Symposium on Planetary Science 2015,
2015/02/17, Tohoku Univ.

Research with modeling of planetary atmosphere at MPS since 2004

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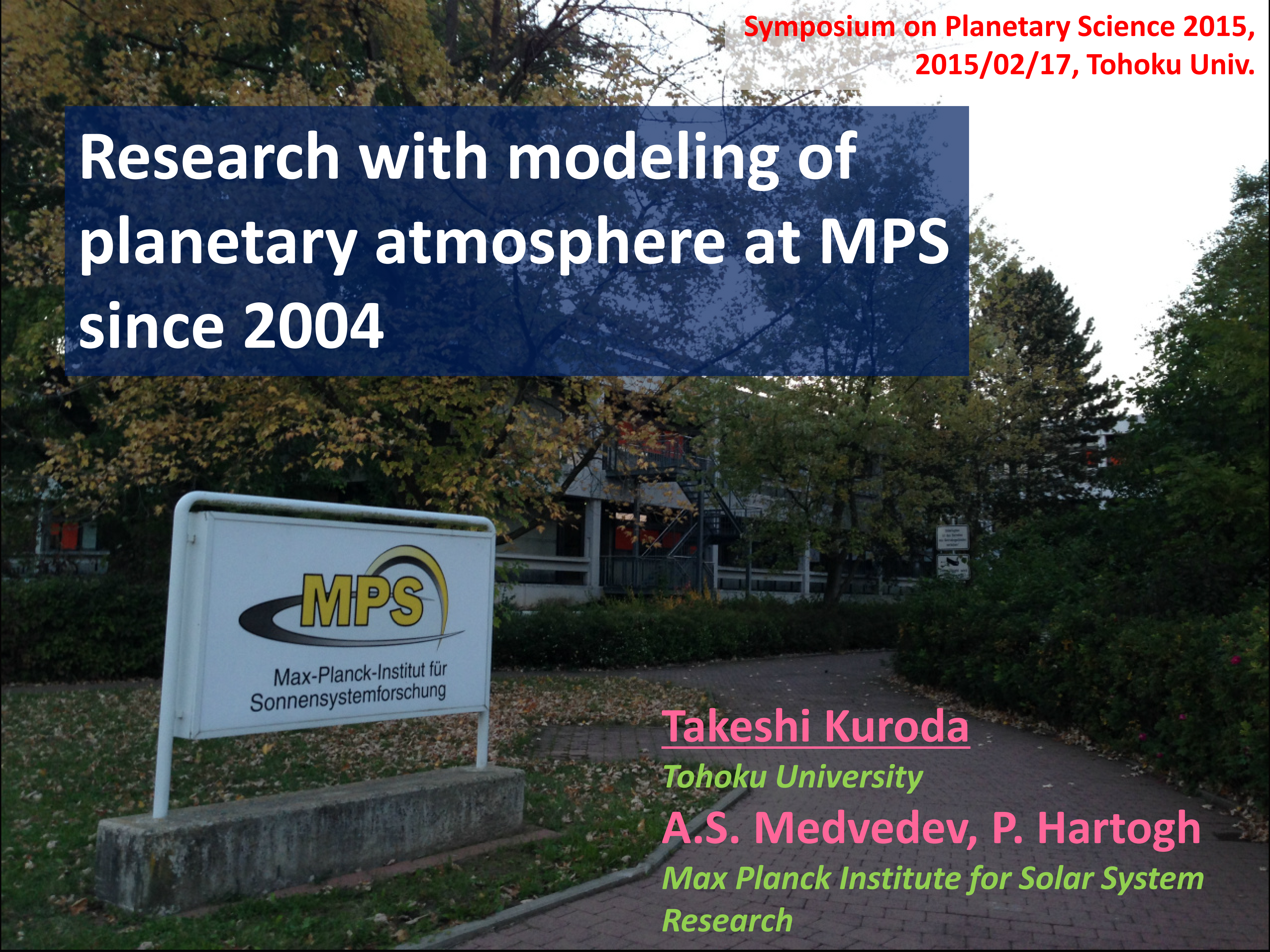
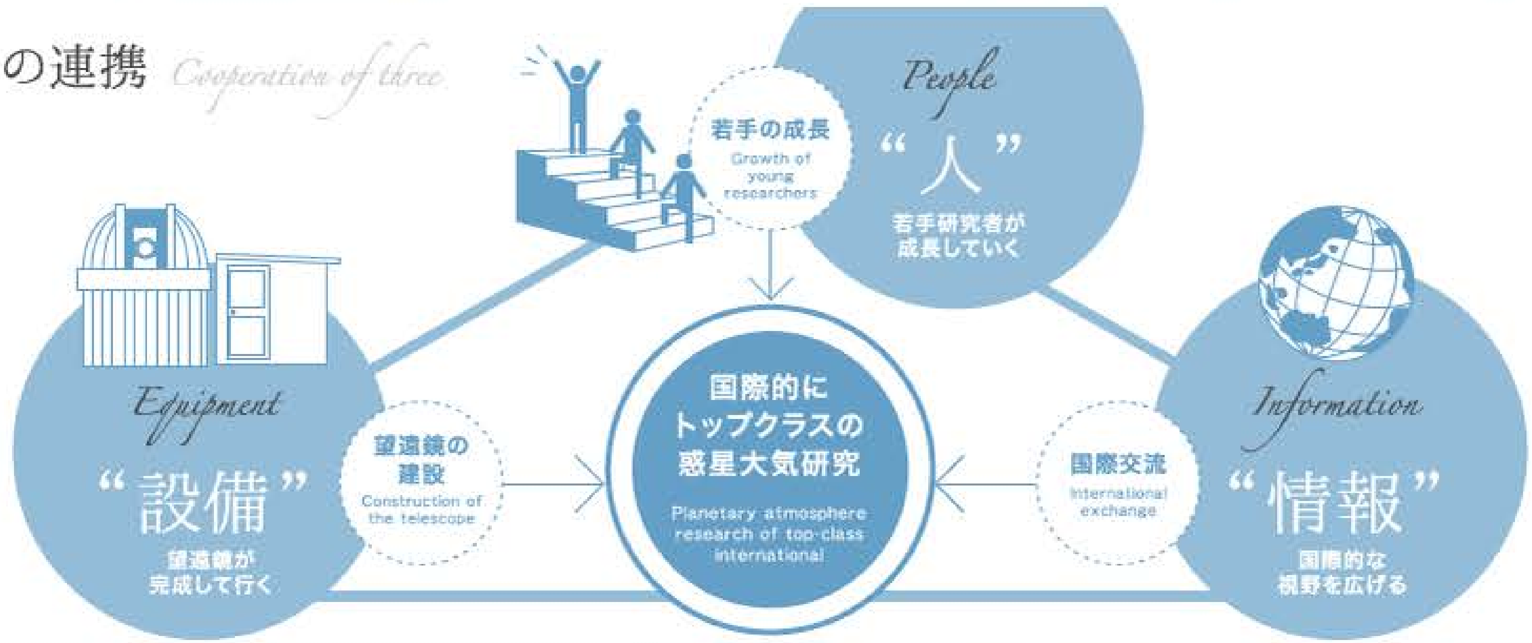


Promotion of the strategic research program for overseas assignment of young scientists and international collaborations

Intensification of international collaborations for planetary plasma and atmospheric dynamics research based on the Hawaiian planetary telescopes

Planetary and Space Physics Group
Graduate School of Science Tohoku University, Japan

3つの連携 *Cooperation of three*



About MPS

- The name of institute used to be 'Max Planck Institute for Aeronomy (MPAE)', and changed to 'Max Planck Institute for Solar System Research (MPS)' from 1 July 2004.
- Science sections now available are:
  - Sun and Heliosphere
  - Planets and Comets
  - Physics of the Interior of the Sun and Sun-like Stars (New from 2011)




Start to work at MPS

- Kuroda started to work at MPAE in April 2004, entering the 'International Max Planck Research School' (IMPRS) which accepts Ph.D. students from all over the world.
- Medvedev started to work at MPAE in June 2004.
- Then the institute was in Katlenburg-Lindau (now moved to Goettingen).
- We joined the team of Dr. P. Hartogh, which covers the remote sensing and atmospheric science.

