Current status and future prospects of the observations and modeling of Martian atmosphere

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TOHOKU
UNIVERSITY

Contents of this talk

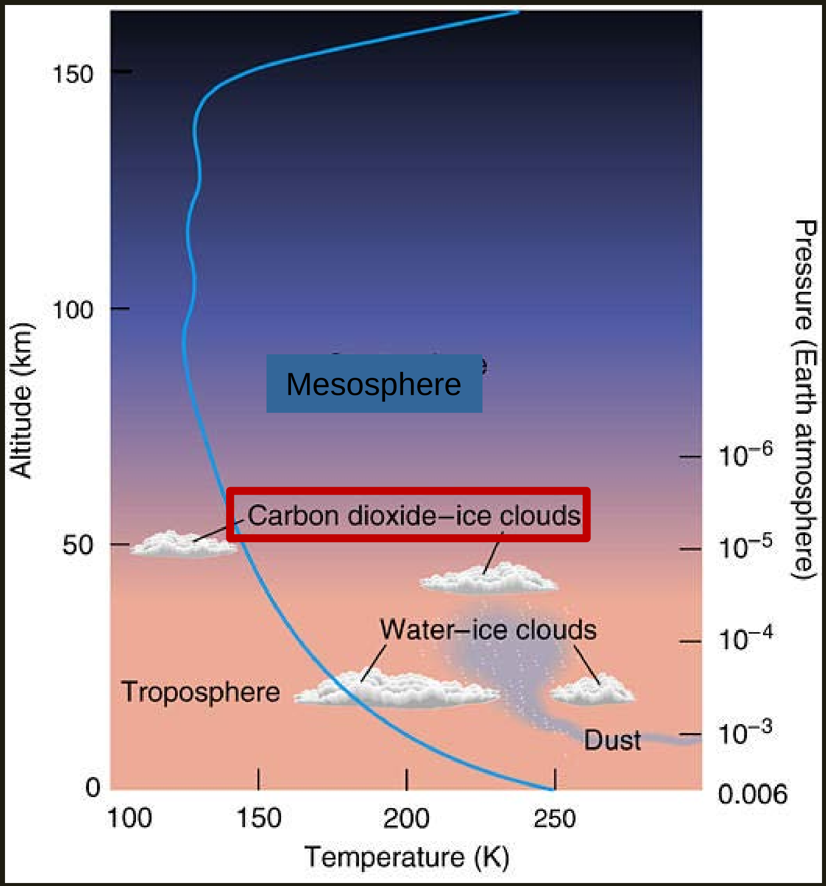
- CO_2 ice clouds and seasonal ice cap deposits in polar night
- Other recent interesting topics
- Future prospects

CO_2 ice clouds and seasonal ice cap deposits in polar night

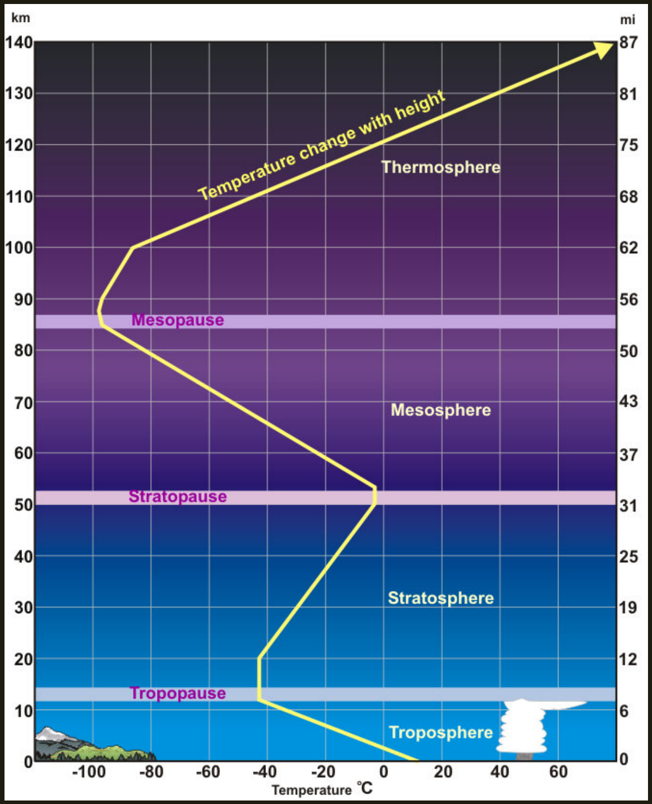
Asahi Shimbun,13 May 2013

Atmospheric environment on Mars

Vertical structure



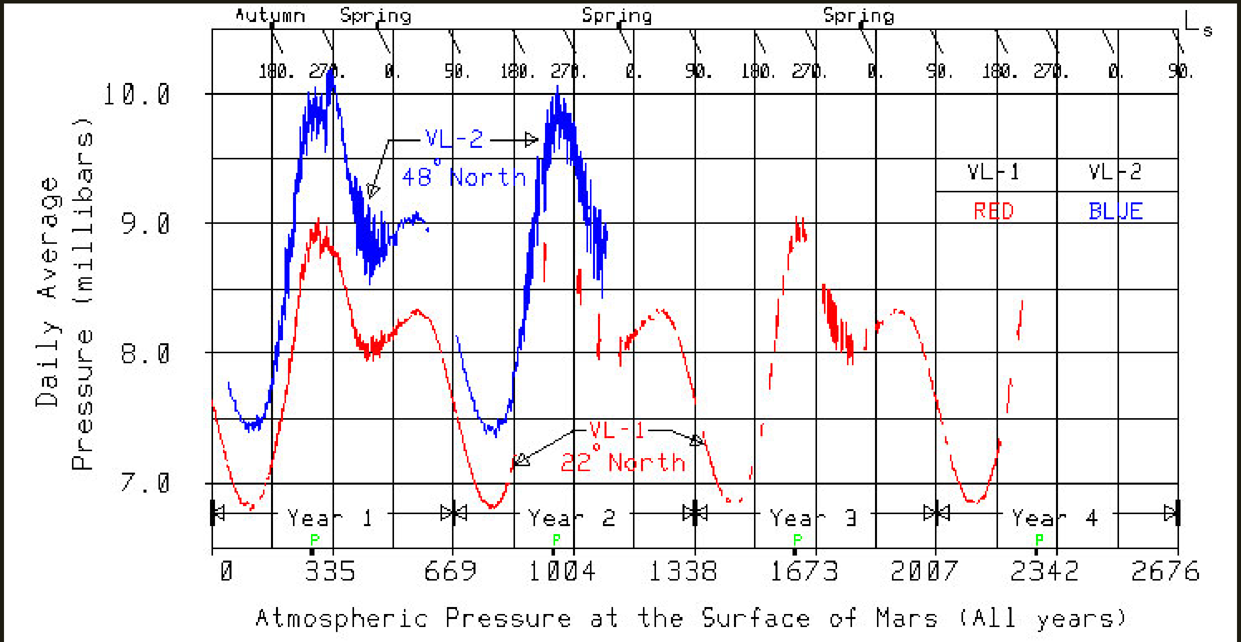
(Ref: on Earth)



- No stratosphere
- Dust and water ice clouds: up to ~40 km height
- CO_2 ice clouds: higher than ~40 km, and polar night (lower than ~40 km)

Condensation of CO_2 on Mars

Annual change of surface pressure (Viking)



[*Tillman et al.*, 1993]

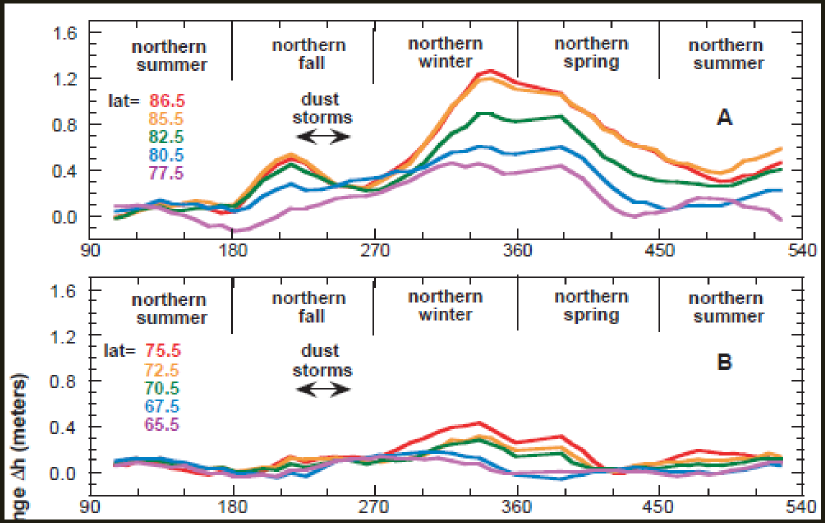
- CO_2 occupies 95.3 % of the Martian atmosphere.
- The atmospheric temperature can go below the condensation level of CO_2 (~145 K at 6 hPa), mainly in winter poles.
- The CO_2 atmosphere condenses in winter poles, which results in the formation of seasonal polar cap and large annual variance of pressure (~25 %).

Northern seasonal polar ice cap of CO_2

North polar cap (Hubble space telescope)

[*Cantor et al.*, 1998]

Elevation change of polar regions (MGS-MOLA)



[*Smith et al.*, 2001]

- Seasonal polar ice caps are known by ground-based telescopes since Herschel (18th century).
- The shape of recessing northern seasonal cap is relatively circular, but with slight asymmetricity.
- The cap accumulates up to ~1.2 m, and the elevation change is prominence in the north of 80° N.

