CPS 6th International School of Planetary Sciences

Planetary Atmospheres

--- Sisters, relatives and ancestors of our own

January 4-9, 2010

Hotel Seapal Suma, Kobe, Japan

# CPS 6th International School of Planetary Sciences Planetary Atmospheres --- Sisters, relatives and ancestors of our own

January 4-9, 2010, Hotel Seapal Suma, Kobe, Japan

Hosted by
Center for Planetary Science (CPS) under the Global COE Program: "Foundation of International Center for Planetary Science", a joint project between Kobe University and Hokkaido University.

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**Monday, January 4, 2010**

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|---|---|
| 15:00 | Registration Open |
| 19:00 - 20:00 | Welcome Drink Service at Lecture Hall |
| 20:00 - 21:00 | Dinner |

**Tuesday, January 5, 2010**

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|---|---|
| 7:30 - 9:00 | <Breakfast> |
| 9:00 - 9:15 | **Opening Keynote Speech**: Yushitsugu Nakagawa |
| 9:15 - 10:30 | **Lecture 1-1**: Peter L Read<br>*Climate and atmospheric circulation of the Mars (1)* |
| 10:30 - 10:50 | <Coffee/Tea Break> |
| 10:50 - 12:10 | **Lecture 1-2**: Peter L Read<br>*Climate and atmospheric circulation of the Mars (2)* |
| 12:30 - 13:30 | <Lunch> <Coffee> |
| 14:00 - 15:15 | **Lecture 2-1**: Francois Forget<br>*Martian Climate: from the Past to the Present (1)* |
| 15:15 - 15:45 | <Coffee/Tea Break> |
| 15:45 - 17:00 | **Lecture 2-2**: Francois Forget<br>*Martian Climate: from the Past to the Present (2)* |
| 18:00 - 19:00 | <Dinner> |
| 19:00 - 21:00 | **Poster 1** |

**Wednesday, January 6, 2010**

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|---|---|
| 7:30 - 9:00 | <Breakfast> |
| 9:00 - 10:10 | **Lecture 3-1**: Yoshihisa Matsuda<br>*Dynamics of the super-rotation of Venus atmosphere (1)* |
| 10:10 - 10:30 | <Coffee/Tea Break> |
| 10:30 - 11:30 | **Lecture 3-2**: Yoshihisa Matsuda<br>*Dynamics of the super-rotation of Venus atmosphere (2)* |
| 11:30 - 11:50 | <Coffee/Tea Break> |
| 11:50 - 12:30 | **Lecture 4**: Takeshi Imamura<br>*Planned Observation by Venus Climate Orbiter* |
| 12:30 - 13:30 | <Lunch> |
| 13:30 | <Photo> |

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|---|---|
| 14:00 - | <Excursion> |

**Thursday, January 7, 2010**

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|---|---|
| 7:30 - 9:00 | <Breakfast> |
| 9:00 - 10:15 | **Lecture 5-1**: Dimitri Titov<br>*Past and Future of Venus Exploration (1) (tentative)* |
| 10:15 - 10:45 | <Coffee/Tea Break> |
| 10:45 - 12:00 | **Lecture 5-2**: Dimitri Titov<br>*Past and Future of Venus Exploration (2) (tentative)* |
| 12:30 - 13:30 | <Lunch> <Coffee> |
| 13:30 - 14:45 | **Lecture 6**: Kensuke Nakajima<br>*Structure of Moist Convection in Planetary Atmosphere* |
| 14:45 - 15:15 | <Coffee/Tea Break> |
| 15:15 - 16:30 | **Lecture 7-1**: Tapio Schneider<br>*Principles of planetary circulations, from Earth to Neptune (1)* |
| 16:30 - 16:45 | <Coffee/Tea Break> |
| 16:45 - 18:00 | **Lecture 7-2**: Tapio Schneider<br>*Principles of planetary circulations, from Earth to Neptune (2)* |
| 18:30 - 19:30 | <Dinner> |
| 19:30 - 21:00 | **Poster 2** |

**Friday, January 8, 2010**

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|---|---|
| 7:30 - 9:00 | <Breakfast> |
| 9:00 - 10:15 | **Lecture 8-1**: Yutaka Abe<br>*How to make a Habitable Planet (1)* |
| 10:15 - 10:45 | <Coffee/Tea Break> |
| 10:45 - 12:00 | **Lecture 8-2**: Yutaka Abe<br>*How to make a Habitable Planet (2)* |
| 12:30 - 13:30 | <Lunch> <Coffee> |
| 13:30 - 14:45 | **Lecture 9-1**: Kevin Zahnle<br>*Origin and Evolution of Planetary Atmospheres (1)* |
| 14:45 - 15:15 | <Coffee/Tea Break> |
| 15:15 - 16:30 | **Lecture 9-2**: Kevin Zahnle<br>*Origin and Evolution of Planetary Atmospheres (2)* |
| 19:30 - 21:30 | <Banquet> |

**Saturday, January 9, 2010**

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|---|---|
| 7:30 - 9:00 | <Breakfast> |
| 9:00 | <Adjourn> |

Poster 1-2 (All posters will be on display Monday-Friday)

**P-01 ANDO Hiroki**
The observation of the lunar ionosphere by the dual-spacecraft radio occultation method

**P-02 ARI Ginaldi**
Vertical and Surface Carbondioxide Observation at LAPAN INDONESIA

**P-03 BARATOUX David**
Martian volcanic rocks: signature of planetary evolution

**P-04 BARSTOW Joanna**
Determining vertical cloud structure on Venus using near-infrared spectroscopy

**P-05 CHOI David**
The Meteorology of Giant Planets Revealed Through Automated Cloud Feature Tracking

**P-06 FATHRIO Ibnu**
Study of MJO Phenomena using atmospheric Radar, Optical Long wave Radiation (OLR) and Tropical Rainfall Measurement Mission (TRMM)

**P-07 HEINZELLER Dominikus**
CEPD - Chemical Evolution of Protoplanetary Disks

**P-08 ISHIWATARI Masaki**
DCMODEL: Hierarchical models for geophysical fluid dynamics and planetary atmospheres

**P-09 IWAYAMA Takahiro**
Green's function for a generalized two-dimensional fluid

**P-10 KATO Ryohei**
Numerical modeling of large-scale vortices in Jupiter's atmosphere

**P-11 KOUYAMA Toru**
Horizontal structures of planetary-scale waves at the cloud top deduced from Venus cloud images

P-12 KURAMOTO Kiyoshi

Stratospheric CO2 ice cloud greenhouse for sporadic warming of early Mars

P-13 KUROKAWA Hiroyuki

Atmospheric Structures of Ocean Planets:a Study of Mechanisms to Determine Inner Edge of Habitable Zone

P-14 LI Yanjie

Generalized Nonlinear Subcritical Moist Symmetric Instability

P-15 LOLACHI Ramin

Preliminary Vertically Resolved Martian Atmospheric Water Vapour Radiance Analysis with Mars Climate Sounder

P-16 MENDONCA Joao

New results from the Oxford Venus GCM

P-17 MURAKAMI Shin'Ya

The effect of filaments on the axisymmetrization process of the 2D elliptic vortex with non-uniform vorticity.

P-18 NODA Satoshi

Numerical Experiments of Atmospheric General Circulations on a Synchronously Rotating Planet

P-19 OGOHARA Kazunori

Favorable regions for dust storm expansion on Mars

P-20 OHTSUKI Shoko

Temporal variations of the Venus oxygen night airglow observed from ground

P-21 PICCIALLI Arianna

Zonal thermal winds in Venus mesosphere

P-22 PORTYANKINA Ganna

Retrieval simulations of the vertical profiles of water vapour and other chemical species in the Martian atmosphere using PACS

P-23 SAITO Naoaki

Interaction between Thermal Convection and Mean Flow in a Rotating System

P-24 SAYANAGI Kunio

Observation and Modeling of Saturn’s northern hemisphere Ribbon and Hexagon

P-25 **SPIGA Aymeric**
An exploration of the intense fine-scale meteorology on Mars by modeling and observations

P-26 **SUGIMOTO Norihiko**
Nonlinear interaction between vortical flows and gravity waves in geophysical fluids

P-27 **SUGIYAMA Ko-Ichiro**
Numerical Modeling of Moist Convection in Jupiter's Atmosphere

P-28 **SUN Cheng**
The relationship between Ferrel cell anomaly and annular mode in the Southern Hemisphere

P-29 **TAKAGI Masahiro**
Dynamical effects of thermal tides on the Venus atmospheric superrotation

P-30 **TAKAHASHI Yoshiyuki**
Numerical simulations of planetary atmospheres with land and the ocean by using a general circulation model

P-31 **TAKE Naoki**
Dynamics of Venus cloud observed by Venus Express / VMC

P-32 **TERAGUCHI Tomoko**
Energy transport of Venusian turbulence estimated by the VEX/VMC UV image analysis

P-33 **THRASTARSON Heidar Thor**
General Circulation Modeling of Close-in Extrasolar Planets

P-34 **WATKINS Chris**
Gravity Wave Dynamics in Hot Extrasolar Planet Atmospheres

P-35 **WOOD Richard**
A general theorem on angular-momentum changes due to potential vorticity mixing and on potential-energy changes due to buoyancy mixing

**P-36　YAMAMOTO Hiroki**

Multiple stable solutions of Boussinesq fluid primitive equations

**P-37　YAMASHITA Tatsuya**

Two-dimensional numerical experiments of Martian atmospheric convection with condensation of the major component with condensation of the major component"

**P-38　YAMAZAKI Akira**

Selective Absorption Mechanism for the Maintenance of Blocking

**P-39　ZALUCHA Angela**

An Analysis of Pluto Occultation Light Curves Using an Atmospheric Radiative-conductive Model

**P-40　ZHANG Xi**

Photolysis of H2SO4 as a source of SO2 and SO in the mesosphere of Venus

# Lecture Abstract

Planned Observation by Venus Climate Orbiter

Takeshi Imamura (JAXA)

The Venus Climate Orbiter (PLANET-C project) of Japan will be launched in May 2010 and arrive at Venus in December 2010. The aim of the mission is to understand the mechanism of the Venus' atmospheric dynamics, with secondary targets being the exploration of the ground surface and the zodiacal light observation during the cruise to Venus.