MAOAM
Martian Atmosphere Observation And Modeling
Max Planck Institut für Aeronomie

MAOAM project

MAOAM = Mars Atmosphere Modeling And Observation

- Started in April 2002
- Project of the development of a Mars General Circulation Model (MGCM) which covers from surface to thermosphere, related to the planned sub-millimeter observations of Martian atmosphere
- Members (in 2004):
  - Dr. Paul Hartogh (PI)
  - Dr. Alexander S. Medvedev (Atmospheric modeling)
  - Dr. Christopher Jarchow (Data retrieval)
  - Geronimo Villanueva (Instrument development & modeling, now NASA Goddard)
  - Ryu Saito (Atmospheric modeling, now JAMSTEC)
  - Takeshi Kuroda (Atmospheric modeling)

MAOAM project

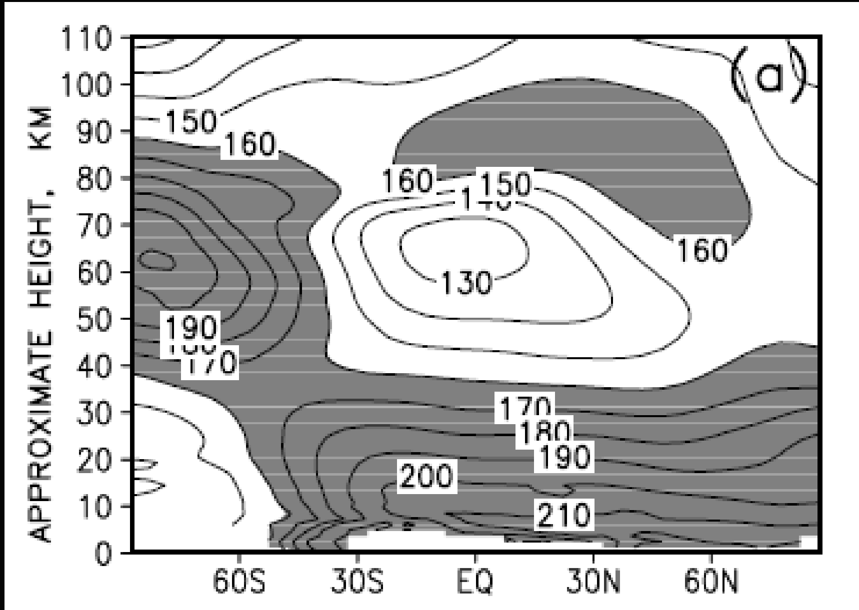
MAOAM Martian Atmosphere Observation And Modeling

Max Planck Institut für Aeronomie

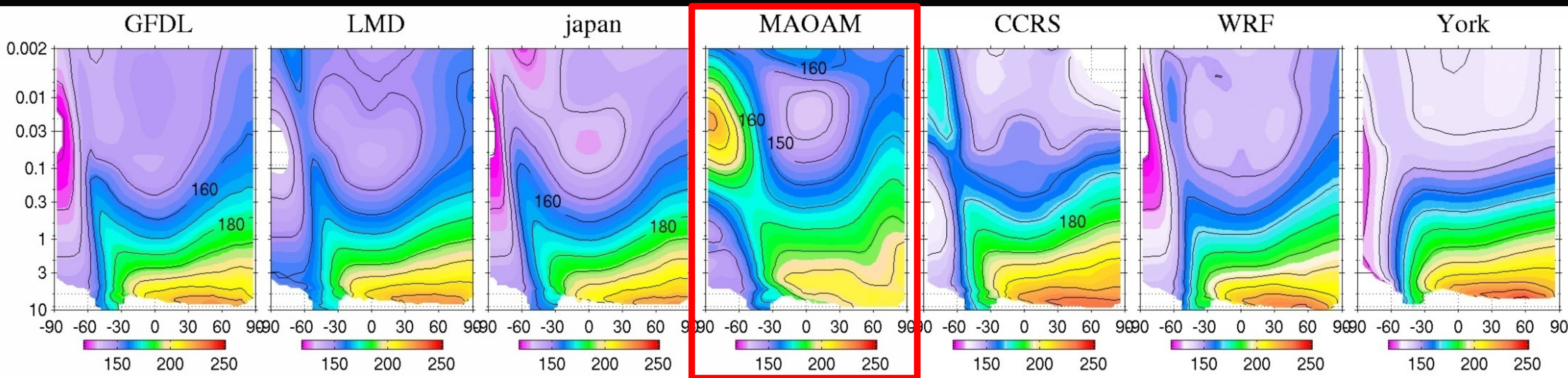
MAOAM = Mars Atmosphere Modeling And Observation

- Based on COMMA (COlogne Model of the Middle Atmosphere), from surface to ~130km height (lower thermosphere)
- New efficient non-LTE radiation scheme (A.G. Feofilov (now LMD in France) and A.A. Kutepov (now NASA Goddard))
- Kuroda's contribution: Implementation of a dust radiation scheme
- First paper was published in 2005 (Hartogh et al., JGR)

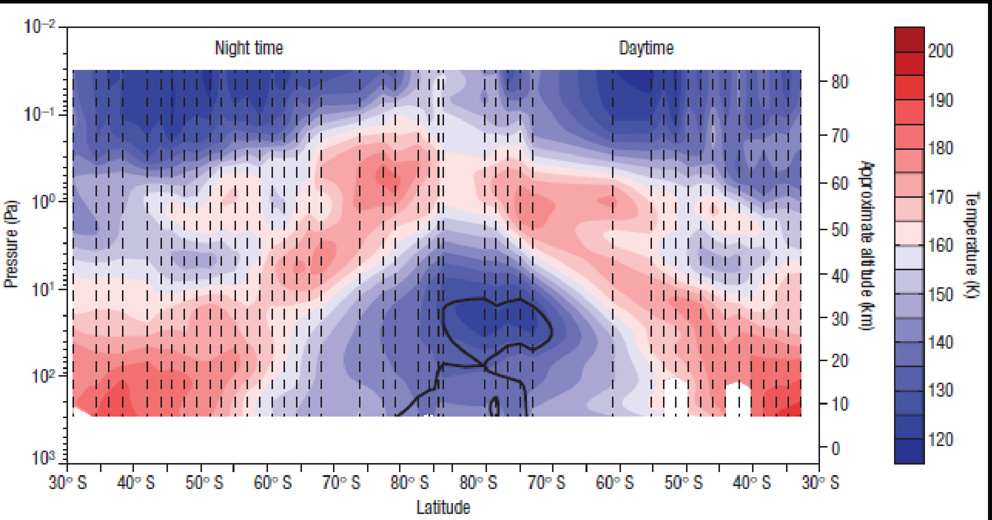
Strong polar warming produced



GCM intercomparison in 2006 (Second workshop on Mars atmosphere modelling and observations @Granada, Spain)



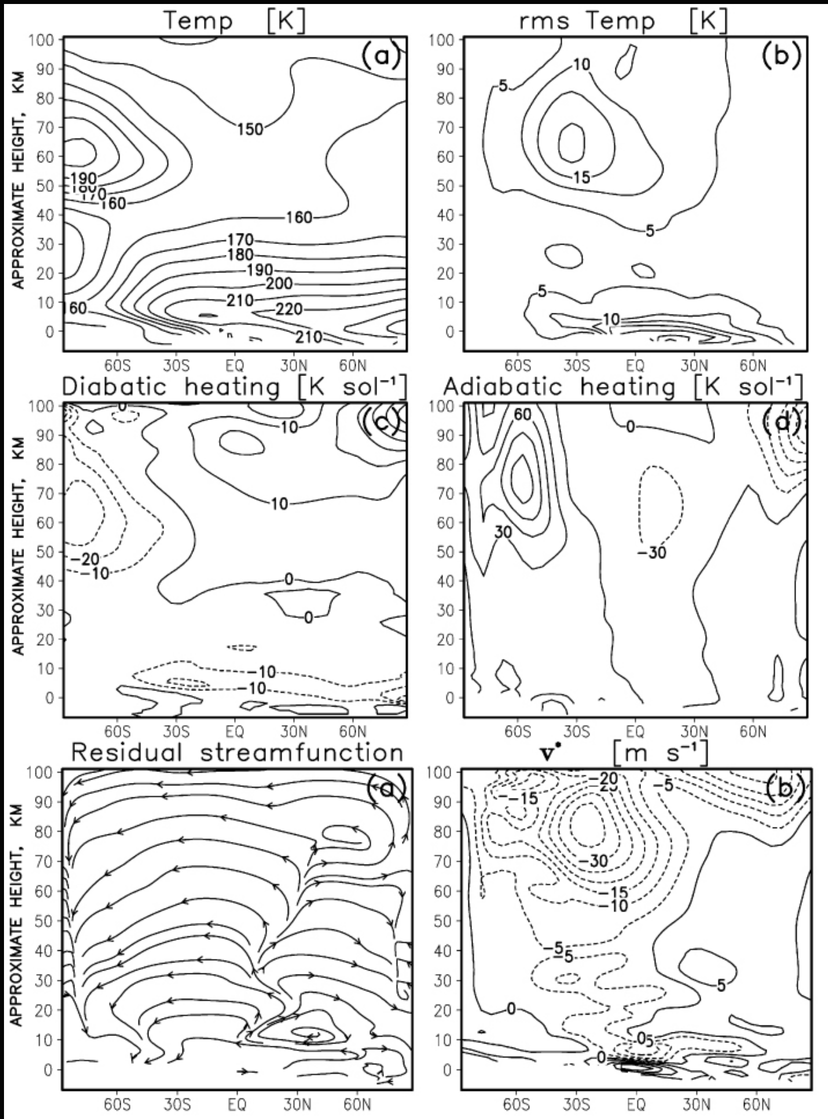
MCS observation [McCleese et al., 2008]