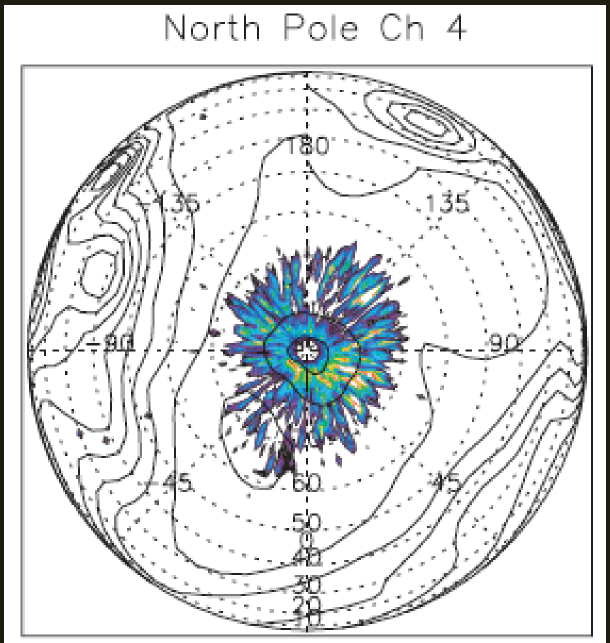
CO_2 snowfall in north polar regions

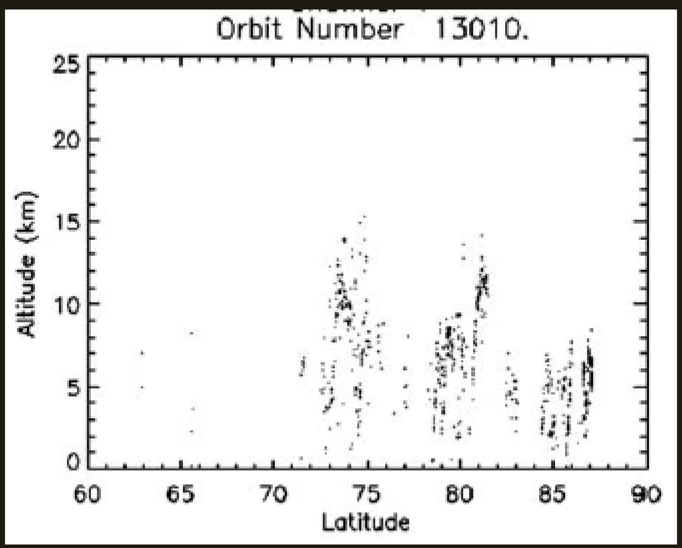
Cloud echoes (MGS-MOLA)

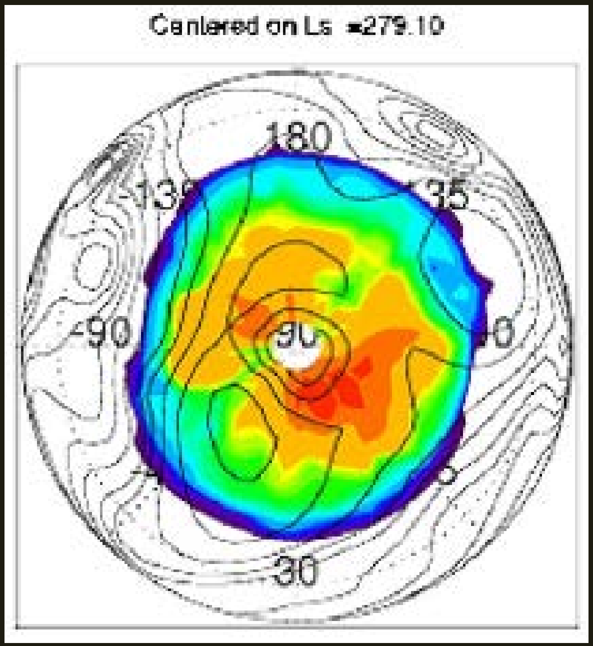
Frequency

Vertical distribution

Surface deposition rate of CO_2 seasonal ice cap (NASA/Ames MGCM)







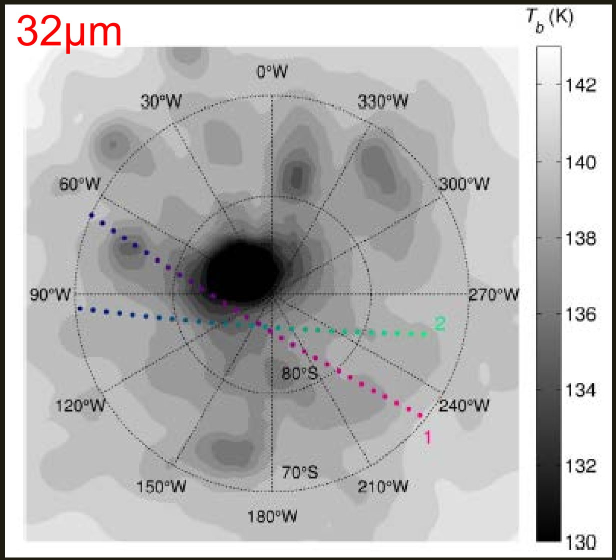
[*Colaprete et al.*, 2003, 2008]

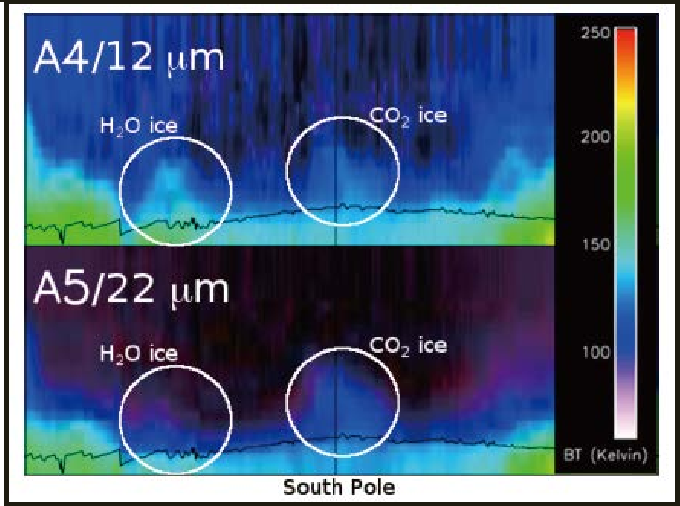
- The cloud echoes are observed in the north of 70° N below the altitude of 15 km.
- There is a longitudinal dependence in the latitude of ~80° N, with a peak in 45°-90° E.
- Maximum cloud particles size is estimated to 50-200 μm.
- Simulated CO_2 deposition is maximum in 0°-60° E in ~80° N.

CO_2 snowfall in south polar regions

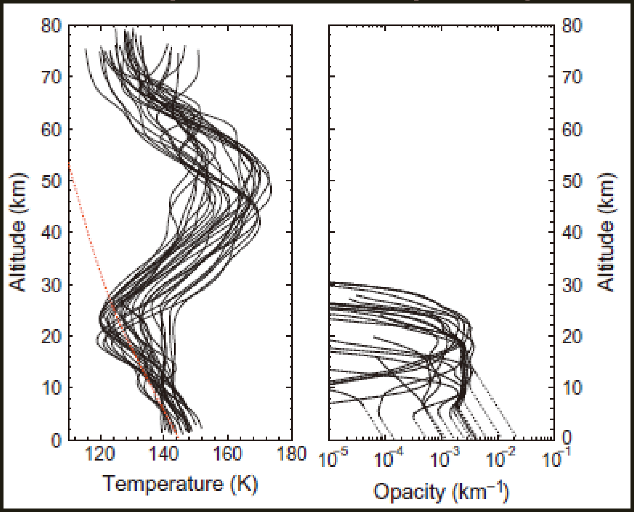
Recent detailed studies with observation/simulation

MCS Brightness temperature [*Hayne et al.*, 2014]



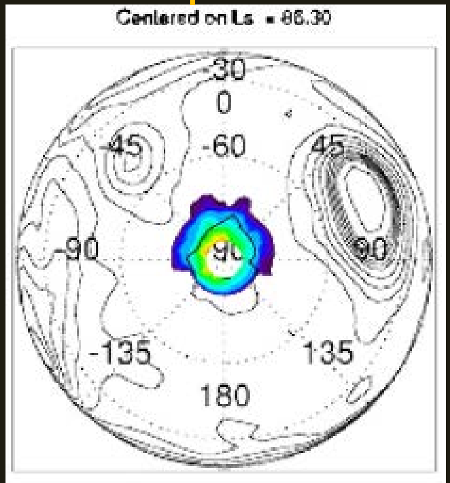


MCS retrieved temperature/opacity

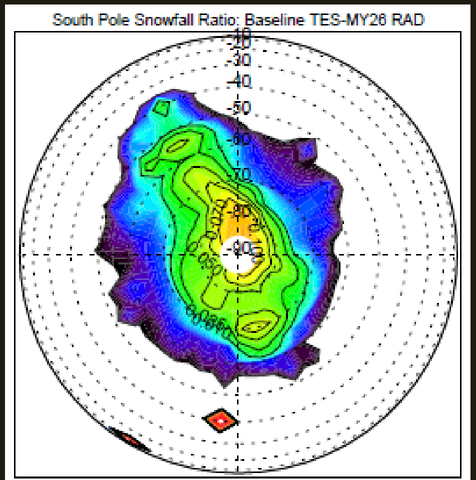


- Seems to be more 'choppy' than the northern clouds.
- Contribution of snowfall to the seasonal cap formation is very small (<10%).
- Zonal structure changes seasonally…? [*Colaprete et al.*, 2008; *Dequaire et al.*, 2014]

(NASA/Ames MGCM) Surface deposition rate



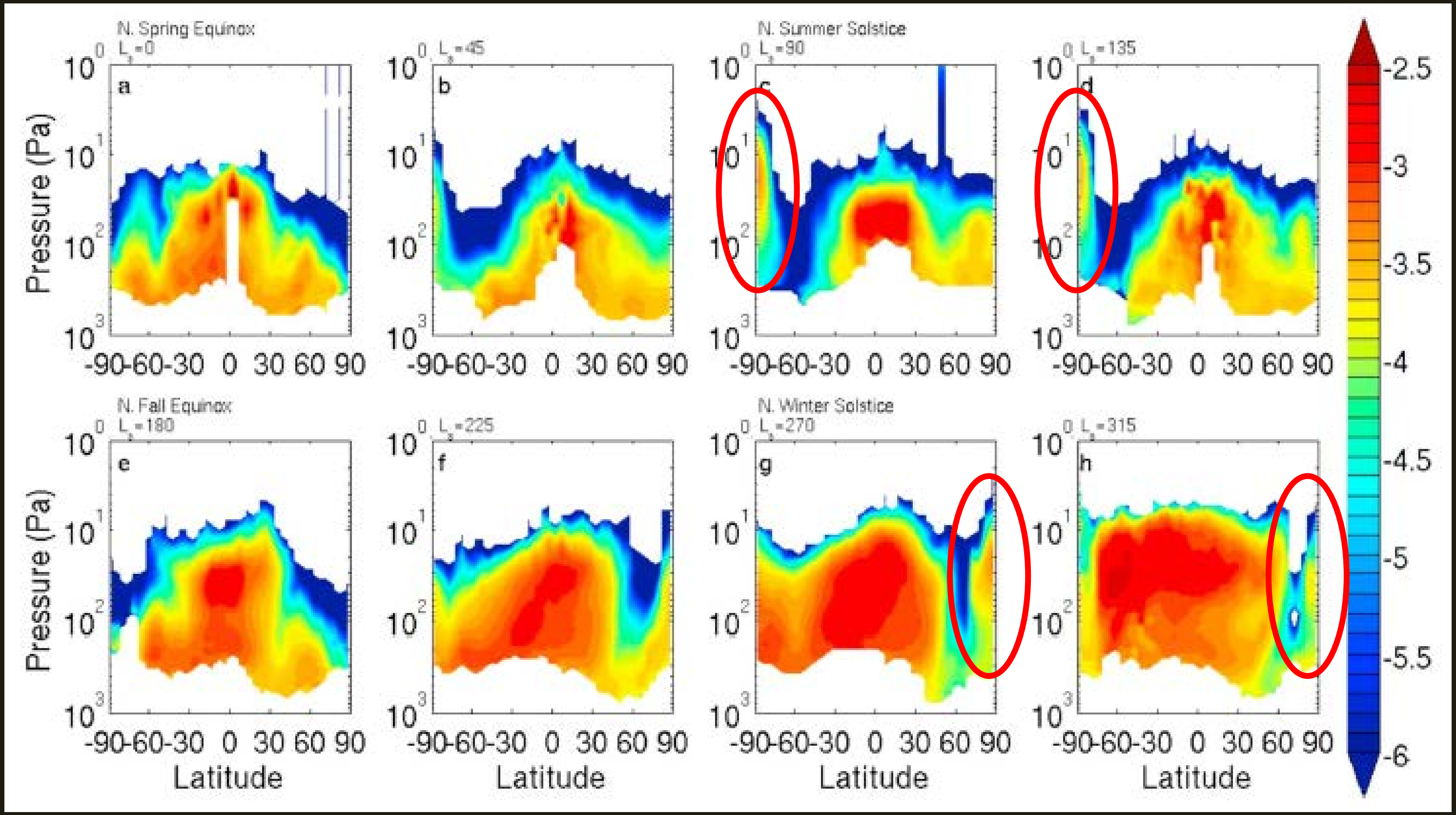
Ratio of snowfall to total ice deposition



