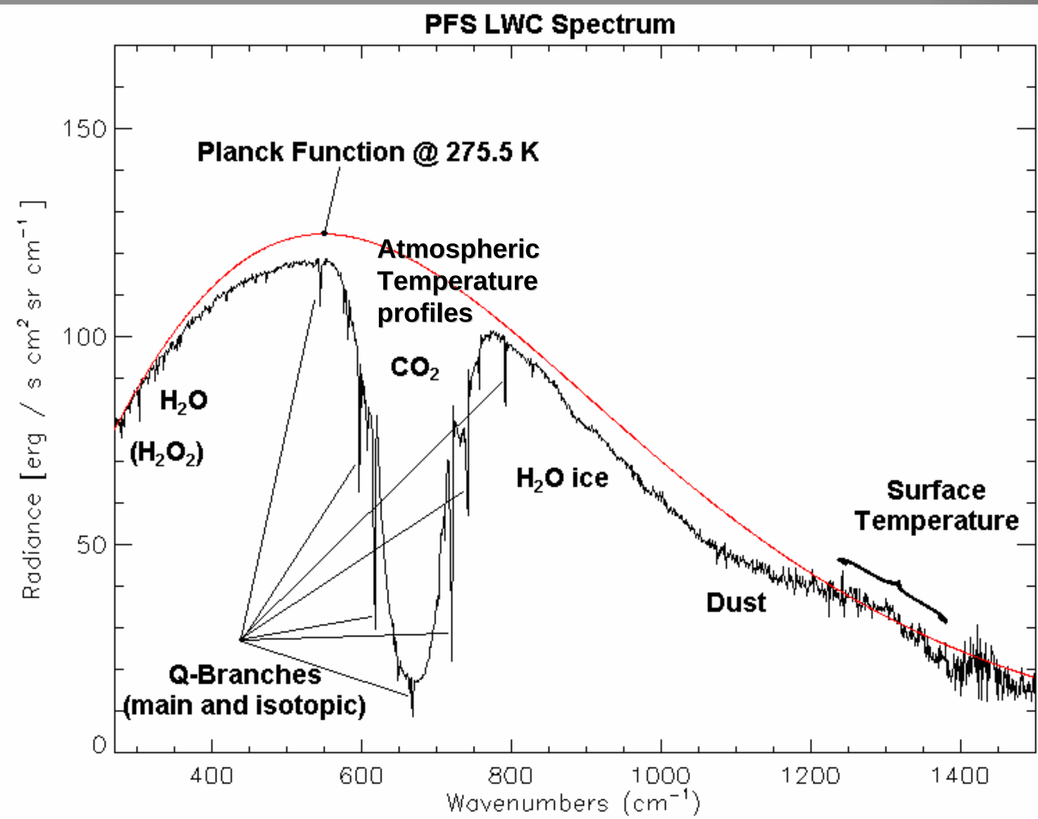
PFS provide unique data necessary to improve our knowledge of the atmospheric properties, composition and dynamics, as well as the surface-atmosphere interaction.

The discovery of Methane of Mars, the analysis of complex dynamical phenomena that occur in the Martian polar regions, the study of the minor species and the non-LTE emission in the Martian Atmosphere are only some of the important scientific results achieved by the analysis of PFS data.

PFS Calibrated Spectra

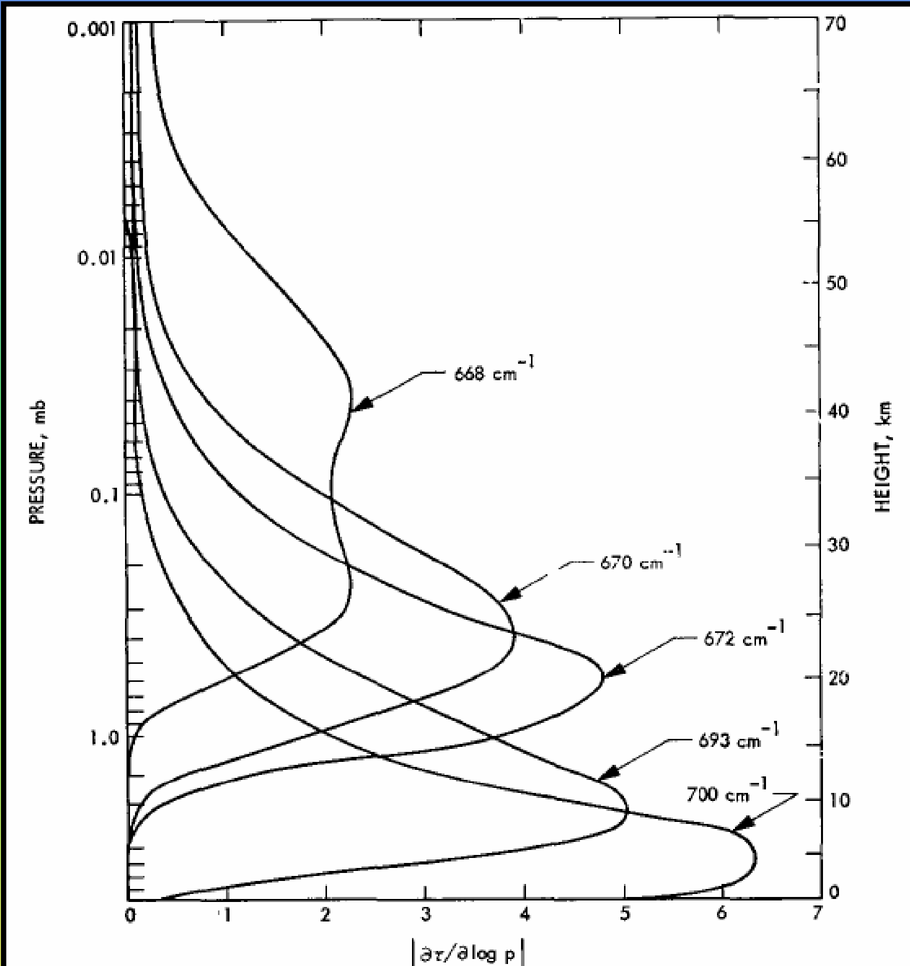
SWC Calibration
M. Giuranna et al. (2005a) - PSS 53, 975–991



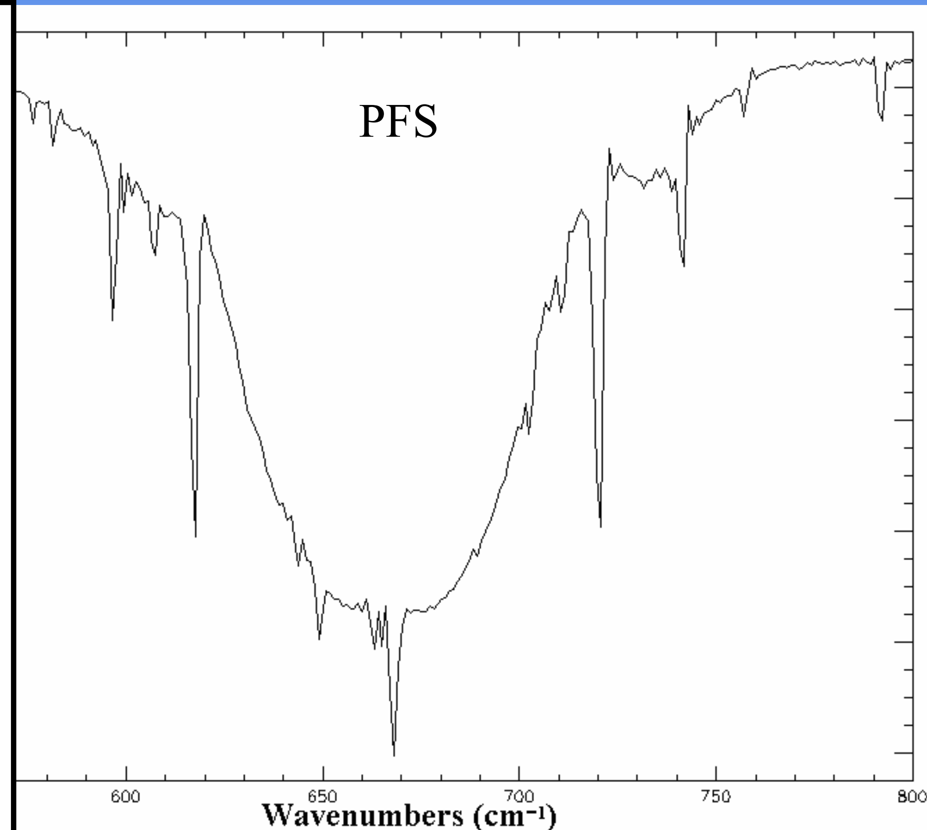


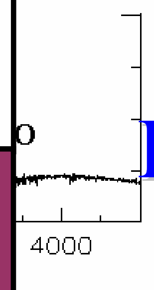
LWC Calibration
M. Giuranna et al. (2005b) - PSS 53, 993–1007

Vertical Temperature Profiles



Sample weighting functions for the 667cm-1 CO_2 band. The examples shown give an indication of the height range over which information on the temperature profile can be obtained.





Basic Concepts

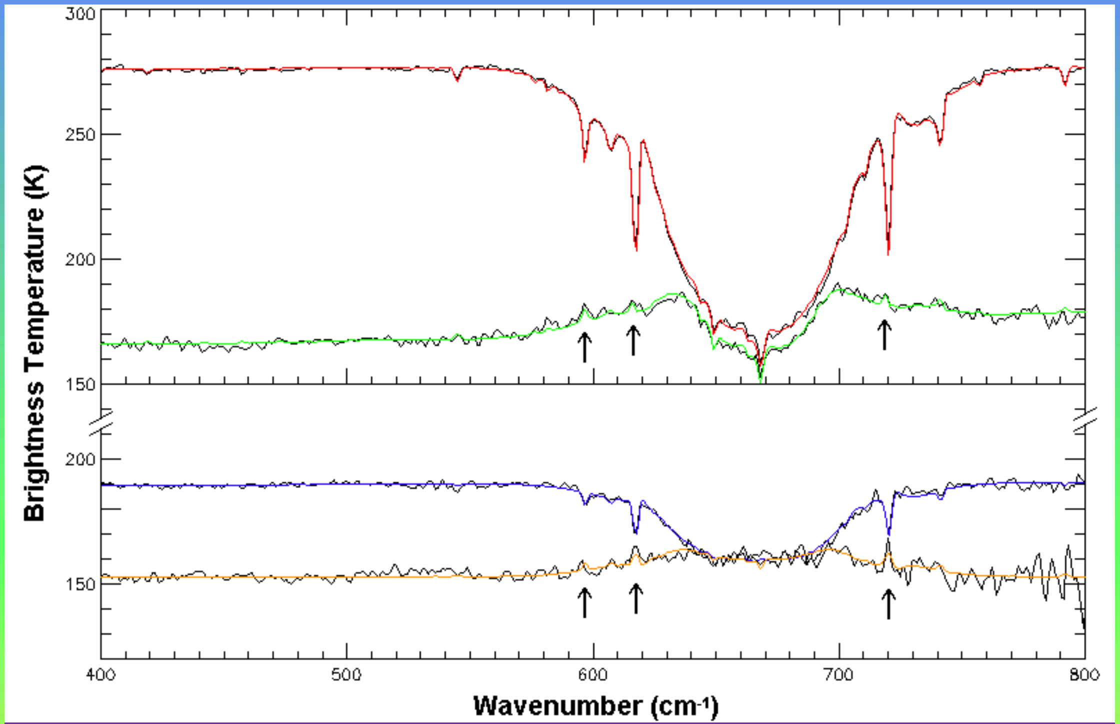
Vertical Temperature Profiles

The observed LWC radiance depends on several parameters of the atmosphere and surface of Mars, as described by radiative transfer theory:

- the surface temperature and emissivity
- the column density of dust and water ice
- the air temperatures as a function of altitude
- the surface pressure
- the column density of H_2O and CO.

Adopting the very general formalism of Bayesian analysis, an algorithm for the scientific analysis of individual calibrated PFS measurements has been developed, allowing the simultaneous retrieval of the above mentioned parameters.

Noteworthy, the high spectral resolution of PFS allows the detection of several different thermal gradients in the atmosphere, as demonstrated by the effective modeling in the same spectrum of absorbing and emitting Q-branches.



Typical quality of PFS spectra modeling for different thermal conditions of the atmosphere. *Black curves*: single spectra measured by PFS. *Colored curves*: synthetic spectra.

The Retrieval

Grassi et al. (2005) - PSS 53, 1017–1034

Vertical Temperature Profiles

Information on vertical temperature profiles in Martian atmosphere can be retrieved from measurements of the thermal radiation emitted by the planet in the spectral range corresponding to the main absorption band of CO_2 which is centered at 667 cm^{-1} (15μm).

The contributions of the radiation emitted / absorbed by CO_2 to the total radiance at a given wavenumber is maximum for the atmospheric levels where unity optical thickness is achieved.

In this way a relation (**weighting function**) between the temperature at a given height in the atmosphere and a given wave number is established, which is the basis for retrieving a temperature profile.

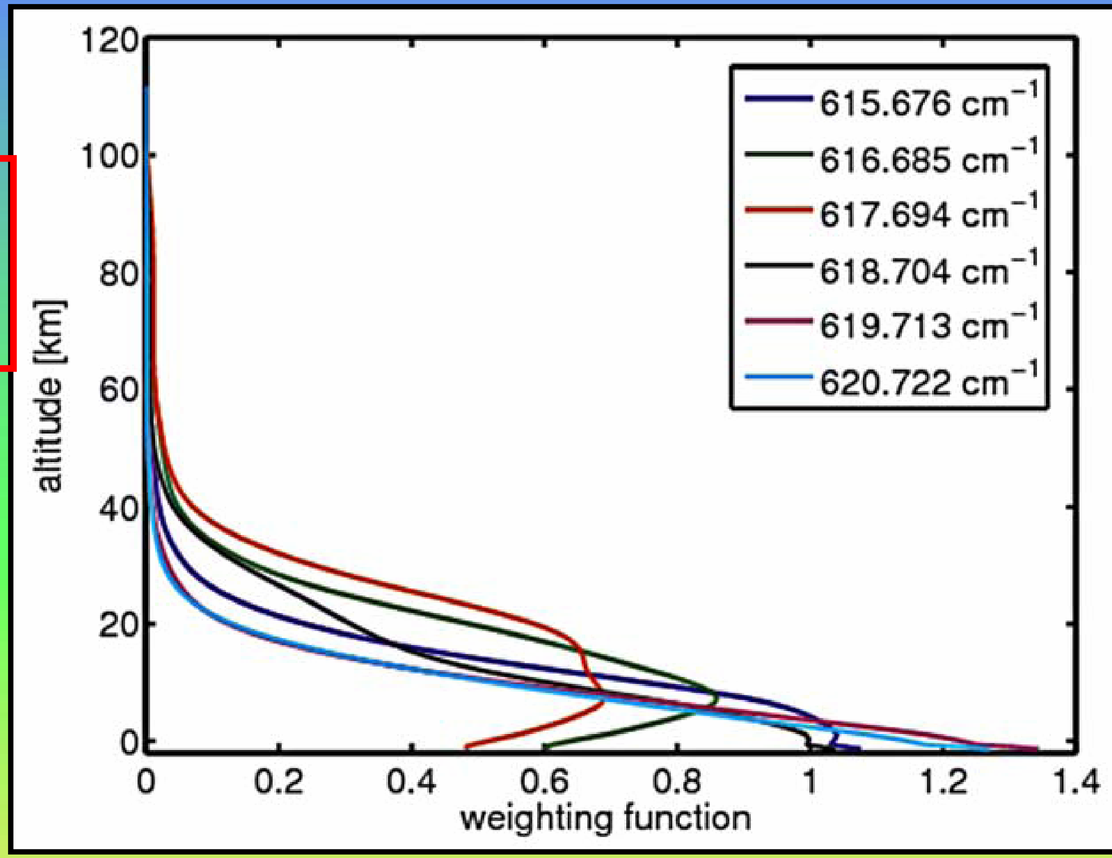
The temperature of high atmospheric layers can be associated with the center of the CO_2 absorption band.