- Only MAOAM correctly reproduced the winter polar warming above ~60 km!

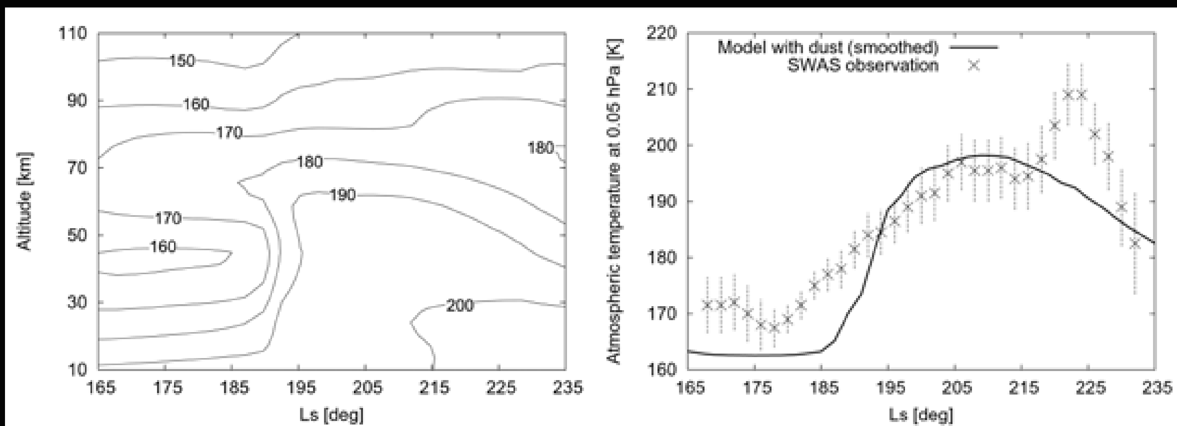
Diabatic/adiabatic heating rates and meridional transport in the middle atmosphere [Medvedev and Hartogh, 2007, Icarus]

- Winter polar warmings in the middle atmosphere of Mars occur due to the adiabatic heating associated with the downward branch of the cross-equatorial meridional circulation.
- The meridional transport is maintained primarily by dissipating large-scale planetary waves (enhanced by topography) and solar tides.



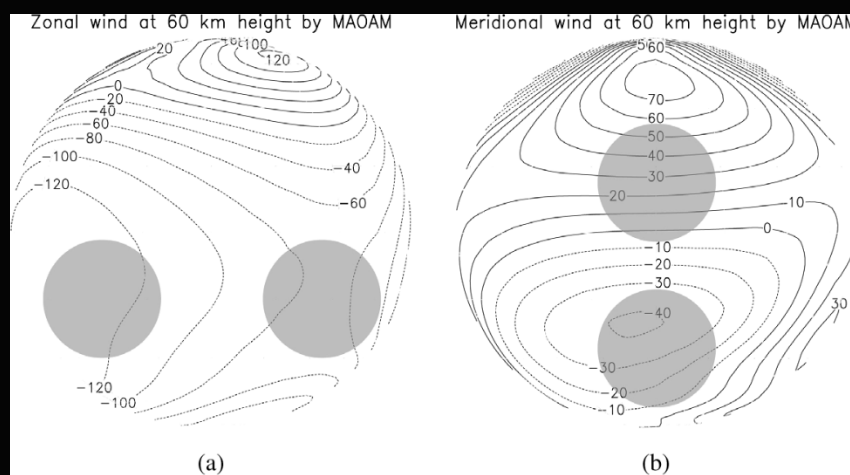
With the sub-millimeter observations

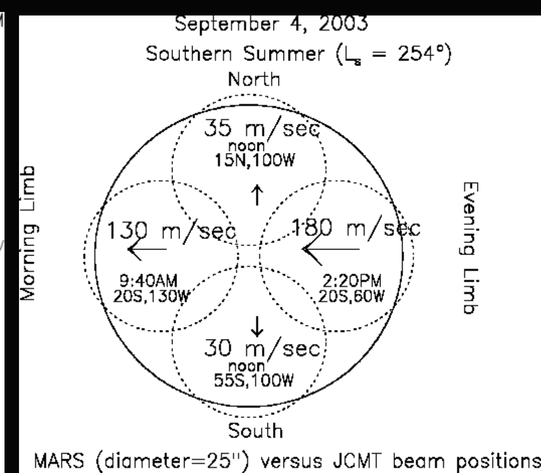
Check the numerical results by MAOAM-GCM in comparison with the available sub-millimeter observations



Change of global-mean temperature due to the 2001 global dust storm [Kuroda et al., 2006, Advances in Geosciences]

Wind velocity in ~60 km height [Kuroda and Hartogh, 2007, Advances in Geosciences]





Advantages of sub-millimeter wavelengths in the observations of Martian atmosphere

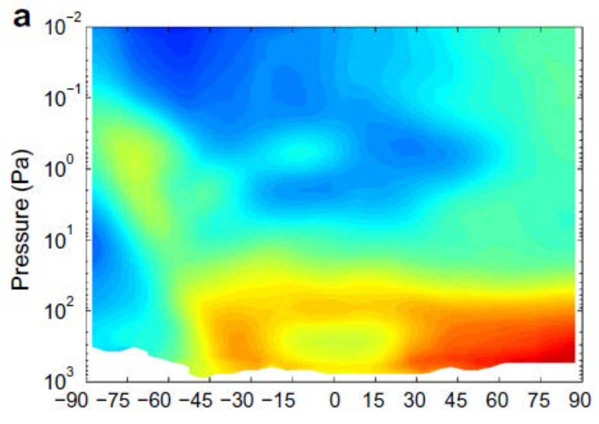
1. Easy retrieval

Radiative transfer calculations are simple, because the direct scattering and emission by Martian dust are negligible due to the small particle sizes (~2 μm) relative to the observing wavelength.

2. Up to higher altitude

It can probe temperatures from the surface to greater than 80 km in altitude, typically higher than other retrieval methods. (up to ~40 km by MGS-TES nadir, ~60 km by MGS-TES limb)

Later MRO-MCS succeeded in the mapping of temperature up to ~80 km (0.01 Pa), but the sub-millimeter observation is possible to make the mapping in even higher altitudes.



[Heavens et al., 2010]

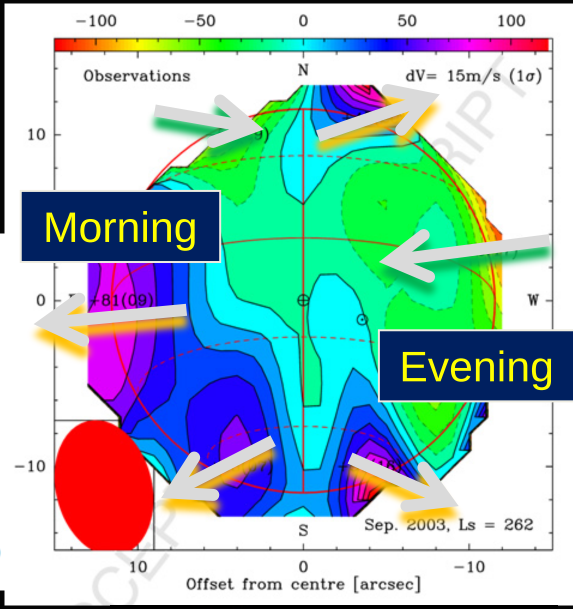
3. Direct observation of the wind

Winds can be retrieved from Doppler shifts detected on the rotational lines of CO.