CO_2 snowfall in polar regions

[*McCleese et al.*, 2010]

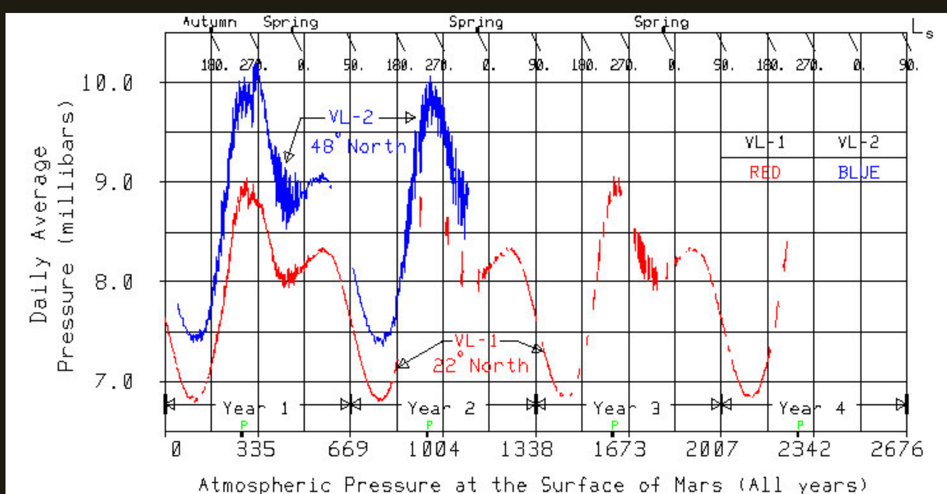
MRO-MCS (density-scaled opacity of dust)



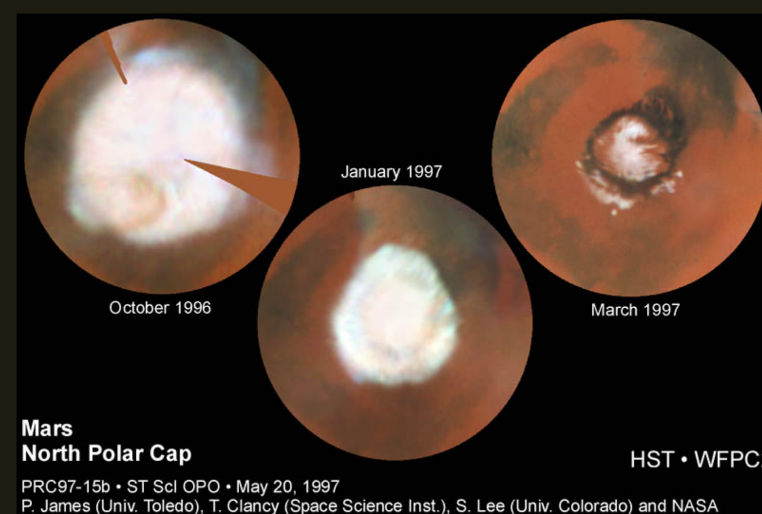
- There are signals of 'dust' in winter polar regions (higher than 70°), which are thought to be of CO_2 ice clouds.
- Polar CO_2 ice clouds are peaked in ~20-40 km altitude.
- The data is too sparse to detect the longitudinal dependence. (the details will be shown later)

Questions

- How is the CO_2 snowfall simulated in the MGCM? Are the results consistent with the observations?
- How does the atmospheric dynamics affect the longitudinal dependence of CO_2 snowfall?
- Is the CO_2 snowfall related to the deposition of seasonal ice cap, and changes of mass?



[*Tillman et al.*, 1993]



[*Cantor et al.*, 1998]

About polar night CO_2 ice clouds: from my recent publication

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 1484–1488, doi:10.1002/grl.50326, 2013

Carbon dioxide ice clouds, snowfalls, and baroclinic waves in the northern winter polar atmosphere of Mars

Takeshi Kuroda,[1] Alexander S. Medvedev,[2] Yasumasa Kasaba,[1] and Paul Hartogh[2]

Research Highlights,
Nature Geoscience, May 2013

PLANETARY SCIENCE

Snow storms on Mars *Geophys. Res. Lett.* http://dx.doi.org/10.1002/grl.50326 (2013)

During the martian winter, carbon dioxide in the planet's atmosphere condenses to form ice clouds and snow. Model simulations suggest that the formation of airborne ice is promoted by the passage of planetary waves.

Takeshi Kuroda of Tohoku University, Japan, and colleagues identified the mechanisms of ice cloud formation in the high northern latitudes of Mars, using a general circulation model. In the model, ice clouds formed north of 70° N, at altitudes of up to 40 km. Ice cloud formation coincided with the presence of eastward-travelling planetary waves, a dominant feature of winter-time atmospheric dynamics in the north. The passage of these waves lowered local air temperatures below the carbon dioxide condensation level, at which point ice emerges.

Ice particles generated below about 20 km altitude fell to the surface as snow, potentially contributing to polar ice cap formation. Deposition was greatest in regions impacted by planetary waves. Given the regularity of these waves, the authors argue that deposition to the surface can be reliably predicted. *AA*

On a local TV news (TBC), 8 June 2013

DRAMATIC MGCM

DRAMATIC = Dynamics, **RA**diation, **MA**terial **T**ransport and their mutual **I**ntera**C**tions

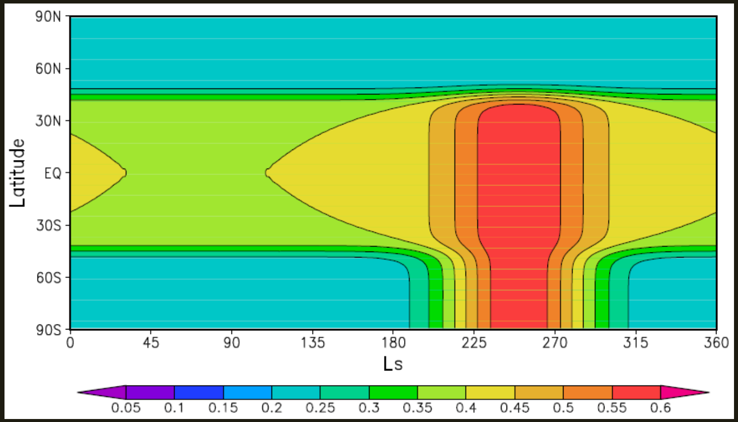
[Kuroda et al., 2005-2013]

Current status

Dynamical core	CCSR/NIES/FRCGC AGCM 5.7b (MIROC 4.0) 3-dimensional primitive equations, spectral solver
Resolutions	Horizontal resolution of ~5.6°×5.6° (T21) (grid interval of ~333km at the equator) 69 layers with σ levels, the model top is at ~100km.
Radiation	CO_2: Absorption and emission in the infrared wavelength (15μm, 4.3μm) and near-infrared solar absorption (only LTE effects) Dust: Absorption, emission and scattering in 0.2-200μm
Tracers	H_2O/HDO vapor and ice, CO_2 ice
Surface	Realistic topography, albedo, thermal inertia and roughness, deposition of CO_2 and H_2O/HDO ice

Dust distribution

- Standard observed opacity without global dust storm; 0.2-0.6 in visible, higher near the perihelion (northern autumn and early winter), zonally constant



CO_2 cycle scheme

- Condensed CO_2 ice falls with the gravitational sedimentation.
- Thermal effects (exchange with latent heat and potential energy) and mass change (between CO_2 atmosphere and ice) are considered.
- The sedimentation velocity of the CO_2 ice particle depends on its size and density.
- The particle size of CO_2 ice clouds is defined as a function of height (*), density is set to 1600 kg m^{-3}.
- Supersaturation (constant rate of 1.35) is considered.

$$r_0(z) = r_{z0} \exp(-z/h) \quad (*)$$

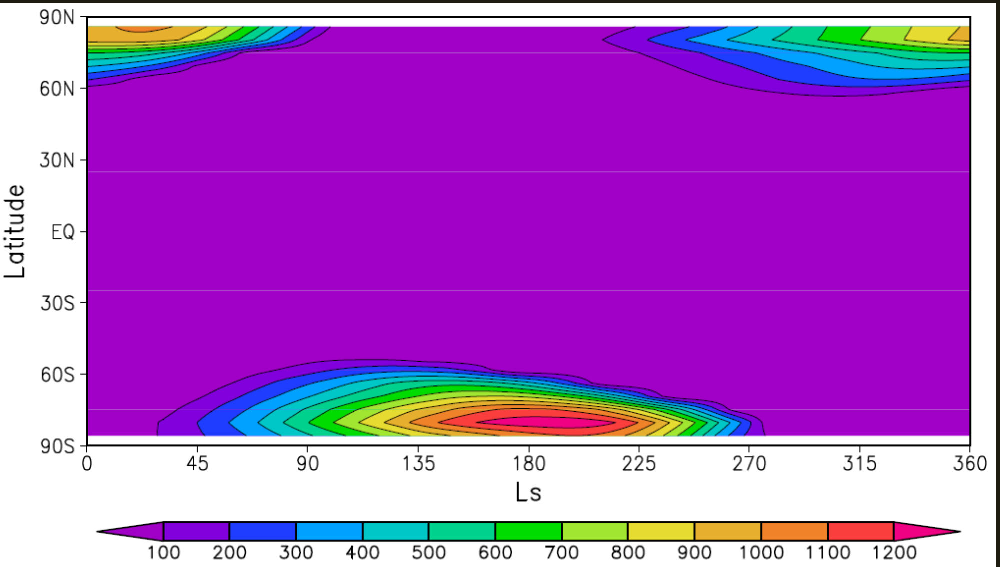
r_{z0}: Radius of particle at 0 km height (50 μm for CO_2 ice)

h: Scale height of particle (20 km for CO_2 ice)