The onboard scientific instruments altogether sense different levels of the atmosphere. The deepest level will be investigated by the 1-μm Camera (IR1) at 0.90, 0.97 and 1.01 μm wavelength, which are known to be relatively absorption free (so-called atmospheric windows), enabling us to see the deep atmosphere and the ground surface through the clouds on the nightsides. In addition to the studies of cloud properties and sub-cloud H2O vapor, suspected volcanic activities will be searched for and the surface emissivity distribution will be mapped with IR1. This camera will also observe the lower cloud on the dayside. The 2-μm Camera (IR2) will observe the middle and lower atmosphere at 1.73, 2.26 and 2.32 μm wavelengths, which are also atmospheric windows. The distribution of sub-cloud CO will be studied by differentiating 2.26 and 2.32 μm images to understand the production, circulation and dissociation processes of this molecule. The cloud top is covered by the Ultraviolet Imager (UVI), which maps SO2 and unknown absorbers at wavelengths 283 and 365 nm on the dayside. The meso- to global-scale structures in the upper cloud will be mapped by the Longwave Infrared Camera (LIR) at 10 μm wavelength both on the dayside and nightside. Variations in the cloud top height will be studied also by IR2 with its 2.02-μm filter (a CO2 absorption band) applied to the dayside. The Lightning and Airglow Camera (LAC) will detect yet-to-confirm lightning in the clouds and also observe night airglows at visible wavelengths in the lower thermosphere. In addition to the imaging-camera suite above, Radio Science (RS) technique will be used to observe the vertical profiles of atmospheric temperature, sub-cloud H2SO4 vapor, and ionospheric plasma.

With these instruments dedicated to meteorological study, we are planning a systematic imaging sequence to detect meteorological phenomena with various temporal and spatial scales. The elliptical, near-equatorial orbit is suitable for obtaining successive global images to derive cloud-tracked wind vectors. Using such wind data, together with cloud and minor gas maps, the characteristics of meridional circulation, mid-latitude jets and various wave activities will be studied. Close-up images of meso-scale features and limb images will also be obtained near the periapsis.

Dynamics of the super-rotation of Venus atmosphere

Yoshihisa Matsuda

In this lecture, dynamics of the Venus atmosphere is fully discussed in the light of planetary (or geophysical) fluid dynamics. It is known that the zonal flow, which is called as "super-rotation" or "four-day circulation", predominates in the Venus atmosphere. The maximum rotational velocity of the atmosphere is 60 times as large as that of its solid part. It is strange that such fast zonal flow continues to be maintained. Moreover, this circulation is apparently in contradiction to a simple prediction as to a general circulation of Venus atmosphere, namely, the circulation between day and night sides.

In this lecture, the several mechanisms so far proposed for explaining the super-rotation are explained in detail. The validity of each mechanism is critically reexamined in the context of the knowledge obtained in recent studies. The numerical simulations of the super-rotation by GCM are recently developed. The results of the simulations are also discussed.

Climate and atmospheric circulation of Mars: Introduction and context

Peter L Read [University of Oxford]

The planet Mars is the most Earth-like planet in the Solar System, at least concerning its atmosphere and climate. This is largely because of its size, very similar rotation rate to the Earth and its thin but dynamically and radiatively active atmosphere. It has also been the most extensively explored and studied planet in recent years, both from orbiting spacecraft equipped with remote sensing instruments and from in situ landers, as well as from Earth-based telescopes. As a result, a great deal is now known about the present state of the planet and its near-surface environment; enough to construct and constrain quite sophisticated models to simulate its meteorology and climate. In this lecture I will provide a wide-ranging survey of what is known about the present climate and meteorology of Mars and how different components interact to form its general atmospheric circulation.

On the largest scales, the overall structure of the Martian atmosphere is determined by the absorption and scattering of solar radiation by the surface and atmosphere, thermal emission of radiation and their variations with latitude and season. Radiative balance is the main factor determining the surface temperature which, during polar winter seasons, can fall to the freezing point of carbon dioxide, the principal atmospheric constituent. As a result, the surface pressure at all points on the planet exhibits large seasonal variations while up to 25% of the atmospheric mass cycles between the atmosphere and dry ice deposits on the surface, falling as `dry snow' in drifts up to 2-3 m deep. Such large mass exchanges, however, seem to result in relatively small perturbations to the day to day meteorology. The large-scale circulation consists of low latitude Hadley cells, with baroclinic cyclone-anticyclone weather systems at mid-high latitudes, much as on Earth. But because Mars has no oceans to moderate temperature fluctuations at the surface, the Hadley circulations are more intense than on Earth and are typically dominated by a single cell crossing the equator. Continental-scale topography also plays a major role, steering cross-equatorial flow into ocean-like western boundary currents.

Intraseasonal meteorology is dominated by a mixture of diurnal tides, dust storms and baroclinic transient weather systems. Suspended atmospheric dust has a strong effect on the intensity of diurnal tides, especially at the semi-diurnal period. This in turn can affect the surface winds and hence the frequency and intensity of dust storms, some of which occasionally develop into planetary scale events. Baroclinic instability plays a major role in mid-high latitudes, much as on Earth, but with stronger seasonal variations. In general, lower planetary wavenumbers are favoured on Mars than on Earth, largely because of the smaller planetary radius but similar Rossby deformation radius, and lead to less complex chaotic behaviour than on Earth. Nevertheless, Martian meteorology is chaotic on a wide range of scales, enhanced also by the action of dust and consequent nonlinear radiative feedbacks. On the smallest scales, the meteorology is dominated by convective plumes and vortices (known as 'dust devils', by analogy with similar features found in terrestrial deserts), most prevalent in early afternoon, occasional dust storms, and local circulations induced by nearby topography. The Martian planetary boundary layer is typically very active, being strongly convective (at low-mid latitudes) during the day but very strongly statically stable at night, with consequent formation of nocturnal jets and gravity waves, especially downstream of topographic features. This rich meteorology is occasionally visualised in the formation of tenuous clouds of water or $CO_2$ ice.

As well as surveying the climate and meteorology of Mars on scales from a few km to the size of the planet itself, we will also consider the wider dynamical context within which both Mars and the Earth are found. At least some of the differences noted between the two planets can be interpreted with reference to a broader appreciation of the various dynamical regimes of planetary atmospheric circulation, especially as parameters such as the planetary size and rotation speed are varied. We will conclude with a brief discussion of what is known about the range and diversity of such circulation regimes and where Earth and Mars lie within them.

Martian Climate : from the Past to the present

Francois Forget,

LMD, Institut Pierre Simon Laplace, Paris.

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At present time, Mars is a dry and cold planet. Its climate system is nonetheless complex and highly variable, mostly because of the coupling between the atmospheric circulation with the dust cycle (lifting of dust by the wind, able to modify the atmosphere radiative properties) and the $CO_2$ cycle (condensation and sublimation of the $CO_2$ atmosphere in seasonal polar caps). A peculiar water cycle does occur on Mars, with water vapor transported by the atmosphere between the poorly known subsurface reservoirs and the polar caps, allowing the formation of clouds, hazes and frost. However, the amount of water involved remains very small. Consequently, surface ice is unstable for more than one season outside the polar regions. Furthermore, the atmosphere is so cold or so dry that the presence of liquid water, never detected, is unlikely anywhere on the surface.

Things may have been different in the past. The surface of Mars is characterized by multiple geological evidences that suggest that various kind of glaciers and ice sheets formed not that long ago at low and mid-latitudes, and that liquid water existed at and near the Martian surface at various time in its history.

In practice, two concepts of past climate (or "paleoclimate") must be distinguished for Mars. On the one hand, it appears that the climate was sometime different from what it is today throughout most of its history and until quite recently on the geological timescale (a few millions ago, or even a few thousand years ago) because of the oscillations of Mars orbit and rotation parameters. On Earth variations of obliquity between 22° and 24.5° seem to have resulted in major climate changes. Mars obliquity is thought to have undergone much larger variations from 0° to more than 60°. These oscillations affected surface temperatures, the dust and $CO_2$ cycles, and the water cycle, inducing the mobilization and accumulation of large ice deposits (glaciers, polar caps) in various locations on the planets.

On the other hand, the observations of the geology and mineralogy of the oldest surface on Mars (dating back to more than 3.8 billion years ago) provide evidence that the Martian climate was then completely different then, with abundant liquid water on the surface. Such clement conditions are surprising because most experts believe that at that time, the young sun was less dense than today and its luminosity 25% lower than at present time. Mars may have been warmed by a thicker atmosphere containing greenhouse gas and clouds, a young Sun warmer than expected, high geothermal fluxes, or episodically by large impacts.

**Past, present and future of the Venus exploration**

**D. V. Titov**

Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany.