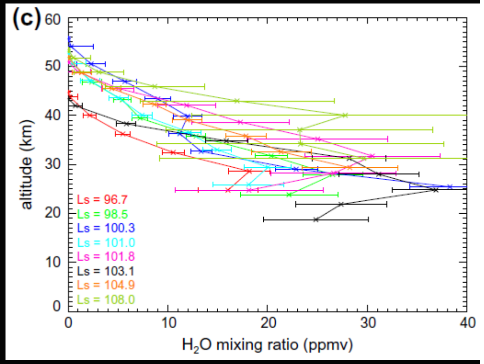
4. Detection of the vertical profiles of water vapor

Detection of hygropause (cut-off height of water vapor) shows the hint of global transport of water.

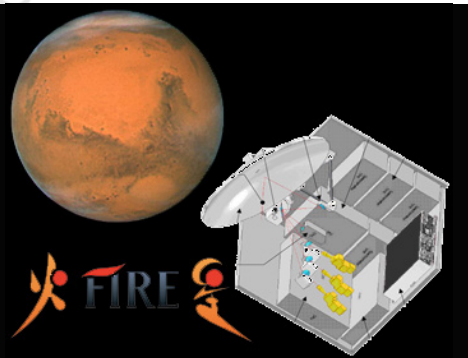
Doppler wind plot at the height of ~50km by PdBI telescope [Moreno et al., 2009], but the horizontal/ vertical resolution is low from ground-based.



Vertical profiles of water vapor detected by SPICAM [Maltagliati et al., 2013], but the continuous mapping is difficult with the solar occultation.



→ International proposal of Sub-millimetre Sounder FIRE (Far-InfraRed Experiment) (2008-) [Kasai et al., 2012, PSS]



Use of the Japanese MGCM

DRAMATIC MGCM [Kuroda et al., 2005, J.Meteor.Soc.Jpn]

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

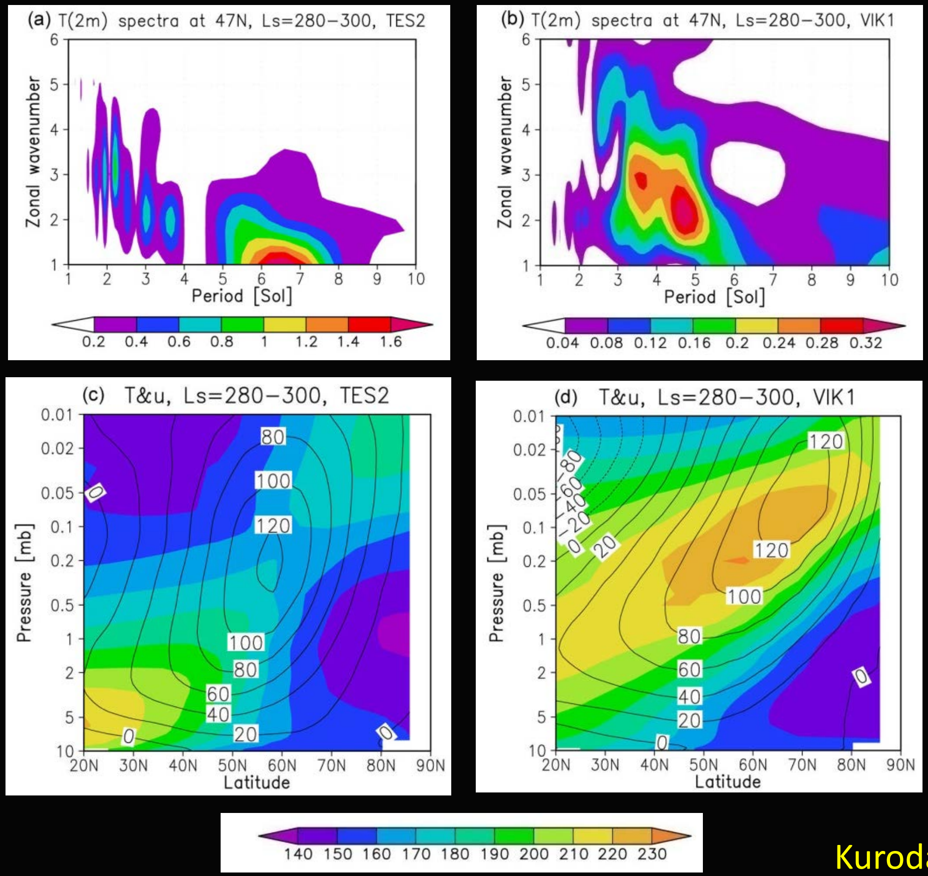
Dynamical core	CCSR/NIES/FRCGC AGCM 5.7b (MIROC) 3-dimensional primitive equations, spectral solver
Resolutions	Horizontal resolution of ~5.6° × 5.6° (grid interval of ~333km at the equator) 30 layers with σ levels, the top is at ~80km.
Surface parameters	Realistic topography, albedo, and thermal inertia
Radiation	CO_2: Absorption and emission in the infrared wavelength (15μm, 4.3μm) and near-infrared solar absorption Dust: Absorption, emission and scattering in 0.2-200μm

Studies of atmospheric dynamics with DRAMATIC MGCM

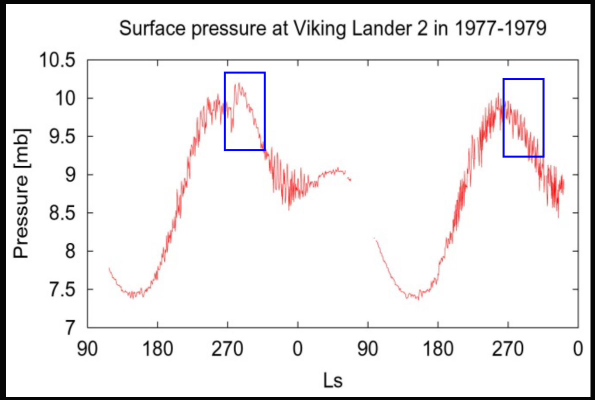
Baroclinic waves [Kuroda et al., 2007, GRL]

Simulated changes of the spectral decomposition near the surface and zonal-mean fields in Ls=280˚-300˚

τ~0.2 τ~4.2



observations by Viking Lander 2
(47.97˚ N, 225.74˚ W)



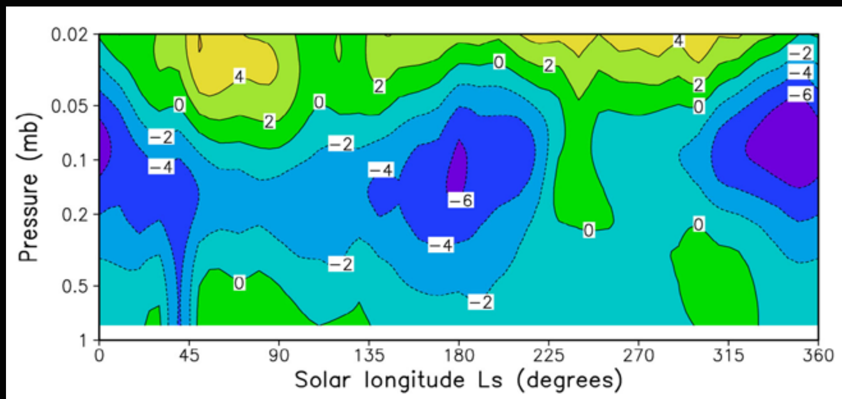
[*Barnes*, 1980, 1981]

- Due to the global dust storm in northern winter, the wave amplitudes are significantly smaller and dominant zonal wavenumber is larger, which agree with the Viking Lander 2 data.
- Stabilized atmospheric fields and weaker vertical wind shear cause the changes above.