Gradually approaching the wings of this band, the wave numbers will correspond to temperatures of lower atmospheric layers.

When close to the surface, the maximum values of weighting functions pertaining to different wavelengths occur at the same pressure level.

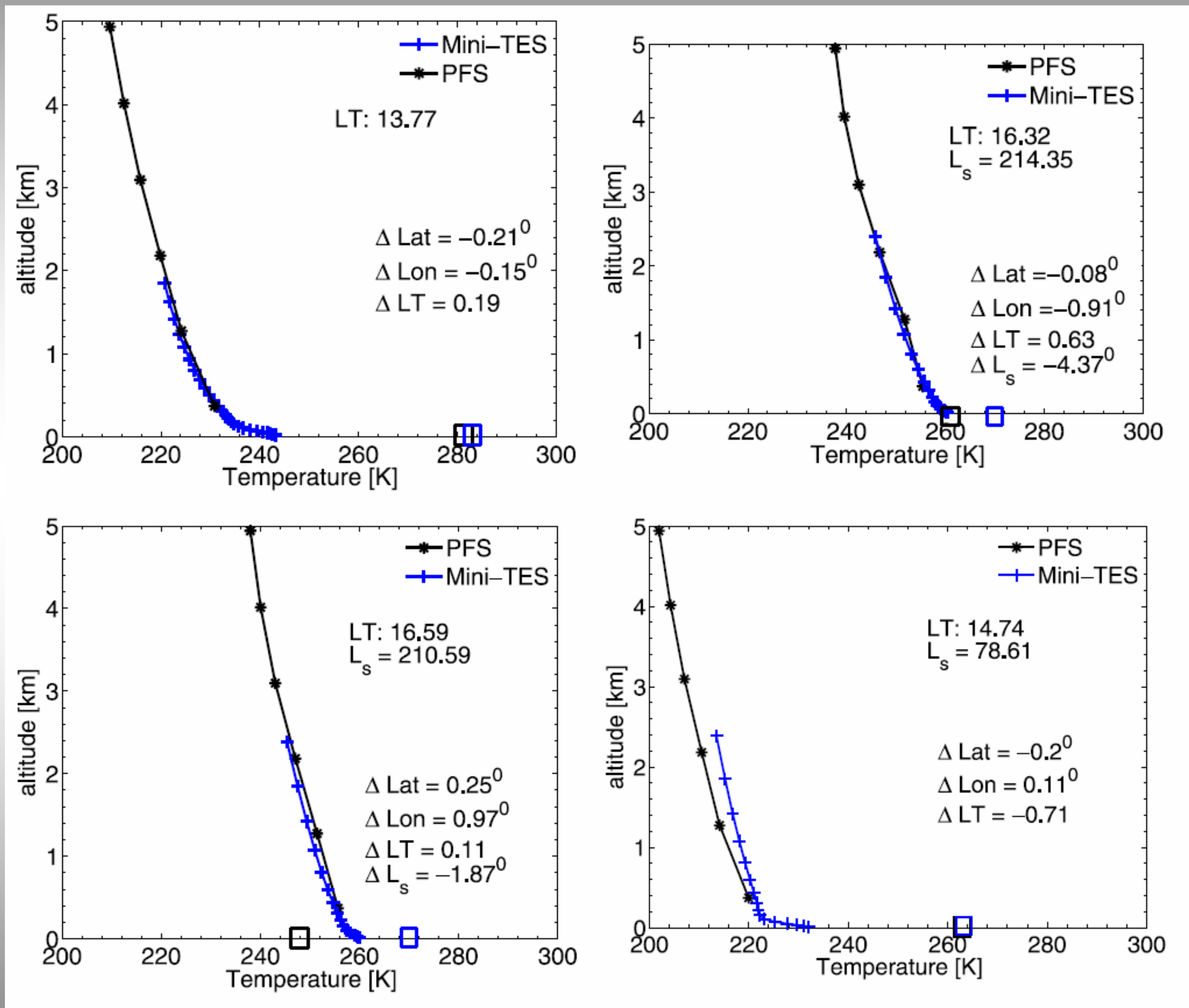
This implies that the radiances measured in the wings of the CO_2 band, which convey information about the atmospheric temperature in layers adjacent to the surface, do not allow us to unequivocally retrieve the temperature. In other words, for the atmospheric layers close to the soil, the temperature becomes less certain.

Remarkable difficulties are encountered in the definition of the temperature profile in the lowest parts of the atmosphere (< 5 km) due to the lack of well-defined weighting functions peaking at these lowest levels.



Basic Concepts

Simultaneous observations of the Martian atmosphere by PFS/MEX and Mini-TES/MER (P. Wolkenberg et al., 2009, JGR 114)



Purpose:

Confirm validity of PFS temperature profiles below 5 km by comparing them with the Mini-TES retrievals.

Method:

Temperature profiles retrieved from PFS and Mini-TES were selected according to strict criteria.

Results:

- Retrieval of temperature profiles below 5 km obtained from downward-looking measurements by PFS is largely consistent with upward-looking temp. retrievals from Mini-TES given the different vertical resolutions of the two instruments and their combined uncertainties.
- Temperatures at 370 m were in most cases identical from PFS and from Mini-TES.

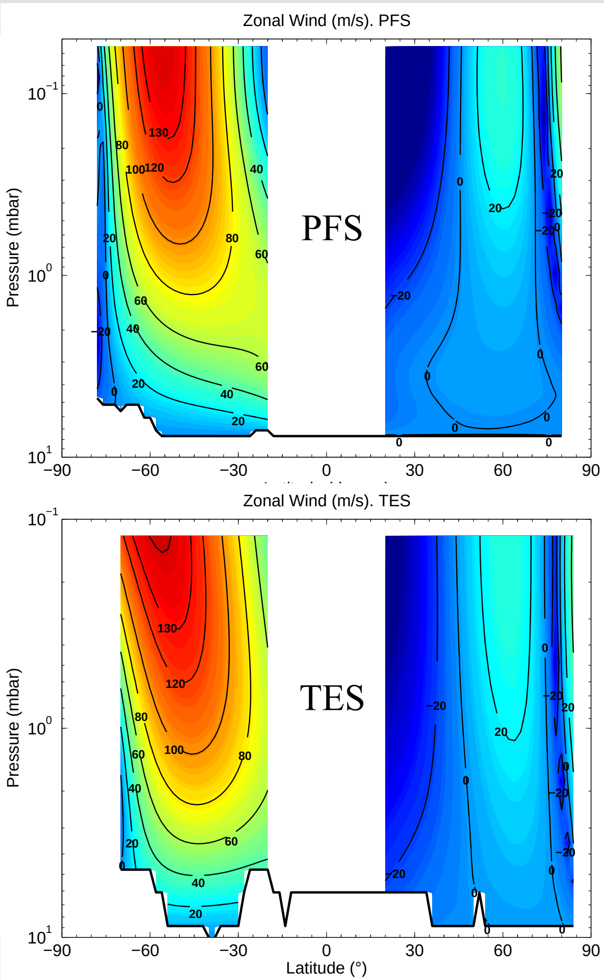
We have the Temperature profiles…

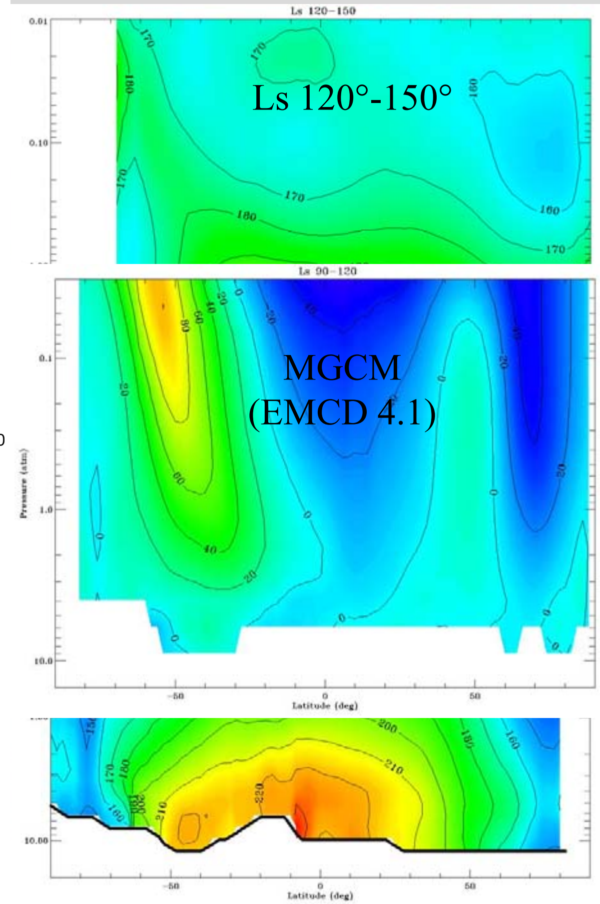
- **Global scale**
  (e.g., global circulation, weather and climate, dust storms…)

- **Regional scale**
  (e.g., polar regions, planetary waves, dust storms…)

- **Local scale**
  (e.g., Olympus Mons, Valles Marineris, dust storms…)

Seasonal evolution of mean Meridional Temperature cross-section and Zonal Wind derived from PFS-MEX (M. Giuranna et al., in preparation)





Temperature fields:

Confirmation of hemispherical symmetry (asymmetry) during equinoxes (solstices).

Hadley Circulation:

Evidences for meridional circulation (Hadely cells).

Confirmation of two Hadley Cells during equinoxes.

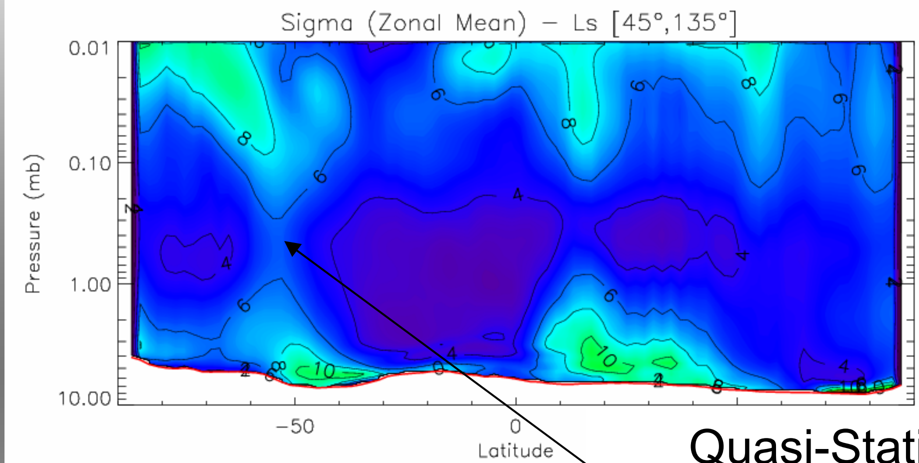
Zonal Winds (geostrophic approx):

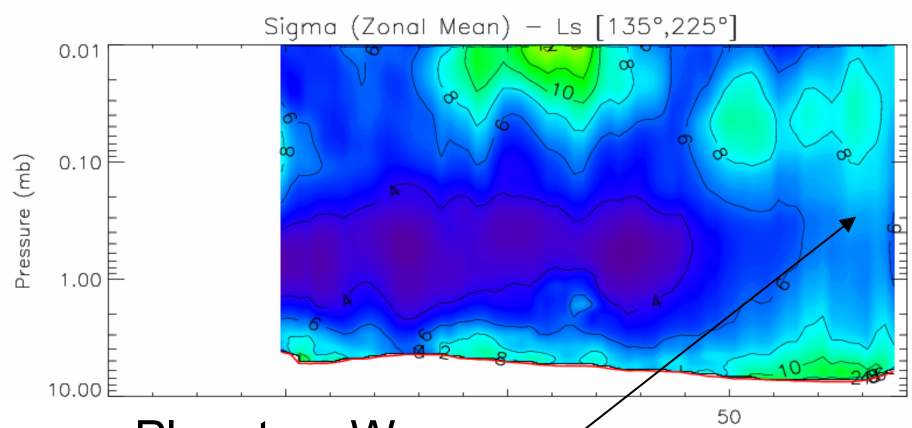
Comparison with TES: very good agreement .

Comparison with models: good agreement for fields structure, less for numerical values.

Seasonal evolution of mean Meridional Temperature cross-section and Zonal Wind derived from PFS-MEX (M. Giuranna et al., in preparation)

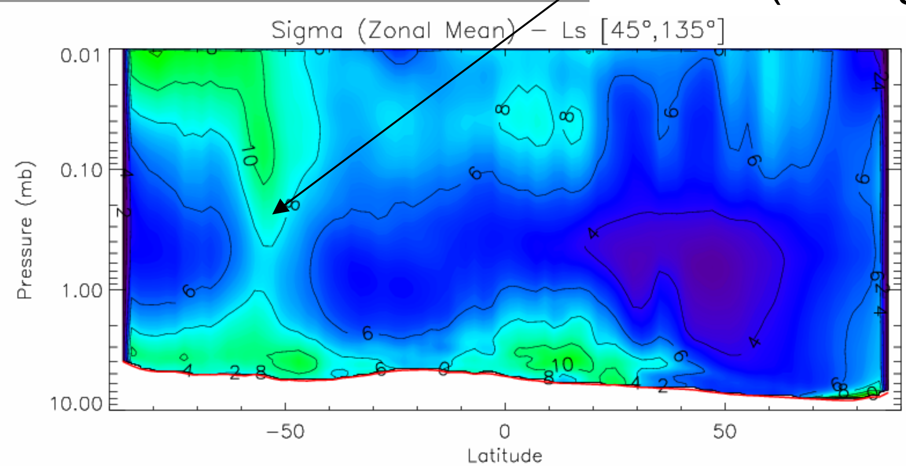
South Winter | **Morning** | **South Spring**

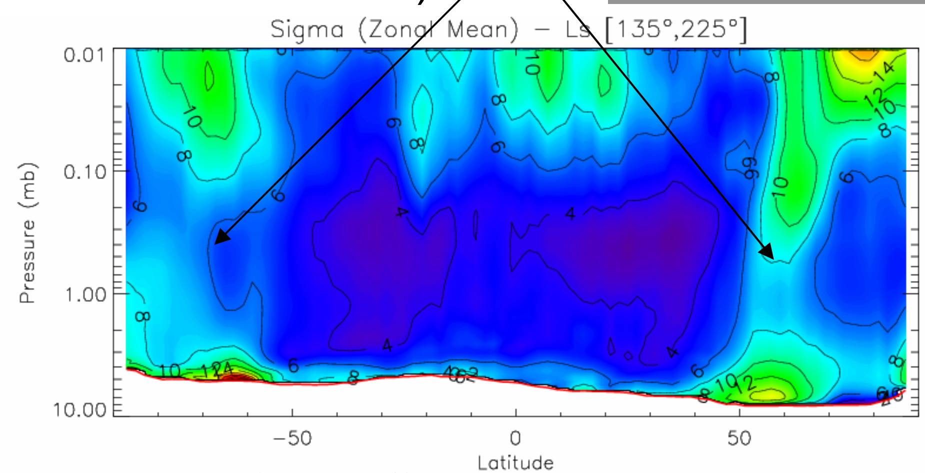




Quasi-Stationary Planetary Waves

(Strongest in the afternoon)