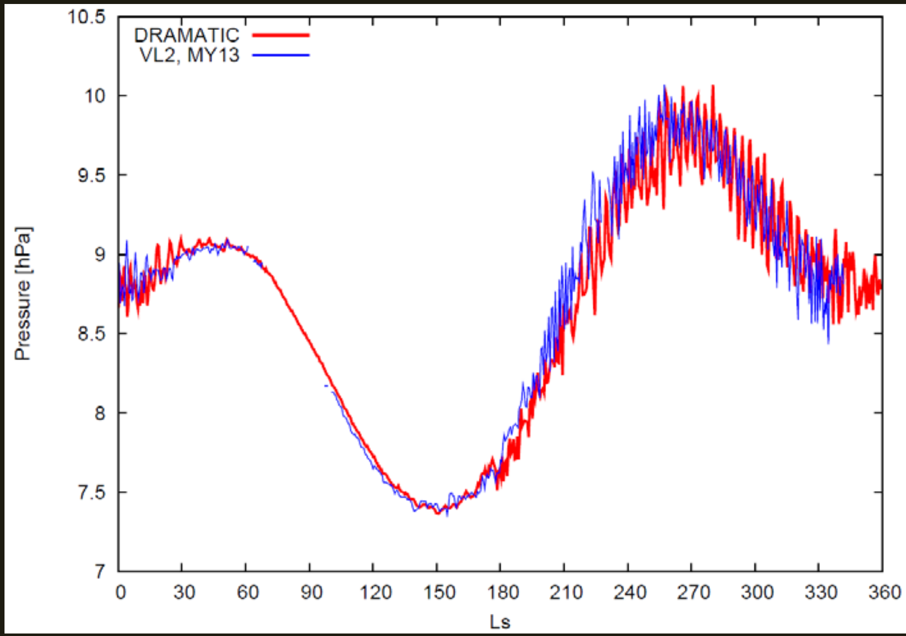
→ 1 μm at ~78 km height

Simulated seasonal changes of CO_2 ice caps and atmospheric mass

CO_2 ice cap thickness [kg m^{-2}]



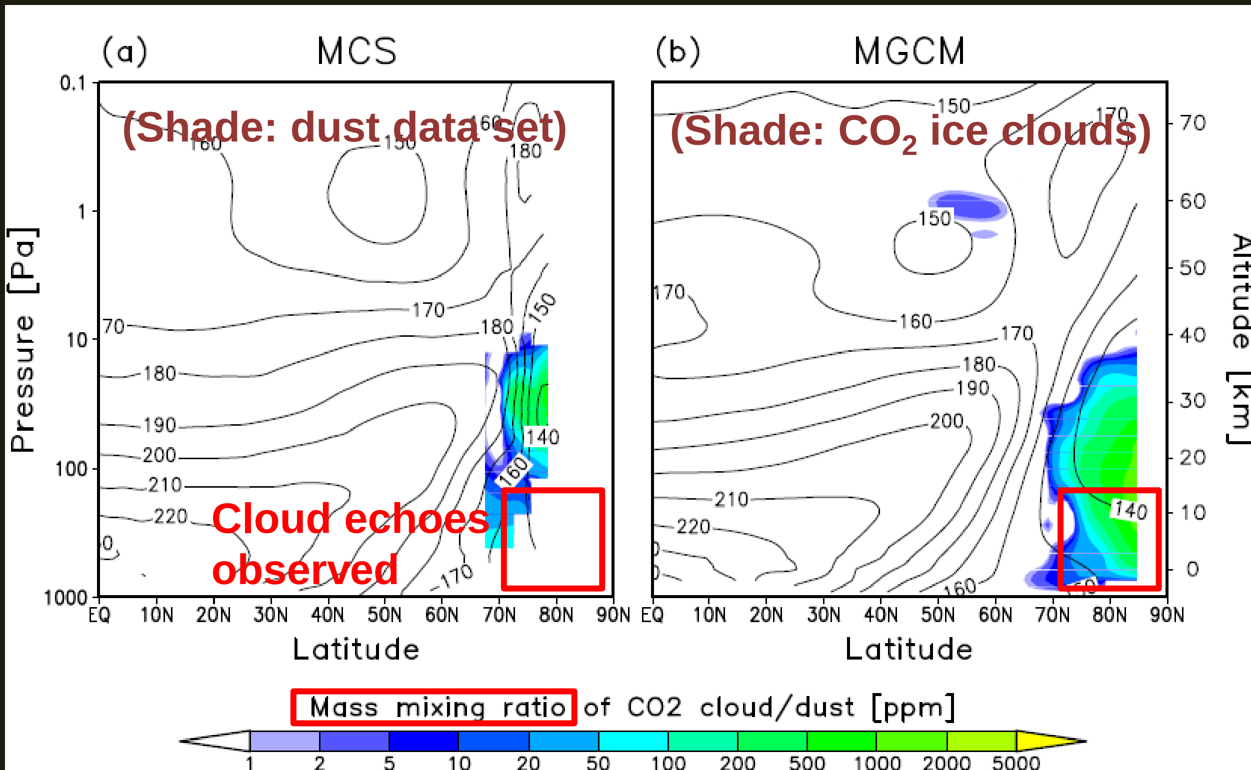
Surface pressure in comparison with Viking Lander 2 observations



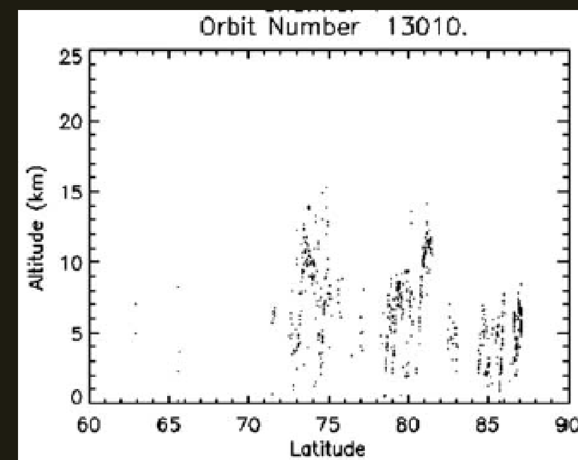
Simulated CO_2 ice cloud distribution: comparison with MRO-MCS data (Ls=255°-285° averaged)

$$q_d = \frac{\Delta\tau}{\Delta z}\frac{4\,r_{eff}\,\rho_d}{3\,Q_e\,\rho}$$

Formula of mass mixing ratio (proportional to the density-scaled dust opacity)

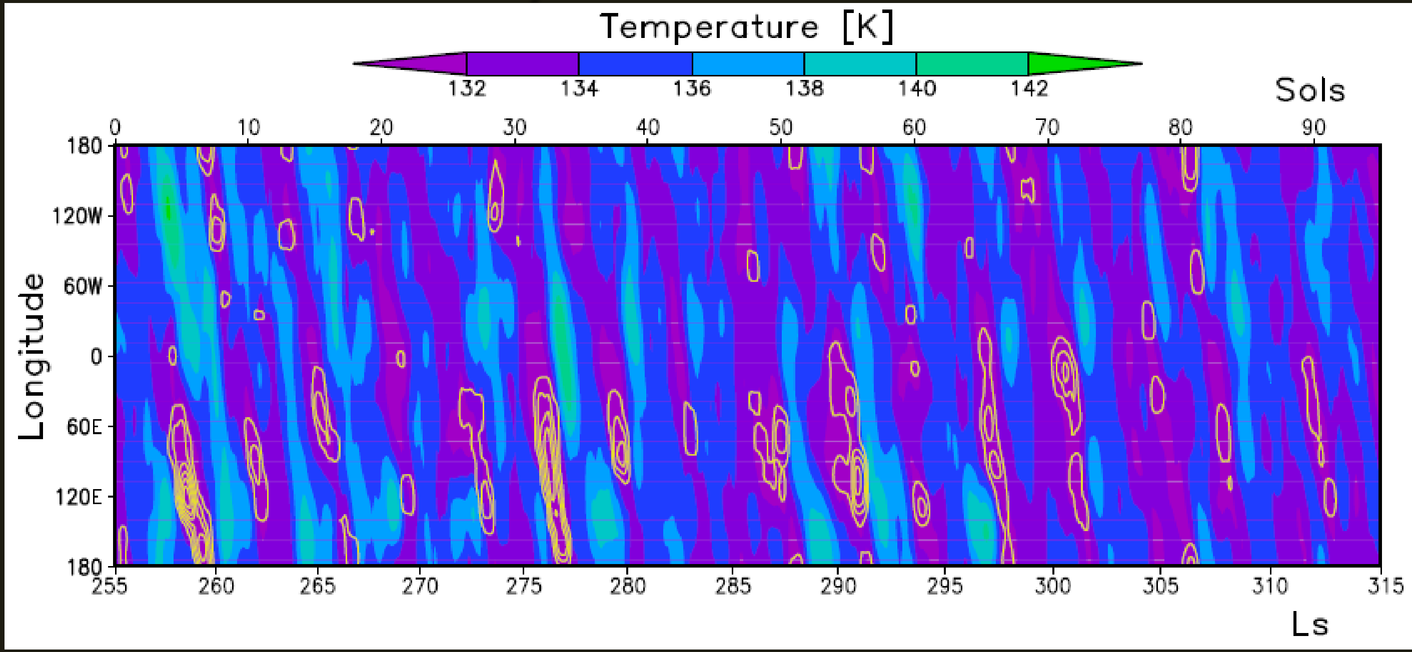


Cloud echoes (MGS-MOLA)



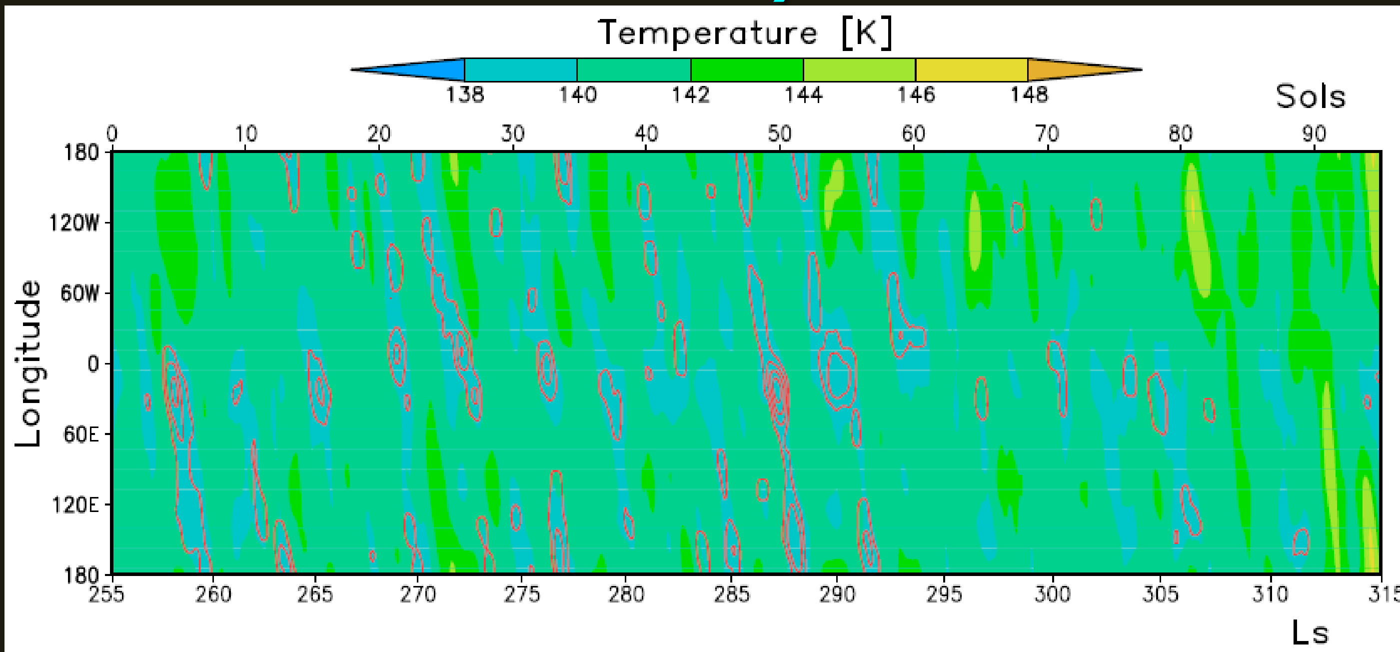
- The signal of 'dust' (CO_2 ice clouds) is seen between the altitude of 15-40 km in MRO-MCS data, which is consistent with the MGCM simulation.
- The MGCM simulated also the CO_2 ice clouds below 15 km which MRO-MCS does not detect, but the clouds in lower altitudes are consistent with the MGS-MOLA cloud echo observations.
- The MGCM also simulates mesospheric clouds in northern midlatitudes.