Kuroda et al., *GRL* **34**, doi:10.1029/2006GL028816 (2007)

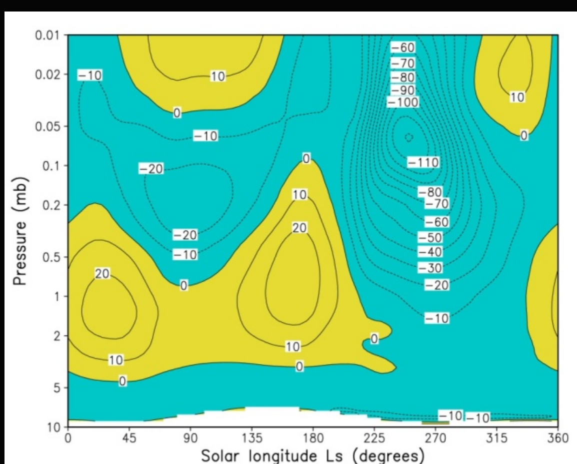
Semi-annual oscillations [Kuroda et al., 2008, GRL]

MGS-TES limb measurements of the difference of temperature between day and night (T_{2pm}-T_{2am}),during MY24-25, 10˚S-10˚N averaged

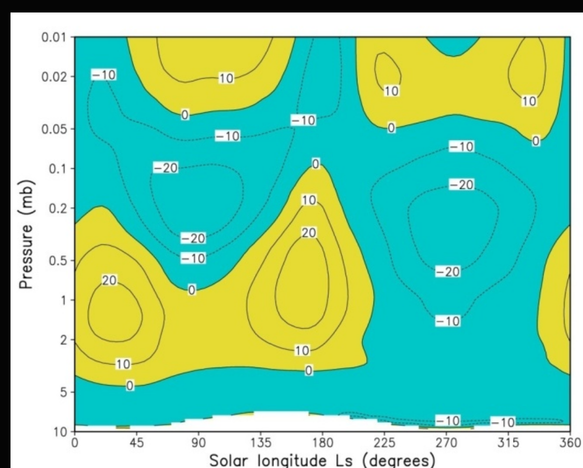


Zonal-mean zonal wind in MGCM, 10˚S-10˚N averaged
(TES2 dust scenario)

τ~ 0.2 1.0



Uniform τ~0.2



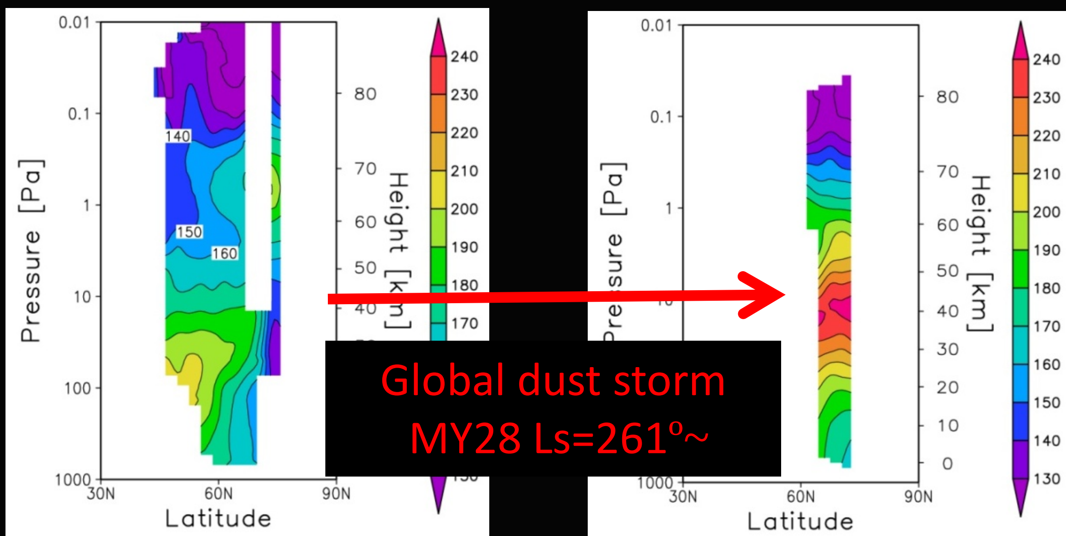
- MGS-TES data shows a clear semi-annual signal in the thermal tide amplitude above equatorial region, and it is consistently reproduced in the MGCM.
- MGCM showed that the thermal tide drives the semi-annual oscillation of zonal wind as known in terrestrial strato- and mesosphere.
- Dust affects to accelerate the easterly wind above the equatorial region, by strengthening the meridional circulation.

Kuroda et al., *GRL* **35**, doi:10.1029/2008GL036061 (2008)

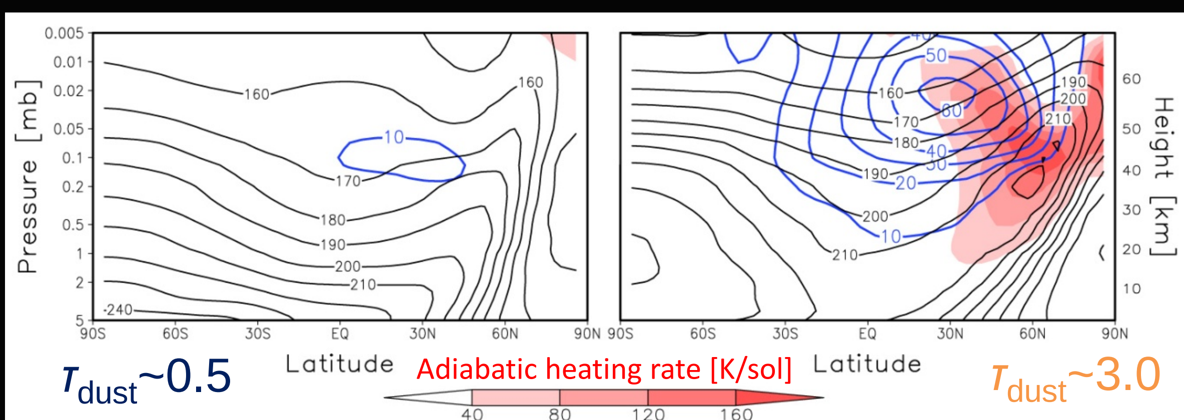
Winter polar warming due to global dust storm [Kuroda et al., 2009, J.Meteor.Soc.Jpn]

Daytime temperature

Ls=260° Ls=270°



Simulated temperature and meridional wind for Ls=270



- MRO-MCS observed a strong polar warming due to a global dust storm, which the temperature at ~40km height above the North Pole increases in 60-70 K.
- MGCM showed that it is due to a strong adiabatic heating which relates to the strong meridional transport to the winter pole and the dissipation of eddies (thermal tides, stationary waves, gravity waves).

Kuroda et al., *J. Meteor. Soc. Japan* **87**, 913-921 (2009)

Review paper published

Aeolian Research 3 (2011) 145–156

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Review Article

Influence of dust on the dynamics of the martian atmosphere above the first scale height

Alexander S. Medvedev [a,*], Takeshi Kuroda [a,b], Paul Hartogh [a]