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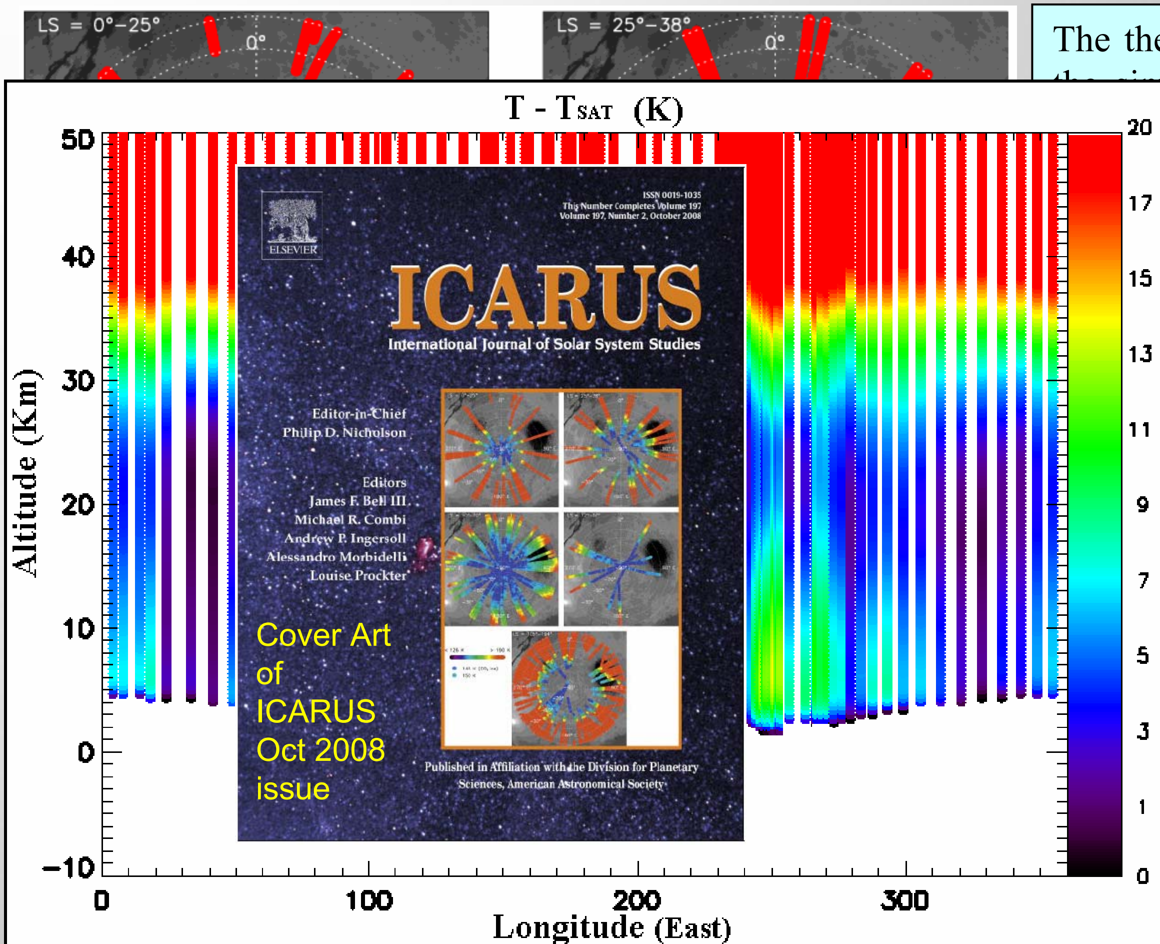
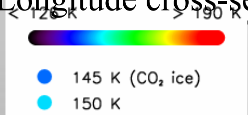
PFS/MEX observations of the condensing CO_2 south polar cap of Mars

(M. Giuranna et al., 2008, Icarus 197, 386–402)



Longitude cross-section at −85° latitude showing $T - T_{SAT}$ as a function of altitude.



The therm… the simul… th… p… ar…

By comparing the measured vertical temperature profiles with the CO_2 condensation temperature at different altitudes we can establish if, where and at which altitudes CO_2 snow falls may be allowed.

… basis of the surface temperatures, we can … t… s… n…

If the atmospheric temperatures are always above the CO_2 condensation temperature in the whole column, the snowfall hypothesis can be undoubtedly rejected.

…fte… **…etry** observed for the residual cap **has** … u…

In **early-fall**, **the CO_2 condensation in the atmosphere is not allowed**, the atmospheric temperature being always several degrees above the CO_2 condensation temperature at any altitude.

…r … be… …tures. In both cases these temperatures are … fo… the atmos…

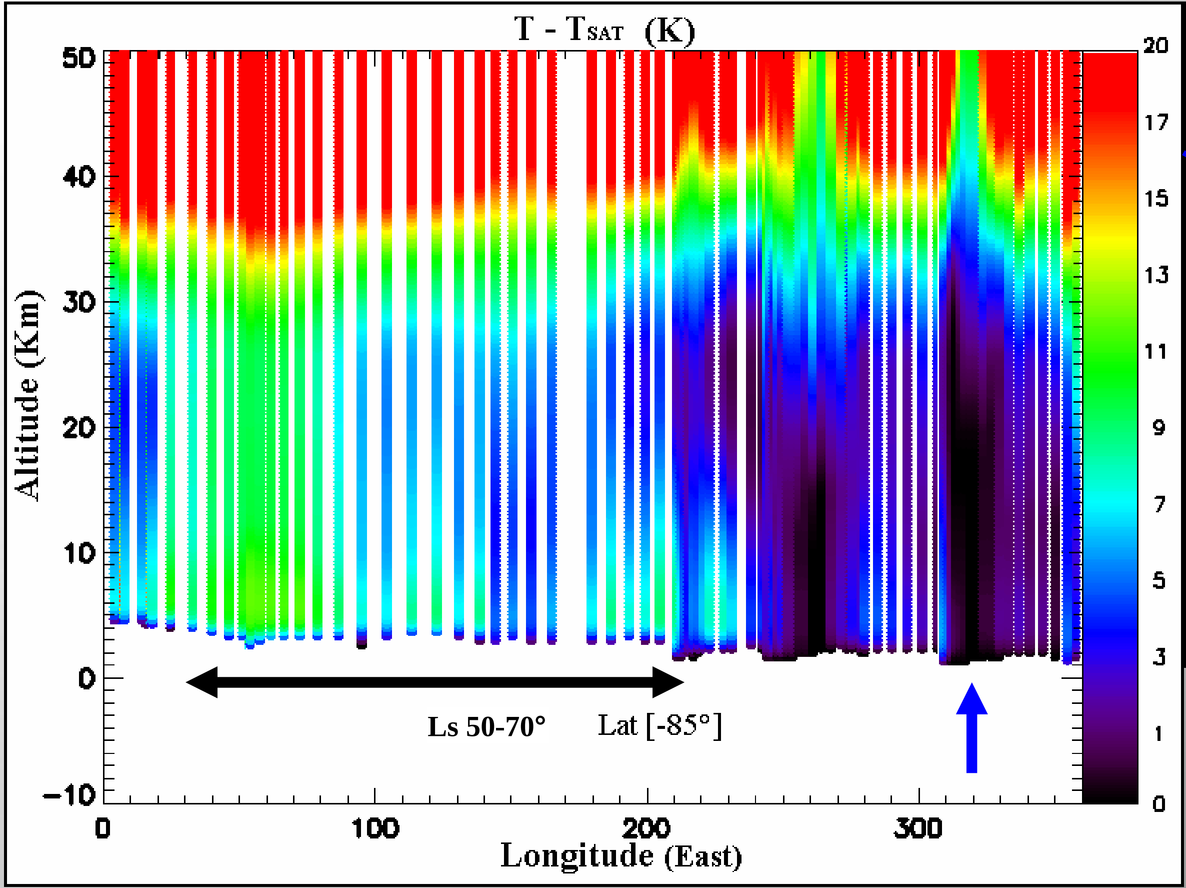
The early-fall south polar cap essentially consists of CO_2 **frost** deposits (direct vapor deposition).

The **vert…** … straightforwardly **answer the question**.

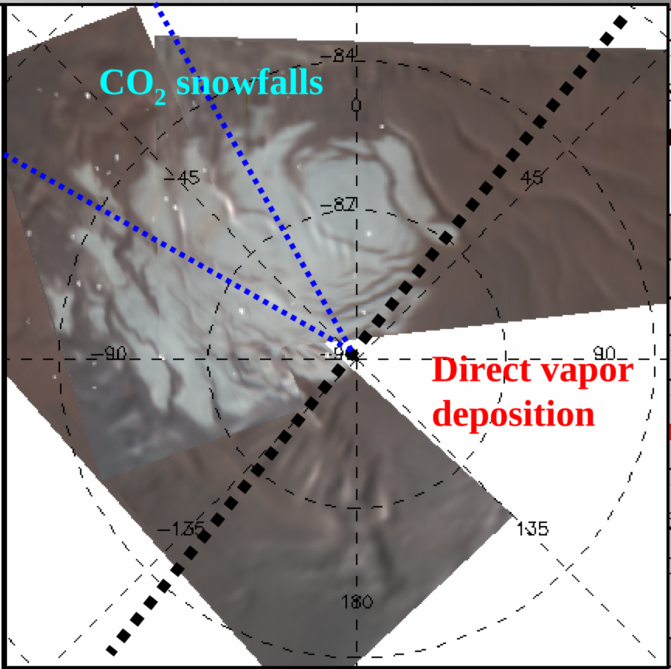
PFS/MEX observations of the condensing CO_2 south polar cap of Mars

(M. Giuranna et al., 2008, Icarus 197, 386–402)

These two distinct regional climates are the main responsible for the residual south polar cap asymmetry.



Longitude cross-section at –85° latitude showing $T – T_{SAT}$ as a function of altitude.



In the western hemisphere, atmospheric condensation is allowed in the entire 0-30 km column; surface ice accumulation is dominated by precipitation.

PFS/MEX observations of the condensing CO_2 south polar cap of Mars

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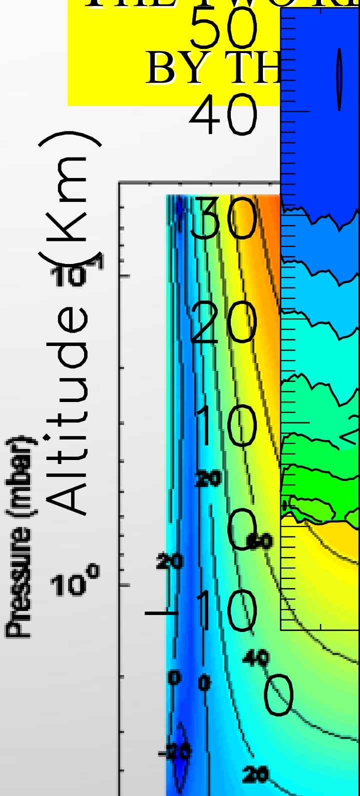

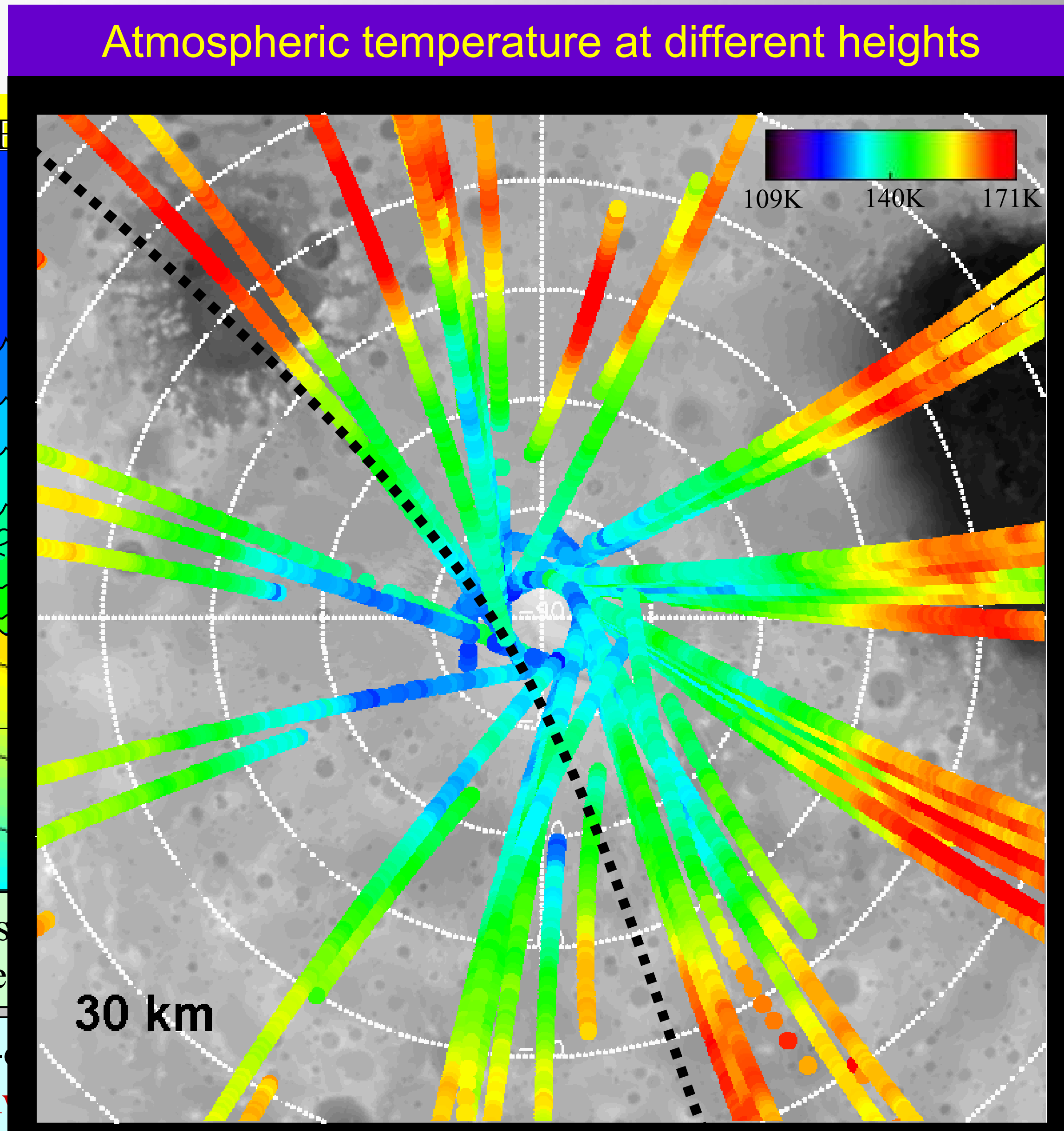

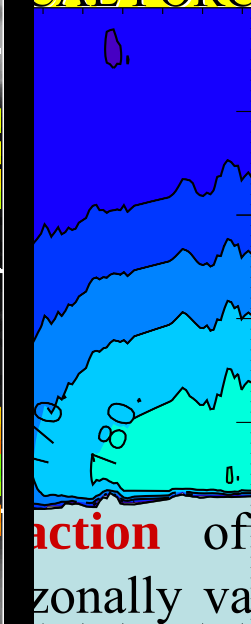

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…zonally varying
…y **excites**
… waves, which
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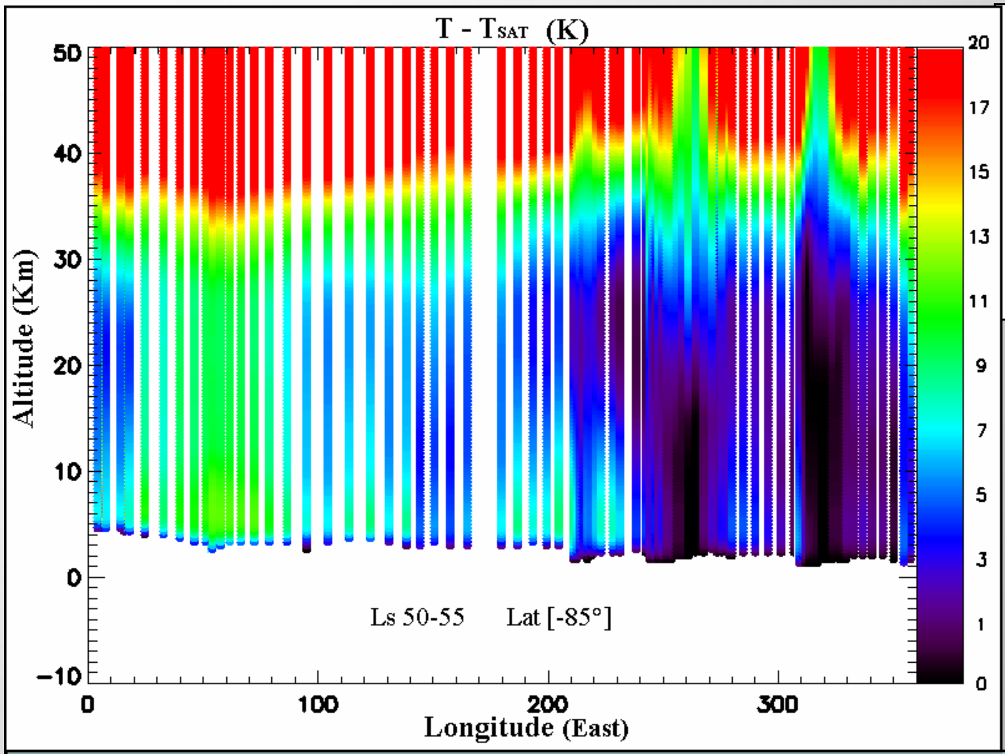
The wave achieves … …here the phase is
about 40°E. Hence … …st edge of Hellas.