Longitudinal dependence of CO_2 snowfall (80°N, 50Pa: ~25km altitude) (Smoothed to be daily-averaged values)

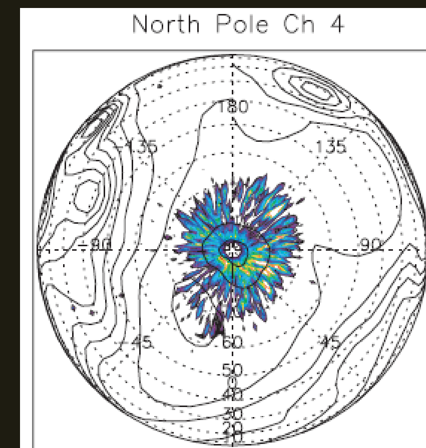


- The formation of CO_2 ice clouds is obviously along with the cold phases of eastward propagating planetary waves with zonal wave-number of 1 from baroclinic/barotropic instability (5-6 sols period).
- Also the longitudinal dependence of CO_2 ice cloud formation is large, with peaks in 60°-120° E and 90°-120° W before Ls~275°, while only in 60°-150° E in Ls~275°-295°.
- We show for the first time that the planetary waves strongly modulate the CO_2 snowfall.

Longitudinal dependence of CO_2 snowfall (80°N, 225Pa: ~10km altitude) (Smoothed to be daily-averaged values)

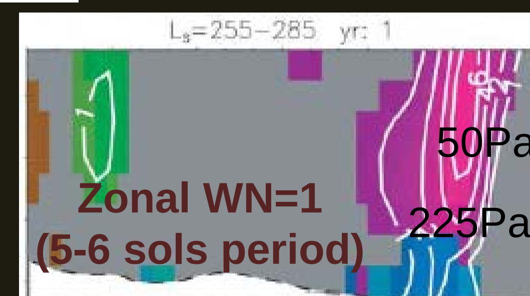


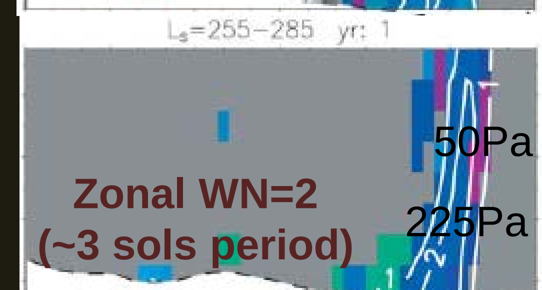
Cloud echoes (MGS-MOLA)



- The CO_2 snowfall is still modulated by baroclinic waves, including the components with shorter periods (~3 sols).
- The peak of longitudinal dependence moves to 0°-60° E (close to the cloud echo observations).

Structure of transient (baroclinic) waves

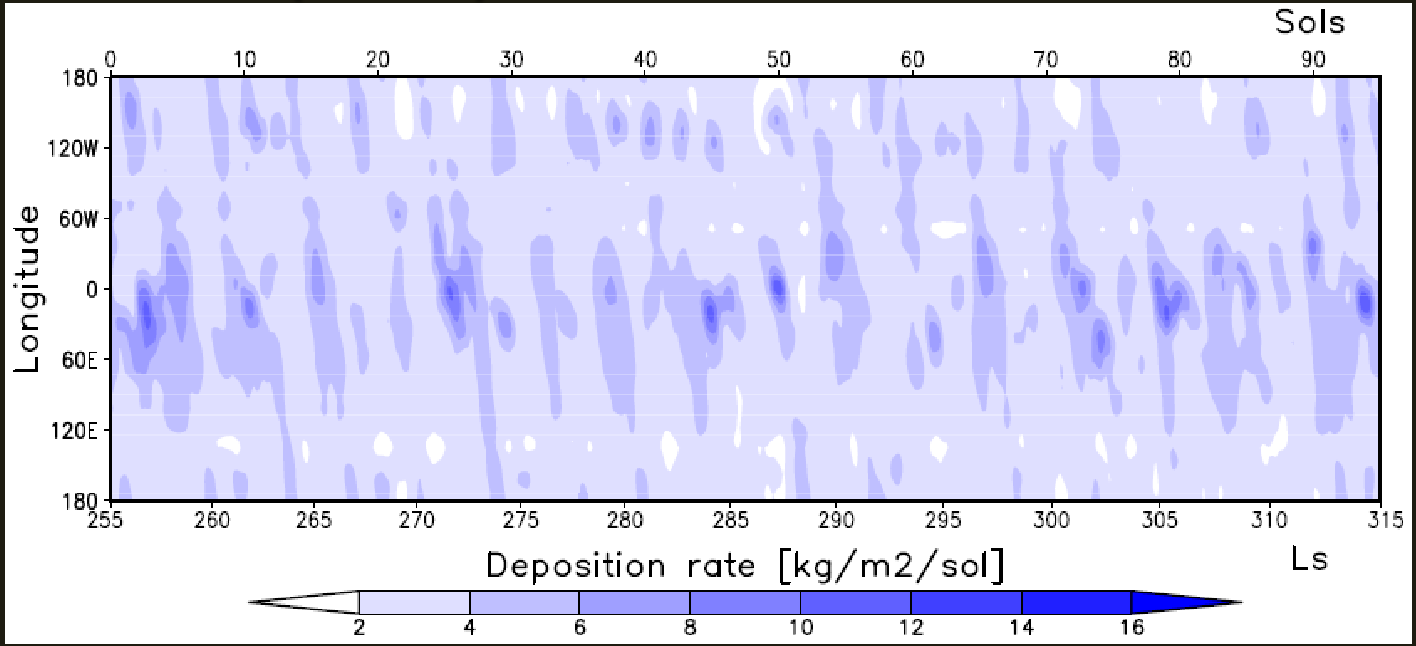




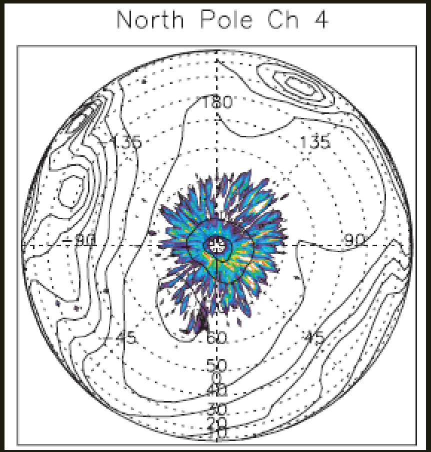
[*Banfield et al.*, 2004]

Longitudinal dependence of CO_2 ice deposition on surface (80°N)

(Smoothed to be daily-averaged values)



Cloud echoes (MGS-MOLA)



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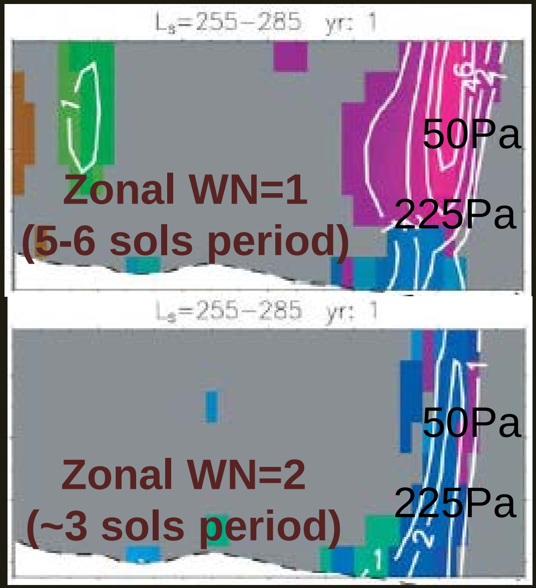
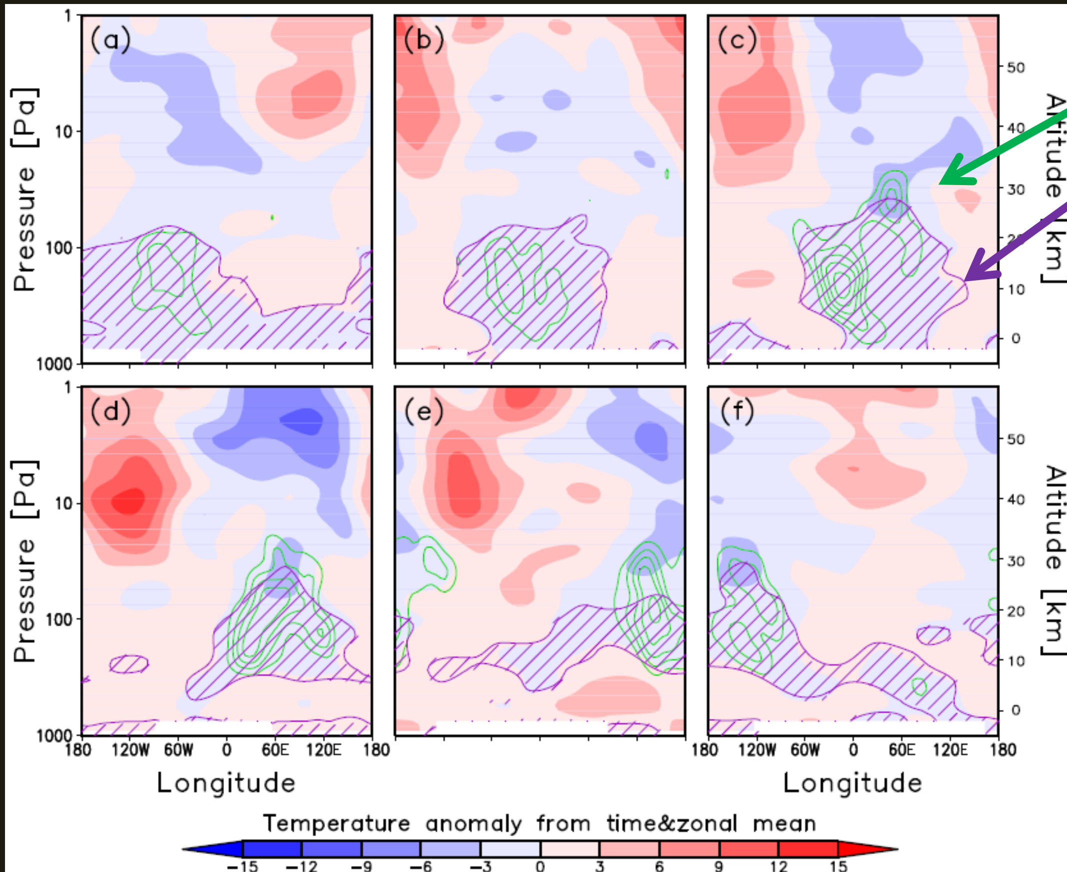


