Crossing Boundaries in Planetary Atmospheres:

From Earth to Exoplanets

American Geophysical Union

CHAPMAN CONFERENCE

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Annapolis, MD

AGU Chapman Conference on Crossing Boundaries in Planetary Atmospheres: From Earth to Exoplanets

Annapolis, Maryland
24-28, June 2013

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AGU Chapman Conference on Crossing Boundaries in Planetary Atmospheres: From Earth to Exoplanets

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No photography will be permitted during scientific sessions.

Meeting At A Glance

Sunday, 23 June

5:00 a.m. – 7:00 p.m. Welcome Reception

Monday, 24 June

8:45 a.m. – 9:00 a.m. Welcome and Opening Remarks

9:00 a.m. – 10:30 a.m. Session I - Big Questions – Frontiers of the Science in Each Subfield
- Invited talk – Earth: Tapio Schneider
- Invited talk – Planetary: Francois Forget
- Invited talk – Exoplanets: Jim Kasting

10:30 a.m. – 11:00 a.m. Coffee Break

11:00 a.m. – 12:00 p.m. Contributed talks (20 min. each)
- Georg Feulner
- Yamila Miguel

Discussion and plan for afternoon

12:00 p.m. – 1:30 p.m. Lunch on Your Own

1:30 p.m.- 3:30 p.m. Facilitated Small Breakouts (with representatives from each discipline)
Is it possible to create a universal taxonomy to classify planetary atmospheres and different Earth climates?
- Dynamical Considerations Astronomical
- Influences Composition/Climate Influences
- Dry vs. Aquaplanet vs. Different Mixed Land-ocean Configurations

3:30 p.m. – 4:00 p.m. Break

4:00 p.m. – 5:30 p.m Plenary Session: Facilitators report outcomes of breakouts, group discussion

Tuesday, 25 June

9:00 a.m. – 10:00 a.m. Session 2: Composition/Chemistry/Aerosols/Radiation
- Invited talk: David Catling
- Contributed talks (15 min. each)
- Sarah Hörst
- Julie Moses

10:00 a.m. – 10:30 a.m. Coffee Break

10:30 a.m. – 12:00 p.m. Panel-led plenary discussion with invited panel members to frame question(s) for open discussion

12:00 p.m. – 1:30 p.m.	Lunch on Your Own
1:30 p.m. – 2:30 p.m.	Session 3: Dynamics Invited talk: Adam Showman Contributed talks (15 min. each) Yohai Kaspi Boris Galperin
2:30 p.m. – 4:00 p.m.	Panel-led plenary discussion with invited panel to frame question(s) for open discussion
4:00 p.m. – 4:30 p.m.	Coffee Break
4:30 p.m. – 6:00 p.m.	Poster Session #1

Wednesday, 26 June

9:00 a.m. – 10:00 a.m.	Session 4: Observation and Data Analysis Approaches Invited talk: Leigh Fletcher Invited talk: Daphne Stam Invited talk: David Diner
10:00 a.m. – 10:30 a.m.	Break
10:30 a.m. – 12:00 p.m.	Panel-led plenary discussion with invited panel to frame question(s) for open discussion
12:00 p.m. – 1:30 p.m.	Lunch on Your Own
1:30 p.m. – 2:30 p.m.	Session 5: Modeling, data assimilation, dealing with sparse data Invited talk: Dorian Abbot Invited talk: Ralph Kahn
2:30 p.m. – 4:00 p.m.	Panel-led plenary discussion with invited panel to frame question(s) for open discussion
4:00 p.m. – 4:30 p.m.	Coffee Break
4:30 p.m. – 6:00 p.m.	Poster session II

Thursday, 27 June

9:00 a.m. – 10:00 a.m.	Session 6: Looking to the future Invited talk: Stacey Boland Invited talk: Heidi Hammel
10:00 a.m. – 10:30 a.m.	Coffee Break

10:30 a.m. – 12:30 p.m.	Plenary Discussion: Where do we go from here?

EOS meeting summary (conference organizing committee)

Special section of an AGU journal with cross-cutting papers from the conference (e.g., GRL)?

How to foster communication across disciplines? (e.g., a proposal for an AGU Focus Group?)

The funding silo barrier to cross-discipline research

12:30 p.m.	Adjourn

SCIENTIFIC PROGRAM

SUNDAY, 23 JUNE

5:00 p.m. – 7:00 p.m.	**Welcome Reception** Windjammer

MONDAY, 24 JUNE

8:45 a.m. – 9:00 a.m.	**Welcome Remarks**
	Session I - Big Questions - Frontiers of the Science in Each Subfield Ballroom C
9:00 a.m. – 9:30 a.m.	**Tapio Schneider |** Grand Challenges in Global Circulation Dynamics **(INVITED)**
9:30 a.m. – 10:00 a.m.	**Francois Forget |** Can Global Climate Models Simulate All Terrestrial Planets in the Solar System and Beyond? **(INVITED)**
10:00 a.m. – 10:30 a.m.	**James Kasting |** Big Questions About the Existence of Earth-like Exoplanets **(INVITED)**
10:30 a.m. – 11:00 a.m.	**Morning Coffee Break (Monday)**
	Contributed Talks: Big Questions - Frontiers of Science in Each Subfield Ballroom C
11:00 a.m. – 11:20 a.m.	**Georg Feulner |** Lessons from three-dimensional climate simulations of the faint young Sun paradox
11:20 a.m. – 11:40 a.m.	**Yamila Miguel |** Exploring Super-Earth Atmospheres
11:40 a.m. – 12:00 p.m.	All
12:00 p.m. – 1:30 p.m.	**Lunch (Monday)**
3:30 p.m. – 4:00 p.m.	**Afternoon Coffee Break (Monday)**
1:30 p.m. – 3:30 p.m.	**Breakout Session: Universal Taxonomies for Atmospheres and Climates Facilitators: Program Committee members, 5 groups, ~ 2 facilitators per group** Ballrooms B&C, Skipjack (3rd floor), Windjammer
4:00 p.m. – 5:30 p.m.	**Plenary Discussion - Breakout Reports** Monday afternoon report out from break-out groups

TUESDAY, 25 JUNE

	Session II - Composition / Chemistry / Aerosols / Radiation Ballroom C
9:00 a.m. – 9:30 a.m.	**David C. Catling |** Atmospheric Chemistry and Radiation in the Solar System as Guides to Exoplanet Atmospheres **(INVITED)**
9:30 a.m. – 9:45 a.m.	**Sarah M. Horst |** Haze Formation During the Rise of Oxygen in the Atmosphere of the Early Earth
9:45 a.m. – 10:00 a.m.	**Julianne I. Moses |** Photochemistry and Transport-Induced Quenching on Hot-Jupiter Exoplanets
10:00 a.m. – 10:30 a.m.	**Morning Coffee Break (Tuesday)**
10:30 a.m. – 12:00 p.m.	**Panel-led Plenary Discussion I**
12:00 p.m. – 1:30 p.m.	**Lunch (Tuesday)**
	Session III - Dynamics Presiding: Peter Read Ballroom C
1:30 p.m. – 2:00 p.m.	**Adam Showman |** Atmospheric Dynamics of Exoplanets **(INVITED)**
2:00 p.m. – 2:15 p.m.	**Yohai Kaspi |** Three-dimensional Atmospheric Circulation and Climate of Terrestrial Exoplanets
2:15 p.m. – 2:30 p.m.	**Boris Galperin |** The Regime of Zonostrophic Macroturbulence and Its Application for Characterization of Large-scale Circulation on Jupiter and Other Giant Planets
2:30 p.m. – 4:00 p.m.	**Panel-led Plenary Discussion II**
4:00 p.m. – 4:30 p.m.	**Afternoon Coffee Break (Tuesday)**
4:30 p.m. – 6:00 p.m.	**Poster Session I** Atrium
T-1	**Inna Polichtchouk |** Intercomparison of General Circulation Models for Hot Extrasolar Planets
T-2	**Junling Huang |** Evidence for a secular increase in power generated by the Hadley circulation

T-3 **Abigail M. Rymer |** Negative Ions in the Solar System

T-4 **Tiffany Kataria |** Atmospheric circulation modeling of GJ 1214b: Including effects due to collisionally induced absorption from CO_2-CO_2 collisions

T-5 **Gennady G. Kochemasov |** Siberian Atmospheric High: Its Formation in Frame of the Solid Earth Sector Tectonics

T-6 **Toby Stangier |** Direct Wind Measurements in the Atmospheres of Mars, Earth and Venus

T-7 **Howard Houben |** We've Been Doing It Wrong

T-8 **Ramses M. Ramirez |** Habitable Zones around Main Sequence stars : Greenhouse and anti-greenhouse effects of H2 and CH4

T-9 **Nikole K. Lewis |** A Look Under the Hood of the SPARC/MITgcm: Recent Updates, Results, and Future Plans

T-10 **Everett Schlawin |** A Near-Infrared Transmission Spectrum of the Hot Jupiter Corot-1b

T-11 **Swagata Payra |** A Comparative Analysis of Remote Sensing Observations Over Northwestern India

T-12 **Dmitrij Titov |** A new view of Earth's sister: Insights following seven years of observation with Venus Express

T-13 **Shawn Domagal-Goldman |** Moving ModelE to Mars

T-14 **Jacqueline Radigan |** Observations of cloud and weather phenomena in the atmospheres of cool brown dwarfs

T-15 **Emily Rauscher |** Evaluating the Inf luence of Magnetic Drag and Heating on Atmospheric Circulation Near the Photospheres of "Hot Jupiters"

T-16 **Aymeric Spiga |** Convection, turbulence, waves: a comparative analysis of mesoscale processes on Mars and the Earth, and perspectives for other planetary environments

T-17 **James Cho |** Dynamics of Ionized Giant Planet Atmospheres

T-18 **Pratik K. Dave |** Calibration of Spaceborne Microwave Radiometers with GPS Radio Occultation Measurements

T-19 **Robert Boschi |** How do Changes in the Planetary Rotation Effect Bi-stability and Climate Sensitivity in the Habitable Zone?