More than 25 spacecraft from the USA and the Soviet Union visited Venus in the 20th century, but in spite of the many successful measurements they made, a great number of fundamental problems in the physics of the planet remained unsolved. In particular, a systematic and long-term survey of the atmosphere was missing, and most aspects of atmospheric behaviour remained puzzling. After a hiatus of more than a decade in Venus research the European Space Agency (ESA) took up the challenge and sent its own spacecraft to our planetary neighbour. Venus Express continues and extends the investigations of earlier missions by providing detailed monitoring of processes and phenomena in the atmosphere and near-space environment of Venus. Radio, solar and stellar occultation, together with thermal emission spectroscopy, sound the atmospheric structure in the altitude range from 150 to 40 km, revealing strong temperature variations driven by radiation and dynamical processes. VIRTIS and SPICAV spectrometers study vertical and latitudinal distribution of trace gases in the mesosphere (70-100 km) and middle and lower troposphere (< 40 km) and observe non-LTE emissions of $O_2$, NO, OH and $CO_2$. The imaging experiments VIRTIS and VMC monitor the cloud morphology and details of general circulation. The magnetometer (MAG) and ASPERA (Analyser of Space Plasmas and Energetic Atoms) measure the magnetic field and densities of neutral atoms, ions and electrons *in-situ*. These observations determine the structure and properties of the circumplanetary plasma and characterize escape processes at Venus. The Akatsiki (JAXA) spacecraft expected to arrive at Venus in the end of 2010 will continue remote sensing meteorological survey of the Venus atmosphere. Future missions to Venus will be focused on in-situ investigations of chemistry, clouds, dynamics and evolution of the Venus atmosphere onboard descent probes and balloons.

Principles of planetary circulations, from Earth to Neptune

Tapio Schneider

Beginning with a survey of angular momentum and energy conservation for planetary atmospheres, these lectures will develop constraints on atmospheric flows that can be derived from fundamental physical laws. In particular, it will be shown how turbulent transport of angular momentum and energy enter the conservation laws and how these turbulent transports depend on mean-flow quantities in rapidly rotating atmospheres. Fundamental constraints on atmospheric circulations will be stressed. For example, it will be discussed how the observed angular momentum fluxes in the upper atmospheres of giant planets constrain the unobserved flow at depth and rule out the viability of large classes of flow models. Alternative flow models that are consistent with the observed constraints will be presented.

Structure of Moist Convection in Planetary Atmospheres

Kensuke Nakajima, Kyushu University

Convection plays a major role in shaping the structure of planetary atmospheres through the vertical transport of energy that is supplied by radiative processes. Due to the large temperature and/or pressure difference over the convecting layer, the convection in the planetary atmospheres is often associated with the phase change of its constituents. The resulting condensed material sometimes becomes macroscopic size through "microphysical processes", i.e., diffusion growth and mutual collision. This types of convection is called "moist" or "cloud" convection. The most familiar example is the cumulonimbus clouds in the earth's atmosphere, but recent observations show the existence of similar phenomena in the atmospheres of Jupiter, Saturn and Titan. Furthermore, some theoretical studies suggests possible importance of moist convection in the evolutions of early atmospheres of Mars and Earth.

In this lecture, the moist convections that is (or was) taking place in various planetary atmospheres will be classified based on several criteria, which are (i) whether the component subject to the phase change is major or minor constituent, (ii) if it is minor component, whether its molecular weight is heavier or lighter than the major (non-phase changing) components, (iii) whether the direction of motion associated with the phase change is upward or downward, (iv) whether the timescale of the microphysical processes are rapid or not, and (v) the depth of the layer associated with the phase change relative to the whole depth of atmosphere. Then, the structure of convection and the structure of atmosphere that develops with it will be demonstrated with the aid of simplified numerical experiments on some typical cases. Finally, the variation of the structure of cloud convections resulting from the interaction between the convection and larger-scale atmospheric motions will be briefly touched.

How to make a Habitable Planet

Yutaka Abe, The University of Tokyo

About 400 exoplanets have been already found. Although Earth-sized planets have not been found yet owing to their small mass, terrestrial planets should also exist around many Sun-like stars. It is a very interesting question how often there are planets with a surface condition habitable for life. Real necessary and sufficient conditions for life are not well constrained yet. However, terrestrial-life requires existence of liquid water during at least some periods of their life. Therefore, we may consider existence of liquid water as a conventional necessary condition. In the following, we call a terrestrial planet with some amount of liquid water on its surface 'a water planet.' We discuss the formation and possible variety of water planets.

The condition for the existence of liquid water on a planet has been investigated based on a one-dimensional radiative-convective equilibrium model. The ice-albedo feedback, which causes the complete freezing, and the runaway greenhouse, which causes the complete evaporation, play important role in determining the existence of liquid water at a given moment. Atmospheric escape and degassing from planetary interior are important for keeping liquid water in geological time scale.

One dimensional studies treat globally and annually averaged surface condition with an averaged solar flux. However, even if the annual average of the solar flux is unchanged, the annual average of the temperature or the state of water can be different. Orbital eccentricity and obliquity affect the seasonal change of insolation. Snow and ice show a strong ice albedo feedback. Since this is a highly nonlinear feedback, the resulted annual mean surface temperature cannot be predicted by annual solar flux. It is well known that the small change of the Earth’s eccentricity and obliquity is causing the glacial-interglacial cycle of Earth’s climate change.

In addition abundance of water itself affects the surface environment significantly. Most of the previous studies on the habitable zone implicitly assume an oceancovered 'aqua' planet that has a large amount of liquid water like the present Earth. However, there is a possibility of a habitable 'land' planet that is covered by vast dry desert but has locally abundant water. Ancient Mars might be in such a state. The conditions for the existence of liquid water can be different for a less water land planet from that of an aqua planet, because both the ice-albedo feedback and the runaway greenhouse are enhanced by abundant water.

# Poster Abstract

# The observation of the lunar ionosphere by the dual-spacecraft radio occultation method

○H.Ando[1], T. Imamura[2], T. Iwata[2], Z. Yamamoto[2], N. Mochiduki[2], Y. Kono[3], K. Matsumoto[3], Q Liu[4], H. Noda[3], H. Hanada[3], Y. Futaana[5], K. –I. Oyama[6], A. Nabatov[7], A. Saito[8]

[1]:The University of Tokyo, [2]:ISAS/JAXA, [3]:NAOJ, [4]:Shanghai Astronomical Observatroy, Chinese Academy of Science, [5]:Swedish Institute of Space Physics, [6]:National Central University, [7]:Ukrainian Academy of Science, [8]:Kyoto University

Radio occultation experiments performed in Luna Mission in the 1970s indicated the existence of the lunar ionosphere with large electron densities of the order of 1000 $cm^{-3}$. On the other hand, theoretically the lunar ionosphere is thought to have densities on the order of 1 $cm^{-3}$ when we consider that the solar wind electric field sweeps ions and electrons away and that the low density of the lunar neutral atmosphere is as low as $10^5$ -$10^6$ $cm^{-3}$. The radio science (RS) experiments in the SELENE (KAGUYA) mission aims at solving this problem.

We have tried to detect the lunar ionosphere by receiving the radio waves emitted from the two sub-satellites Rstar and Vstar at the same time. In this method, Rstar is used to measure the Earth's ionosphere contribution while Vstar is occulted by the moon; the difference between the two measurements gives the lunar ionosphere component without being disturbed by the Earth’s ionosphere. However, we are forced to use two S-bands whose frequencies are close to each other (2218MHz and 2287MHz) because of the specification of the Rstar’ transponder. This results in a relatively large uncertainty in the derived electron density. Moreover, the two sub-satellites must be present within the beam diameter of the ground antenna, and consequently, the number of opportunities of observations is limited.

The observation by this method could cover the solar zenith angle (SZA) ranging from 70 to 120 degrees, but we do not see a steady increase of the electron densities normally in this range, except for two cases having SZA = 74.4 and 82.2.

# VERTICAL AND SURFACE CARBONDIOXIDE OBSERVATION AT LAPAN INDONESIA

Ginaldi Ari Nugroho
Researcher staff in National Institute Aeronautics and Space (LAPAN) Bandung
email : ginaldi.lapan@gmail.com

ABSTRACT

National Institute of Aeronautics and Space (LAPAN) is an Indonesian research institute that involved in atmospheric research and also its atmospheric composition. Over the year several program have been assemble to provide the better knowledge on atmospheric composition especially carbon dioxide ($CO_2$). $CO_2$ as part of the green house gases which presume to be a trigger of temperature changes or global warming. LAPAN have developed an instrument to monitor both vertical and fixed carbon dioxide monitoring in the troposphere layer. Both of this instrument can measure up to 2000 ppm of $CO_2$ value using NDIR (Non Dispersive Infra Red) method. The vertical instrument have been conducted to analyze the vertical profile of carbon dioxide in the troposphere layer. Carbon dioxide sensor carried by meteorogical balloon which can be tracked to find the droop zone location and monitored its trajectory from ground based. The surface $CO_2$ monitoring also have been made to monitor carbon dioxide continuously. The purpose of this instrument is to analyze the variation (the day and night variation, seasonal variation) of carbon dioxide concentration continuously and dynamically, and to observe the convection, mixing height and the study of boundary layer.

Martian volcanic rocks: signature of planetary evolution

D. Baratoux, M.J. Toplis, O. Gasnault, M. Monnereau and B. Trey

The recent accumulation of mineralogical, chemical and morphological observations of the surface of Mars allows us to take a fresh look at the evolution of magmatism and volcanism through the ages. There are three types of volcanic landforms on Mars. (1) Low and large shield volcanoes are found in the southern hemisphere (e.g., Syrtis Major, Tyrrhena Patera). In the northern hemisphere, typical shield volcanoes (2) are characterized by elevations above the plain up to 20-30 km, and are considered to be a different class of volcanic landforms. The third kind of volcanic provinces is typical of plains volcanism with long lava flows and clusters of small shield volcanoes analogous to the terrestrial situation at the Snake river plain. The elementary composition of these volcanic landforms has been recently documented from GRS (Mars Odyssey). We will show here that the chemical composition of volcanic landforms evolves with time. These compositions have been compared to the primary liquids that can be derived from the primitive mantle of Mars using Pmelt for the thermodynamic modeling of liquid and solid phases equilibriums. The decrease of Si abundance with time in the Martian volcanic rocks is interpreted as a progressive deepening of the source of the magma and a decrease of the degree of partial melting, a case consistent with the progressive cooling of the planet.