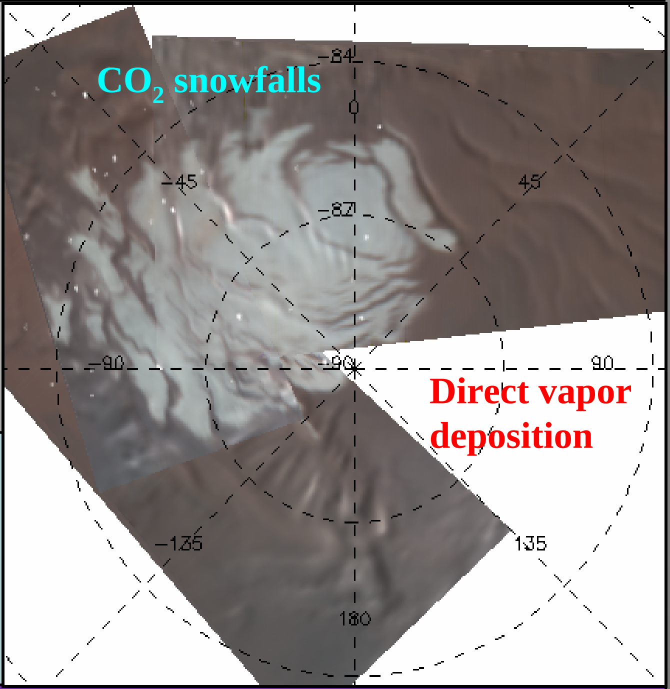
The wavenumber-… …sulting in adiabatic
cooling, and down… …ng.

PFS/MEX observations of the condensing CO_2 south polar cap of Mars

(M. Giuranna et al., 2008, Icarus 197, 386–402)



The wavenumber-one planetary wave establishes a high-pressure zone over much of the eastern hemisphere, preventing CO_2 condensation in the atmosphere during the Fall season.



Different **amounts of CO_2 ice deposited** in the two hemispheres; different **sublimation rates** due to different grain sizes between CO_2 (fresh) snow and frost; different amount of **heat stored in the subsurface**:

The dry ice sublimes entirely in the eastern hemisphere, while in the western hemisphere it survives all year long as the RSPC.

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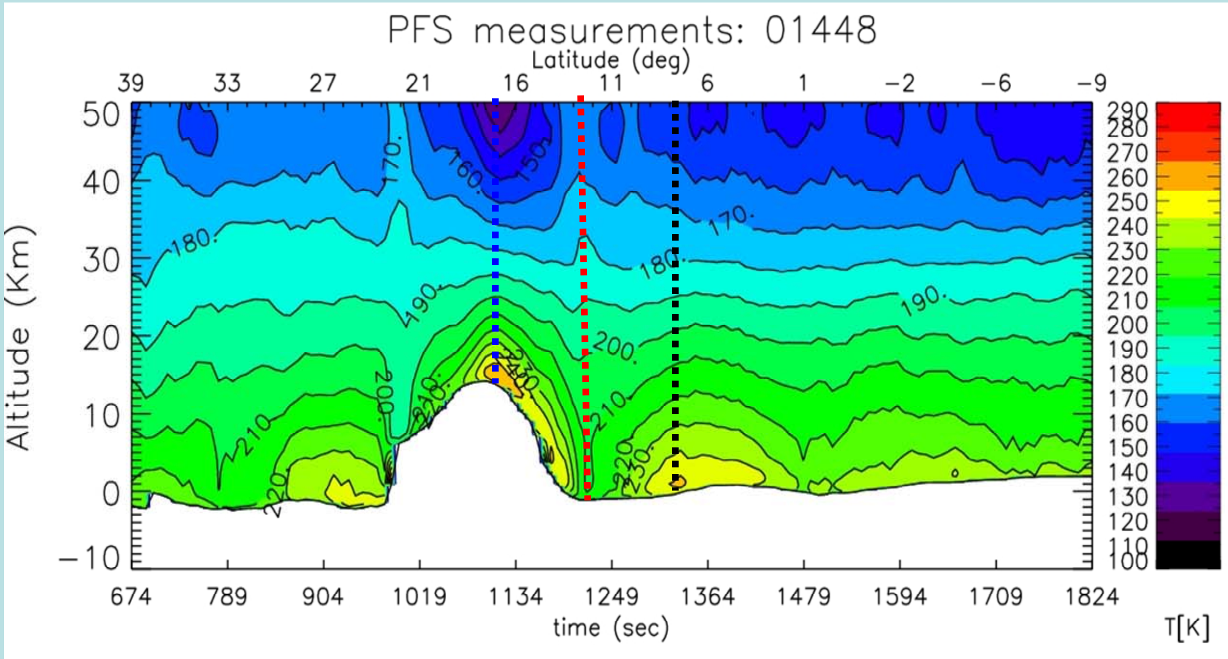
The atmospheric temperatures over Olympus Mons on Mars: An atmospheric hot ring (P. Wolkenberg et al., 2010, Icarus, in press)



Striking features:

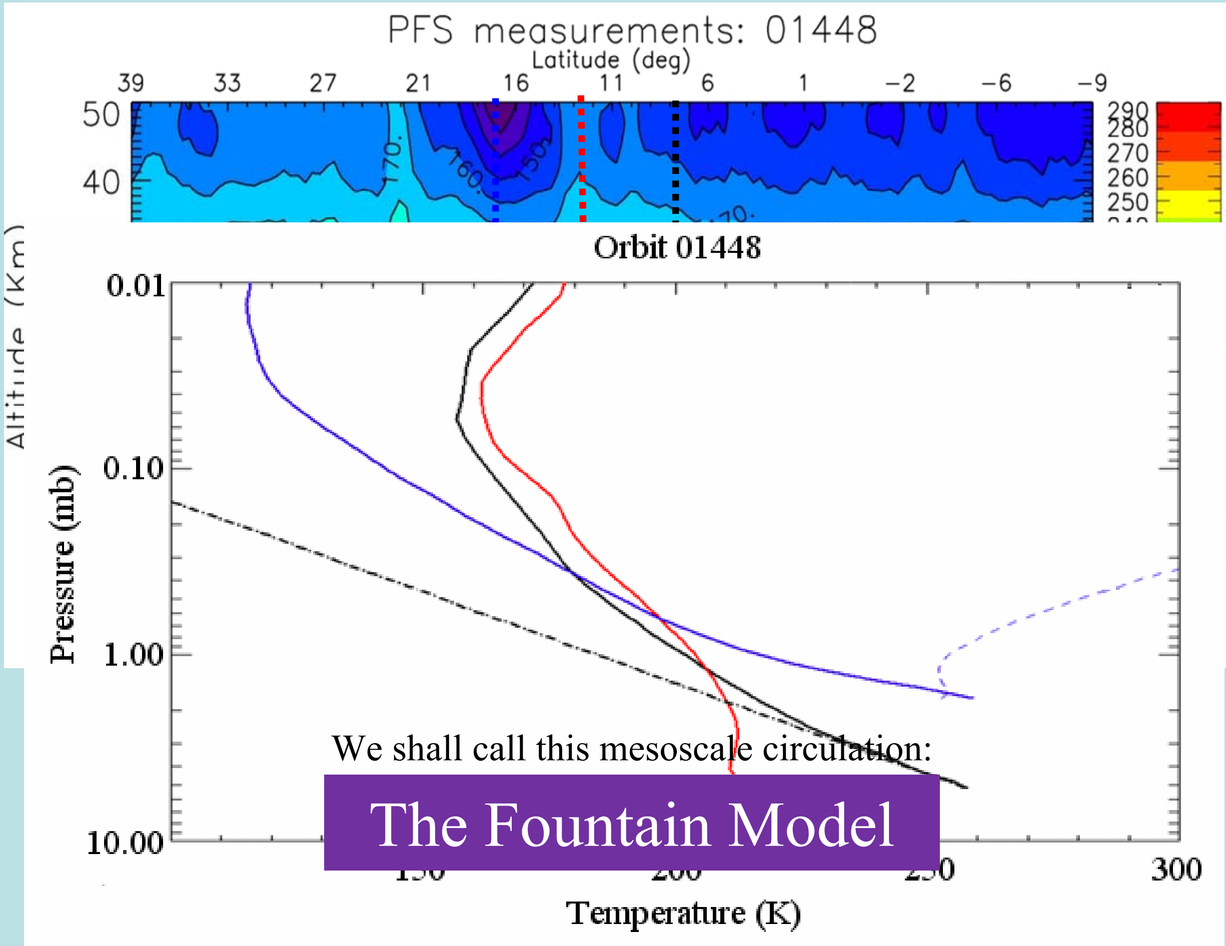
There are three striking features characterizing the volcanic region:

- **two warm regions** (north and south of the volcano at 8° N and 26° N, i.e. respectively at 10° and 8° latitudinal distance, which we shall call thermal bumps or hot ring);
- **two cold regions** almost vertically isothermal (temperature at 40 km 10 K higher than surrounding)
- **one region on top the volcano** with a high temperature just above it, decreasing quicker with altitude, where the coldest temperature of the entire region is also observed.

The surface temperature shows no special feature.

To understand the meaning of the three features mentioned above, we now study some single atmospheric temperature profile.

The atmospheric temperatures over Olympus Mons on Mars: An atmospheric hot ring (P. Wolkenberg et al., 2010, Icarus, in press)



Interpretation:

The hot spot on top of the volcano acts as the motor for a mesoscale circulation.

Solar heating: the local air parcels reach a temperature so high that they become unstable and move upward, with strong adiabatic expansion.

A cold collar is generated at the foot of the volcano: air parcels are sucked upward , and adiabatically cooled.

At some level the air parcels are pushed side ways resulting in a quasi isothermal vertical profile.

Finally, the air parcels fall downward and are compressed adiabatically. They follow the adiabatic lapse rate and form a "**hot ring**" around Olympus Mons.

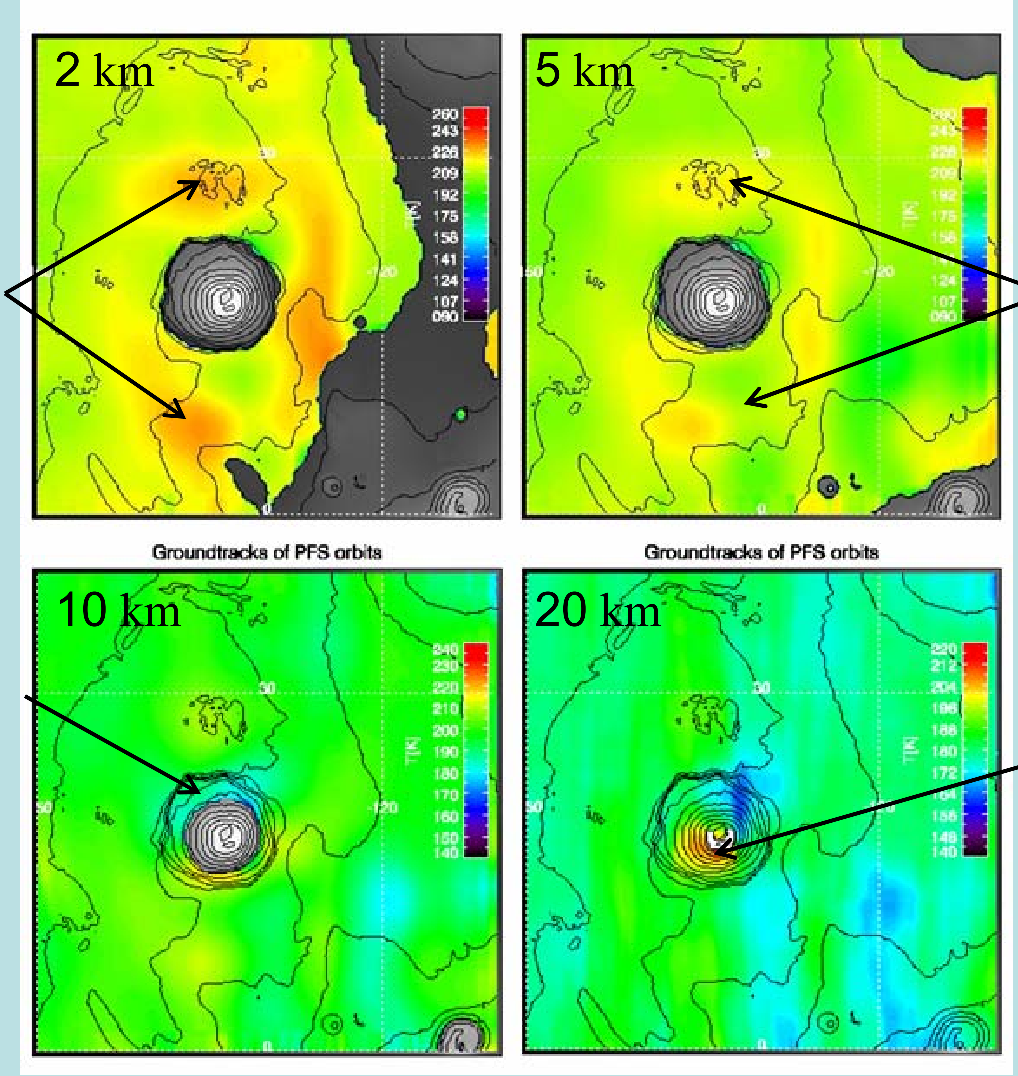
from the previous figure.