T-20 **Arielle Moullet |** Exploring the diversity of atmospheres in the Solar System with the Atacama Large Millimeter Array (ALMA) and the K. Jansky Very Large Array (JVLA)

T-21 **Nancy Chanover |** Colors in the Giant Planet Atmospheres

T-22 **Heidar T. Thrastarson |** General Circulation and Variability of Close-In Exoplanet Atmospheres

T-23 **Stephen Thomson |** Jupiter's Unearthly Jets: A New Idealized Model

WEDNESDAY, 26 JUNE

Session IV - Observation and Data Analysis Approaches
Ballroom C

9:00 a.m. – 9:20 a.m. **Leigh N. Fletcher |** The Diversity of Giant Planets: Infrared Characterisation beyond the Cloudy Veil **(INVITED)**

9:20 a.m. – 9:40 a.m. **Daphne M. Stam |** Uncovering Exoplanets Using Spectropolarimetry **(INVITED)**

9:40 a.m. – 10:00 a.m. **David J. Diner |** Seeing the Earth in 4D **(INVITED)**

10:00 a.m. – 10:30 a.m. **Morning Coffee Break (Wednesday)**

10:30 a.m. – 12:00 p.m. **Panel-lead Discussion III**

12:00 p.m. – 1:30 p.m. **Lunch (Wednesday)**

Session V - Modeling, Data Assimilation, Sparse Data and Data Limitations
Presiding: Linda Sohl
Ballroom C

1:30 p.m. – 2:00 p.m. **Dorian S. Abbot |** Clouds in Wacky Climates **(INVITED)**

2:00 p.m. – 2:30 p.m. **Ralph Kahn |** Airborne Particles – What We've Learned About Their Role in Climate From Remote Sensing Observations, and Prospects for Future Advances **(INVITED)**

2:30 p.m. – 4:00 p.m. **Panel-led Discussion IV**

4:00 p.m. – 4:30 p.m. **Afternoon Coffee Break (Wednesday)**

4:30 p.m. – 6:00 p.m. **Poster Session II**
Atrium

W-1 **Anthony Del Genio |** Modulation of Terrestrial Convection by Tropospheric Humidity, and Implications for Other Planets

W-2 **Nadiia Kostogryz |** Polarimetry and physics of atmospheric aerosol of the Earth

W-3 **Nadiya Kostogryz |** THE METHOD OF COMPUTER ANALYSIS A VERTICAL STRUCTURE OF AEROSOL COMPONENT IN THE ATMOSPHERES OF THE GIANT PLANETS

W-4 **Remco de Kok |** Forward-scattered light in transmission measurements of (exo)planetary atmospheres

W-5 **Antonio García Muñoz |** Monte Carlo modeling of the polarimetric signatures of planetary atmospheres

W-6 **Sunal Ojha |** Monitoring spatial and temporal snow cover variability in three major basins from Himalayas

W-7 **Igor Alexeev |** A role of the auroral thermosphere Joule heating in the upper atmosphere energy budget

W-8 **Manoj Joshi |** Cryospheric albedo feedbacks on Earth and other planets

W-9 **Sunita Verma |** On the Sulfate Aerosols Representation in an Interactive Global Climate Chemistry Model

W-10 **Deepak P. Mahtani |** Reanalysis of Warm Spitzer Full Orbit Light Curves of WASP-12 at 3.6μm and 4.5μm

W-11 **Kwing L. Chan |** Numerical simulation of convectively generated vortices: application to the Jovian planets

W-12 **Yixiong Wang |** Terrestrial Planetary Atmospheric Circulation Regimes in a Simplified GCM with Dual-band Radiative-transfer Scheme

W-13 **Sandrine Guerlet |** Saturn's stratospheric dynamics unveiled by infrared observations: signatures of an equatorial oscillation, of a meridional circulation, and comparison with the Earth's stratosphere

W-14 **Jeremy Leconte |** A 3D point of view of the atmosphere of strongly irradiated terrestrial exoplanets: runaway greenhouse and climate bistability

W-15 **Kevin McGouldrick |** Microphysical Model of the Venus Clouds

W-16 **Conor A. Nixon |** The search for new trace species in the stratosphere of Titan using Cassini CIRS

W-17 **Imke de Pater |** Multi-wavelength Observations of Neptune's Atmosphere

W-18 **Scott Osprey |** Gravity-Wave Driven Circulations in the Earths Atmosphere

W-19 **Joseph H. Westlake |** Energetic Neutral Atom Imaging for Probing Planetary Atmospheres

W-20 **Roland Young |** Cassini observations reveal the regime of zonostrophic macroturbulence on Jupiter

W-21 **Robert Tyler |** Resonant Tidal Excitation and Heating of Giant- Planet Atmospheres

W-22 **Scott D. Guzewich |** Links Between Atmospheric Tides and Topography

W-23 **Jonathan Mitchell |** Idealized seasonal cycles in a dry GCM and implications for atmospheric superrotation

W-24 **Junjun Liu |** Formation of Equatorial Superrotation and Multiple jets in Planetary Atmospheres

6:00 p.m. – 8:00 p.m. **Banquet Dinner**

THURSDAY, 27 JUNE

Session VI - Looking to the Future
Ballroom C

9:00 a.m. – 9:30 a.m. **Stacey Boland |** Title TBD

9:30 a.m. – 10:00 a.m. **Heidi Hammel |** Contributed Talk

10:00 a.m. – 10:30 a.m. **Morning Coffee Break (Thursday)**

10:30 a.m. – 12:00 p.m. **Panel-led Discussion V: Where Do We Go From Here?**

ABSTRACTS

listed by name of presenter

Abbot, Dorian S.

Clouds in Wacky Climates ***(INVITED)***

Abbot, Dorian S.[1]

1. Geophysical Sciences, University of Chicago, Chicago, IL, USA

Clouds have a huge impact on the climate of a planet. On Earth, if the clouds forgot that part of their job is to reflect solar energy, we would suffer a runaway greenhouse and end up like Venus. If clouds forgot that part of their job is to absorb infrared radiation emitted by the surface and contribute to the greenhouse effect, we would enter global glaciation. Although they are very important for climate, clouds are very difficult to model and represent the largest source of uncertainty in climate modeling. This results both from insufficient resolution to resolve cloud-scale circulation and incomplete understanding of cloud microphysics. Cloud simulation is therefore the main reason our current models aren't better, and is a critical area to attack if we want to create generalized GCMs that could be easily applied to different planets (the clouds might not be water clouds in this case). In this talk I will discuss how we can use the models we have to gain insight into cloud behavior in climates vastly different from modern Earth. The two examples I will focus on are the Snowball Earth episodes and tidally locked super-Earths near the inner edge of the habitable zone of M-stars.

Alexeev, Igor

A role of the auroral thermosphere Joule heating in the upper atmosphere energy budget

Alexeev, Igor[1]; Belenkaya, Elena S.[1]; Khodachenko, Maxim L.[2, 1]

1. Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University,, Moscow, Russian Federation
2. Austrian Academy of Sciences, Space Research Institute, Graz, Austria

All giant planets in the Solar System and particularly Saturn and Jupiter is known to have an upper neutral atmosphere far hotter than what is expected from solar extreme ultraviolet heating alone. While the measured exospheric temperatures on Saturn and Jupiter are close to 500 K or to 1100 K – 2000 K, correspondingly, solar heating alone induces an exospheric temperature near – 200 K. Till now two main energy deposits discussed in the literature to resolve this contradictions: (1) the gravitation wave dissipation in the upper atmosphere, and (2) the auroral Joule thermosphere heating by the Pedersen ionospheric currents, which closured field-aligned currents generated by magnetosphere-ionosphere. Here we will focus on second energy source. To improve the accuracy of the numerical estimations we derived the analytic formulas that described the dependence of the auroral energy flux on the planetary magnetic field strength, on the solar wind plasma dynamic pressure, and on the breaking from magnetospheric plasma corotation that is essential for Jupiter where the main oval is driven internally at Alvenic radius. We try to extract the main physical phenomena which slightly influent by detail of the atmospheric species and photochemical ionospheric reactions. A comparison with recently Cassini and Galileo data support the importance of the polar region energy input to understanding of the Jupiter and Saturn dynamics.