# Determining vertical cloud structure on Venus using near-infrared spectroscopy

J. Barstow(1), F. Taylor(1), C. Tsang(1), C. Wilson(1), P. Irwin(1), P. Drossart(2), G. Piccioni(3)

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## Abstract

Near-infrared spectra from the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) on Venus Express provide the opportunity for investigating a wide range of Venusian atmospheric parameters. A small peak between 2.5 and 2.6 microns has been recently discovered in VIRTIS nightside spectra, and is shown by radiative transfer modelling to be sensitive to variations in both cloud base altitude and water vapour abundance within the cloud layer. If retrievals of cloud base altitude using this window can be successfully validated, they should provide valuable insight into dynamical processes on Venus.

## Method

VIRTIS seeks to exploit the atmospheric 'windows' in the infrared for which the atmosphere of Venus is transparent. Nightside observations of Venus by Allen and Crawford (1984) resulted in the discovery of high radiance peaks corresponding to windows centred at 1.74 and 2.3 microns. Both are sensitive to properties of the sulphuric acid clouds which exist between altitudes of ~48 and 80 km, covering most of the planet. Smaller peaks between 2.3 and 2.5 microns are sensitive to gaseous abundances.

A new cloud parameterisation has been developed for the NEMESIS planetary atmosphere radiative transfer and retrieval tool (Irwin et al., 2007) which has been used to retrieve cloud base altitude. Retrievals between 2.15 and 2.3 microns wavelength are used to constrain the integrated number density of cloud aerosol particles. This result is carried forward to a second retrieval in the range 2.3–2.6 microns, constraining simultaneously abundances of CO, water vapour and OCS, and cloud base altitude.

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The Meteorology of Giant Planets Revealed Through Automated Cloud Feature Tracking

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We examine the meteorology of the giant planets using our automated cloud feature tracker. Through pattern recognition and correlation optimization, our software returns a dense, regular grid of wind vectors. We measured the winds within Jupiter's Great Red Spot (GRS) and uncovered its distinctive "hollow" structure, its counter-rotating interior, and a newly discovered cyclonic ring around its periphery. This cyclonic ring suggests the presence of a thermally indirect, downwelling secondary circulation at the periphery of the GRS. We also analyzed a time-series of images of Jupiter's White Ovals. Over a decade, the system has evolved from three discrete, white anticyclones to one reddish vortex (Oval BA). Our measurements revealed a modest, non-uniform acceleration of the flow within Oval BA coincident with the coloration event, and areas of organized cyclonic circulation in seemingly turbulent regions near these anticyclones. We have also directly measured the power spectrum of the turbulent kinetic energy present within Jupiter's atmosphere. Our results provide evidence consistent with an inverse cascade of energy from small to large scales that may fuel Jupiter's impressive jet streams and vortices. Finally, our analysis of near-infrared images of silhouetted clouds in Saturn's atmosphere demonstrated that the measured latitudinal zonal wind profile is largely similar to previous measurements utilizing visible-wavelength images. This result, accompanied by a statistical analysis of the cloud features imaged in the near-infrared, yields constraints on the vertical structure and latitudinal temperature gradients of Saturn's atmosphere.

**Study of MJO Phenomena using atmospheric Radar, Optical Long wave Radiation (OLR) and Tropical Rainfall Measurement Mission (TRMM)**

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Indonesia is located in the equatorial region, surrounded by two oceans and two continents. The interaction between land and ocean causes convection activity become more dominant over Indonesia which happened not only in seasonal time scales, but also having experienced the intraseasonal phenomenon known as Madden Julian Oscillation (MJO). MJO is an equatorial traveling pattern of anomalous rainfall that is planetary in scale. Eastward propagation of MJO is usually obvious from the western Indian Ocean and continues to move east to the western Pacific region. MJO cause part of Indonesia region undergo enhanced rainfall activity and cause flood in some regions. LAPAN as one of atmospheric research institution carry out research on MJO using atmospheric radar facilities (in collaboration with RISH-Kyoto University ,JAMSTEC (Japan), BPPT and BMKG) installed on Kototabang, Pontianak and Biak, located along the equatorial line, such as EAR (Equatorial Atmosphere Radar) and BLR (Boundary Layer Radar). We also use OLR data from NOAA satellite and precipitation data from TRMM satellite. Our results show that there is increasing of zonal wind speed during active period of MJO. Eastward propagation of low OLR and precipitation also confirm the propagation of enhanced convection activity over Indonesia. Further analysis using Combined Empirical Orthogonal Function (EOF) and spectral analysis also show that the phenomena associated with the MJO phenomena has dominant period of oscillation about 30 to 60 days.

**Keywords:** Convection, Madden Julian Oscillation, EOF

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Title:
CEPD - Chemical Evolution of Protoplanetary Disks

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Abstract:
Protoplanetary disks undergo a significant evolution from their early phase around a hot, protostellar core to their dispersal after planet formation. As such, they represent a natural and active environment for the creation of simple and complex molecules which may ultimately lead to the evolution of life.

Recent observations of protoplanetary disks around T Tauri stars reveal an active organic chemistry and important molecules such as $H_2O$, OH, $CO_2$ and CO being abundant in the inner disk. Observations probe the chemical composition close to the optically thick disk surface, where these molecules are photo-dissociated continuously by stellar, interstellar and cosmic radiation. A steady supply of the inner disk with these elements might be required to account for the observations.

We present a new project on the chemical evolution of protoplanetary disks in their intermediate phase. Thereby, we plan to focus especially on the effects of turbulent mixing and accretion motion on the chemical composition: strong turbulence might drive the disk chemistry out of equilibrium and replenish the abundances of molecules in the inner disk regions and in the upper disk layers. Likewise, inward accretion may supply the inner disk with molecules from the outer regions where they are frozen onto dust grains.

We address the problem of modeling the combined evolution of the disks' physical and chemical state in a step-by-step approach. We calculate the molecular line emission of the inner 20AU of protoplanetary disks and discuss possible reasons for the discrepancies between theoretical and observed spectra.

# DCMODEL: Hierarchical models for geophysical fluid dynamics and planetary atmospheres

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Seiya Nishizawa (Center for Planetary Science / Kobe University),
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Masatsugu Odaka (Hokkaido University),
Yohei Sasaki (Hokkaido University),
Ko-Ichiro Sugiyama (Hokkaido University),
Tatsuya Yamashita (Hokkaido University)
Yasuhiro Morikawa (National Institute of Information and Communications),
Kensuke Nakajima (Kyushu University),
and
GFD Dennou Club (http://www.gfd-dennou.org/index.html.en)

Numerical models used for simulations of various aspects of planetary atmospheres are getting more and more complex. Correspondingly, it is getting harder and harder to understand what is going on in the model. As an effort to provide a tool-set for filling the gap between complex simulation models and simple conceptual thoughts, "dcmodel" is a project of GFD Dennou Club to develop a series of hierarchical models for research and education of the fields of geophysical fluid and planetary atmospheres.

"Dcmodel" is composed of a several subgroups of models that have various complexities but with a rather unified coding style: spmodel, a series of spectral models for geophysical fluid dynamics; dcpam, a 3D global circulation model on a sphere with the primitive equation; deepconv, a 2-3D atmospheric convection resolving model with the non-hydrostatic quasi-elastic equation. They are equipped by a common input/output library (gtool) and a common spectral transform library (ispack).

GFD Dennou Club is a research and development activity of an inter university basis whose members are scattered in several research/educational institutions in Japan.  In the presentation, our strategy of the project, characteristics of the models, and several numerical results will be presented. Softwares related to dcmodel project are available from the web site of GFD Dennou Club listed below.

References

GFD Dennou Club: http://www.gfd-dennou.org/index.html.en
spmodel: http://www.gfd-dennou.org/library/spmodel/index.htm.en
dcpam: http://www.gfd-dennou.org/library/dcpam/index.htm.en
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ispack: http://www.gfd-dennou.org/library/ispack/ (Japanses page only)

Green's function for a generalized two-dimensional fluid

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Green's function for a generalized two-dimensional fluid, so-called the $\alpha$ turbulence, in an unbounded domain is analytically derived. The generalized two-dimensional fluid is characterized by a relation between an advected quantity, which refers the vorticity, and the stream function including the real parameter $\alpha$. In this study, the Green's function refers the stream function produced by a delta-functional distribution of the vorticity, i.e., the point vortex with the unit strength. It is shown that the Green's function has the form $G_{\alpha}(r) \propto r^{\alpha-2}$ except for particular values of $\alpha$, $r$ being the distance from the point vortex. For $\alpha$ being the positive even numbers, the logarithmic dependence of $r$ appears as $G(r) \propto r^{\alpha-2}(\ln r+C)$, where $C$ is an arbitrary constant. For $\alpha$ being the negative even numbers, $G(r)=(-1)^{|\alpha|/2+1}\nabla^{|\alpha|/2}\delta(\bm{r})$. The azimuthal velocity around the point vortex is also derived. Using the functional form of the azimuthal velocity, the existence of the generalized two-dimensional fluid is discussed.

Numerical modeling of large-scale vortices in Jupiter's atmosphere

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Ko-ichiro SUGIYAMA (Hokkaido Univ)
Kensuke Nakajima (Kyushu Univ)

In Jupiter's atmosphere, there are many large-scale vortices, such as the Great Red Spot and White Ovals. Williams(1996) reproduced large scale vortex resembling the Great Red Spot within a three dimensional numerical model. However, the wind speed and the intensity of temperature anomaly of the large scale vortex became weaker after a long time integration. The decay of the vortex might be caused by the absence of forcing to maintain the zonal mean field. Therefore, we introduce forcing to maintain zonal mean fields, and examine possible sensitivities of the behavior of simulated vortices in the statistically steady state to the type and the intensity of the forcing.