The atmospheric temperatures over Olympus Mons on Mars: An atmospheric hot ring (P. Wolkenberg et al., 2010, Icarus, in press)

The "Hot Ring"

The "Hot Ring"

The "Cold Collar"



The "Hot Spot"
(motor of the
mesoscale circulation)

We have the Temperature profiles…

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- **Local scale**
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Fog phenomena on Mars

(D. T. F. Möhlmann et al., 2009, PSS 57)

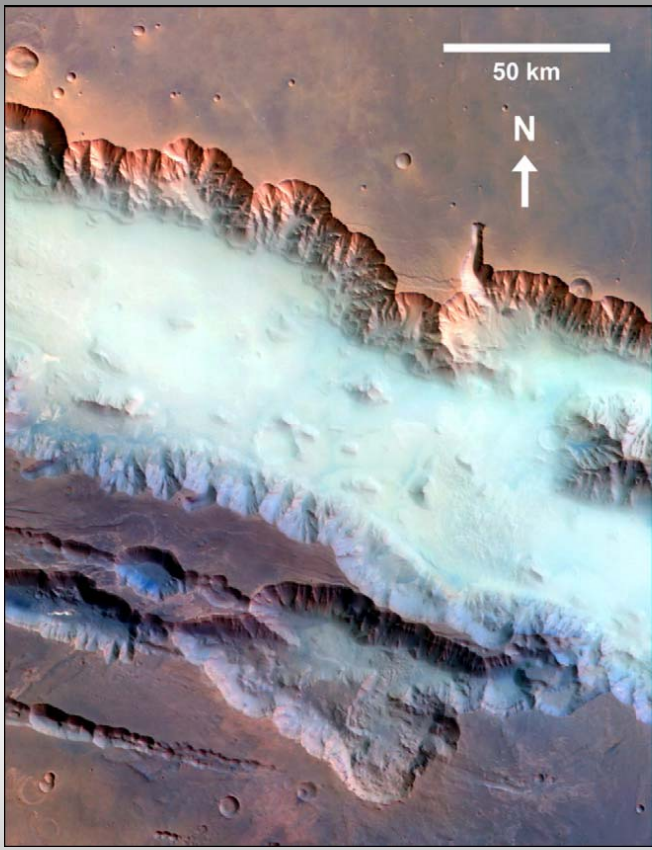


Fig. 1. Morning fog in Valles Marineris at LS = 38°.

The image center is at 14.17°S latitude, 302°E longitude. Local time is 9:20a.m.(May25,2004, orbit438).

Colors are calibrated to improve the visibility of fog. This false color image enhances the visibility of fog phenomena in the valley.

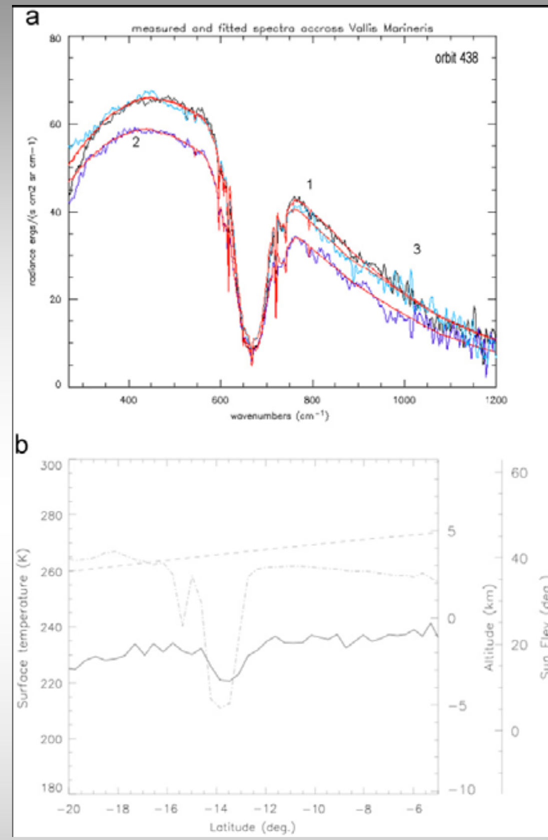


Fig. 2. (a) PFS measured spectra inside (2), on the edge of (3) and outside (1) Valles Marineris. Spectrum 2 shows lower temperatures and the water ice band at 750–900 cm^{-1}.

(b) Surface temperature (solid), height profile (dash-dot) and sun elevation (dashed) across Valles Marineris, measured by PFS for the same part of MEX-orbit 438 as in Fig. 1.

HRSC images show impressive morning fog features inside Valles Marineris and other regions of the surface of Mars.

Temperatures have been determined simultaneously to the imaging by PFS. This identifies water ice rather than frozen CO_2 as the cause of the fog observations.

Numerical estimates of the water vapor pressure and atmospheric water content at the frost-point by a 1-dimensional planetary boundary layer model indicate that conditions in the planetary boundary layer can indeed temporarily favor the formation of ice particles.

The fog phenomena seem to be induced or supported by orographic effects but not directly by the distribution pattern of the atmospheric vapor or by the regional subsurface water content.

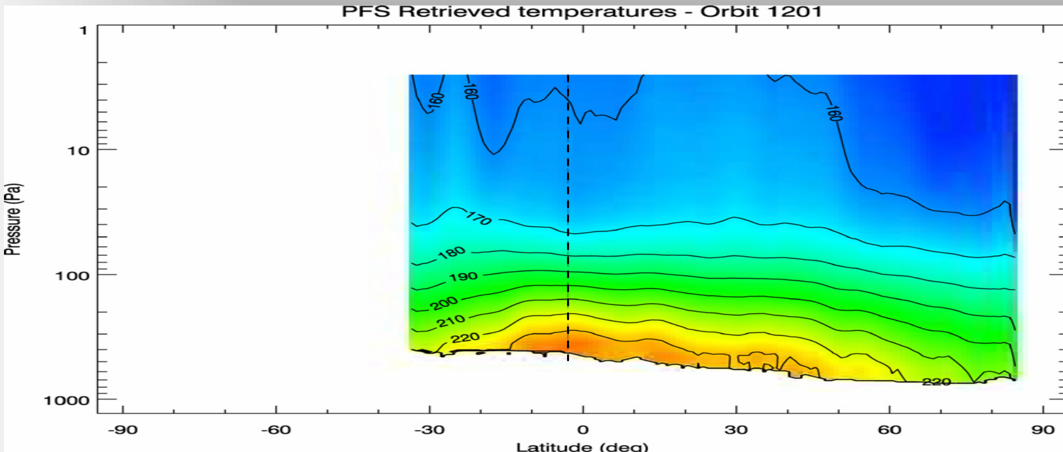
OK, Great!
We have the Temperature profiles…
…Please!…One more!

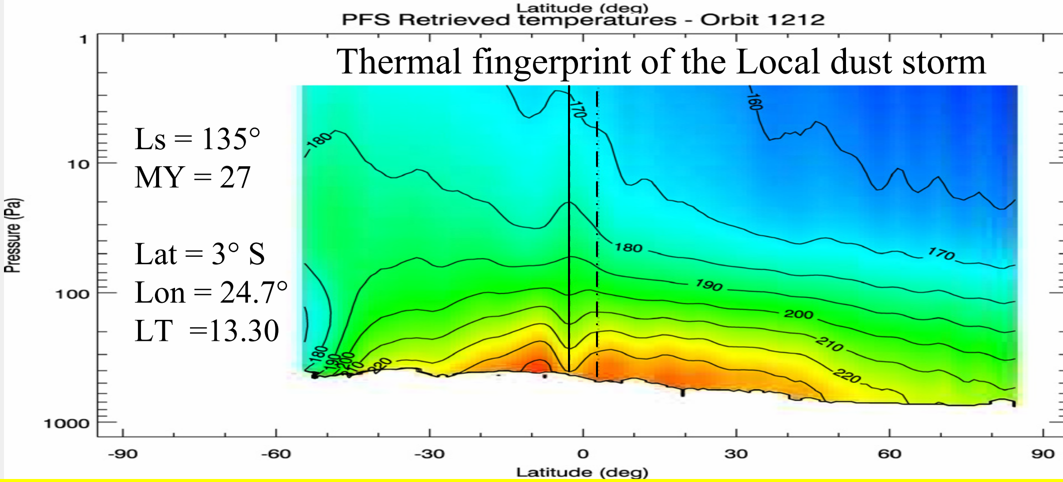
- **Global scale**
  (e.g., global circulation, weather and climate, dust storms…)

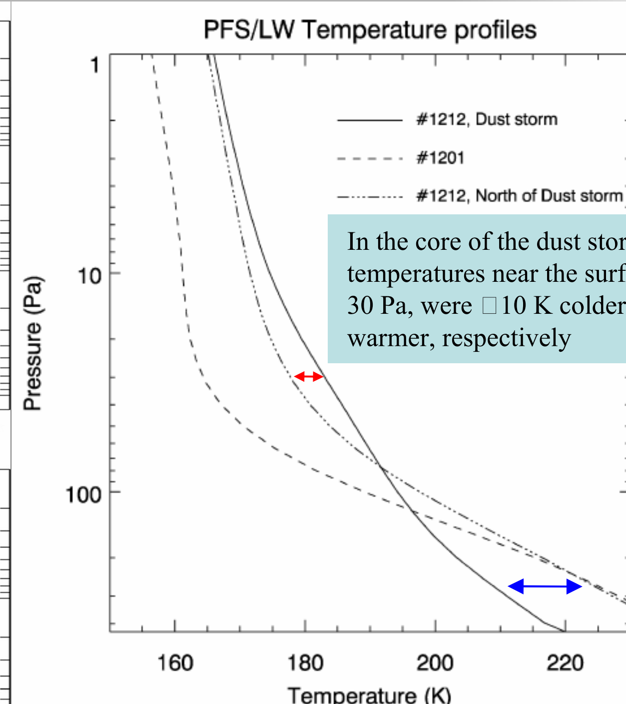
- **Regional scale**
  (e.g., polar regions, planetary waves, dust storms…)

- **Local scale**
  (e.g., Olympus Mons, Valles Marineris, dust storms…)

A study of the properties of a local dust storm with MeX OMEGA and PFS data (Määttänen et al ., 2009, Icarus 201, 504–516)







In the core of the dust storm, the temperatures near the surface and at 30 Pa, were □10 K colder and □5 K warmer, respectively

Net cooling close to the surface and net heating in the upper atmosphere, as expected from theoretical considerations (Gierasch and Goody, 1972).

Atmospheric dust tends to homogenize the vertical temperature profile.

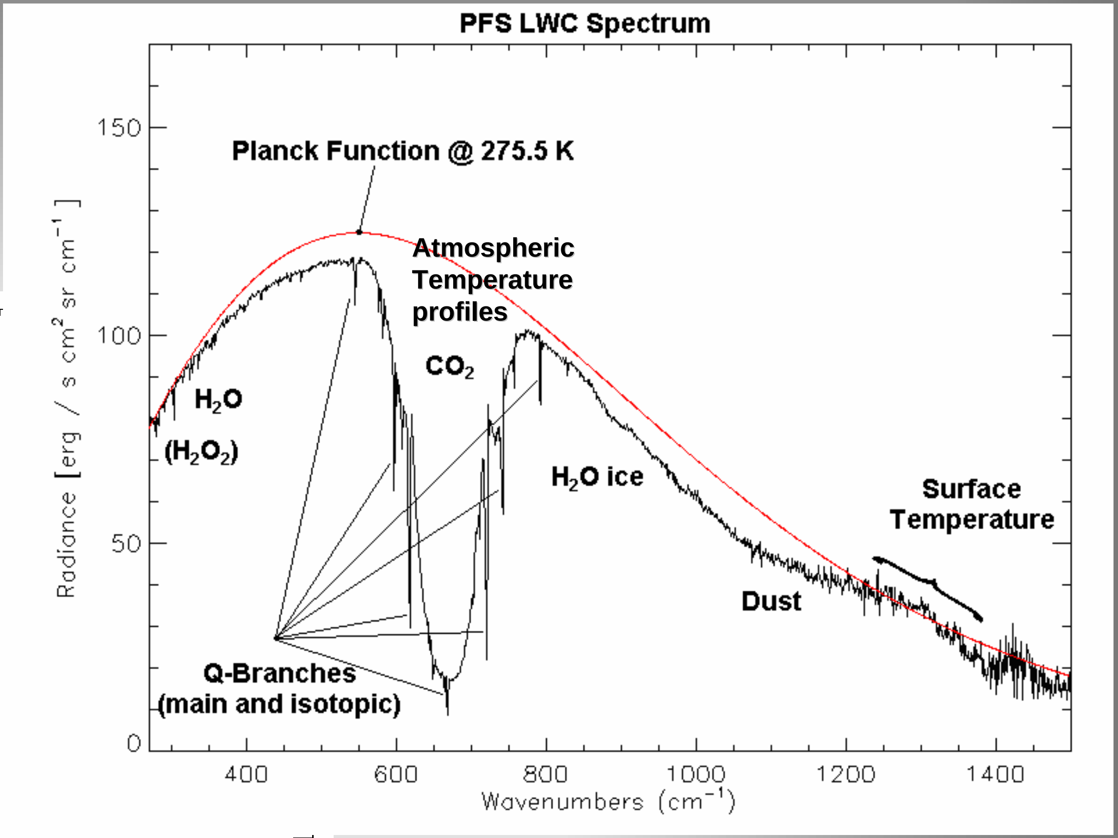
We observe the same trend in our temperature profiles, but with a weaker amplitude than for the regional or global dust storms previously studied.

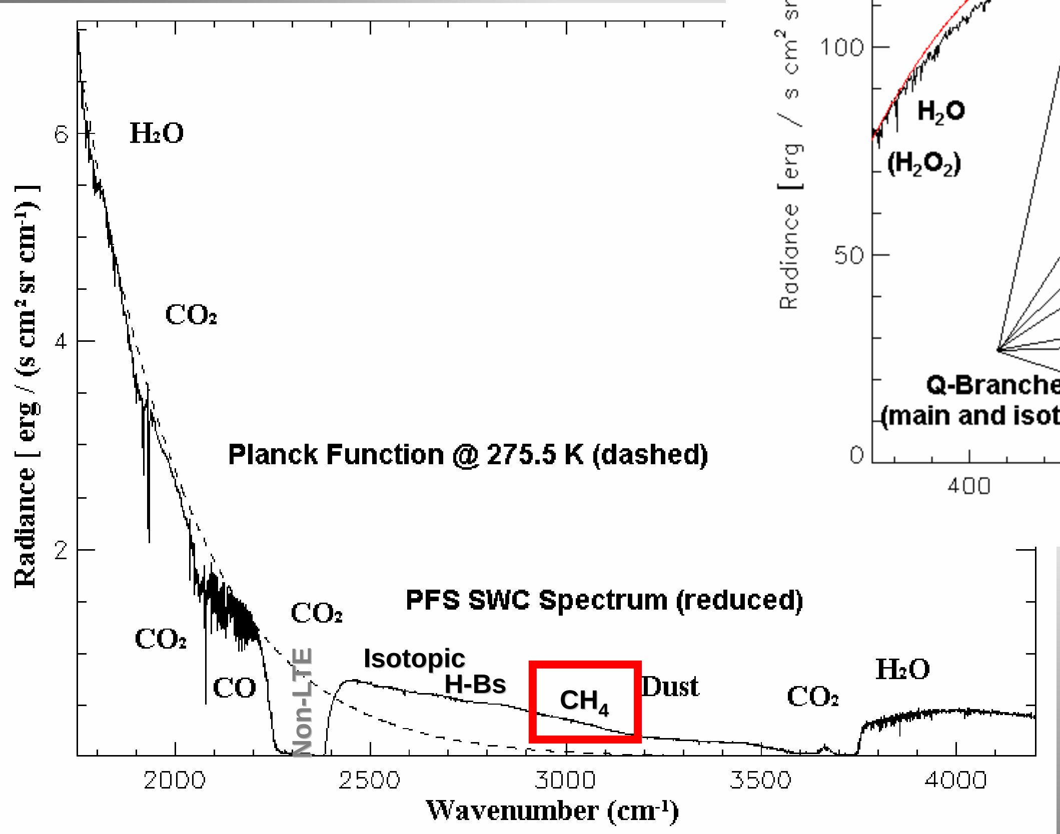
End of Part One

(Temperature Profiles)