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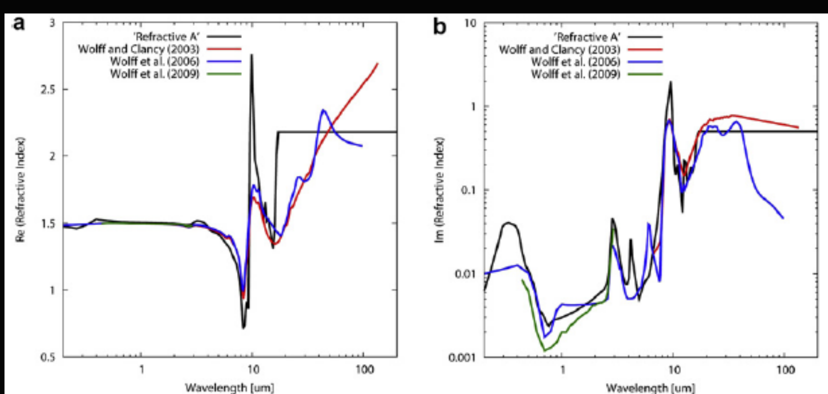
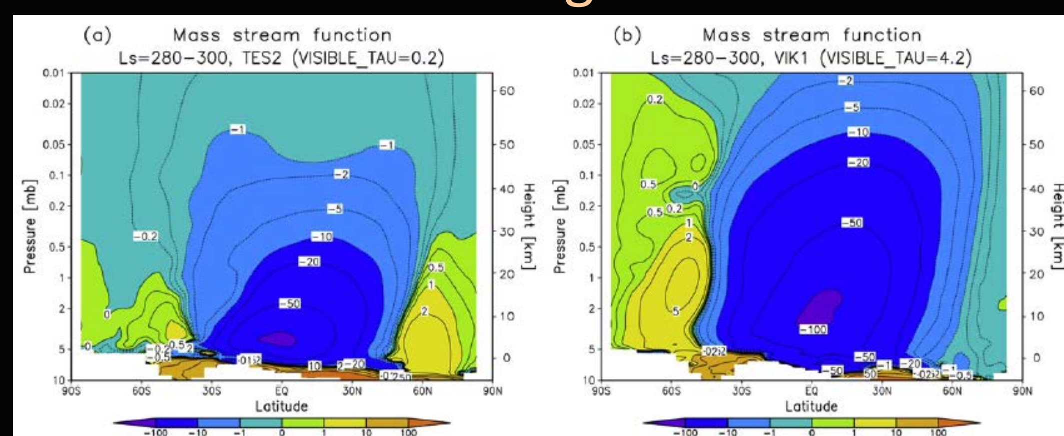
[b] Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan

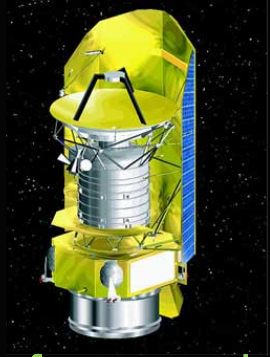
Refractive index of dust



Dust storm changes circulation



For the observations by Herschel Space Observatory



- Operated in 2009-2013
- 'Water and related Chemistry in the Solar System' (PI: Hartogh) was a key program

Preparative study of expected spectra with MAOAM-GCM [Kuroda et al., 2009, Advances in Geosciences]

Mars observation [Hartogh et al., 2010, A&A]

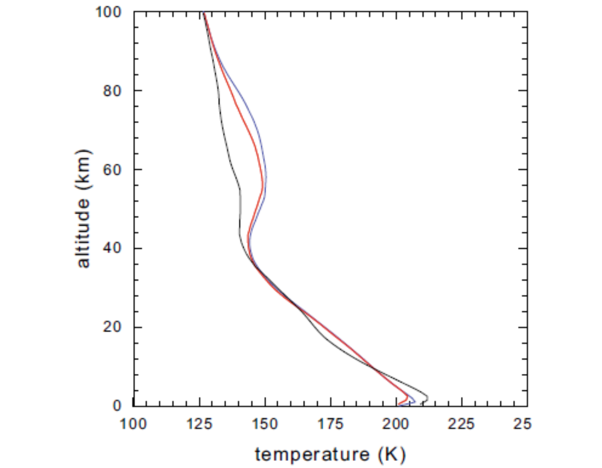


Fig. 1. Temperature profiles predicted by EMCD (blue) (Forget et al. 1999; Lewis et al. 1999), MAOAM (red) (Hartogh et al. 2005; Medvedev & Hartogh 2007), and retrieved vertical profile from simultaneous observations of ^{13}CO and $C^{18}O$.

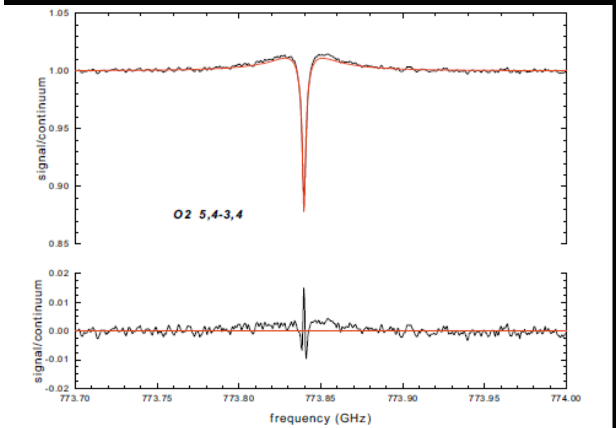
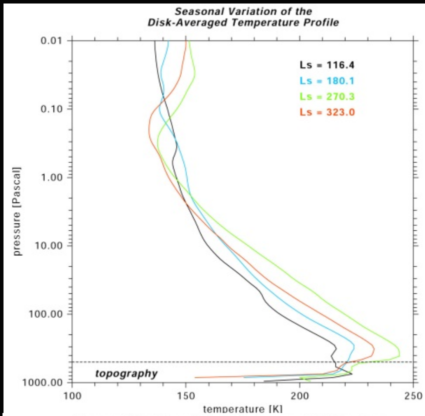
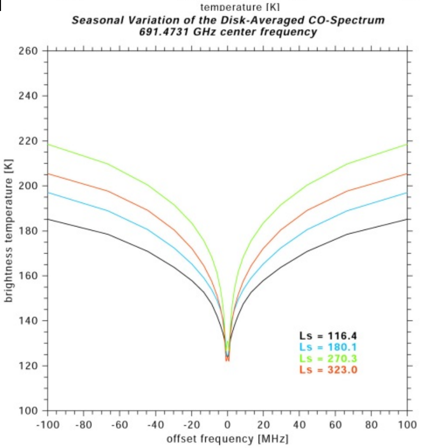


Fig. 4. Observation of O_2 at 774 GHz. The best fit of a constant altitude profile infers a volume mixing ratio of 1400±120 ppm. *The lower panel* shows the difference between observation and model.

Simulated global-mean temperature by MAOAM



Simulated global-mean spectra (691 GHz)