We conduct 13 experiments with four types of forcing: (1)no forcing, (2) momentum forcing to damp the zonal mean winds to the initial structure, (3) thermal forcing to damp the zonal mean temperature to the initial structure, (4) both of the above momentum and thermal forcings. Four values of damping time: $\tau$, which are 30, 100, 300, and 1000days, are used for the thermal and/or momentum forcing terms.

We find that the behavior of simulated vortices depend on the type and the damping time of forcing. Large scale coherent vortices are maintained only in cases with weak forcing. With strong forcing, such vortices are not maintained and the evolution of the model can be classified into two end members: many large scale vortices are generated but their lifetime is short in cases with momentum forcing, whereas no large scale appear in the long run with thermal forcing.

Title :
Horizontal structures of planetary-scale waves at the cloud top deduced from Venus cloud images

Author :
Toru Kouyama (University of Tokyo)
Masato Nakamura (Institute of Space and Astronautical Science)
Takehiko Satoh (Institute of Space and Astronautical Science)
Takeshi Imamura (Institute of Space and Astronautical Science)
Yoshifumi Futaana (Swedish Institute of Space Physics)

Abstract :
Various atmospheric waves are expected to transport angular momentum in the Venus atmosphere, and some of them will result in an accumulation of angular momentum in the upper atmosphere to maintain the super-rotation. Although various hypotheses for the mechanism have been proposed based on the results of numerical simulations, no particular mechanism has been identified as being responsible for the super-rotation due to the lack of observational evidence. Previous observational studies include the derivation of wind vectors by tracking cloud features using Venus cloud images taken by Pioneer Venus, and the spatial structures of atmospheric waves such as thermal tides and equatorial Kelvin waves have been identified. Similar approaches have been applied to the cloud images obtained by Galileo and Venus Express; however, it is difficult to derive the spatial structures of atmospheric waves from the data probably because the technique to derive detailed wind distributions from a limited number of cloud images has been immature. We developed an improved method of tracking cloud features by combining several new calculation techniques that have been developed in other fields, and derived spatial structures of atmospheric waves from Venus images. The results show the spatial structures of thermal tides in the mean velocity distribution in the solar-fixed coordinate and perturbations from an equatorial Kelvin wave and a Rossby wave.

Stratospheric $CO_2$ ice cloud greenhouse for sporadic warming of early Mars

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Tokuta Yokohata, Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology
Kiyoshi Kuramoto, Department of Cosmosciences, Faculty of Science, Hokkaido University

Whereas the activity of liquid-water on ground including precipitation are likely required to explain fluvial geomorphologic features formed about 3.8 billion years ago on Mars, the long-term sustenance of wet and warm climate at that era has been questioned from several lines of evidence. Our new numerical analysis on the thermal structure of moderately thick $CO_2$-$H_2O$ atmosphere including $CO_2$ ice cloud reveals that the $CO_2$ ice cloud possibly forms a stratospheric layer producing significant greenhouse effect strongly depending on the content of cloud condensation nuclei. This result suggests that the wet and warm climate have arisen sporadically due to the variability in supply of atmospheric condensation nuclei on early Mars.

Atmospheric Structures of Ocean Planets:a Study of Mechanisms to Determine Inner Edge of Habitable Zone

Hiroyuki Kurokawa, Taishi Nakamoto
(Department of the Earth and Planetary Sciences, Tokyo Institute of Technology, Japan)

Abstract
Structure of planetary atmosphere is an important factor that governs the planetary surface environment and the habitability of planets (we use the word "habitability" as "having ocean on its surface"). Nakajima et al. (1992) investigated the structure and discussed the habitable zone. They concluded that inner edge of habitable zone was determined by temperature gradient of a moist-convective zone. This mechanism is called "radiation limit". However, they ignored the absorption of central star radiation in the planetary atmosphere and only studied planets like current Earth. So it is not clear whether their "radiation limit" mechanism can work on exoplanets which are being discovered one after another.
We investigated the atmospheric structure of ocean planets generally, considering the absorption. To study a variety of planets, we changed and examined the effects of the radiation flux and the spectral type of the central star, atmospheric composition, and the planetary mass.
We found that a moist-convective zone appears in many cases, and a structure which does not have a moist-convective zone can appear in some cases in which the absorption is significant. In former cases, the inner edge is determined by "radiation limit". But in the latter case, the inner edge is determined by another mechanism.

Generalized Nonlinear Subcritical Moist Symmetric Instability

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Abstract

Starting from nonlinear equations on the f-plane containing frictional dissipation and condensation heating under the Boussinesq approximation, the equation of generalized energy in moist air is presented, and the necessary condition of Subcritical Moist Symmetric Instability (SMSI) is derived. With the meso-scale representative values given, critical values is calculated. It shows that SMSI is likely to occur if the original disturbance wind is larger than 4m/s, even if disturbances are of linearly symmetrical stability. Then one precipitation process is simulated using WRF model and its relationship with SMSI is studied. It is concluded that SMSI is the probable triggering mechanism in this precipitation process.

Preliminary Vertically Resolved Martian Atmospheric Water Vapour Radiance Analysis with Mars Climate Sounder

Mars Climate Sounder (MCS) is an infra-red radiometer on board NASA's Mars Reconnaissance Orbiter (MRO) which was launched in August 2005 and is orbiting Mars in a near circular polar orbit. MCS has nine spectral channels in the range 0.3–50 μm. Goals of MCS include global characterization of atmospheric temperature, dust and water profiles, with a view to observing temporal and spatial variation.

Using Oxford University's multivariate and radiative transfer and retrieval algorithm, NEMESIS, we present a preliminary radiance analysis of the vertically resolved water vapour abundance in the Martian atmosphere in October 2006 (Ls range 114–125° , i.e. northern hemisphere summer). A combination of spectral channels inside and outside the at 50 μm water vapour rotation band are used to perform the analysis.

We then briefly compare the results of the analysis to water vapour results from other instruments/experiments such as the Phobos/Auguste experiment; Thermal Emission Spectrometer (TES) on Mars Global Surveyor; and the Planetary Fourier-Transform Spectrometer (PFS), Ultraviolet and Infra-red Atmospheric Spectrometer (SPICAM), and the Visible and Infra-red Mineralogical Mapping Spectrometer (OMEGA) on Mars Express.

Title

New results from the Oxford Venus GCM

Authors

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Abstract

The circulation of Venus's atmosphere is well known to exhibit strong super-rotation and a variety of enigmatic features which remain poorly understood. Recent work in Oxford has resulted in the development of a simplified general circulation model (GCM) of its atmosphere, which is already capable of quantitatively reproducing some aspects of its meteorology (Lee et al 2007).

In this work we adapt and extend the existing 3D time-dependent numerical circulation of Venus's atmosphere to include a new physically-based radiative transfer formulation in the infrared. This new parameterisation is based on the net exchange approach from Eymet et al 2009, and its accuracy is being studied using a 1D configuration in the GCM. In a preliminary study of atmospheric transport on Venus, the GCM has computed and obtained diagnostics from the surface to an altitude of around 90km over complete annual and diurnal cycles, including simple representations of cloud formation and transport (Lee 2006). Amongst other features, we investigate the possible existence of a transport barrier in the atmosphere of Venus from the analysis of potential vorticity fields (PV). There is also some evidence for meridional transport to be inhibited in the Earth (Shuckburgh et al 2001) and Mars's atmosphere. We studied the nature of the flow by analysing the dominant terms in the meridional component of the equation of motion.

Title:
The effect of filaments on the axisymmetrization process of the 2D elliptic vortex with non-uniform vorticity.

Authors:
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Takahiro Iwayama, Kobe University, Japan.

Abstract:

We numerically investigate effects of filaments on the axisymmetrization process of an elliptic vortex with non-uniform vorticity distribution, as a reconsideration of the work by Melander, et al(1987). Melander, et al(1987) showed that the difference angle between the orientation of an ellipse determined by vorticity contour and that by stream function contour is responsible for the axisymmetrization of the elliptic vortex. They also discussed qualitatively that the existence of the filaments is one of the causes of the difference angle being non-zero. However, there are no quantitative discussion on the effects of the filaments on the difference angle in their study.

First we divide the vorticity field into the vortex core and the filaments. Then we investigate the effects of the filaments on the difference angle numerically with the divided vorticity field.

We find that the filaments significantly affect the difference angle being non-zero at the early stage of the axisymmetrization of the elliptic vortex. However, the effects of the filaments on the difference decrease with time. In turn, the effects by the vortex core which have the vorticity distribution generated by differential rotation becomes relatively large. These results support the discussion of Melander, et al.(1987) qualitatively.

Numerical Experiments of Atmospheric General Circulations on a Synchronously Rotating Planet

Satoshi Noda (Kobe University)
Masaki Ishiwatari (Hokkaido University)
Kensuke Nakajima (Kyushu University)

Yoshiyuki O. Takahashi (Center for Planetary Science / Kobe University)
Yasuhiro Morikawa (National Institute of Information and Communications Technology)
Seiya Nishizawa (Center for Planetary Science / Kobe University)
Yoshi-Yuki Hayashi (Center for Planetary Science / Kobe University)

Many exoplanets whose masses are several times larger than that of the Earth have been discovered. Some of them are within the habitable zone, where liquid water may exist on planetary surface. Previous studies suggested that some of them might be synchronously rotating around the Sun.

For those planets, possible structures of atmospheric general circulations and especially the habitability in the nightside hemisphere where the solar insolation flux is zero have not yet been well investigated.