…next: Minor Species

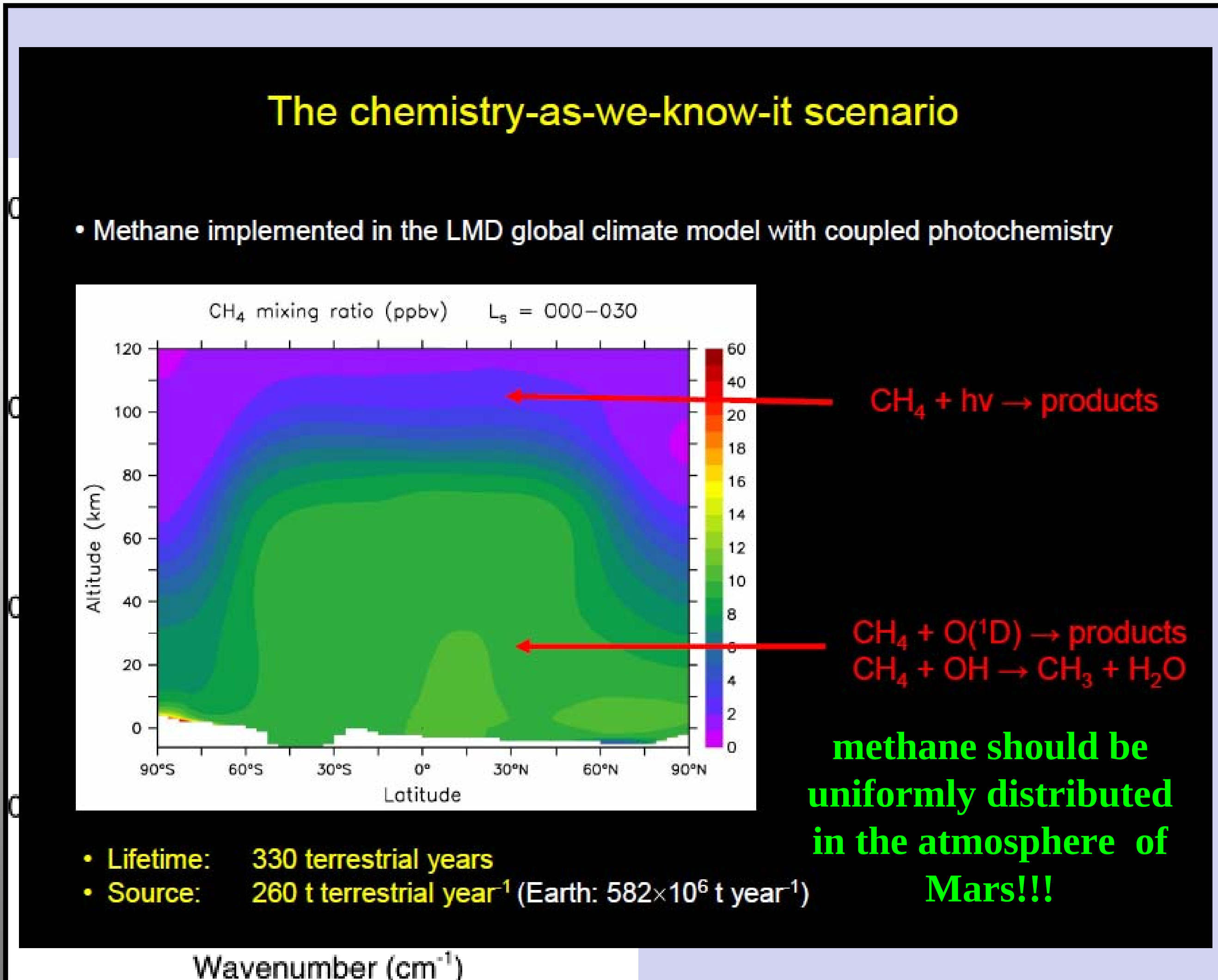
Minor Species in Martian Atmosphere with PFS



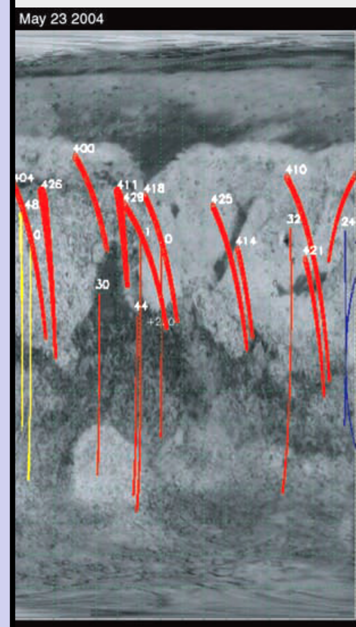


Detection of Methane in the Atmosphere of Mars

(V. Formisano, S. Atreya, T. Encrenaz, N. Igniatiev, M. Giuranna, 2004, **Science**, Vol. 306, 1758-1761)



io of 10 ± 5 ppbv.
re also observed.



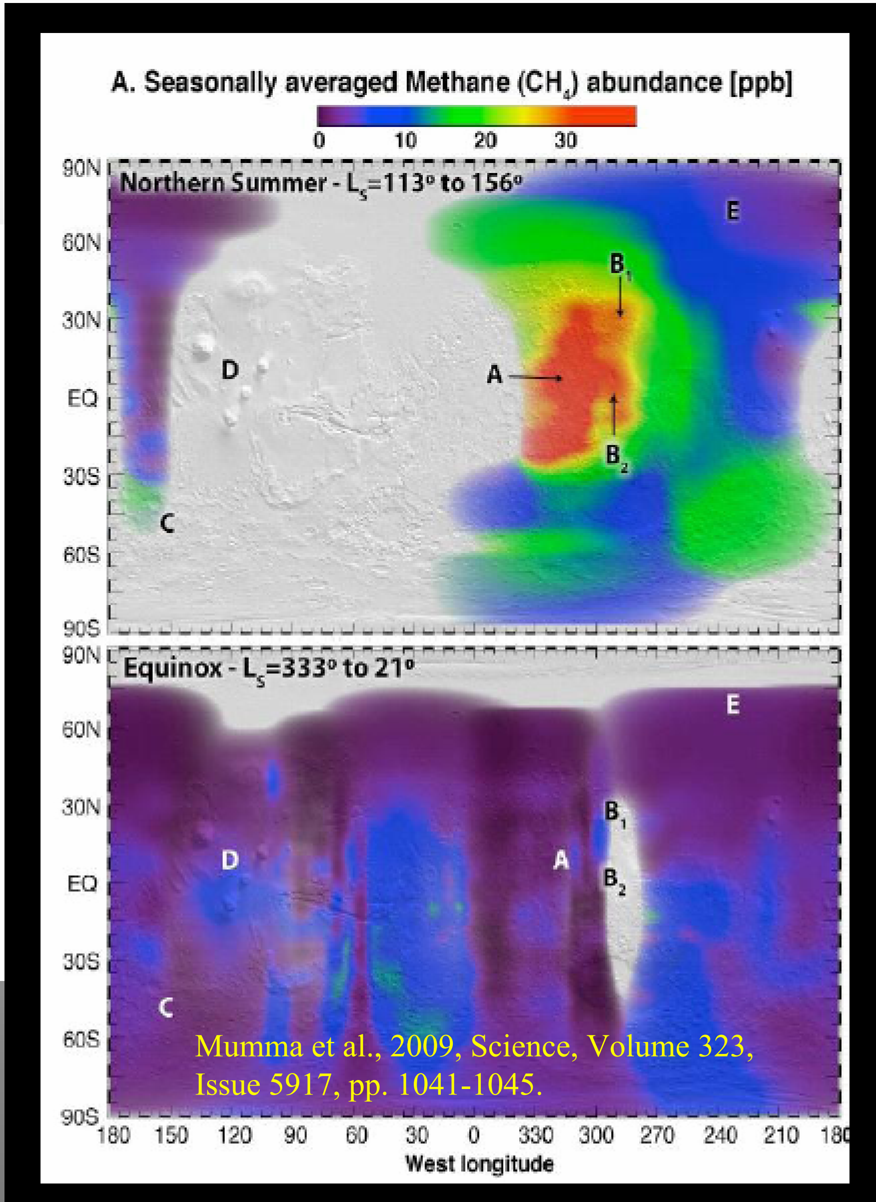
± 1σ uncertainty
ibution: **red** (high
ratio, ~15 ppbv),

Methane inMartian atmosphere:

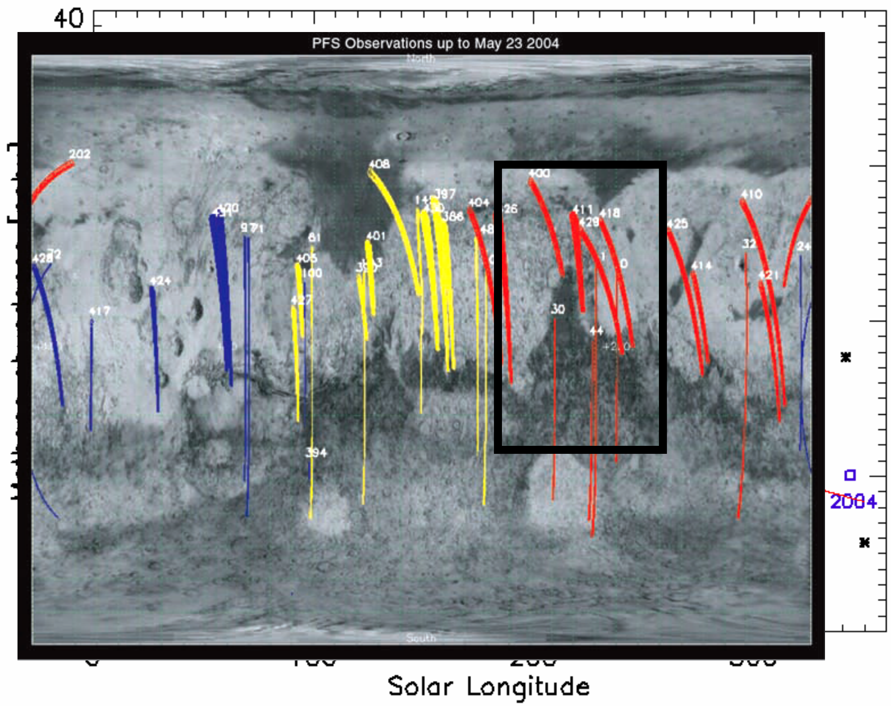
al and seasonal behaviour

3, PSS, Vol. 56, 1194-1203)

emporal distribution of methane (MY27-28)



Mumma et al., 2009, Science, Volume 323, Issue 5917, pp. 1041-1045.



variations. In particular, the decrease of methane

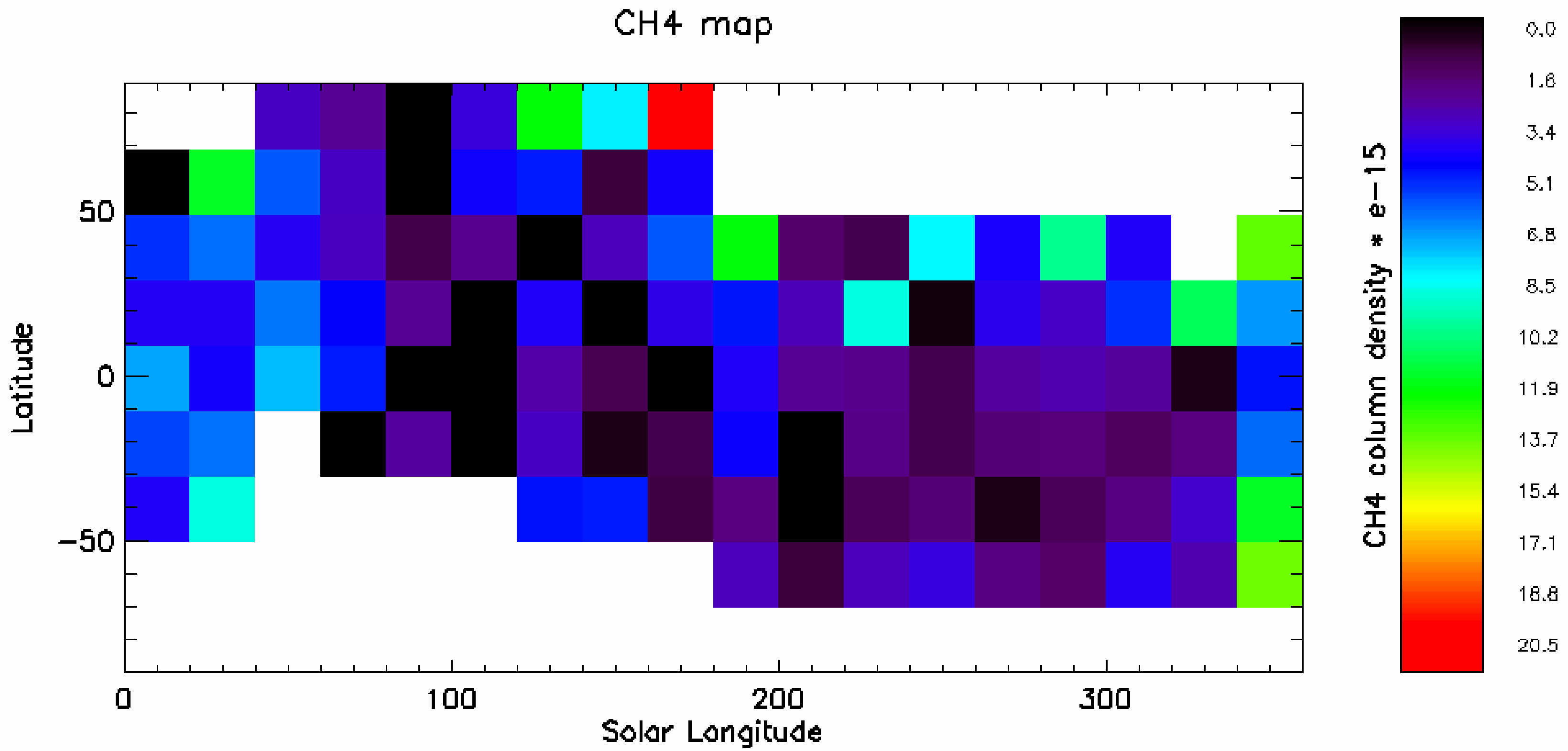
winter indicates a **lifetime of CH_4 lower than**

ng **sources and/or sinks**.

Mapping methane in Martian atmosphere with PFS-MEX data.

(Geminale et al., 2010, PSS, submitted)

20° x 20° map – Latitude vs Solar Longitude (season)



High methane abundances in the northern polar region at the end of Summer.

NOT due to global circulation and/or CO_2 condensation.