Boland, Stacey

Title TBD

Boland, Stacey[1]

1. Jet Propulsion Laboratory, Pasadena, CA, USA

No abstract attached.

Boschi, Robert

How do Changes in the Planetary Rotation Effect Bi-stability and Climate Sensitivity in the Habitable Zone?

Boschi, Robert[1]; Lucarini, Valerio[1, 2]; Pascale, Salvatore[1]

1. Theoretical Meterology, University of Hamburg, Hamburg, Germany
2. Mathematics and Statistics, University of Reading, Reading, United Kingdom

Planetary atmospheres with a condensing phase may experience bi-stability, i.e. a warm, moist atmosphere and a deep frozen, dry state (Snowball), despite having the same value for the solar constant. Consequently, a planet in the habitable zone, may be totally frozen and so unfit for sustaining life. In this study we deal with the effect of varying the rotation rate of a planet (Ω) on its bistability properties. The rotation rate has a major influence on the atmospheres general circulation and thus on its ability to distribute heat between warm and cold regions. By using a general circulation model, PlaSim, we consider several values of the rotation rate, from tidally locked (Ω/Ω_E = 1/360, where Ω_E is the Earth's rotation rate), to that of slowly rotating (Ω/Ω_E = 1/30) planets. For each value of Ω, we slowly modulate the solar constant between 1510 and 1000 W/m^2 and perform a hysteresis experiment. It is found that the width of the Bi-stable region, i.e. the range of climate states - determined here by changes in S* - which support two climatic attractors, reduces when the rotation rate is decreased and disappears - signifying the merging of both attractors - for climates with a rotation rate of less than 1/135 – 1/180. Crucial to the loss of bi-stability is the longitudinally asymmetric distribution of solar radiation, incident on the planet's surface. For regimes where bi-stability is found, the longitudinally asymmetric heating is

sufficiently compensated for by the strong zonal winds, which redistribute heat and maintain the meridional temperature gradient across all longitudes. Conversely, for mono-stable regimes, the energy transport associated with zonal winds becomes insufficient, resulting in large zonal temperature gradients along the equatorial band. Furthermore, the results found here confirm and re-enforce the robustness of those found in Boschi et al (2013), showing that, for climates which support bi-stability, it may be possible to parameterise variables such as the material entropy production and the meridional heat transport in terms of the surface and brightness temperatures, within reasonably well defined upper and lower bounds, even when considering a wide range of planetary rotation speeds and changes to the infrared opacity. This paves the way for the possibility of practically deducing fundamental properties of planets in the habitable zone from relatively simple observables.

Catling, David C.

Atmospheric Chemistry and Radiation in the Solar System as Guides to Exoplanet Atmospheres *(INVITED)*

Catling, David C.[1]; Robinson, Tyler D.[2]

1. Earth and Space Sciences, U. Washington, Seattle, WA, USA
2. Astronomy, U. Washington, Seattle, WA, USA

From a chemical point of view, there are two types of atmospheres: oxidizing and reducing. Features such as the type of aerosols and atmospheric structure then follow. Ignoring highly tenuous atmospheres, oxidizing ones include those of Venus, Earth, and Mars. The inclusion of Venus is nuanced by restricting consideration to its stratosphere, which is what is most easily observed remotely. In an oxidizing atmosphere, carbon is predominantly in the form of CO2, and so terrestrial and Venusian stratospheres are cooled by CO2. The photochemistry of SO2 and OCS produces sulfate aerosols. On Earth, most oxidized sulfur is surface or oceanic sulfate, so that stratospheric sulfate hazes, in the so-called Junge layer, do not become optically thick. Venus's haze is like a dense version of Earth's Junge layer. Microphysics cause Venus's haze to become optically thick primarily below the ~0.1 bar level where UV photolysis of SO2 peaks. We expect sulfate hazes on Earth-like exoplanets with oxidizing atmospheres, with associated climatic cooling from shortwave albedo. A volcanically active early Mars would also have sulfate aerosols. In the reducing atmospheres of Titan and the giant planets, carbon exists as CH4. Methane photochemistry produces hydrocarbon hazes at high altitude, given the level of CH4 photolysis. These haze particles cannot grow large or numerous enough at high altitude to interact greatly with thermal radiation. So, unlike Venus, the hazes in reducing atmospheres have a minor effect in the thermal IR. However, shortwave radiation absorbed by hazes and CH4 heats the upper atmosphere. This energy cannot be efficiently radiated away by the primary stratospheric coolants (acetylene and ethane), thus causing strong inversions. Such chemistry and radiative consequences should occur in similar atmospheres on exoplanets. (We note that 'hot Jupiters', which can have very different chemistry, comprise only a small minority of exoplanets.) Thick atmospheres in the Solar System have a common structure arising from radiative-convective equilibrium. All have convection up to a radiative-convective boundary at a gray IR optical depth of about unity or more, above which a tropopause temperature minimum occurs at ~0.1 bar. There, the gray IR optical depth is far less than unity, allowing stratospheric heating to dominate, compared to gray IR optical depths ranging 2-10 at the 1 bar level. A common tropopause pressure is related to the pressure-dependence of absorption processes. Venus is unusual in that its tropopause minimum is not discernable in the global mean yet is clearly present at mid to high latitudes. This may be an effect of dynamics influencing the haze and energy budgets. In exoplanet atmospheres that are similar composition to those in the Solar System, vertical structures with ~0.1 bar tropopauses and inversions can be predicted from a common physics, including the inability of high altitude hazes to become optically thick in the thermal IR for microphysical reasons. In conclusion, there are many common features amongst the atmospheres of the Solar System. Such features are rooted in photochemical and physical principles, and likely extend to many exoplanets.

Chan, Kwing L.

Numerical simulation of convectively generated vortices: application to the Jovian planets

Chan, Kwing L.[1]; Mayr, Hans G.[2]

1. Mathematics, Hong Kong University of Science and Technology, Hong Kong, China
2. Applied Physics Labboratory, Johns Hopkins University, Baltimore, MD, USA

Numerical experiments are performed to study the possibility of long-lived vortex generation in rotating convection zones. The domain of computation is a rectangular box with fixed latitude. The fully compressible fluid equations are solved using an explicit, strongly conservative finite difference method. A total of eight cases covering two different latitudes and four different rotation rates were computed. As the rotation rate increases, a long-lived cyclone first appears. The high latitude environment is more favourable for vortex formation. An anticyclone appears when the rotation is adequately fast. Both types of long-lived vortices are generated by thermo-mechanical instabilities,arising from a positive feedback of the absolute vorticity and the inhibitive effect of rotation on convection. Possible implications of the numerical results to the Jovian planets are discussed.

Chanover, Nancy

Colors in the Giant Planet Atmospheres

Chanover, Nancy[1]; Simon, Amy[2]; Hudson, Reggie[2]

1. Astronomy, New Mexico State University, Las Cruces, NM, USA
2. NASA Goddard Space Flight Center, Greenbelt, MD, USA

We present and interpret ground-based optical spectra of Jupiter and Saturn recently acquired in an effort to characterize candidate coloring agents, or chromophores, in the atmospheres of the gas giant planets of our solar system. Surprisingly, despite hundreds of years of observations, we still do not know the identity of the trace chemical compounds that color the atmospheres of the giant planets. Previous analyses have attempted to identify a specific chemical that is responsible for the colors, but none has yet been conclusively proven. We acquired spatially resolved optical spectra of various regions in the atmospheres of both Jupiter and Saturn in February 2013 using the Dual Imaging Spectrograph (DIS) on the Astrophysical Research Consortium's 3.5-meter telescope at Apache Point Observatory. The spectra cover the range of 300-1000 nm, with a spectral resolution of R ˜ 1200. For the observations of both Jupiter and Saturn, we used DIS with the 6 arcminute long slit aligned with the planets' latitudinal bands and stepped the slit north-south to build up a spectral image cube with spectra at all locations on the planet. This enables the extraction of subapertures within the slit corresponding to specific locations, e.g. the Great Red Spot on Jupiter, during the data reduction process. We compare the optical spectra of various colored regions in the giant planet atmospheres to laboratory data of candidate chromophores. This work will provide insight into the upper tropospheric dynamics and circulation patterns on Jupiter and Saturn that provide a stable environment for the creation and/or sustenance of chromophores. This work also will improve our understanding of the evolution of the Outer Solar System. Our chromophore study will advance our understanding of Jupiter's and Saturn's atmospheres, and perhaps (by extension) those of giant planets in general. This will help further our understanding of the different evolutionary pathways of the gas giant planets of our solar system, providing a process-oriented view of their variations in cloud colors.