Here, we performed numerical experiments on possible structures of general circulations on synchronously rotating planets by using our atmospheric general circulation model, dcpam (http://www.gfd-dennou.org/library/dcpam/index.htm.en).

We assume a synchronously rotating planet which has the same values of the parameters such as the radius, solar constant, and so on as those of the Earth. Axial inclination is assumed to be zero, and the surface is assumed to be covered with "swamp" (zero heat capacity wet surface). The radiative processes are quite crude and we assume no cloud condition. The values of rotation rate we examine are, 1, 2/3, and 4/5 times that of the Earth (hereafter, referred to as "Control", "Case 2/3", and "Case 4/5", respectively).

Because of the efficient atmospheric heat transport, the time mean surface temperature along the equator in "Case 4/5" are between 280K and 330K. An interesting aspect is that the time mean circulation fields obtained in "Case 2/3" and "Case 4/5" are equatorially asymmetric, while those "Control" are almost symmetric. The details of those structures will be shown in our poster.

Favorable regions for dust storm expansion on Mars

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Regions favorable (FRs) for expansion of dust storms on Mars are identified. We performed many numerical simulations where, in the northern fall (Ls=180), dust was injected into the atmosphere artificially from dust sources located all over the planet. Such dust transport simulations provide global maps of dust expansibility (i.e. ?gdust expansion potential?h) and show that dust expansibility differs greatly between different regions on Mars. These global maps show that dust loaded from certain areas in the northern mid-latitudes tends to spread widely within a few days. Dust injected in the vast regions around Tharsis and the Sirenum-Aonia regions also tends to spread extensively depending on local time. On the other hand, dust injected at high latitudes in either hemisphere does not spread extensively. Such global maps indicating regions favorable for dust storm expansion are a clue to understanding expansion processes and climatology of great dust storms on Mars. Moreover, none of the approach described in the presentation to understanding expansion processes and climatology of great dust storms has been taken elsewhere. We have to perform additional simulations in other seasons and investigate how and why dust injected around each FR tend to be transported widely.

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Title:

Temporal variations of the Venus oxygen night airglow observed from ground

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Abstract:
1.27-micron O2 airglow on Venus was discovered and has been investigated by ground-based observations [Connes et al., 1979; Allen et al., 1992; Crisp et al., 1996]. The standard scenario for O2 airglow was proposed based on the case of the NO airglow [Bougher et al., 1990]; the O atoms generated by the UV photolysis of CO2 in the dayside upper atmosphere are transported to the night hemisphere, and recombine to form excited oxygen molecules near 100 km in downwelling [Allen et al., 1992]. The shift of the bright region toward the dawn suggests a drag effect by the super-rotation in the thermosphere,
and the rapid change may be due to modulation by gravity waves coming from the lower atmosphere.
Several new ground-based observations of the Venus 1.27-micron O2 airglow were carried out from 2002 to 2007. Spectral image cubes were taken and the distributions of intensity and rotational temperature are derived by analysis
of observed spectra. Moreover we conducted monitoring observations for up to 8 hours in 2007. In this presentation, we will show temporal variations of the
airglow and examine emitting process of the airglow.

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# Zonal thermal winds in Venus mesosphere

A. Piccialli (1), D. V. Titov (1), S. Tellmann (2), A. Migliorini (3), D. Grassi (4), M. Pätzold (2), B. Häusler, (5), G. Piccioni (3), P. Drossart (6)

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Venus' mesosphere (60 – 100 km altitude) lies between two different regimes of atmospheric circulation: a solar – antisolar circulation with speeds of about 120 m $s^{-1}$ in the upper part of the mesosphere and a strong zonal super-rotation with speed of about 100 m $s^{-1}$ at the cloud top (~65 km of altitude). Earlier studies ([1], [2], [3]) have proved that the strong zonal winds near the cloud top are well described by an approximation of the thermal wind equation: the cyclostrophic balance, which directly relates the zonal winds to the mesospheric temperature field. Here we derive zonal winds using the cyclostrophic approximation from VIRTIS and VeRa temperature retrievals. VIRTIS sounds the Venus Southern hemisphere in the altitude range 65 – 90 km with a very good spatial and temporal coverage [4]. VeRa observes both north and south hemispheres between 40 – 90 km of altitude with a vertical resolution of ~500 m [5]. The main features of the winds are: (1) the midlatitude jet with a maximum speed of 80 – 90 ± 10 m/s which occurs around 50°S latitude at 70 km altitude; (2) the fast decrease of the wind speed from 60°S toward the pole; (3) the decrease of the wind speed with increasing height above the jet [6]. The comparison with cloud tracked winds shows a good agreement at midlatitudes; a disagreement is observed near the equator due to the breakdown of cyclostrophic approximation.

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Retrieval simulations of the vertical profiles of water vapour and other chemical species in the Martian atmosphere using PACS

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The Herschel Space Observatory provides for the first time the possibility to retrieve vertical water profiles in the Martian atmosphere. Herschel will contribute to this topic with its guaranteed-time key project called "Water and related chemistry in the solar system". Observations of Mars by Heterodyne Instrument for the Far Infrared (HIFI) and Photodetector Array Camera and Spectrometer (PACS) onboard Herschel are planned in the frame of the program. HIFI with its high spectral resolution enables accurate observations of vertically resolved $H_2O$ and temperature profiles in the Martian atmosphere. Unlike HIFI, PACS is not capable of resolving the line-shape of molecular lines. However, our present study of PACS observations for the Martian atmosphere shows that the vertical sensitivity of the PACS observations can be improved by using multiple-line observations with different line opacities. We have investigated the possibility of retrieving vertical profiles of temperature and molecular abundances of minor species including $H_2O$ in the Martian atmosphere using PACS. In this paper, we report that PACS is able to provide water vapour vertical profiles for the Martian atmosphere and we present the expected spectra for future PACS observations. We also show that the spectral resolution does not allow the retrieval of several studied minor species, such as $H_2O_2$, HCl, NO, $SO_2$, etc.

Title: Interaction between Thermal Convection and Mean Flow in a Rotating System

Name: Naoaki SAITO
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Abstract:
I perform nonlinear time evolutions of thermal convection in a sine-type horizontal shear flow in a rotating system.

In the case that a rotating axis is directed vertically, roll convections are formed at first, and then barotropic eddy is developed. Linear stability analyses and energy analyses show that the barotropic eddy is formed by barotropic instability. Furthermore, it is found that two-stage instability occurs, that is, barotropically-stable initial sine-type shear flow is destabilized by roll convections, and barotropic instability occurs.

On the other hand, in the case that the rotating axis is tilted, roll convections in herringbone pattern are formed and sine-type mean flow is accelerated.
Linear stability analyses show that the herringbone pattern corresponds to the structure of the largest growing eigenmode of initial field, and that the acceleration of mean flow is due to the second-order effect of the eigenmode.
Analysing this effect, I show that contribution of the Colioris force acting on the second-order vertical flow to the acceleration of the mean flow is larger than that of direct momentum transport proposed by Hathaway & Somerville (1987).
Further analyses show that the following process is the most important in the acceleration of mean flow.
At first, heat transport by disturbances generates buoyant deviations.
Next, the buoyant deviations produce second-order vertical flow.
Then, the Colioris force acting on the vertical flow accelerates mean flow.
This process may work as a new mechanism of the acceleration of zonal flows in rotating planets.

Observation and Modeling of Saturn's northern hemisphere Ribbon and Hexagon

Kunio M. Sayanagi and Andrew P. Ingersoll

We report observations and modeling of the ribbon and the hexagon in Saturn's northern hemisphere. Their latitudes coincide with the zonal jets at 47 and 77 degrees planetographic latitude. We report changes in the cloud morphologies at those latitudes, and measure the zonal-mean zonal wind speeds at the cloud level. Our observations of the hexagon also reveal previously unseen features in the northern high-latitudes of Saturn. These observations suggest that these jets are in two separate regimes of meandering. The ribbon jet traces a meandering path that propagates in the downstream direction and its shape changes on timescales as short as several Saturnian rotations. In contrast, the hexagon's six-sided structure has remained unchanged since 1980 (Godfrey, 1988, Icarus; Baines et al., in press at P&SS).

Past studies of meandering ocean currents and our recent numerical investigation of the ribbon jet (Sayanagi et al., submitted to J. Atmos. Sci.) found that meandering jets can emerge from nonlinear saturation of shear instabilities in an unstable jet. These investigations have linked meandering jets to shear instabilities; however, to the best of our knowledge, a systematic process study of the saturation process is yet to be conducted. Using idealized numerical models, our present investigation systematically analyzes the emergence of meandering jets for a range of planetary beta-effect magnitudes and zonal jet profiles to understand what mechanisms set apart the dynamic and stationary regimes exemplified by the ribbon and the hexagon on Saturn.

Our study uses the EPIC atmosphere model (Dowling et al, 1998, 2007).

Title
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An exploration of the intense fine-scale meteorology on Mars by modeling and observations

Authors
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Abstract
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The recent missions to Mars yielded unprecedented views of the Red Planet. High-resolution measurements carried out by the instruments onboard Mars Global Surveyor between 1996 and 2006 revealed the diversity of the Martian meteorological phenomena at various horizontal scales below 100 kilometers. More details were eventually provided by the (still ongoing) high-accuracy measurements of the Mars Exploration Rovers, Mars Express orbiter and Mars Reconnaissance Orbiter.

Large-scale atmospheric circulation (horizontal scale ~ 100-1000 km) can be simulated by general circulation models with coarse grid and simplifying assumptions, such as hydrostaticity. From the early work of the 60s-70s to the recent efforts in the 90s-00s, these tools were crucial to achieve a satisfying understanding of the global climate on Mars, but were proved unable to adress key questions of local meteorology. The need for realistic numerical models able to resolve atmospheric dynamics from the meso-scale (100-1 km) to the micro-scale (<1 km, where larger turbulent eddies are computed by the model) is thus critical.