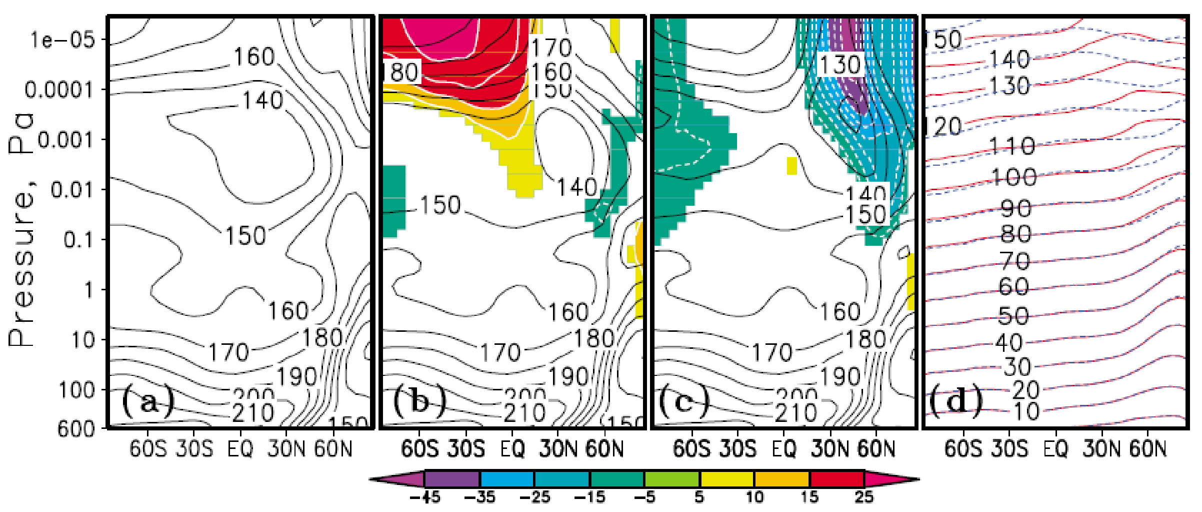


Works in 2010s

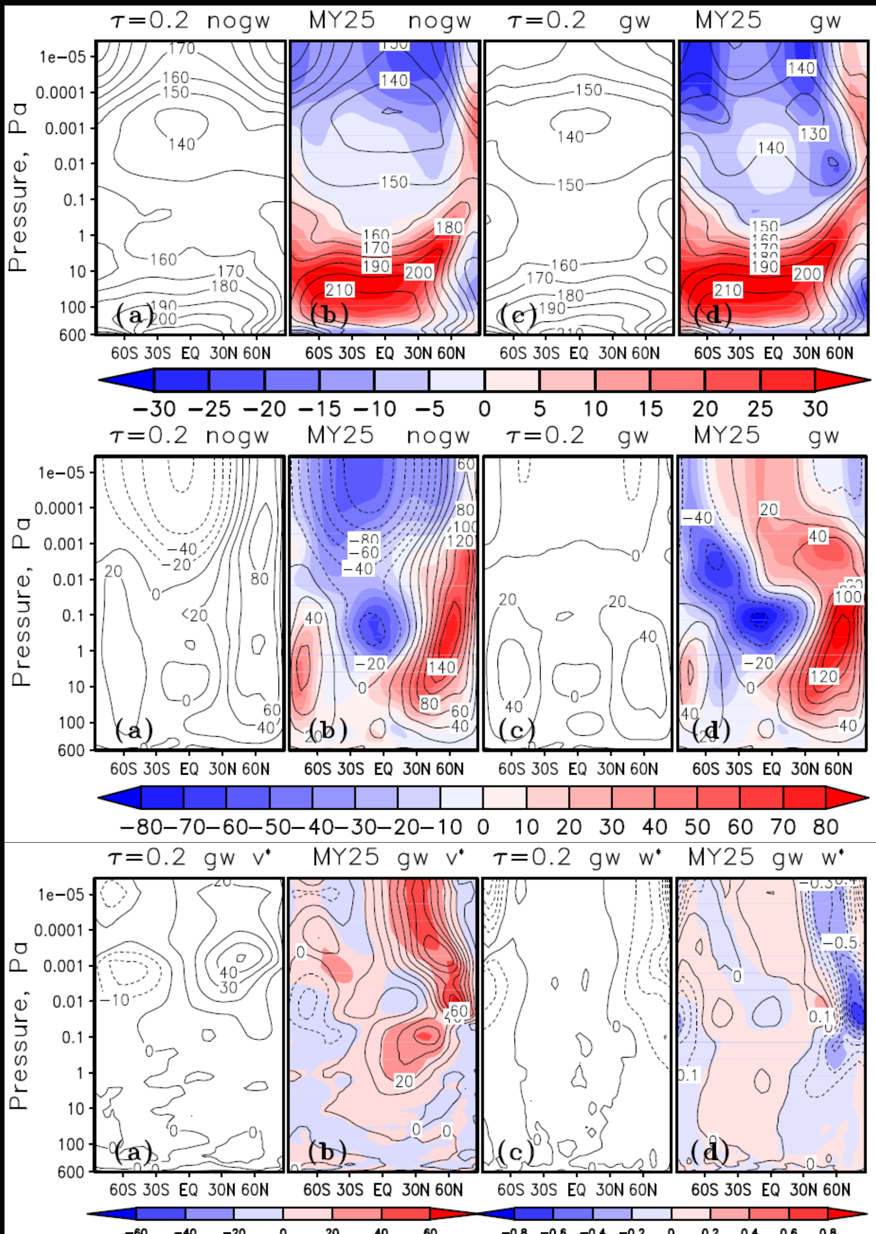
New MAOAM-GCM [Medvedev et al., 2011, JGR; Medvedev and Yigit, 2012, GRL; Medvedev et al., 2013, JGR]

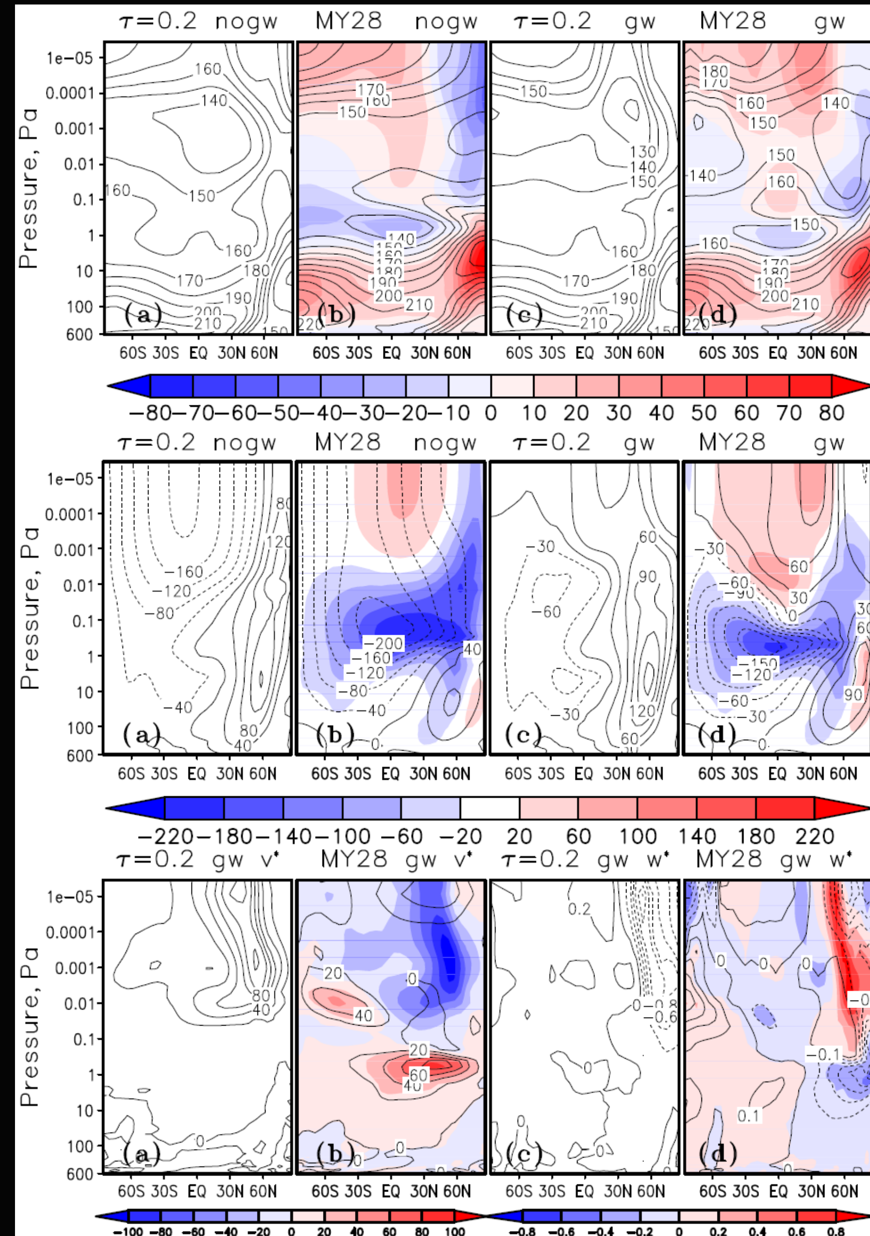
- New dynamical core of Kühlungsborn Mechanistic General Circulation Model (KMCM) with spectral solver
- Horizontal resolution of ~5.6° × 5.6°, 67 hybrid vertical levels up to 150-160 km
- EUV heating is implemented
- Gravity wave drag parameterization (dynamical and thermal effects)

(a) No GW drag
(b) GW drag (only dynamical)
(c) GW drag (dynamical and thermal)
(d) Geopotential height
[Medvedev and Yigit, 2012]