Cho, James

Dynamics of Ionized Giant Planet Atmospheres

Cho, James[1]

1. Queen Mary, University of London, London, United Kingdom

The nonlinear dynamics of ionized planetary atmospheres are presented. Both Solar System and Extrasolar System planets are considered, making use of knowledge gained from Earth and other Solar System ionosphere studies. Fundamental equations in the collision-dominated regime are discussed and high-resolution numerical simulations are presented in idealized settings. The focus is on elucidating mechanisms that control the dynamics and interactions of jets, vortices, waves, currents, and magnetic fields.

Dave, Pratik K.

Calibration of Spaceborne Microwave Radiometers with GPS Radio Occultation Measurements

Dave, Pratik K.[1]; Blackwell, William J.[2]; Cohen, Brian S.[2]; Cahoy, Kerri[1]

1. Space Systems Laboratory, Massachusetts Institute of Technology, Cambridge, MA, USA
2. Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA, USA

Spaceborne microwave radiometers (MWRs) contribute to the monitoring and prediction of meteorological and oceanographic events by measuring atmospheric and terrestrial radiation in the 1—1000 GHz band. In order to calibrate MWR measurements, at least two known-temperature reference sources are required. The cosmic microwave background of cold space at the MWR signal frequency is used as one reference. For the second reference, spaceborne MWRs can use internal calibration targets (ICTs) that radiate energy at a known temperature. ICTs require more mass, power, and volume than can be easily accommodated on small spacecraft, which restricts their use to large spacecraft or significantly limits the resources available to smaller spacecraft. In order to enable MWR missions on small, inexpensive platforms in LEO such as CubeSats, there is a need to develop new ways of performing in-situ calibration. Han and Westwater (2000) investigated the "tipping" calibration technique for ground-based MWRs in which the radiometer scans from zenith downward to the horizon to obtain a profile of the atmosphere where temperatures are known to vary as a function of the declination angle. A spaceborne MWR can also scan a profile of measurements as it is "tipped" through the earth's limb. However, the temperature profile of the limb atmosphere must be accurately known to high vertical spatial and temporal resolution in order to use this measurement as the second calibration reference. Kursinski et al. (1997) demonstrated that it was possible to obtain a high vertical resolution and high accuracy temperature profile of the atmosphere using a space-based receiver to measure transmitted signals from GPS satellites, a technique called GPS radio occultation (GPSRO). In this paper we show that it is feasible for a small spacecraft to host both a GPSRO receiver and a MWR and that, in principle, GPSRO profiles can be used to calibrate the MWR. We investigate the effect of design parameters such as signal frequency, sampling rate, and satellite altitude on the calibration performance of GPSRO-aided MWR calibration.

de Kok, Remco

Forward-scattered light in transmission measurements of (exo)planetary atmospheres

de Kok, Remco[1]; Stam, Daphne[2, 1]

1. SRON Netherlands Institute for Space Research, Utrecht, Netherlands
2. Delft University of Technology, Delft, Netherlands

The transmission of light through a planetary atmosphere in the solar system can be studied as a function of altitude and wavelength using stellar or solar occultations, giving often unique constraints on the atmospheric composition. For exoplanets, a transit yields a limb-integrated, wavelength-dependent transmission spectrum of an atmosphere. When scattering haze and/or cloud particles are present in the planetary atmosphere, forward-scattered light can contribute an additional signal to the transmission spectrum. We explore this effect using a 3D Monte Carlo model and show what consequences there are for the retrieved atmospheric properties when scattering is ignored, which is standard practise.

de Pater, Imke

Multi-wavelength Observations of Neptune's Atmosphere

de Pater, Imke[1]; Fletcher, Leigh[2]; Luszcz-Cook, Statia[3]; deBoer, David[1]; Butler, Bryan[4]; Orton, Glenn[5]; Sitko, Michael[6]; Hammel, Heidi[7]

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We conducted a multi-wavelength observing campaign on Neptune between June and October, 2003. We used the 10-m Keck telescope at near- and mid-infrared wavelengths and the VLA at radio wavelengths. Near infrared images were taken in October 2003 in broad- and narrow-band filters between 1 and 2.5 micron, using the infrared camera NIRC2 coupled to the Keck Adaptive Optics system. At these wavelengths we detect sunlight reflected off clouds in the upper troposphere and lower stratosphere. As shown by various authors before, bright bands of discrete cloud features are visible between 20°S and 50°S and near 30°N, as well as several distinct bright cloud features near 70°S, and the south polar "dot". Mid-infrared images were taken on September 5 and 6 (2003) using the Keck LWS system in atmospheric windows at 8, 8.9, 10.7, 11.7, 12.5, 17.65, 18.75 and 22 micron. At these wavelengths we detect thermal emission from Neptune's stratosphere due to the presence of hydrocarbons, and from near the tropopause due to collision induced opacity by hydrogen. At all wavelengths the South polar region stands out as a bright spot. At 17 - 22 micron also the equatorial region is slightly enhanced in intensity. These characteristics are consistent with later imaging at similar wavelengths (Hammel et al. 2007; Orton et al. 2007). Microwave images were constructed from NRAO VLA data between 0.7 and 6.0 cm. At these wavelengths depths of several up to >50 bar are probed. An increase in brightness indicates decreased opacity of absorbers (e.g., NH3, H2S), since under such circumstances deep, and hence warm levels (adiabatic temperature-pressure profile), will be probed. The multi-wavelength observing campaign in 2003 was focused on obtaining images that probe different altitudes in Neptune's atmosphere. Indeed, this set of data probes altitudes from about 0.1 mbar down to ~50 bar, and hence can be used to constrain the global atmospheric circulation in Neptune's atmosphere. At the meeting we will show our results and interpretation of the findings.

Del Genio, Anthony

Modulation of Terrestrial Convection by Tropospheric Humidity, and Implications for Other Planets

Del Genio, Anthony[1]

1. NASA Goddard Institute for Space Studies, New York, NY, USA

For decades, deep cumulus convection was viewed as having to consist partly of undilute plumes that do not interact with their surrounding environment in order to explain their observed tendency to reach and sometimes penetrate the tropical tropopause. This behavior was built into virtually all cumulus parameterizations used in terrestrial global climate and numerical weather prediction models, and still persists in some models today. In the past decade, though, some embarrassing failures of global models have come to light, notably their tendency to rain over land near noon rather than in late afternoon or evening, as observed, and the complete absence in the models of the Madden-Julian Oscillation, the major source of intraseasonal (30-90 day) precipitation variability in the Indian Ocean, West Pacific, and surrounding continental regions. In the past decade it has become clear that an important missing component of parameterizations is strong turbulent entrainment of drier environmental air into cumulus updrafts, which reduces the buoyancy of the updrafts and thus limits their vertical development. Tropospheric humidity thus serves as a throttle on convective penetration to high altitudes and delays the convective response to large-scale destabilizing influences in the environment. We speculate on whether consideration of these effects on other planets might deepen our understanding of observed phenomena such as the seemingly counter-intuitive presence of deep convection in belts rather than zones on the jovian planets, and the episodic outbreak and disappearance of tropical methane precipitation and delayed seasonal progression of the general circulation on Titan, as well as whether inferences about habitable zone boundaries based on conventional notions of radiative-convective equilibrium might need to be adjusted for unsaturated atmospheres.

Diner, David J.