[*Banfield et al.*, 2004]

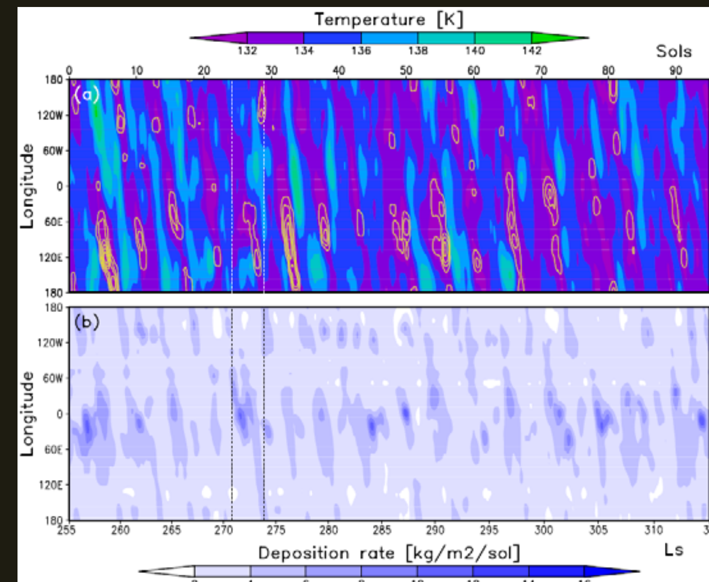
Vertical conditions of CO_2 snowfall

CO_2 ice clouds

Supersaturated (cold)



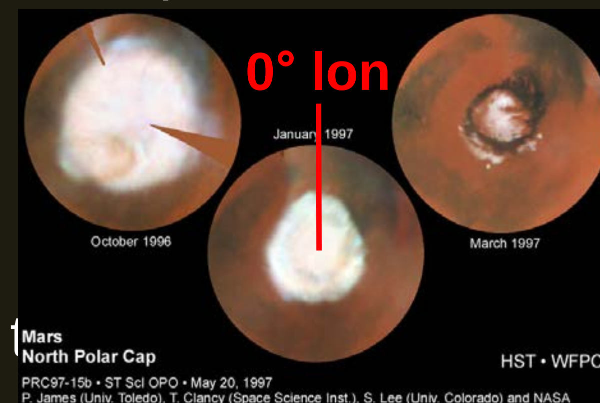
Daily-averaged values, 1-sol interval between Ls=271°-274° (between dotted lines below)

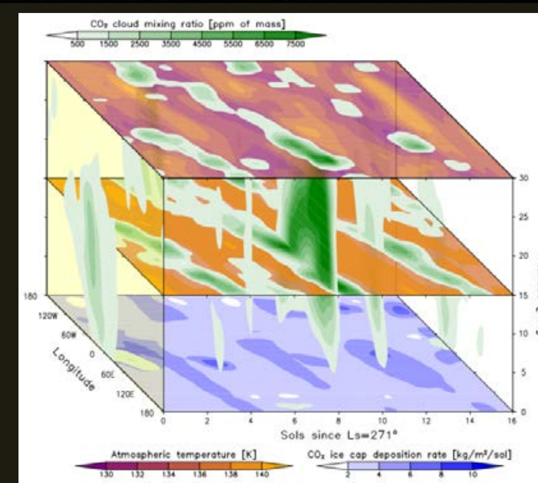


- It takes ~0.2 sols for CO_2 ice clouds at 25 km altitude to fall to surface.
- In the longitude region where the deposition rate is largest (30° W-60° E), ice particles formed up to 20 km can reach the surface.
- In other longitude regions, the ice particles likely sublimate in the lower warmer atmospheric layers.

Summary

- We showed that the formation of CO_2 ice clouds occurs in the 15-40 km altitudes of northern winter polar region (north of 70° N) from the MRO-MCS data. (below, MGS-MOLA has observed the cloud echoes)
- The cloud formations are successfully simulated by the DRAMATIC MGCM, and showed that the cloud formations and ice cap depositions are strongly modulated by planetary waves (barotropic/baroclinic and stationary waves).
- CO_2 ice particles formed below ~20 km can reach the surface in certain altitude region (30° W – 60° E at 80° N where the maximum of the deposition occurs). In other longitudes, t likely to sublimate depending on the phases of the transient waves below.
- Given the regular nature of the transient planetary waves, this study indicates the possibility for the reliable forecasts of CO_2 snow storms.





Simulated CO_2 Snowfall at 80° N

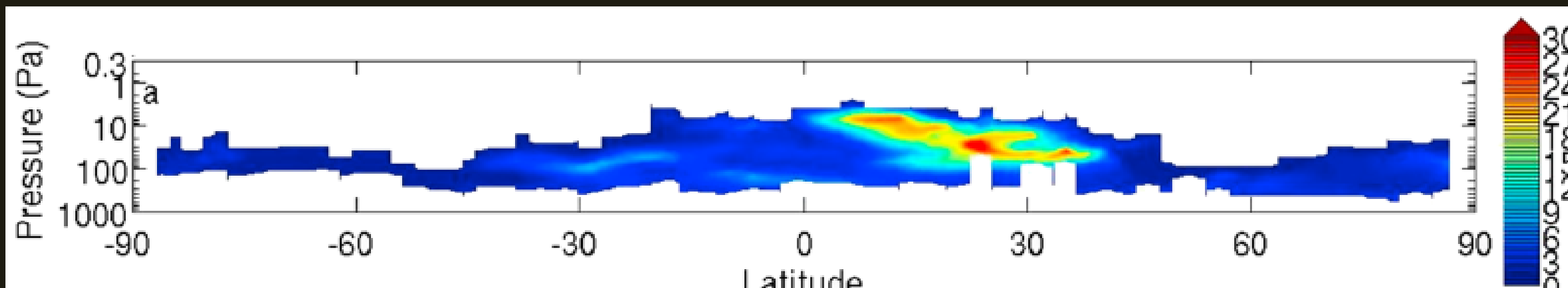
Other recent interesting topics

2014/01/13 – 16 @ Oxford
http://www-mars.lmd.jussieu.fr/
oxford2014/

Seminar by Dr. Marco Giuranna
2014/02/10 @ Tohoku Univ.

Rocket dust storms, katabatic jumps: Key of the vertical profile of dust?

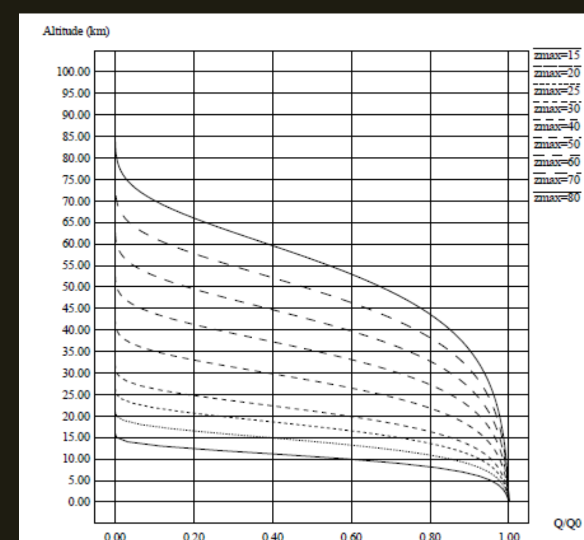
MCS observed vertical dust distributions in northern summer



[*Heavens et al.*, 2011]

- Recently Mars Climate Sounder first observed the vertical profiles of dust, but the structures are different from the theoretically-estimated (so-callled ‘Conrath’) profiles which were used in GCM simulations for a long time.

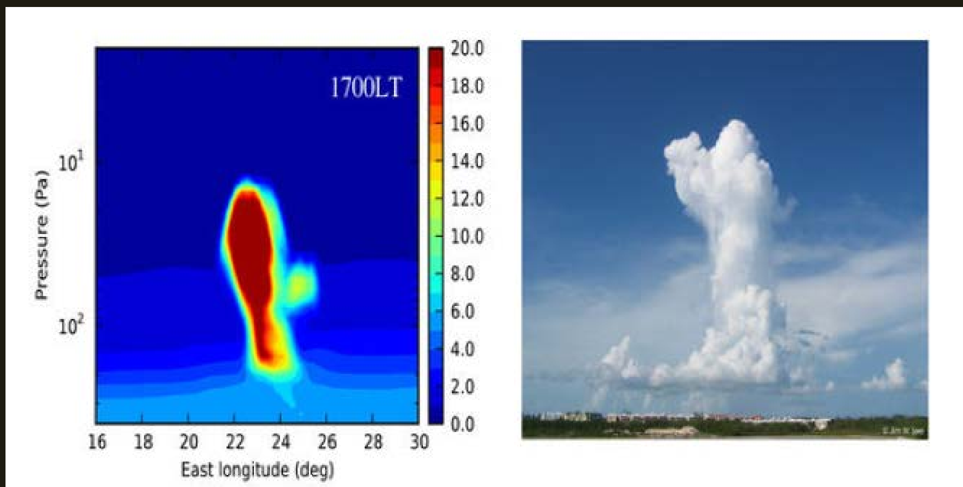
Theoretically-estimated profiles (first proposed by Conrath, 1975)

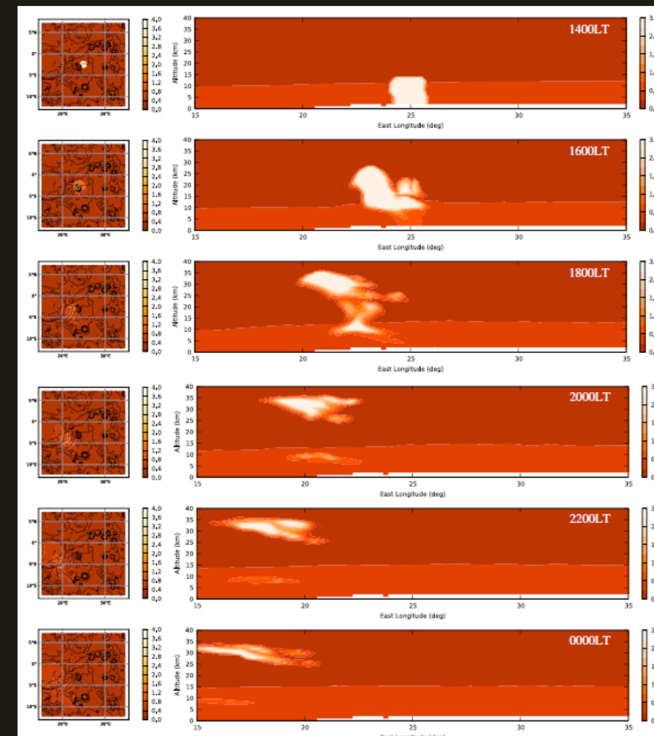


How the ‘detached’ layer appears?