Based on results from our new high-resolution model and references to recent observations, the poster will review the main phenomena composing the Martian regional meteorology : anabatic and katabatic winds, fronts, dust devils, gravity waves, convective plumes, dust storms, wake vortices around giant volcanoes... Any of these Martian events turns out to be more intense than their terrestrial counterparts!

TITLE
Nonlinear interaction between vortical flows and gravity waves in geophysical fluids.

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ABSTRACT
This study investigates nonlinear interaction between vortical flows (balanced modes) and gravity waves (unbalanced modes) in geophysical fluids.
Atmospheric gravity waves play very important roles on the atmosphere and ocean by driving global circulation, since they propagate far away from the source region and put significant amount of momentum and energy flux.
Recent observational studies suggest gravity wave radiation from strong rotational flows, such as polar night jet, sub-tropical jet, and typhoon.
This radiation process is considered as a ``spontaneous gravity wave radiation'', but have not been fully understood.
In the present study, we focus on this new physical process of gravity wave radiation.
To study numerically, we use the most simplified system of shallow water that includes both gravity waves and vortical flows.
In addition, the spectral-like three point combined compact difference (sp-CCD) scheme is used, which has high accuracy as well as the spherical harmonics model.
This model allows us to estimate gravity wave amplitude with high accuracy.
We set a barotropically unstable but balanced jet initially in a rotating shallow water system on a sphere, and gravity waves are radiated continuously in the time evolution of this unsteady jet.
To discuss on the conditions of gravity wave radiation and propagation, we use the analogy with the theory of the aero-acoustic sound wave radiation (Lighthill theory).
We also mention recent theoretical study of spontaneous gravity wave radiation from simple vortex pairs.
Nonlinear interaction between vortical flows and gravity waves in geophysical fluids.

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TITLE

# Numerical Modeling of Moist Convection in Jupiter's Atmosphere

AUTHORs

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ABSTRACT

We perform a long-time numerical simulations of moist convection of Jupiter's atmosphere by using a moist convection model developed by Sugiyama et al. (2009) for the purpose of investigating possible cloud structures and convective motion of Jupiter's atmosphere.
The used model is a two-dimensional cloud convection model that incorporates condensation of H2O and NH3 and the production reaction of NH4SH.
In the simulations, the abundances of condensible volatiles vary over the range estimated in the theory of solar system formation.

One of the most important findings is that neither strength nor structure of moist convection reaches a statistical equilibrium state; quasi-periodic temporal variation of the convective cloud activity exists and the period of the quasi-periodic cycle is roughly proportional to the abundance of water vapor in the sub-cloud layer.
It should also be remarkable that clouds composition and the altitude of the cloud base change greatly according to the quasi-periodic cycle of convective activity.

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The relationship between Ferrel cell anomaly and annular mode in the Southern Hemisphere

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A new index for southern Ferrel cell anomaly (FCA) is defined as the normalized spatial-average in zonal-mean zonal vorticity of 50°S to 60°S in the meridional direction and 300hpa to 700 hpa in the vertical direction. The meridional component of FCA can cause net meridional mass transport in the southern mid-high latitudes, and results in the out-of-phase relationship of sea level pressure anomalies between middle and high latitudes which is well known as the Southern Hemisphere annular mode (SAM). The lead-lag correlation between daily FCA index (FCAI) and SAM index (SAMI) indicates that FCA leads SAM by one day.

Using Kelvin's circulation theorem, a linear and simplified acceleration equation of relative circulation is derived. The formula indicates that difference between the baroclinicity item and Coriolis force item (NxB) which represents imbalance of thermal wind relationship causes the variability of relative meridional circulation directly. The lead-lag correlation between NxB and FCA indicates that NxB leads FCA, especially after 10-20 days band-pass filter being applied to the raw time series.

Dynamical effects of thermal tides on the Venus atmospheric superrotation

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A nonlinear dynamical model on the sphere has been numerically integrated to investigate a generation mechanism of the Venus atmospheric superrotation by the thermal tides. By using the solar heating exciting the diurnal and semidiurnal tides, the atmospheric superrotation extending from the ground to 80 km is generated.
The vertical distributions of the mean zonal flow obtained in our experiments are similar to the observations.
Velocity of the mean zonal wind on the equator reaches about 60--100 m/s near the cloud top level.
A linear theory suggests that the atmospheric superrotation obtained in the present study is generated and maintained by the momentum transport associated with the thermal tides.
Namely, the downward transport of zonal momentum which is associated with the downward propagating semidiurnal tide excited in the cloud layer induces the mean zonal flow opposite to the Venus rotation in the lowest layer adjacent to the ground.
Surface friction acting on this counter flow provides the atmosphere with the net angular momentum from the solid part of Venus.
It is examined how the atmospheric superrotation depends on vertical eddy viscosity and Newtonian cooling.
The result shows that magnitude of the atmospheric superrotation is not so sensitive to vertical eddy viscosity, but strongly influenced by Newtonian cooling.

Numerical simulations of planetary atmospheres with land and the ocean by using a general circulation model

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In order to have insights into the processes characterizing the general circulation of Martian and the Earth's atmospheres, numerical simulations are performed by using a general circulation model (GCM). As a first step, we focus on the structure of the Hadley circulation at solstices and examine the effects of moist processes, planetary radius, and the number of days of a year on it.

The GCM used for this study is dcpam (http://www.gfd-dennou.org/library/dcpam/index.htm.en), which has been developed by GFD Dennou Club (http://www.gfd-dennou.org/index.html.en). By using this model, four simulations are performed. First one, case 1, is simulation of a planet with land and the ocean. The land-ocean distribution, and distribution of sea surface temperature are those of the Earth. Second one, case 2, is simulation of land planet, which does not have water. Third one, case 3, is simulation of land planet with Martian radius. Fourth one, case 4, is simulation of land planet with Martian radius and number of days of a year.

These simulations show that the structure of Hadley cell at solstices changes significantly by changing simulation conditions. The Hadley cell in case 2 is weaker than that in case 1, and vertical extent of cell in case 1 is smaller than that in case2. The latitudinal width of cell in case 3 is larger than that in case 2. Further, the latitudinal width of cell in case 4 is slightly larger than that in case 3. In the presentation, the physical mechanism concerning these changes will be discussed.

Dynamics of Venus cloud observed by Venus Express / VMC

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Abstract

A new cloud tracking method by use of motion-stereo is proposed. From ultraviolet cloud images taken by Venus express / VMC, we tried to estimate both cloud height and wind speed simultaneously, and we obtained 60-70 km cloud heights and ~100 m/s westward wind speeds in the region near the equator to mid-latitudes in the northern hemisphere. The estimated cloud height and wind speed show increase with the increase of latitude.

On the other hand, we applied the traditional tracking method to Venus cloud images near the equator to investigate the meso-scale dynamics of clouds and the distribution of superrotation.

From the results, we will discuss the cloud structure and the dynamics of the Venusian atmosphere.

Energy transport of Venusian turbulence estimated by the VEX/VMC UV image analysis

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In Venusian atmosphere, there are waves with various scales and they compose turbulence. Undertstanding the kinetic energy transportation of turbulence is important to find out about Venusian atmospheric structure. According to the classical turbulence theory, power spectral intensity at the wavenumber k is expressed as follows: P(k)= $C_k k^{-n}$. In this equation, the index –n corresponds to the slope in the logarithmic plot and characterizes the power spectrum. Enstrophy and energy cascade between the turbulence would occur in the case of n=3 and 5/3, respectively. Earlier studies have used the data taken by earlier spacecrafts in the low latitude. However, the details of the power spectrum in the high latitude have been unknown well. Venus Express is in the elliptical orbit and observing the polar region in the South hemisphere.

In this study, we obtained power spectra from the cloud brightness distribution of the UV images at the cloud top by Venus Monitoring Camera (VMC) onboard Venus Express, compared the slope of the spectra with the predicted value. And then we determined latitudinal dependence of the slope and the wavenumber at the inflection point.

The obtained spectra show that the slope in the longer wavelength range is steeper than that in the shorter wavelength range. The obtained slope is nonconsistent and doesn't completely agree with -3 and -5/3. The slope has temporal and latitudinal variations, while the slope obtained from the terrestrial turbulence is constant.

We will analyze other data and closely discuss energy and enstrophy flows.

General Circulation Modeling of Close-in Extrasolar Planets

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Many observed extrasolar planets orbit very close to their host stars. Such an orbit can lead to permanent day/night sides on the planets, due to tidally induced 1:1 spin-orbit synchronization. We use a general circulation model (GCM) to study the three-dimensional flow and temperature structures of extrasolar planet atmospheres subject to heating under such an orbital condition. Our model solves the full primitive equations for the atmospheric region from about 1 mbar to 100 bar, with thermal forcing represented by simple Newtonian relaxation. We have performed an extensive exploration of the physical and numerical parameter space relevant for tidally synchronized giant planets, in idealized scenarios, using HD209458b as a reference planet. The radius, mass, and orbital period (hence rotation rate) are derived from observations.

In our simulations, robust features include a small number of jets and large-scale coherent vortices (often in the form of a pair of modons). The temperature distribution is strongly associated with the flow structures, and is far from a simple hot-day/cold-night scenario---despite the strong thermal forcing on the dayside. The large vortices generally exhibit variability in time, translating or oscillating in longitude with corresponding variability in the position of relative hot and cold regions. In addition, although robust features can be identified in general, we have found a significant sensitivity to the initial flow state, which is presently unknown for the extrasolar planets. The latter result highlights the unsuitability of using GCMs for making *quantitative* ``predictions'', as have been done in recent extrasolar planet circulation studies found in the literature.