Seeing the Earth in 4D ***(INVITED)***

Diner, David J.[1]; Garay, Michael[1]; Davis, Anthony[1]; Kalashnikova, Olga V.[1]; Xu, Feng[1]

1. Jet Propulsion Laboratory, Pasadena, CA, USA

We live in a world of three spatial dimensions. While multispectral imaging is a well-known tool for capturing spatial variability in the horizontal plane, sensing atmospheric vertical structure and surface texture is generally associated with active instruments such as lidars, radars, or scatterometers. Yet a purely passive technique, multiangle imaging, is a powerful remote sensing modality that makes use of natural illumination—sunlight—to probe the 3D structure of the atmosphere and surface on a variety of spatial scales. To illustrate this point, images and geophysical retrievals from two instruments, the Multiangle Imaging SpectroRadiometer (MISR), flying on NASA's Earth-orbiting Terra spacecraft, and the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI), flying on NASA's ER-2 high-altitude aircraft, are presented to show how multiangle imagery makes it possible to map the shapes of airborne particles, the textures of ocean surfaces and vegetated and ice-covered terrains, and the morphological characteristics of cloud fields and aerosol plumes. Moreover, time lapse between multiangle views samples the temporal realm on scales of several minutes, supplementing the three spatial dimensions with a 4D view of height-resolved vector winds, from billowing plumes of smoke and dust to the roiling clouds of major storms. MISR views the Earth at 446, 558, 672, and 866 nm at nine discrete along-track view angles ranging from nadir to 70° forward and backward of nadir. AirMSPI is a prototype for a future spaceborne successor to MISR, and broadens the spectral coverage with channels at 355, 380, 445, 470*, 555, 660*, 865*, and 935 nm (polarization is measured in the bands marked with an asterisk). Polarimetry brings heightened sensitivity to the size, shape, and refractive index of aerosol and cloud particles. Multiangular radiometric and polarimetric observations sample the scattering phase functions of aerosols and clouds, yielding clues to particle size and shape through the application of optical scattering and (typically) 1D radiative transfer (RT) theories. Geometric retrievals making use of stereoscopic parallax and automated pattern matching generate heights and winds at the tops of clouds. Given the limitations of 1DRT retrievals in heterogeneous scenes, we are exploring reconstruction of the atmosphere as a 3D spatial environment, invoking technologies adapted from biomedical imaging and computer vision, such as computed and optical tomography, to infer the distribution of airborne particles. We also aim to overcome the limitations of conventional look-up table approaches in which particle property retrievals are based on a prescribed set of models, using optimization methods to enable a more thorough exploration of the parameter space. In light of the large volumes of data and complexity of the retrieval problem, future advances in computational hardware, software, and algorithms will be necessary to implement these paradigm shifts and to fully capitalize on the rich information content of multiangle, multispectral, and polarimetric imagery. The potential rewards include detailed characterizations of aerosol and cloud distributions in space and time, and accurate inferences of their impacts on our climate and the quality of the air we breathe.

Domagal-Goldman, Shawn

Moving ModelE to Mars

Domagal-Goldman, Shawn[1]; Kiang, Nancy Y.[2]; Aleinov, Igor[3, 2]; Clune, Thomas L.[1]; Del Genio, Anthony D.[2]; Kelley, Maxwell[3, 2]; McElwain, Michael W.[1]; Pavlov, Alexander A.[1]; Sohl, Linda E.[3, 2]; Way, Michael J.[2]; Mandell, Avi M.[1]; Schmidt, Gavin A.[2]

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2. NASA Goddard Institute for Space Studies, New York City, NY, USA
3. Columbia University, New York City, NY, USA

This presentation will discuss an ongoing effort to modify the ModelE general circulation model (GCM), maintained by the NASA Goddard Institute for Space Studies, to simulate the Mars environment. This is the first step in a long term effort to create a flexible GCM applicable to both solar system and extrasolar planets. In this presentation, we will outline our long term plans for the model, and discuss our progress to-date. This goal of this project, tentatively titled the Generalized Rocky ExoPlanet GCM (GREP GCM), is to create a flexible planetary GCM that is permanently tied to the modeling software for a well-maintained Earth GCM. This will provide the (exo)planetary sciences community with continued updates from the Earth sciences community and will provide the Earth sciences community with a model that is constantly tested for maximum flexibility. Likewise, it will give the planetary GCM community a new model to compare with existing 1-dimensional models, expanding the validation capabilities for the ModelE code by applying to extreme environments. On top of an overview of the GREP GCM effort, this presentation will provide the audience with a real-time view of the pitfalls that can arise when modifying an Earth-tuned GCM for simulating another planet. Specific experiments we will discuss include changing the planet's surface type, topography, size, and orbital parameters. These "easy changes" have necessitated changes to ModelE's base code and identified the limitations of the existing model in extreme conditions. Thus, our effort is already providing feedback to the Earth GCM. If the model's migration to Mars is complete by the Chapman conference, we will also present preliminary results from GCM simulations of the red planet, and compare these results to prior 1-D and GCM simulations.

Feulner, Georg

Lessons from three-dimensional climate simulations of the faint young Sun paradox

Feulner, Georg[1]; Kienert, Hendrik[1]; Petoukhov, Vladimir[1]

1. Potsdam Institute (PIK), Potsdam, Germany

The faint young Sun paradox, the puzzling question what kept early Earth warm enough to allow for liquid surface water despite a 20-25% fainter Sun, is of importance for our understanding of Earth's environment during a time when life first appeared on our planet. It is also highly relevant for the question of planetary habitability both within the solar system and around other stars. Traditionally, the faint young Sun paradox has been investigated with one-dimensional radiative-convective climate models using a fixed albedo value and thus neglecting effects like the ice-albedo feedback. Here we present results from the first coupled three-dimensional climate simulations for early Earth taking into account the smaller continental area, the higher rotation rate and fully interactive changes in sea-ice and clouds. We find that the ice-albedo feedback in connection with the higher rotation rate leads to significantly higher carbon dioxide concentrations required to prevent global glaciations than previously estimated based on one-dimensional models. Furthermore, to develop a deeper understanding of ancient climates we characterize the physical principles shaping Earth's climate system at these early times and discuss the sensitivity of our results to continental configuration, rotation rate as well as model parametrization for radiative transfer and sea-ice physics.

Fletcher, Leigh N.

The Diversity of Giant Planets: Infrared Characterisation beyond the Cloudy Veil *(INVITED)*

Fletcher, Leigh N.[1]

1. Atmospheric, Oceanic and Planetary Physics, University of Oxford, Oxford, United Kingdom

Of the 860+ planets discovered to date, the vast majority are giant, hydrogen-rich gas planets under conditions of extreme irradiation. Our characterisation of these distant worlds is in its infancy, but our own collection of gaseous worlds exist on the same continuum of planetary types, and could be considered as a template for their interpretation. Yet there is much we still don't understand about the origins, vertical structure and chemistry of our own giant planets. Condensation chemistry, for example, provides a first approximation to the cloud decks of the giants, from the familiar ammonia-water mix of our cool jovians to the hot silicate and iron clouds of the hot roasters. Yet spectroscopic detections of the major condensate clouds in our own solar system is hampered by spectral contaminants, spatial variability (e.g., jovian hotspots) and photolytically-generated species (e.g., diphosphene on Saturn), rendering clouds as the limiting uncertainty in our understanding of giant planet spectroscopy. The banded structures common to each of our giants is subject to global-scale variability (such as the recent fade and revival of Jupiter's South Equatorial Belt and storm eruptions on Saturn) and seasonal perturbations (Saturn's slowly-reversing seasonal asymmetries, polar phenomena and Neptune's changes in global brightness). The circulation regimes, revealed by the distribution of dynamical tracers, appear to vary dramatically as we move from the stratosphere (wave dominated and radiatively cooled) to the deeper troposphere (convective overturning, lightning and eddy-driven winds and storms). Their bulk chemical composition, imprinted from the proto-planetary nebula during the epoch of planetary formation, is poorly known and open to a variety of different interpretations. Infrared observations of temperatures, winds, clouds and composition will be presented with the aim of describing the common phenomena shaping the appearance of the giants and what, if any, implications this has for the diversity of Jupiter-class objects being discovered around other stars. We will highlight future observational strategies for Jupiter (high resolution spectro-spatial mapping in support of the Juno and JUICE missions) and the other giants (long term seasonal monitoring) to reveal new insights into our collection of gas giants.

Forget, Francois

Can Global Climate Models Simulate All Terrestrial Planets in the Solar System and Beyond? *(INVITED)*

Forget, Francois[1]

1. LMD, IPSL, Paris, France

For about forty years, Earth climatologists have been developing Global Climate Models (GCMs) to simulate our climate system, its evolution, as well as countless processes like photochemistry, the CO2 cycle, coupling with the oceans, the hydrosphere, the biosphere, etc. Because these models are almost entirely built on physical equations, rather than empirical parameters, several teams have been able to adapt them to the other terrestrial bodies that have a solid surface and a thick enough atmosphere. In our solar system, that includes Mars and Venus, but also Titan, Triton and Pluto. The ambition behind the development of GCMs is high: the ultimate goal is to build numerical simulators only based on universal physical or chemical equations, yet able to reproduce or predict all the available observations on a given planet, without any ad-hoc forcing. In other words, we aim at creating in our computers virtual planets "behaving" exactly like the actual planets. In reality of course, nature is always more complex than expected, but we learn a lot in the process. In spite of the apparent complexity of climate systems, GCMs are based on a limited number of equations. Relatively complete climate simulator can be developed by combining a few components like a "dynamical core", a radiative transfer solver, a parametrisation of subgrid-scale turbulence and convection, a thermal ground model, a volatile phase change code, possibly completed by a

few optional schemes. In theory, many of these components are not specific to a planet. Our experience in the Solar System has confirmed that they GCM parametrizations can be applied without major changes to various terrestrial planets. On this basis we can envisage the development of a "universal" climate model able to simulate any type of climate, i.e. with any atmospheric cocktail of gases, clouds and aerosols, for any planetary size, and around any star. At LMD, we have recently developed such a generic tool, which is useful to conduct scientific investigations on the potential climates on terrestrial exoplanets, or to explore the possible past environments in the solar system. Can we trust such a model when no direct observation is available? Some lessons have been learned in our Solar system: In many cases, GCMs work. They have been able to simulate many aspects of planetary climates without difficulty. In some cases, however, problems have been met, sometime simply because a process has been forgotten in the model or is not yet correctly parametrized, but also sometime because the climate regime seems to be the result of a subtle balance between processes which remain model sensitive or which are the subject of positive feedback and instabilities. Building virtual planets with GCMs, in light of the observations obtained by spacecrafts or from the Earth, is a true scientific endeavour which can teach us a lot on the deep nature of climate systems. GCM can also help us predict and explore the possible environments on terrestrial exoplanets. For this last goal however, we need to deal with another scientific question: which atmospheres can we assume? This depends on complex processes (origins of volatile, atmospheric escape, geochemistry). Our experience in the solar system is not sufficient to address this question. In any cases, observations are needed.