Possible source in the perennial ice? (e.g., clathrate hydrates [E. Chassefiere])

Issues

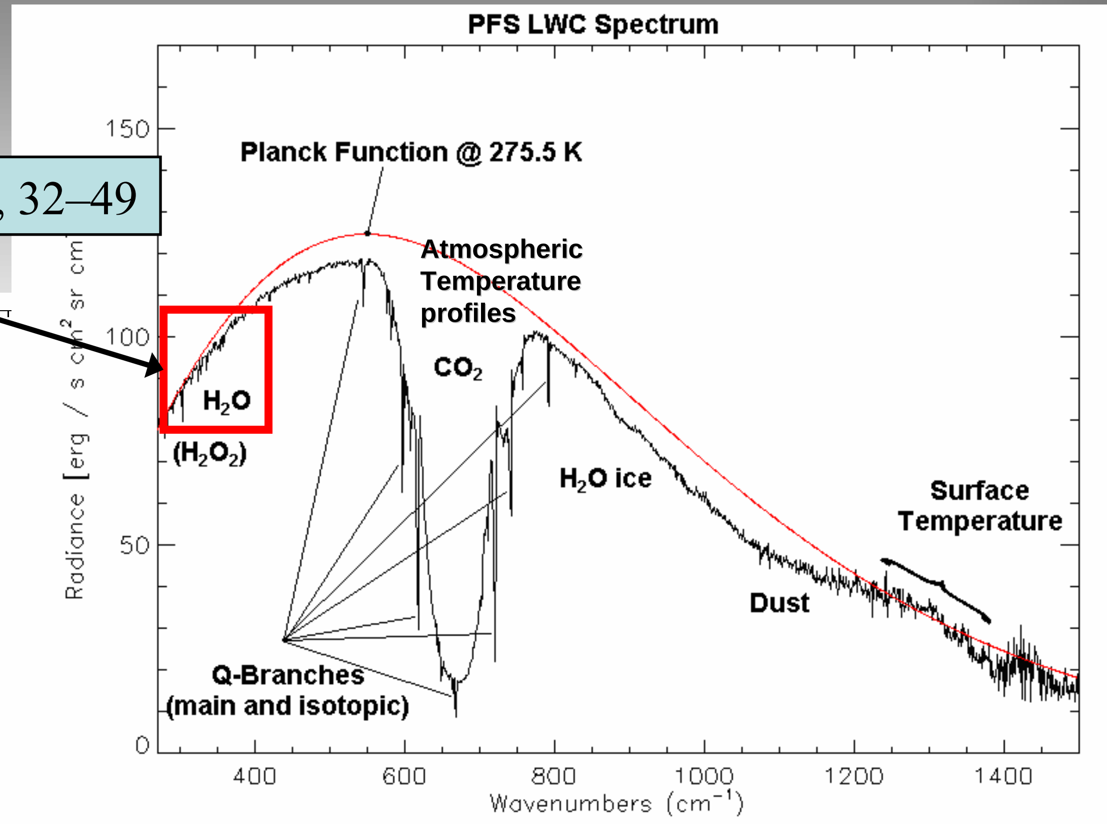
- The "conventional" atmospheric chemistry does not produce measurable methane variations on Mars, even in the case of a current, episodic, and localized source.
- The condensation/sublimation cycle of CO_2 should generate large-scale methane variations at high latitudes (*but they differ from what is observed).*
- CSHELL/NIRSPEC: In the most favorable case, an atmospheric CH_4 lifetime of less than 200 days is necessary to reproduce the observations.
- PFS: measurements at high latitudes require a lifetime of less than ~3 years. Longitudinal variations at high latitudes and seasonal trends at mid-to-low latitudes cannot be reproduced.
- The CH_4 source: quantitative agreement with the observations requires considerable amounts: 50 000 – 150 000 tons.

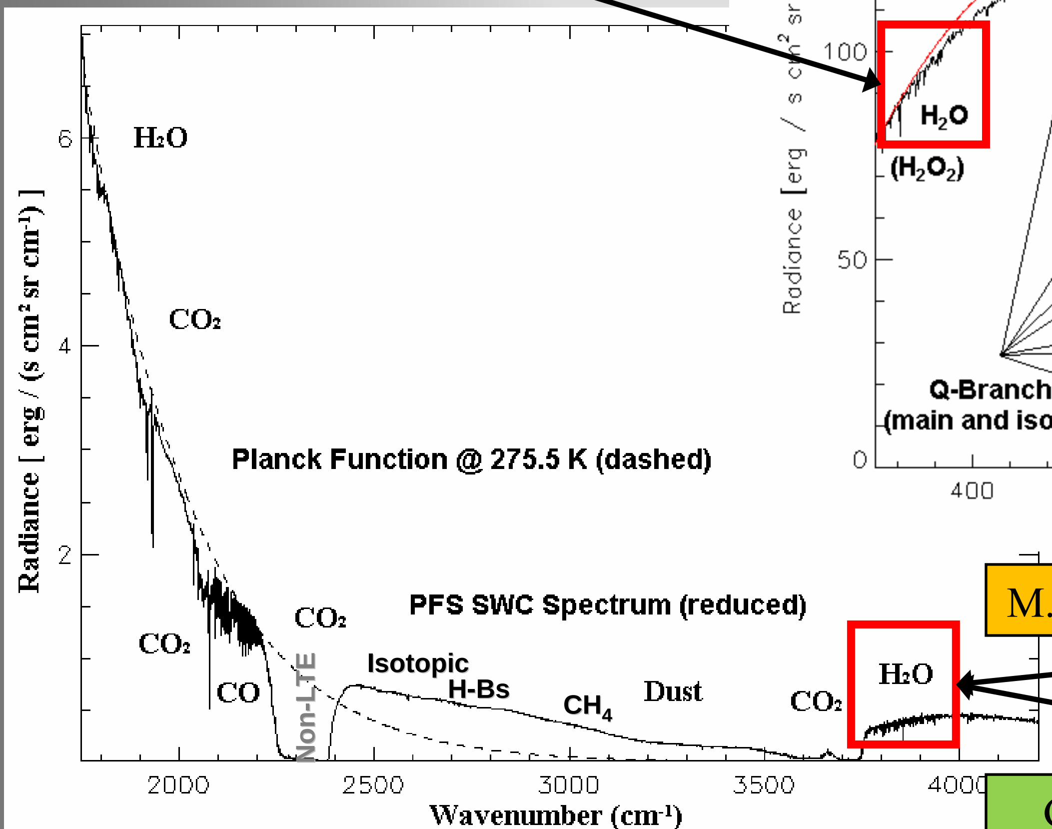
This was just a quick overview…

SEE NEXT TALK BY M. MUMMA

Minor Species in Martian Atmosphere with PFS

T. Fouchet et al. (2007) - Icarus 190, 32–49



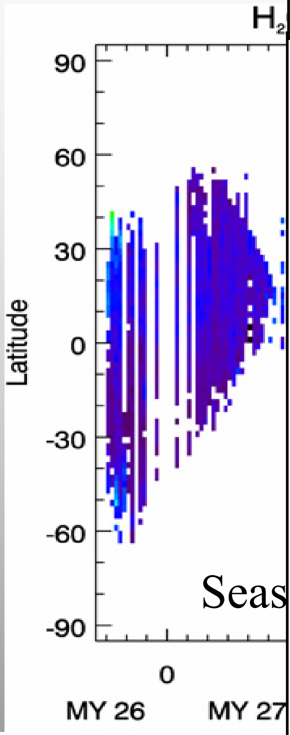


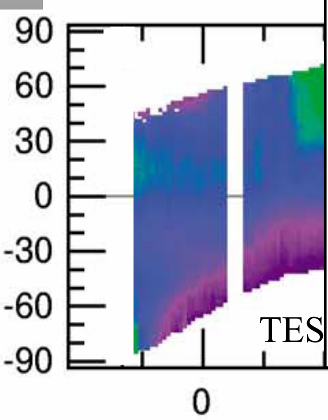
M. Tschimmel et al. (2008) - Icarus 195, 557–575

G. Sindoni and V. Formisano, PSS, submitted

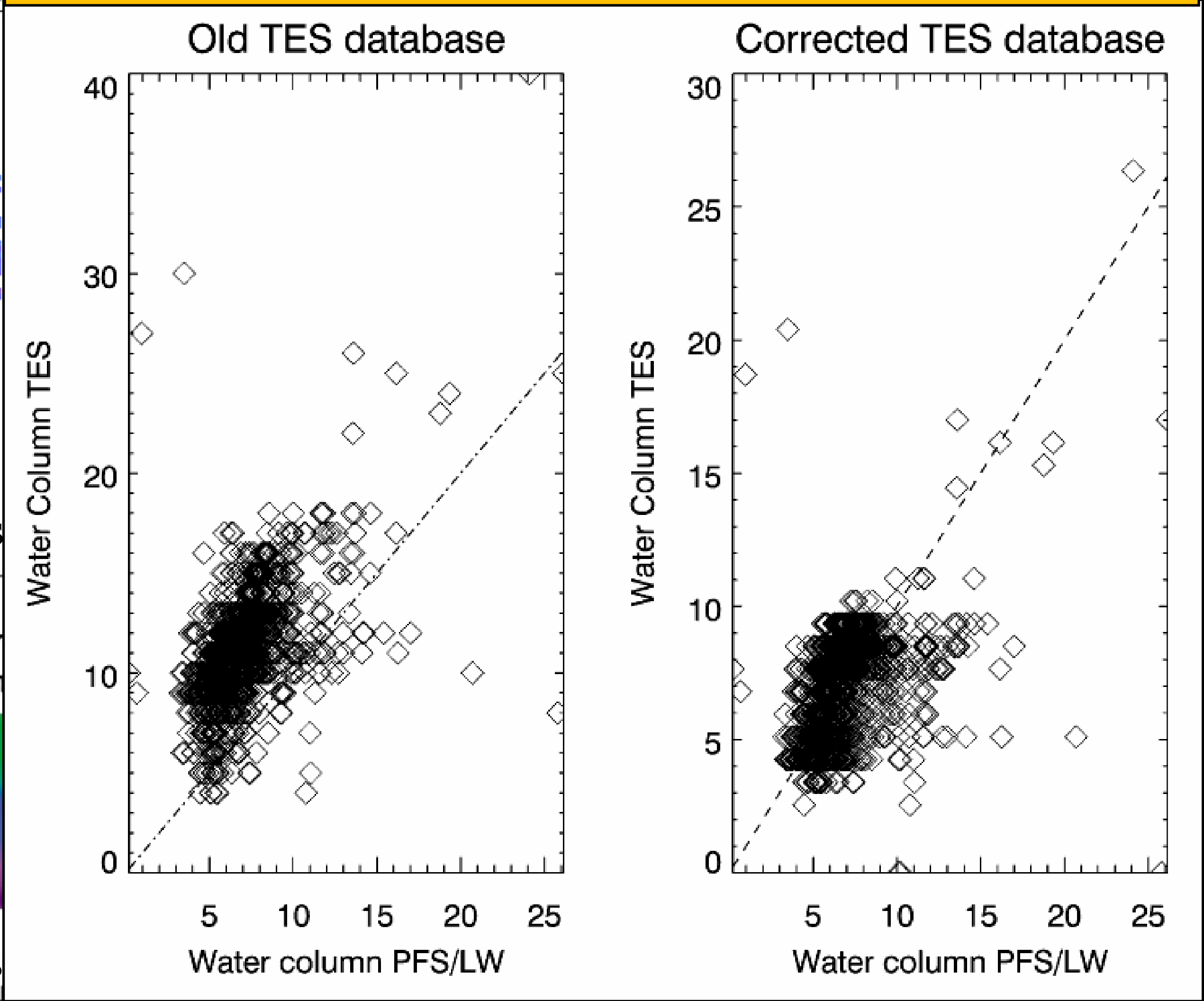
Martian water vapor: Mars Express PFS/LW observations

(T. Fouchet et al., 2007 - Icarus 190, 32–49)





Good agreement after correction of TES retrievals



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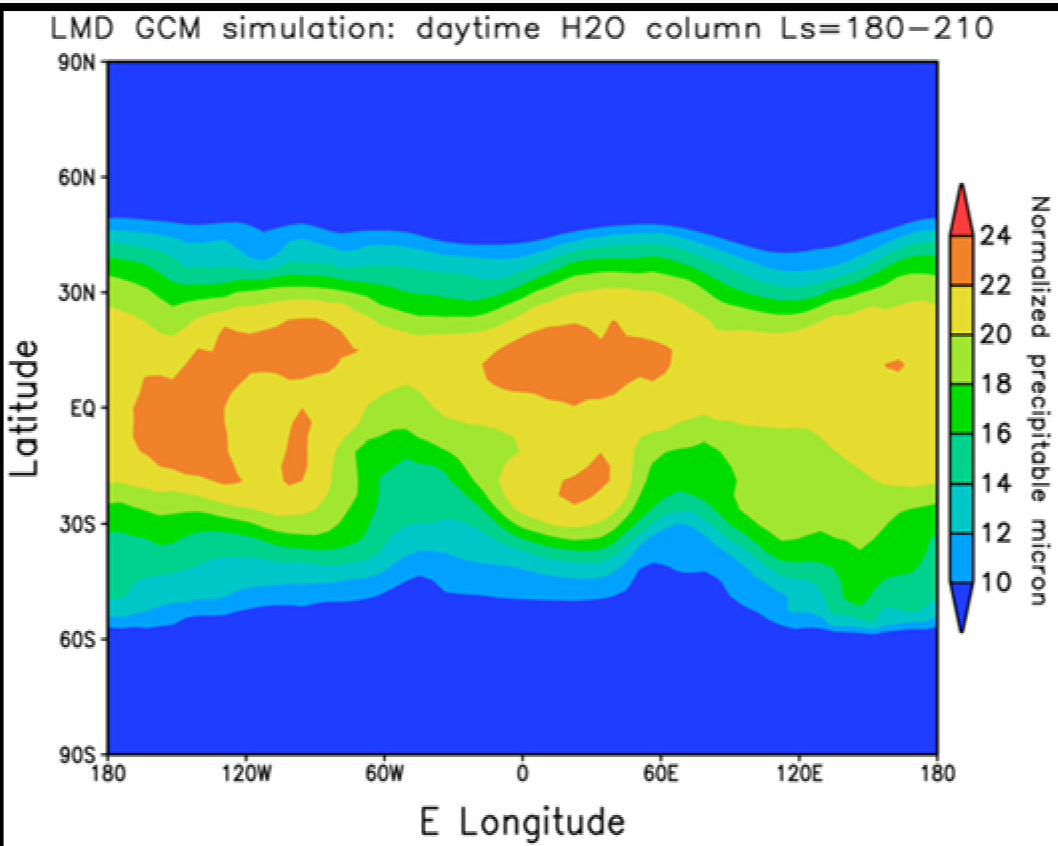
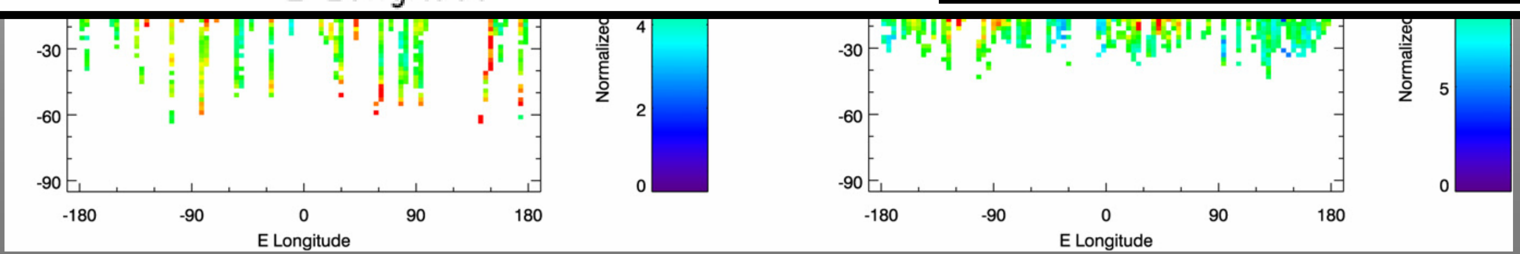
Martian water vapor: Mars Express PFS/LW observations

(T. Fouchet et al., 2007 - Icarus 190, 32–49)