Gravity Wave Dynamics in Hot Extrasolar Planet Atmospheres

Chris Watkins & James Y-K. Cho

Many extrasolar planets are expected to possess stably-stratified atmospheres and thus support the propagation of gravity waves. The importance of gravity waves in the atmospheres of Solar System planets is well known. We study the propagation of gravity waves in hot extrasolar planet atmospheres and their effects on the background mean flow. First, we review the derivation of the linear equation that governs the dynamics of gravity waves and apply it to a model of an atmosphere based on HD209458 b, a representative "hot-Jupiter" planet. We find that gravity waves can exhibit a wide range of behaviours even in a single, simple atmospheric profile. The waves can provide a means for significant acceleration and deceleration of the mean flow, by transporting momentum between atmospheric layers. The waves can also provide significant heating (approximately 100 K per planetary rotation) to the region of the atmosphere about 10 scale heights above the source location. Further, gravity waves can provide a mechanism to transport heat and momentum from the day–side of tidally locked planets to the night–side, helping to homogenize the atmosphere. Finally, we discuss what work needs to be undertaken to enable future circulation models of extrasolar planet atmospheres.

A general theorem on angular-momentum changes due to potential vorticity mixing and on potential-energy changes due to buoyancy mixing

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An initial zonally symmetric quasigeostrophic potential-vorticity (PV) distribution $q_i(y)$ is subjected to complete or partial mixing within some finite zone $|y| < L$, where $y$ is latitude. The change in $M$, the total absolute angular momentum, between the initial and any later time is considered. For standard quasigeostrophic shallow-water beta-channel dynamics it is proved that, for any $q_i(y)$ such that $dq_i/dy > 0$ throughout $|y| < L$, the change in $M$ is always negative. This theorem holds even when "mixing" is understood in the most general possible sense. Arbitrary stirring or advective rearrangement is included, combined to an arbitrary extent with spatially inhomogeneous diffusion. The theorem holds whether or not the PV distribution is zonally symmetric at the later time. The same theorem governs Boussinesq potential-energy changes due to buoyancy mixing in the vertical. For the standard quasigeostrophic beta-channel dynamics to be valid the Rossby deformation length $L_D \gg \epsilon L$ where $\epsilon$ is the Rossby number; when $L_D = \infty$ the theorem applies not only to the beta-channel, but also to a single barotropic layer on the full sphere, as considered in the recent work of Dunkerton and Scott on "PV staircases". It follows that the $M$-conserving PV reconfigurations studied by those authors must involve processes describable as PV unmixing, or anti-diffusion, in the sense of time-reversed diffusion. Ordinary jet self-sharpening and jet-core acceleration do not, by contrast, require unmixing, as is shown here by detailed analysis. Mixing in the jet flanks suffices. A corollary is a powerful generalization of Arnol'd's first stability theorem.

Multiple stable solutions of Boussinesq fluid primitive equations

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Multiple solutions are interesting topics of planetary atmospheric general circulations. Matsuda (1980, 1982) suggested that there are multiple equilibrium solutions (a solution with strong zonal wind and weak meridional circulation, and that with weak zonal wind and strong meridional circulation) in some Venus-like parametric ranges using an axisymmetric low order (highly truncated) idealized model.
Recently Kido and Wakata (2008) showed multiple stable solutions in a Venus-like atmospheric general circulation model.

In the present study we explore multiple stable solutions of axisymmetric 2-D and non-axisymmetric 3-D Boussinesq fluid primitive equations with a simple Newtonian heating/cooling, to investigate whether the existence of multiple solutions is robust or not.

The key parameters of the equations are the thermal Rossby number, the horizontal Ekman number, and the ratio of the Newtonian heating/cooling time constant to the planetary rotation period. Parametric sweep experiments were carried out to explore multiple solution in the axisymmetric 2-D model. Our numerical results show the parametric region where the multiple solutions exist is qualitatively similar to that of Matsuda (1980). In addition, our results show that there are not only steady stable solutions but also unstable steady solutions in the axisymmetric 2-D model.

Comparing the results of 2-D model and 3-D model, we are going to discuss the robustness of multiple solutions and their properties.

Two-dimensional numerical experiments of Martian atmospheric convection with condensation of the major component

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For the purpose of calculating possible features of thermal convection with condensation of major component which may occur in the Martian atmosphere, we extend "deepconv", 2D non-hydrostatic convection model (http://www.gfd-dennou.org/library/deepconv/index.htm.en).
The basic equations are the quasi-compressible equations of Klemp and Wilhelmson (1978) with additional terms representing the condensation of major component.
Cloud particles are assumed to grow by diffusion process.
Representing the radiative process crudely, the atmosphere is subjected to horizontally uniform body heating near the surface and horizontally uniform body cooling in the convection layer.
As initial temperature profile, we choose profile of Martian polar cap.

In the system whose major component condenses, the degree of supersaturation is expected to have a significant influence on the convective structures (Colaprete et al., 2003).
The magnitude of buoyancy may be heavily controlled by the degree of supersaturation.
When supersaturation is inhibited, cloudy parcel can obtain no buoyancy because its temperature is constrained by the saturation temperature.
Following Glandorf et al. (2002), we adopt the values of critical saturation ratio (Scr) as 1.0 and 1.35.

In case of Scr = 1.35, quasi-equilibrium state is established after 30-day integration; the circulation is weak, and all the domain except for the shallow layer near the surface is covered with clouds.
In case of Scr = 1.0, all of clouds evaporate and strong dry convection with one cell develops.
In this case, quasi-equilibrium state is not established within the 40-day integration.
These results suggest that convective cloud structure depends significantly on the value of Scr.

Selective Absorption Mechanism for the Maintenance of Blocking
Akira Yamazaki* and Hisanori Itoh (Department of Earth and Planetary Sciences, Kyushu University)
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Atmospheric blocking is one of the most influential phenomena in global atmospheric environments. The understanding of its dynamical processes is important to clarify weather extremes and the stratosphere-troposphere coupling and to extend forecast periods. Shutts (1983) evaluated the effect of synoptic eddies on the maintenance of blocking in his numerical model and proposed the Eddy Straining Mechanism (ESM); a positive feedback mechanism between synoptic eddies and a blocking. However, some pieces of evidence have shown that the ESM does not work well in several real cases of the block maintenance. Thus, we propose a more realistic mechanism of the block maintenance named as the Selective Absorption Mechanism (SAM), in which a blocking anticyclone selectively and exclusively absorbs synoptic anticyclones. In this study, we verify the effectiveness of the SAM by observational analyses and simple numerical experiments. Ten episodes of blocking that occurred in the mid-North Pacific and the eastern North Atlantic between 1990 and 2005 are investigated. Trajectories of synoptic anticyclones and cyclones during blocking persistent periods are analyzed and show the selective absorption of anticyclonic eddies by the blocking highs. We also perform numerical experiments using the nonlinear barotropic vorticity equation on a beta-plane channel. The maintenance rate of blocking is quantitatively evaluated by using an areal averaged method. The result supports the block maintenance by the SAM. From the above two results, we can conclude that the SAM is more adaptive as the block maintenance mechanism than the ESM.

An Analysis of Pluto Occultation Light Curves Using an Atmospheric Radiative-conductive Model

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Stellar occultations are a vital tool for obtaining the vertical temperature structure of Pluto's atmosphere. Previous methods for deriving the atmospheric structure from the occultation light curve either assumed a mathematically convenient form for the temperature as a function of altitude that may not necessarily have been physically appropriate, or they required an upper boundary condition that may have induced systematic errors when not chosen properly. Using the radiative-conductive model of Strobel et al. 1996 (Icarus, 120, 266-289), radiative equilibrium temperature profiles may be calculated as a function of surface pressure, temperature, and radius, methane mixing ratio, and CO mixing ratio. The radiative equilibrium temperature profiles are interpolated on a grid of these variables, such that a model light curve may be calculated for any set of parameters within the grid. The model light curves are least-squares fit to occultation data from the years 1988 (Millis 1993, Icarus 105, 282-297), 2002 (Elliot et al. 2003, Nature 424, 165-168), 2006 (Elliot et al. 2007, AJ 134, 1-13), and 2007 (Person et al. 2008, Astron. J. 136, 1510-1518), for which surface pressure, surface radius, and methane mixing ratio are able to be determined.

Photolysis of $H_2SO_4$ as a source of $SO_2$ and SO in the mesosphere of Venus

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Recent observations from Venus Express suggest that the mixing ratio of $SO_2$ in the mesosphere (85-110 km) is in the range 0.1-5 ppm (Belyaev et al. 2009). As these values are larger than the abundance of $SO_2$ in the atmosphere of Venus above the cloud tops, the results are puzzling. Independent ground-based measurements reported large spatial and temporal variability of SO and $SO_2$ as well as their enhanced concentrations in the mesosphere region (Sandor et al. 2007). We propose that these puzzling observations could be explained if there is a new source of $SO_2$ and SO in the mesosphere of Venus derived from the photolysis of $H_2SO_4$. The proposed mechanism has four components: (1) $SO_2$ from the deep atmosphere is oxidized just above the cloud tops, resulting in the formation of $H_2SO_4$ aerosols (Yung and DeMore 1982), (2) transport of $H_2SO_4$ aerosols from the cloud tops to the mesosphere, (3) evaporation of $H_2SO_4$ aerosols in the region of elevated temperature, and (4) photolysis of $H_2SO_4$, $SO_3$ and SO. In this work we examine the impact of the variability of $H_2O$ and $H_2SO_4$ on $SO_2$ and SO in a simple model. We note that elevated values of $SO_2$ were observed in the terrestrial upper stratosphere by the Atlas shuttle mission (Rinsland et al. 1995). The authors attributed the source of $SO_2$ to photolysis of $H_2SO_4$, via a similar mechanism as proposed here.