Galperin, Boris

THE REGIME OF ZONOSTROPHIC MACROTURBULENCE AND ITS APPLICATION FOR CHARACTERIZATION OF LARGE-SCALE CIRCULATION ON JUPITER AND OTHER GIANT PLANETS

Galperin, Boris[1]; Sukoriansky, Semion[2]; Dikovsky, Nadejda[2]; Young, Roland[3]; Read, Peter L.[3]; Lancaster, Andrew J.[3]; Armstrong, David[4]

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4. Astrophysics Research Centre, Queen's University, Belfast, United Kingdom

Most large-scale planetary circulations feature large Reynolds numbers and thus are highly turbulent. These circulations can be characterized by a hierarchy of statistical moments. These moments should account for the effects of stratification, rotation and meridional variation of the Coriolis parameter, or a β-effect. In the linear limit, these factors support different classes of anisotropic dispersive waves. In a nonlinear system, the waves modify turbulence. Directions along which waves do not propagate designate slow manifolds. A slow manifold corresponding to a β-effect is represented by a system of alternating zonal jets. It is characterized by a small number of parameters. On fast rotating giant planets, where turbulence is maintained by a small-scale convective forcing atmospheric circulation undergoes inverse energy cascade that feeds large-scale structures in the horizontal and causes barotropization in the vertical. As a result, the slow manifold associated with the Rossby-Haurwitz waves acquires barotropic features and accumulates most of the kinetic energy of large-scale circulation. The emerging flows regime is called zonostrophic macroturbulence. Numerical simulations of this regime show that its zonal spectrum is very steep while the non-zonal spectrum preserves the Kolmogorov-Kraichnan (KK) form typical of non-rotating two-dimensional turbulence. A non-dimensional parameter indicative of a presence of the zonostrophic regime is the zonostrophy index $R\beta$. Both the spectra and the zonostrophy index can be used to detect this regime in observations. The steep zonal spectrum of the zonostrophic regime has been detected in the observational data for all giant planets. The non-zonal spectrum on Jupiter was analyzed recently using the data collected during Cassini fly-by in December 2000. The analysis revealed strong spectral anisotropy. The zonal spectrum is steep, the non-zonal spectrum indeed obeys the KK law. In another presentation (by Roland Young et al.) the spectral data is used to estimate the inverse cascade rate ε and the zonostrophy index $R\beta$ for the first time. The value of $R\beta$ places Jupiter's circulation in the zonostrophic regime. We use the spectral data to analyze the energetics of Jupiter's circulation and the interaction between zonal flows and the Great Red Spot. We compute the rate of the energy exchange W between the non-zonal structures and the large-scale zonal flow. Of particular importance is that W exceeds ε by an order of magnitude. It has important implications for the long-standing conundrum of unrealistically high rate of energy transfer to zonal flows. The meridional diffusivity Ky in this regime is given by an expression that depends on ε and β. The value of Ky estimated from the spectra was compared against data from the dispersion of stratospheric gases and debris resulting from the Shoemaker-Levy 9 comet and Wesley asteroid impacts in 1994 and 2009. Ky was found to be in good agreement with estimates for both impacts.

García Muñoz, Antonio

Monte Carlo modeling of the polarimetric signatures of planetary atmospheres

García Muñoz, Antonio[1]

1. ESA/RSSD, Noordwijk, Netherlands

The stellar light scattered from a planet's atmosphere is polarized. Despite the well-known potential in the technique of polarimetry, the characterization of the polarization spectrum of the Solar System planets remains incomplete, even in those cases where measurements are available. This is

partly due to the complexity of the polarization phenomenon in scattering media and the difficulty for its accurate modeling. The interest in polarimetry has increased over the last years because the technique presents clear advantages for the detection and characterization of exoplanets and their atmospheres through the analysis of the planet's disk-integrated signal. Phenomena such as the rainbow, glint and Rayleigh/Mie scattering, which have associated polarized signatures, have been postulated as indicators of various atmospheric properties. In this communication, we present an ongoing effort whose ultimate goal is to build a tool capable of predicting both the spatially-resolved and disk-integrated polarization signature of planets. For that purpose, we explore the capacities of the Monte Carlo sampling method in its application to solving the vector radiative equation. Monte Carlo sampling is particularly efficient when the required SNR is not particularly high and/or when the spectral resolution is moderate. We will present the current status of the project, including validation exercises and ongoing applications to planets of the Solar System and beyond.

Guerlet, Sandrine

Saturn's stratospheric dynamics unveiled by infrared observations: signatures of an equatorial oscillation, of a meridional circulation, and comparison with the Earth's stratosphere

Guerlet, Sandrine[1]; Fouchet, Thierry[2]; Sylvestre, Melody[1, 2]; Spiga, Aymeric[1]; Flasar, Mike[3]; Moses, Julianne[4]; Forget, François[1]

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Saturn's atmosphere is mainly composed of molecular hydrogen and helium (for 99.5%) and of methane (CH4, ~0.45%). Methane plays an important role, as its absorption of solar photons is responsible for the presence of a stratosphere. Methane photo-dissociation at high altitudes also triggers a rich photochemistry, leading to the formation of hydrocarbons such as ethane (C2H6) and acetylene (C2H2). Hydrocarbons are the main coolants in the stratosphere, and their distribution is governed both by photochemistry and dynamics. Temperature fields and hydrocarbon production and destruction rates also undergo a significant seasonal forcing, with one Saturn year equal to 29.5 Earth years. Detailed observations of temperature and hydrocarbon fields are needed to study this complex system, where radiative transfer, photochemistry and dynamics are coupled. Since the arrival of the Cassini spacecraft around Saturn in 2004, our knowledge of Saturn's stratospheric thermal structure, chemistry and dynamics has greatly increased. In particular, the analysis of thermal infrared spectra from the CIRS instrument, acquired in limb viewing geometry, allows the retrieval of vertical profiles of temperature and hydrocarbon abundances from ~10 mbar to ~0.01 mbar. Results from the analysis of 2005 to early 2010 limb data have revealed : 1)The signature of an equatorial oscillation, characterized by an alternating pattern of cold and warm anomalies with altitude, propagating downwards with a period estimated to 15 Earth years (half a Saturn year). This dynamical phenomenon is analogous to the Earth's Quasi-Biennal Oscillation and to an equatorial oscillation also observed in Jupiter's stratosphere. 2)Signatures of meridional, seasonal circulation. In particular, a local enhancement in hydrocarbons is observed under the ring's shadow, where photochemical production is expected to exhibit a local minimum. It can be interpreted as the signature of a downwelling branch of a meridional circulation cell. These observational results have motivated the development of a new General Circulation Model of Saturn's stratosphere, that will help better interpret Cassini observations and explore the atmospheric dynamics of the giant planet. It will also be a tool for use in comparative planetology studies, for instance for the study of the mechanisms of equatorial oscillations and meridional circulation in different planetary atmospheres, including the Earth. We will also present the latest results from the analysis of 2010-2012 Cassini/CIRS limb data, including the evolution of the thermal structure of the equatorial oscillation and seasonal variations observed in temperature and hydrocarbon distributions at mid-latitudes, that will bring new constraints to the meridional circulation. We will also briefly introduce Saturn's GCM currently under development at the Laboratoire de Meteorologie Dynamique.

Guzewich, Scott D.