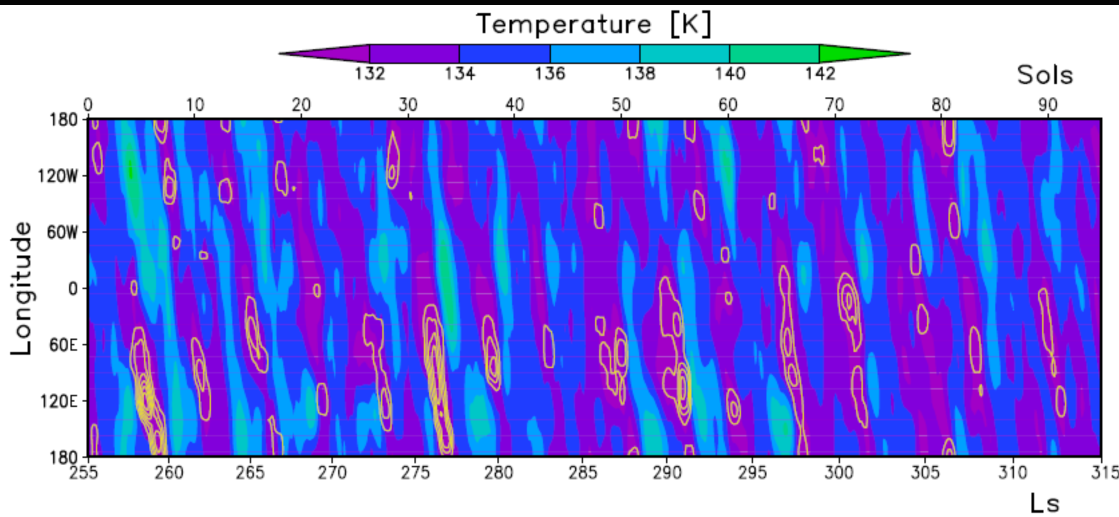


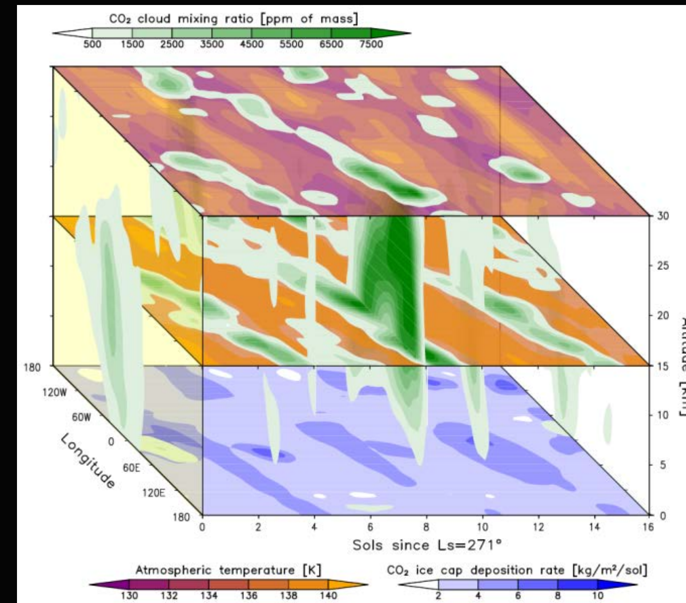
Effects of the global dust storm in MY25 and MY28 on the thermosphere [Medvedev et al., 2013]





CO_2 snowfall in DRAMATIC MGCM [Kuroda et al., 2013, GRL]





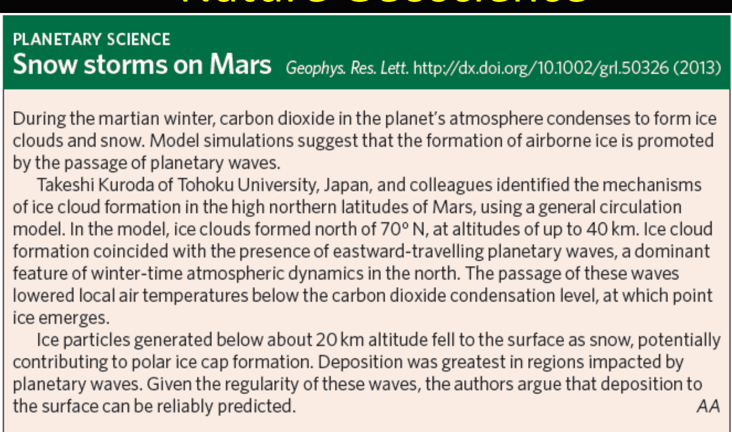
- Strong modulation of snowfall due to the planetary waves in northern winter pole was shown.

Press released by MPS! (08 May 2013)

Research Highlights, Nature Geoscience

On Asahi Shimbun, 13 May 2013

On a local TV news


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.

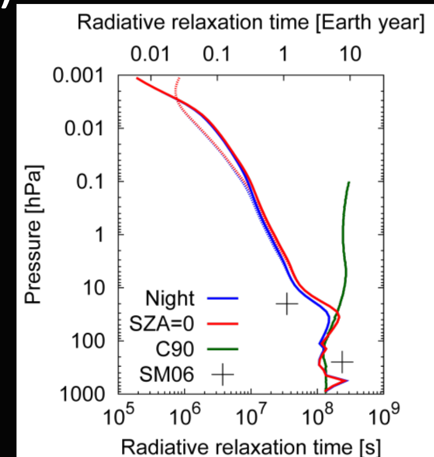
Ice particles generated below about 20 km altitude fell to the surface as snow, potentially contributing to polar ice cap formation. Deposition was greatest in regions impacted by planetary waves. Given the regularity of these waves, the authors argue that deposition to the surface can be reliably predicted.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

Jupiter GCM for JUICE/SWI

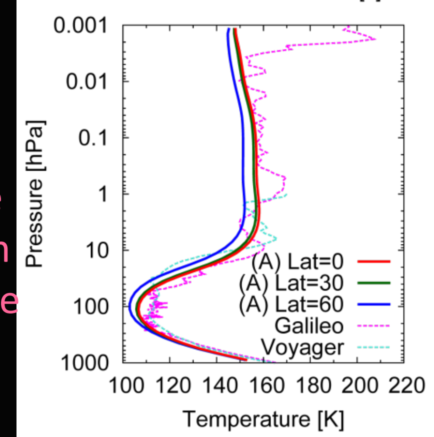
- We are developing a Jupiter stratospheric GCM which is also adoptable to Saturn and exoplanets
- Log-pressure vertical coordinate, grid model
- Development of a radiation code for Jupiter (Kuroda)
- Make higher resolution for Jupiter

Radiation code for Jupiter [Kuroda et al., 2014, Icarus]

Radiative relaxation time

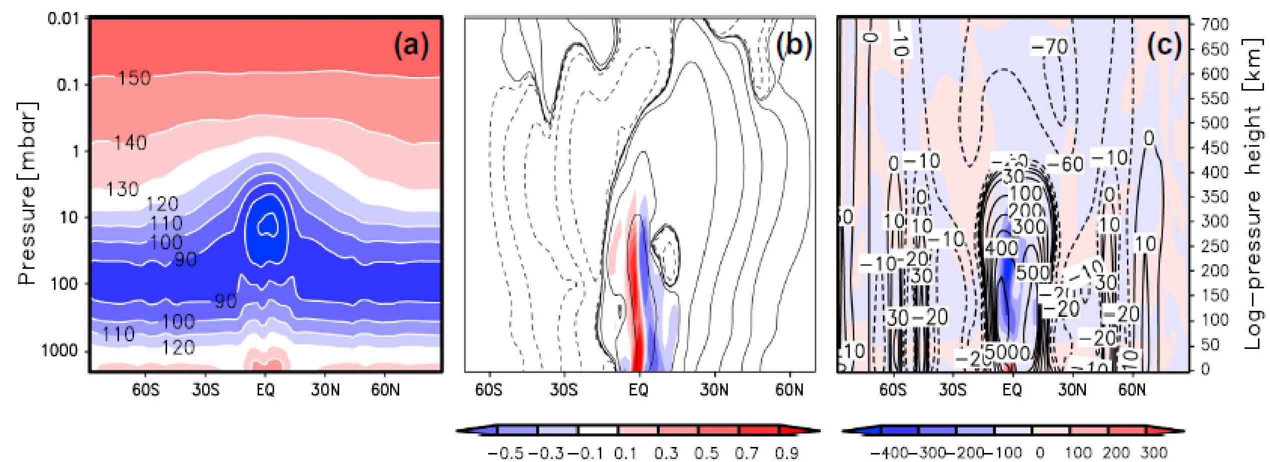


Radiative-convective equilibrium temperature



Results of Saturn-like 90×120 (4°×1.5°) grid point model [Medvedev et al., 2013, Icarus]

Temperature | Meridional/vertical circulation | Zonal wind and its acceleration



Summary

- We developed a Mars GCM which targets up to the thermosphere, and recently we are having publications which precede the dynamics of upper atmosphere.
- Also using Kuroda's MGCM developed in Japan, we have made number of publications about the dynamics and CO_2 snowfall.
- Moreover, we have an emphasis on the simulation of gas giants for the future JUICE mission.

Welcome to the new MPS and our group! Also new Ph.D. students are welcome! (http://solar-system-school.de)