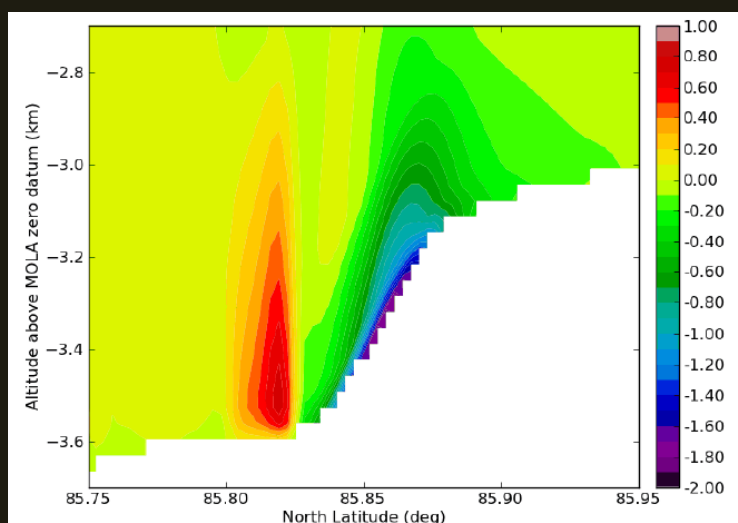
Rocket dust storms, katabatic jumps: Key of the vertical profile of dust? [*Spiga et al.*, 2014]

Rocket dust storm
(vs terrestrial cumulonimbus)





Katabatic jump

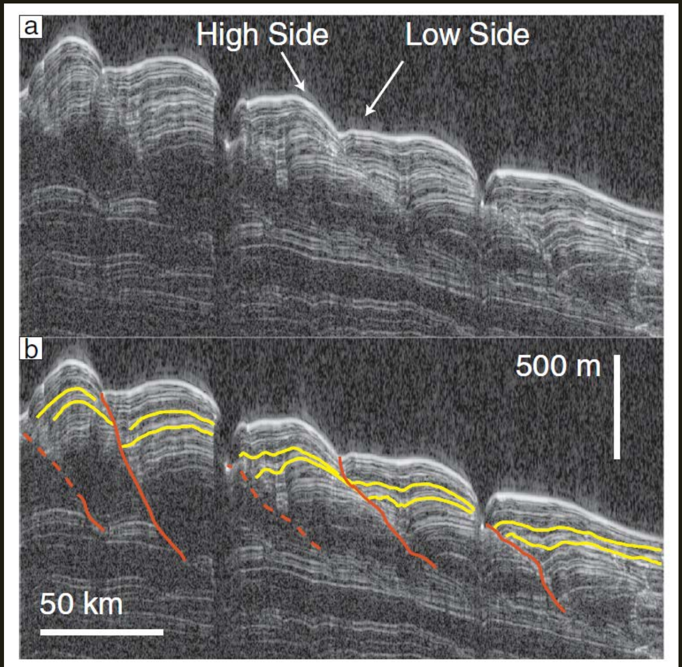


- A mesoscale model simulates the features which may relate to the existence of ‘detached’ layer of dust.

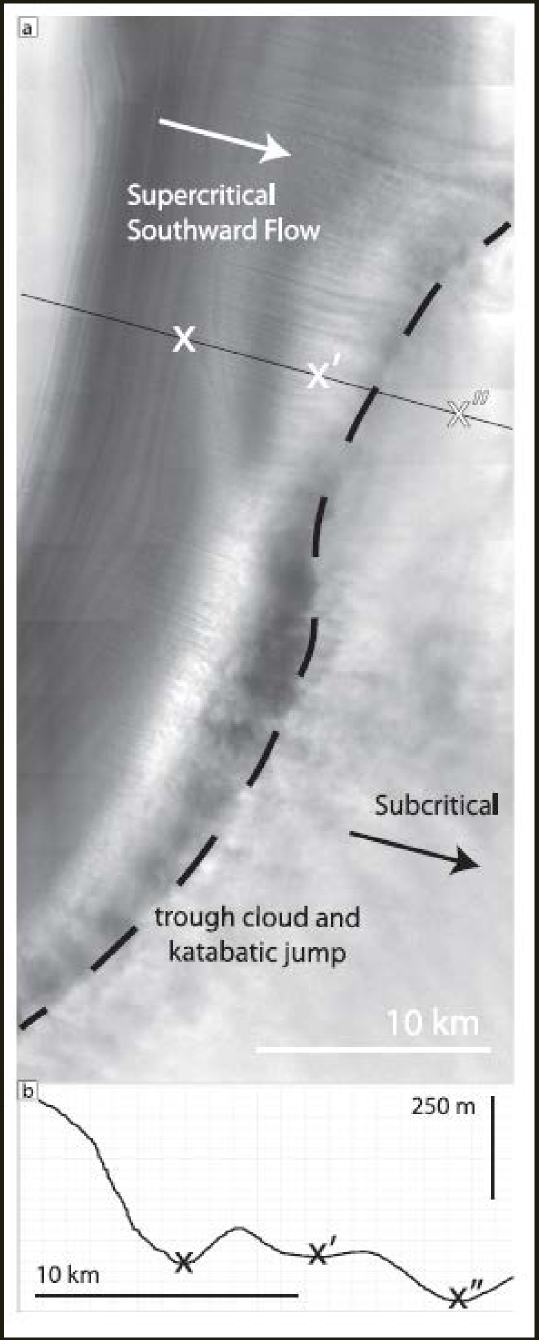
Katabatic jumps, 'sea breeze': Key of polar layered deposits

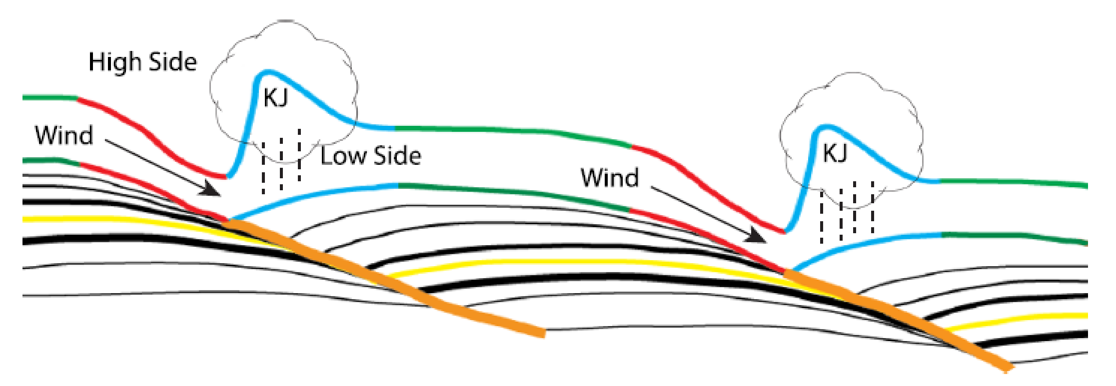
[*Smith et al.*, 2013, 2014]

North polar layered deposits (MRO-SHARAD observation)



- Katabatic jumps also may affect to make the ice clouds together with the phenomenon like 'sea breeze' on Earth.

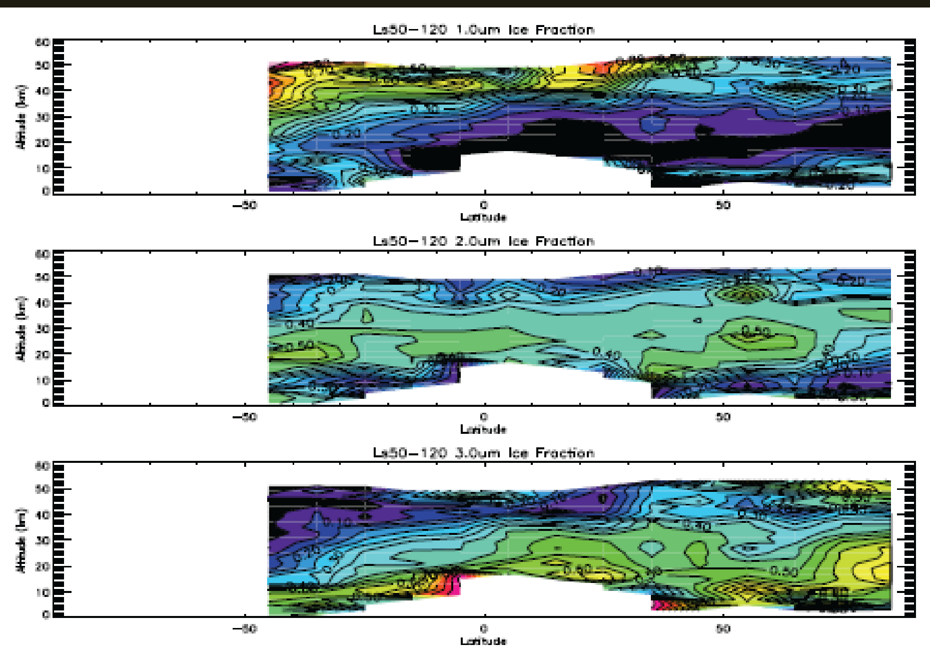


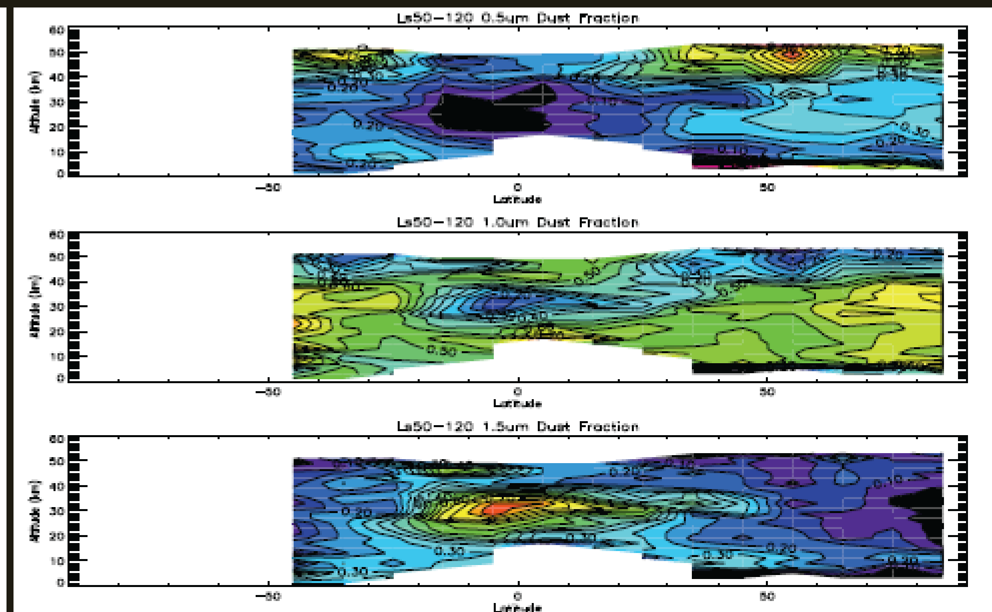


Water ice clouds/dust particle size distributions observed by MRO/CRISM

Detected fractional representations

Water ice (1.0, 2.0, 3.0 μm) Dust (0.5, 1.0, 1.5 μm)