Links Between Atmospheric Tides and Topography

Guzewich, Scott D.[1]; Toigo, Anthony[2]; Wilson, John[3]; Talaat, Elsayed[2]; Zhu, Xun[2]; Smith, Michael D.[1]

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2. Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA
3. Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA

Abstract: Atmospheric Kelvin waves have been observed on all 4 terrestrial bodies with significant atmospheres (Venus, Earth, Mars and Titan), and we expect to find them in exoplanet atmospheres as well. On Mars, the presence of a unique topographic dichotomy between the northern and southern hemispheres leads to significant modification of Martian atmospheric tides, particularly the wavenumber 1 diurnal Kelvin wave. Tidal theory suggests this Martian non-migrating tide is forced by the interaction of the migrating diurnal tide with the longitudinal wavenumber 2 component of the topography. Using observations from the Mars Climate Sounder, simulations with the MarsWRF general circulation model and a linear tidal model, we examine the influence of the topographic dichotomy on the diurnal Kelvin wave. Our results suggest that meridional topography should not be neglected when calculating the expected tidal response in a terrestrial planetary atmosphere.

Hammel, Heidi

Contributed Talk

Hammel, Heidi[1]

1. MIT, Washington, DC, USA

Abstract not available.

Horst, Sarah M.

Haze Formation During the Rise of Oxygen in the Atmosphere of the Early Earth

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Atmospheric aerosols play an important role in determining the radiation budget of an atmosphere and can also provide a wealth of organic material to the surface. Photochemical hazes are abundant in reducing atmospheres, such as the N_2/CH_4 atmosphere of Titan, but are unlikely to form in oxidizing atmospheres, such as the N_2/O_2 atmosphere of present day Earth. However, information about haze formation in mildly oxidizing atmospheres is lacking. Understanding haze formation in mildly oxidizing atmospheres is necessary for models that wish to investigate the atmosphere of the Early Earth as O_2 first appeared and then increased in abundance. Previous studies of the atmosphere of the Early Earth have focused on haze formation in $N_2/CO_2/CH_4$ atmospheres. In this work, we experimentally investigate the effect of the addition of O_2 on the formation and composition of aerosols. Using a High-Resolution Time-of-Flight Aerosol Mass Spectrometer (HR-ToF-AMS) (see e.g. [1]) we have obtained in situ composition measurements of aerosol particles produced in $N_2/CO_2/CH_4/O_2$ gas mixtures subjected to FUV radiation (deuterium lamp, 115-400 nm) for a range of initial $CO_2/CH_4/O_2$ mixing ratios. In particular, we studied the effect of O_2 ranging from 2 ppm to 2%. The particles were also investigated using a Scanning Mobility Particle Sizer (SMPS), which measures particle size, number density and mass loading. A comparison of the composition of the aerosols will be presented. The effect of variation of O_2 mixing ratio on aerosol production, size, and composition will also be discussed. [1] Trainer, M.G., et al. (2012) Astrobiology, 12, 315-326.

Houben, Howard

We've Been Doing It Wrong

Houben, Howard[1]

1. Bay Area Environmental Research Institute, Sonoma, CA, USA

All the long term computer modeling of planetary atmospheres that has been done to date is wrong, and here's why: Angular momentum conservation places severe restrictions on fluid flow, which are difficult to preserve in general circulation models, but which are easily understood analytically. Among these is the wave-mean flow non-interaction theorem. This theorem requires that zonal forcing by waves be balanced (in the time and zonal mean) by the meridional circulation. The only remaining physical force available for driving the super-rotation or strong differential rotation which has been observed in all seven deep atmospheres in the solar system is external (tidal) torques. This was proposed by Gold and Soter (*Icarus* **14,** 16-20, 1971) for the Venus super-rotation, but has generally been disregarded by the rest of the community, perhaps because they did not provide a realistic model for the resulting zonal wind variation with height. Heat generated by the action of these torques (which is not the same as the traditional tidal dissipation) controls the deep atmospheric thermal structure, which is therefore not adiabatic or barotropic. The (so-called) thermal wind balance then dictates the atmospheric density (or pressure) distribution. This is opposite to the normal formulation of an atmospheric general circulation model with a hydrostatic relation between pressure and density, temperatures determined by radiative or convective heating, and the winds ultimately balancing the temperature gradients. Such models are useful in numerical weather prediction. They start from a state that is the best available approximation to the current atmospheric state and study perturbations to it for a short period of time. But, in spite of the name general circulation model, they are not necessarily capable of generating the initial state, even in the zonal mean. The primacy of the wind field in determining the true atmospheric structure is based on the physical reality that it is difficult to change a system's angular momentum (mean zonal wind). On the other hand, energy is readily radiated to space or absorbed from external sources (allowing heating and cooling). The good news is that the new formulation for the mean zonal wind is easily solved – examples for the sun and giant planets will be shown – and provides clues to the deeper structure of the bodies in question, including magnetic dynamo action. It also provides the proper starting point for weather modeling of these objects.

Huang, Junling

Evidence for a secular increase in power generated by the Hadley circulation

Huang, Junling[1]; McElroy, Michael[1]

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The Hadley system provides an example of a thermally direct circulation. The power and thermodynamic efficiency of the cells constituting this circulation have not as yet been quantified. Here we use assimilated meteorological data covering the period January 1979 to December 2010 to show that the thermodynamic efficiency of the Hadley system, considered as a heat engine, has been relatively constant over the 32 year period covered by this analysis, averaging 2.6 %. Over the same interval, the power generated by the Hadley regime, has risen at an average rate of about 0.51 TW per year, reflecting an increase in energy input to the system corresponding to the observed trend in surface temperatures. Models for future climate suggest that the increase in tropical surface temperatures observed recently is likely to persist. Production of kinetic energy is projected to grow accordingly.

Joshi, Manoj

Cryospheric albedo feedbacks on Earth and other planets

Joshi, Manoj[1]; Shields, Aomawa L.[2]; Haberle, Robert M.[3]

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Cryospheric, or snow and ice albedo feedbacks, are important contributors to global feedbacks in climate and climate change, and yet can vary widely in magnitude depending on the nature of the planetary system. For example, M stars comprise 80% of main sequence stars, so their planetary systems might provide the best chance for finding habitable planets, ie: those with surface liquid water. Models of broadband albedo or reflectivity of water ice and snow for simulated planetary surfaces orbiting two observed red dwarf stars (or M stars), using spectrally resolved data of Earth's cryosphere, suggest that the albedos of ice and snow on planets orbiting M stars are much lower than their values on Earth. This is because of the gradual reduction of the albedos of snow and ice at near-infrared wavelengths greater than 1μm, combined with M stars emitting a significant fraction of their radiation at these same longer wavelengths. Our results imply that the ice/snow albedo climate feedback is significantly weaker for planets orbiting M stars than for planets orbiting G-type stars such as the Sun. As a consequence of this, runaway feedbacks such as those associated with "snowball Earth" episodes might be far less likely on planets orbiting M-stars. In addition, planets with significant ice and snow cover will have significantly higher surface temperatures for a given stellar flux if the spectral variation of cryospheric albedo is considered, suggesting that the outer edge of the habitable zone will lie further away from the parent star. We also discuss how the above results will be modified by atmospheric effects associated with atmospheric gases and aerosol, and also how different stellar characteristics affect the above feedbacks.

Kahn, Ralph

Airborne Particles – What We've Learned About Their Role in Climate From Remote Sensing Observations, and Prospects for Future Advances *(INVITED)*

Kahn, Ralph[1]

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Desert dust, wildfire smoke, volcanic ash, biogenic and urban pollution particles, all affect the regional-scale climate of Earth in places and at times; some have global-scale impacts on the column radiation balance, cloud properties, atmospheric stability structure, and circulation patterns. Remote sensing has played a central role in identifying the sources and transports of airborne particles, mapping their three-dimensional distribution and variability, quantifying their amount, and constraining aerosol air mass type. The measurements obtained from remote sensing have strengths and limitations, and their value for characterizing Earth's environment is enhanced immensely when they are combined with direct, in situ observations, and used to constrain aerosol transport and climate models. A similar approach has been taken to study the role particles play in determining the climate of Mars, though based on far fewer observations. This presentation will focus what we have learned from remote sensing about the impacts aerosol have on Earth's climate; a few points about how aerosols affect the climate of Mars will also be introduced, in the context of how we might assess aerosol-climate impacts more generally on other worlds. Reference: Kahn, R.A., 2012. Reducing the uncertainties in direct aerosol radiative forcing. Surveys in Geophysics 33:701–721, doi:10.1007/s10712-011-9153-z.

Kaspi, Yohai

Three-dimensional Atmospheric Circulation and Climate of Terrestrial Exoplanets

Kaspi, Yohai[1]; Showman, Adam[2]

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The recent discoveries of terrestrial exoplanets and super Earths extending over a broad region of orbital and physical parameter space suggests that these planets will span a wide range of climatic regimes. Characterization of the atmospheres of warm super Earths has already begun and will be extended to smaller and more distant planets over the coming decade. The habitability of these worlds may be strongly affected by their three-dimensional atmospheric circulation regimes, since the global climate feedbacks that control the inner and outer edges of the habitable zone—

including transitions to Snowball-like states and runaway-greenhouse feedbacks—depend on the equator-to-pole temperature differences, pattern of relative humidity, and other aspects of the dynamics. Here, using an idealized moist atmospheric general circulation model (GCM) including a hydrological cycle, we study the dynamical principles governing the atmospheric dynamics on such planets. In this presentation we will review how the planetary rotation rate, planetary mass, surface gravity, heat flux from a parent star and atmospheric mass affect the atmospheric circulation and temperature distribution on such planets. We will elucidate the possible climatic regimes and diagnose the mechanisms controlling the formation of atmospheric jet streams, Hadley cells, and the equator-to-pole temperature differences. Finally, we will discuss the implications for understanding how the atmospheric circulation influences the global-scale climate feedbacks that control the width of the habitable zone.