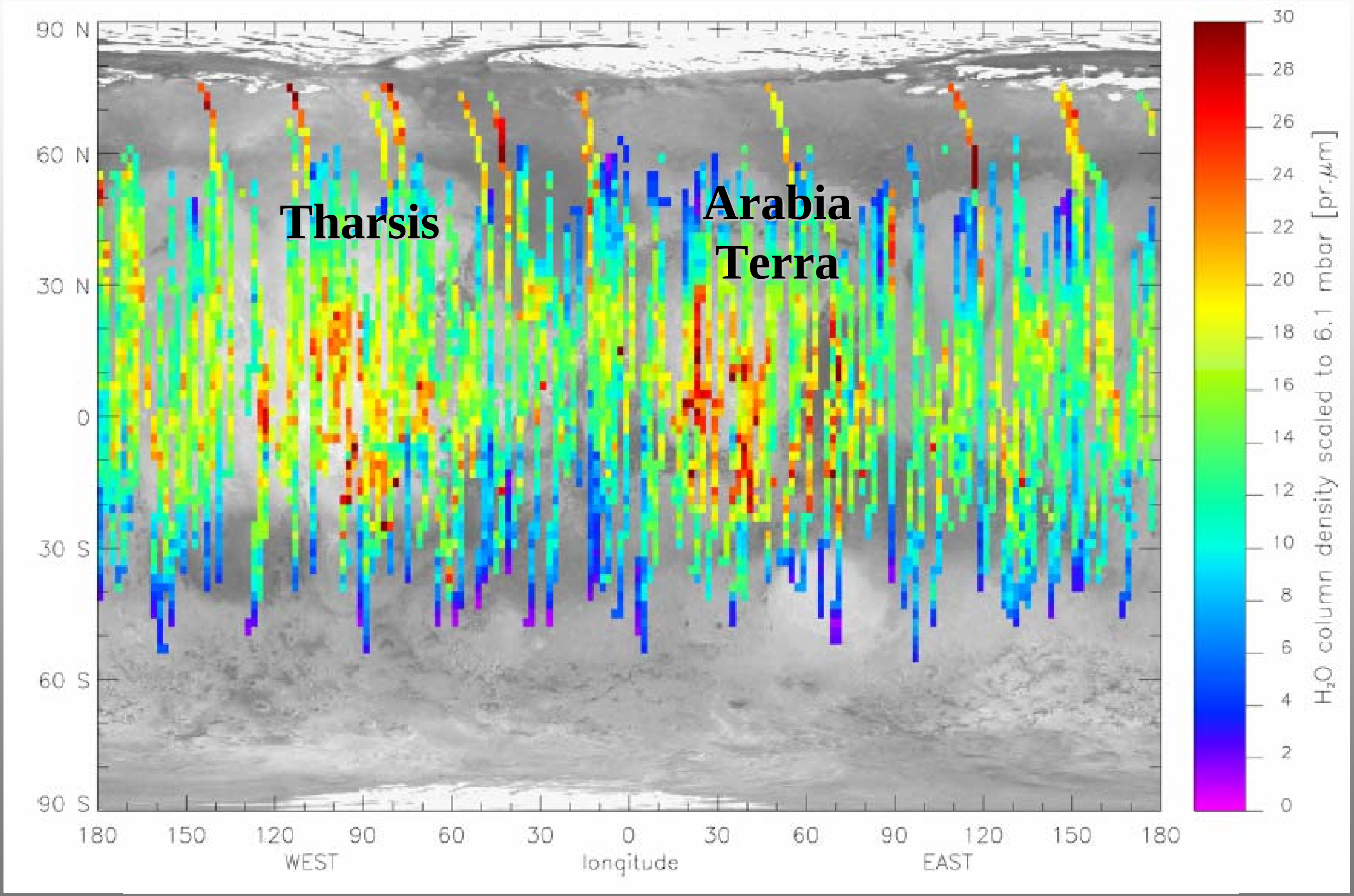


The simulation produces spatial variations with maxima of water vapor near Tharsis (120◦ W) and Arabia Terra (30◦ E) in qualitative agreement with the observations. This suggests that these spatial variations are probably caused by some atmospheric dynamical or physical processes, and that a subsurface water source (not included in the model) is not necessarily involved.



Investigation of water vapor on Mars with PFS/SW of Mars Express

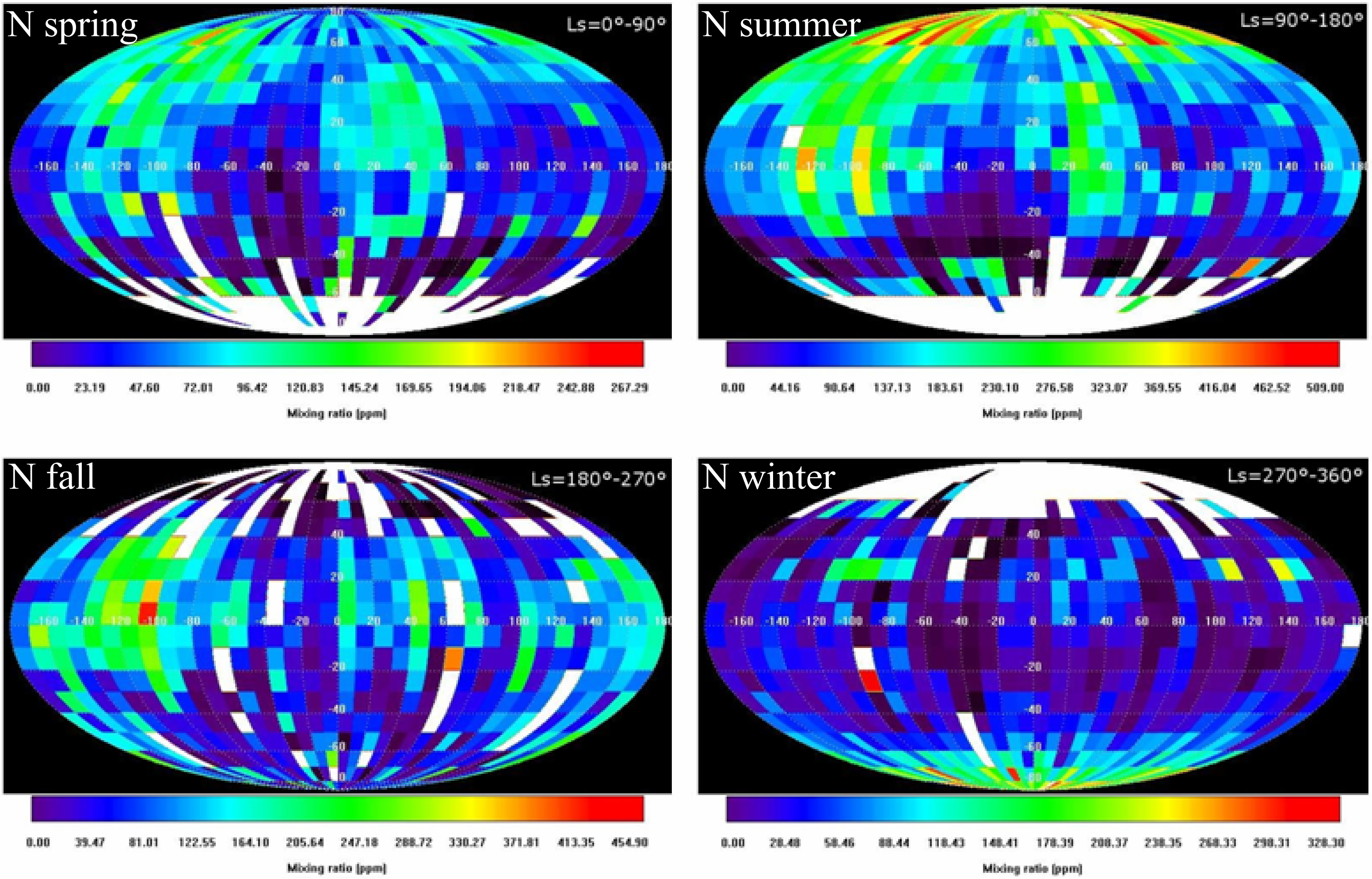
(M. Tschimmel et al., 2008 - Icarus 195, 557–575)



Observations of Water Vapor and Carbon Monoxide in the Martian Atmosphere with the SWC of PFS/MEX

(G. Sindoni and V. Formisano, PSS, submitted)

10°x10° maps of retrieved abundance of water vapour as a function of Longitude and Latitude

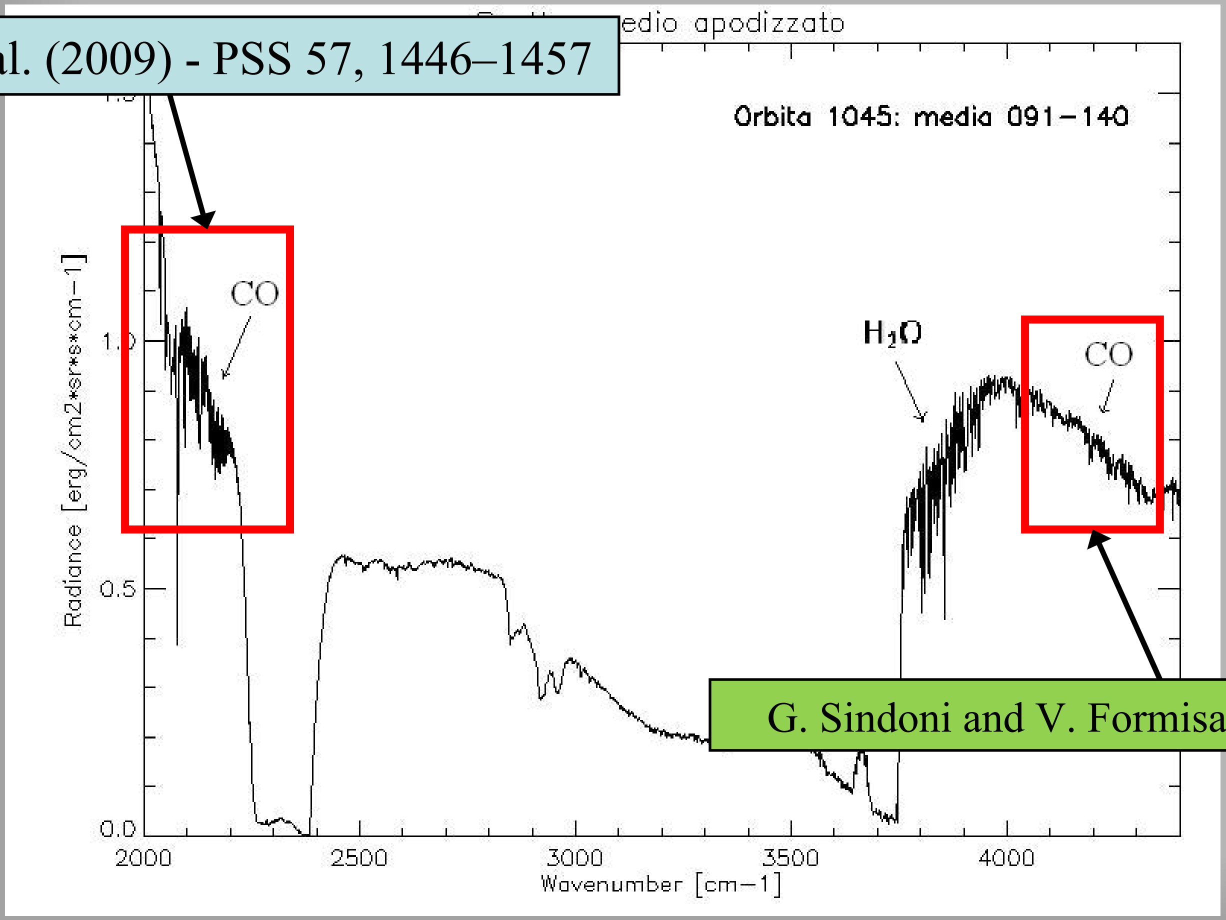


There is much more…

- Ground-based observations
- OMEGA
- SPICAM
- PFS/LWC
- PFS/SWC
- TES
- CRISM
- MAWD
- …

SEE NEXT TALK BY O. KORABLEV

Minor Species in Martian Atmosphere with PFS

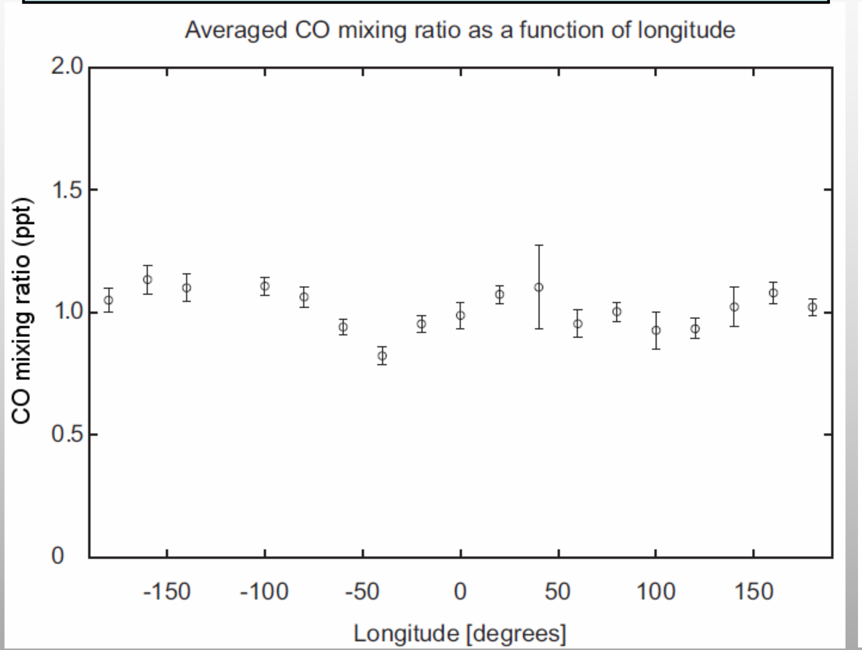


Billebaud et al. (2009) - PSS 57, 1446–1457

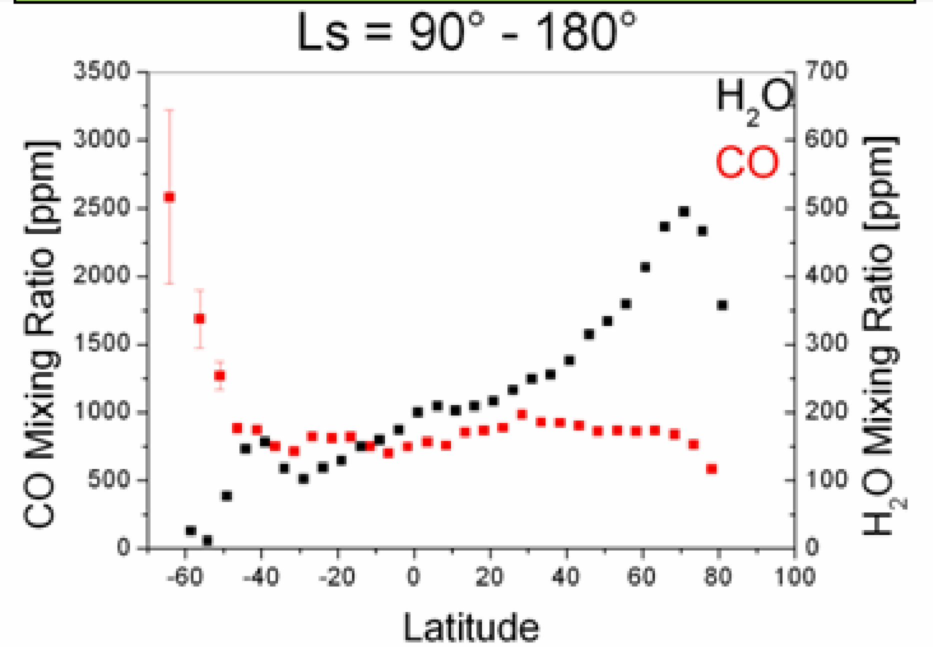
G. Sindoni and V. Formisano, PSS, submitted

CO analyses with PFS data

Billebaud et al. (2009) - PSS 57, 1446–1457



G. Sindoni and V. Formisano, PSS, submitted



CO: almost uniform longitudinal distribution; globally averaged mixing ratio ~ 1.1 ppt;

Mixing ratio slightly higher than the “standard” value (0.8 ± 0.3 ppt, Kaplan et al., 1969);

Enrichment in wintry hemisphere (non-condensible gas);

Anti-correlation with H_2O abundance, only for H_2O abundances > 350 ppm.

There is much more…

- Isotopic Ratios (C^{12}/C^{13}, H/D, $O^{16}/O^{17}/O^{18}$,…)
- H_2O_2
- Oxygen Dayglow
- NON-LTE emission (CO_2, CO, …)
- CO_2 ice clouds
- Polar Vortex
- Limb Observations (Structure of atmosphere, vertical distributions, high altitude aerosols, equatorial cloud belt,…)
- …

…Interested anyone?...

THANK YOU