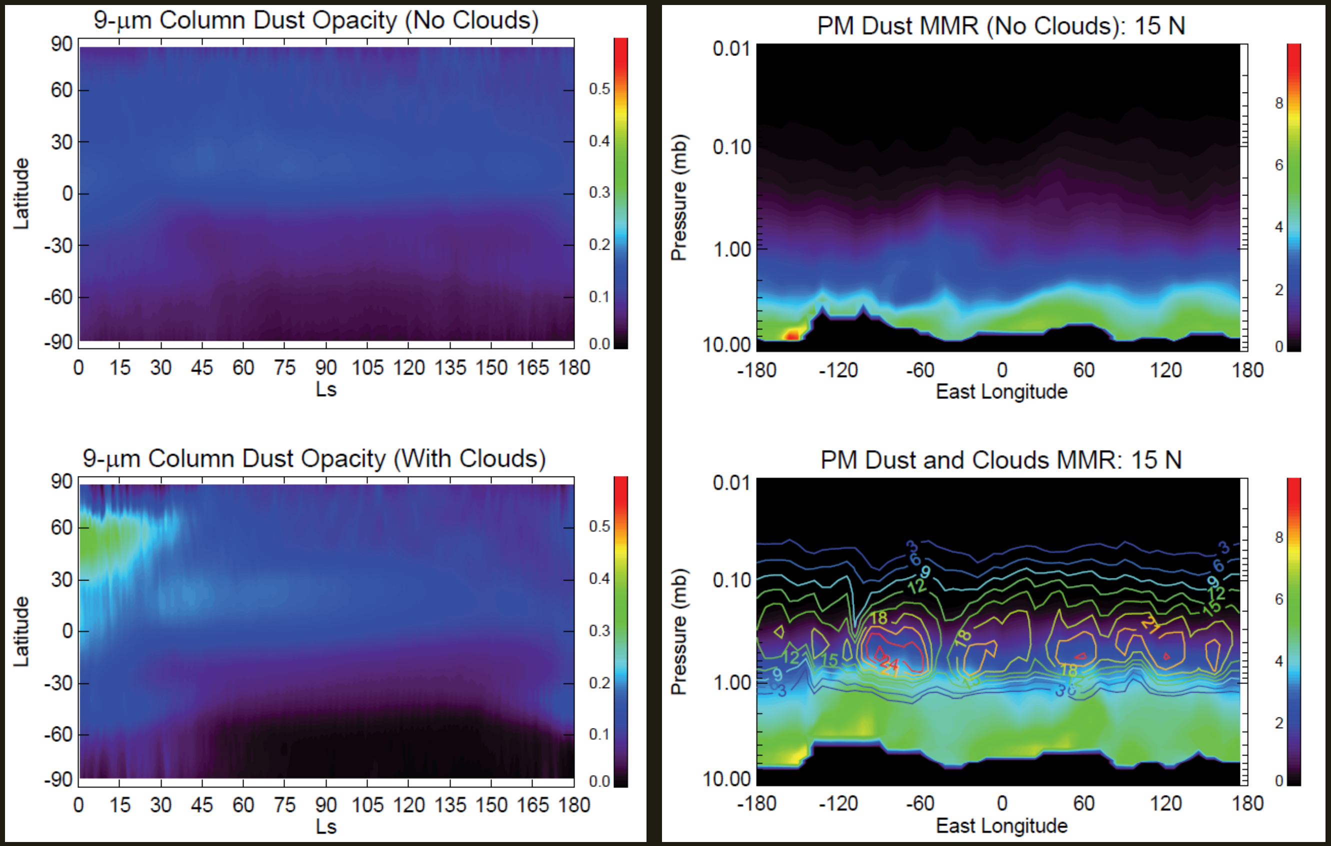
[*Guzewich et al.*, 2014]

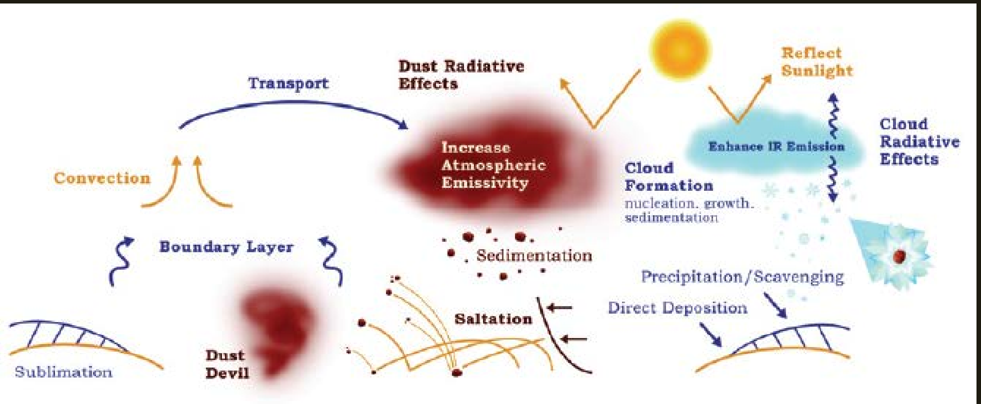
- Distributions of different particle sizes of water ice and dust are detected from the observational data.

Effect of water ice clouds on the dust distributions

Simulations of dust distributions without (upper) and with (lower) water clouds

[*Kahre et al.*, 2014]

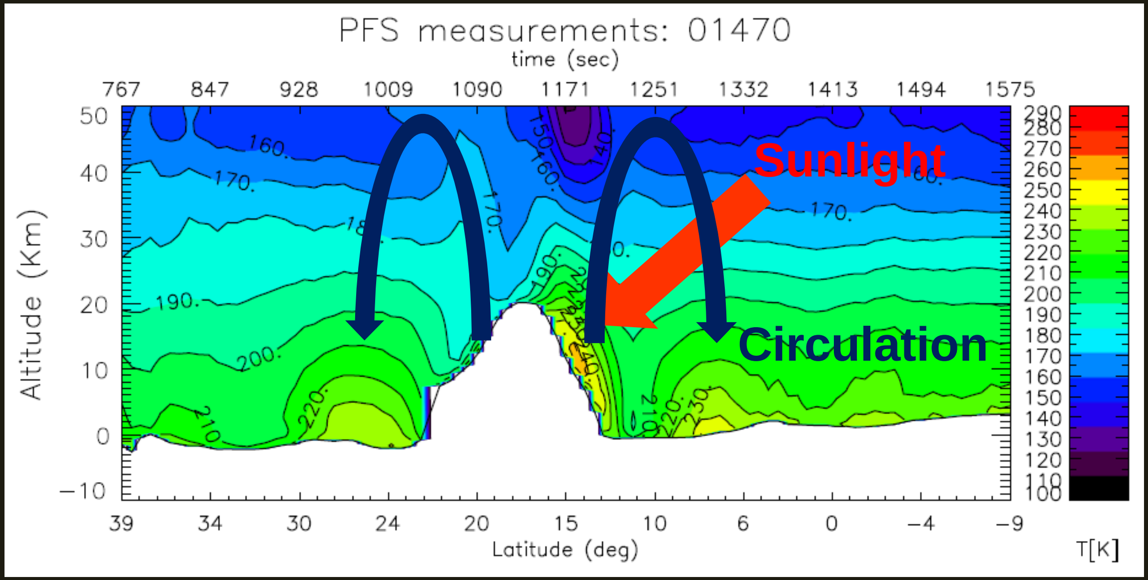


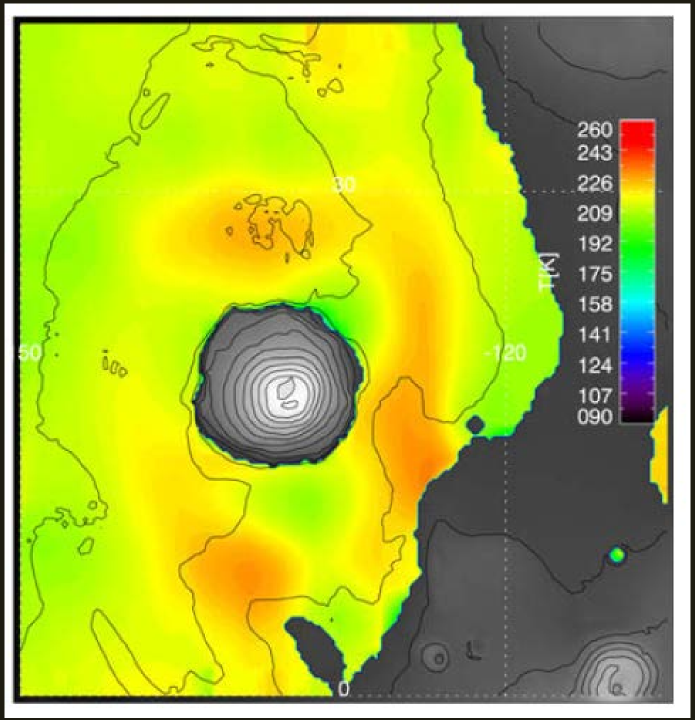


- Water ice clouds enhance the circulation, not only by their radiative effects but also by contributions to change of the distributions of dust.

Atmospheric temperature over and around Olympus Mons: MEx-PFS observation

2km-altitude daytime temperature





[*Wolkenberg et al.*, 2010]

- Observed temperature fields over and around Olympus Mons indicate the atmospheric circulations around the mountain.

Future prospects

Meteorological features of smaller scale (mesoscale) are becoming more and more important!

- Katabatic flows, conio-cumulonimbus (rocket dust storm), etc. due to topographic effects, convections, etc…
- Such small-scale features, as well as the microphysics and radiative effects of water ice clouds, affect the distributions of dust which strongly connects to the thermal features and circulations of atmosphere.
- Gravity waves, though I didn’t mention in this talk, are also generated by such small-scale features.

Supposed approaches

- More observations especially targeting the boundary layers (remote sensing, radio occultation, from landers)
- Supports by GCMs with higher resolution