Kasting, James

Big Questions About the Existence of Earth-like Exoplanets ***(INVITED)***

Kasting, James[1]

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The pace of discovery of exoplanets has accelerated over the past 15 years. Today, more than 800 exoplanets have been identified from ground-based RV measurements, along with another ~2300 “planet candidates” from transit measurements by Kepler. But our knowledge of Earth-like exoplanets is still in its infancy. A handful of possibly rocky (<10 M_{Earth}) planets have been identified from the ground and Kepler combined. Most of these orbit M stars, rather than FGK stars that are more like the Sun. None of these planets has been examined spectroscopically, though; indeed, none of the known potentially habitable planets can be studied, even by the very capable upcoming JWST mission. We will likely need to wait for a TPF (Terrestrial Planet Finder)-type direct imaging mission to find and examine nearby Earth-like planets. Direct imaging is not confined to transiting planets, and so the probability of observing nearby planets is much higher. In order to determine how big such a TPF telescope must be, one needs to know the value of η_{Earth}—the fraction of stars that have a rocky planet within their habitable zones. Both Kepler and RV are contributing to our knowledge of this parameter. The best current dataset is from Kepler, and it consists of a sample of ~4000 M stars (Dressing and Charbonneau (D&C), Ap. J. Lett., in press). These authors estimate that η^{Earth} 0.15 (+.13/-.06) for their sample. But D&C may have been overly pessimistic in their choice of habitable zone boundaries and in their definition of an Earth-like planet. They considered only planets with radii <1.4 REarth; however, planets with radii up to $\sim^{2R}{}_{Earth}$ are considered likely to be rocky. Furthermore, the outer edge of the habitable zone is almost certainly farther out than the “1st CO_2 condensation” limit used by D&C. Kopparapu (Ap. J. Lett., in press) has shown that for more reasonable choices of habitable zone limits, and with habitable zone boundaries redefined from new climate calculations, the likely value of Earth is between 0.48 and 0.61. These latter values are in rough agreement with a similar estimate of η_{Earth} for M stars by Bonfils et al. (A&A, 2011, submitted) of 0.41 (+0.54/-0.13) based on RV measurements. Whether such a value would also apply to more Sun-like stars is currently unknown. If it does, however, then the frequency of Earth-like planets may be relatively high, making it easier to design a TPF-type telescope to find and characterize them.

Kataria, Tiffany

Atmospheric circulation modeling of GJ 1214b: Including effects due to collisionally induced absorption from CO_2-CO_2 collisions

Kataria, Tiffany[1]; Showman, Adam P.[1]; Fortney, Jonathan J.[2]; Marley, Mark S.[3]; Freedman, Richard S.[3, 4]; Lupu, Roxana E.[3]

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4. SETI Insitute, Mountain View, CA, USA

Atmospheric circulation modeling plays an important role in the characterization of extrasolar planets, helping to constrain observations that probe exoplanetary atmospheres. These models have proven quite successful in understanding observations of transiting close-in exoplanets, particularly when the planet is passing through secondary eclipse. At this point in the orbit, the planet’s dayside is visible from Earth, and one can place constraints on the thermal structure of the atmosphere. Circulation models have been used to characterize the atmospheres of hot Jupiters (e.g. Showman et al. 2009, Dobbs-Dixon and Lin 2008, Cho et al. 2008, Rauscher and Menou 2010, Heng et al. 2010, Kataria et al. 2013), hot Neptunes (e.g. Lewis et al. 2010), and super Earths (e.g Menou et al. 2012, Zalucha et al. 2012). In this continuing study, we model the atmospheric circulation of GJ 1214b, a transiting super Earth discovered by the MEarth survey (Charbonneau et al. 2009). Many groups have conducted observations of GJ 1214b to constrain its atmospheric composition (e.g. Bean et al. 2010, 2011; Croll et al. 2011; Crossfield et al. 2011; de Mooij et al. 2012; Berta et al. 2012; Fraine et al. 2013). While most observations favor an atmosphere with a high-mean molecular weight (MMW), low MMW atmospheres (i.e. H_2-dominated) have not been completely ruled out, particularly if clouds, hazes, or disequilibrium chemistry are present. Nevertheless, the composition of the atmosphere will substantially affect the planet’s temperature structure, and hence the atmospheric dynamics. We use the SPARC/MITgcm (Showman et al. 2009) to model the circulation of GJ 1214b. This model couples a two-stream implementation of the multi-stream, non-grey radiative transfer scheme developed by Marley and McKay (1999) with the dynamical core of the MITgcm (Adcroft et al. 2004). The radiative transfer code solves the two-stream radiative transfer equations, using the correlated-k method to solve for the upward/downward fluxes and heating rates. In previous work, we have shown that if we assume a hydrogen-dominated atmosphere, the dynamical regime resembles that of a canonical hot Jupiter, whose flow is dominated by equatorial eastward superrotation. Here, we present results for high MMW atmospheres, with compositions ranging from 100% H_2O to 100% CO_2. For CO_2-dominated atmospheres, the flow is dominated by superrotation not at the equator, but at high latitudes. We also include effects due to pressure-induced absorption by CO_2-CO_2 collisions, exploring the extent to which this opacity source affects the heating and dynamics of the atmosphere, particularly at deeper pressures.

Kochemasov, Gennady G.

SIBERIAN ATMOSPHERIC HIGH: ITS FORMATION IN FRAME OF THE SOLID EARTG SECTOR TECTONICS

Kochemasov, Gennady G.[1]

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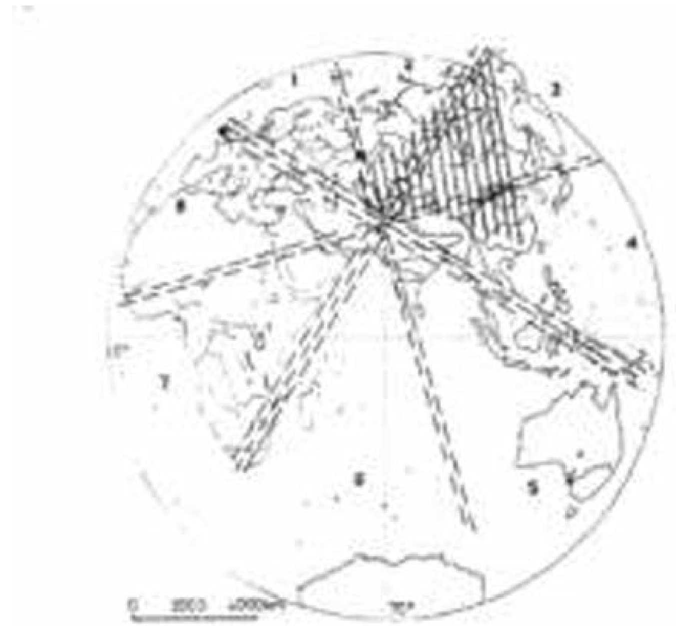
G. G. Kochemasov IGEM RAS, Moscow, Russia, <kochem.36@mail.ru> The Siberian High is a massive collection of cold and very cold dry air that accumulates on the Eurasian terrain for much of the year, usually centered on Lake Baikal. It reaches its greatest size and strength in the winter. Its genesis at the end of the Arctic summer is caused by the convergence of summer air flows being cooled over interior northeast Asia as days shorten. It is a bit larger and more persistent than its counterpart in North America. Triangular in shape it has the apex extending in the west to the Caspian Sea and the base anchored in the northeast near the Verkhoyansk Mountains of Siberia and in the southeast near the Chin Ling Mountains of east-central China. The Siberian High position and its triangular shape (Fig.) show that it is anchored in and controlled by the uplifted Asian sector of the Earth's eastern hemisphere (segment). The tectonic and geomorphologic construction of this segment is caused by an interference of standing inertia-gravity lithospheric waves whose origin is related to elliptical keplerian orbit of the planet. The elliptical orbit means periodical changes in the Earth's accelerations during orbiting. It means that the planet suffers warping action of inertia-gravity waves. They in rotating body have interfering ortho- and diagonal directions producing uplifted and subsided blocks. The fundamental wave1 long $2\pi R$ produces hemispheric (segmental) dichotomy: the uplifted eastern continental and subsided western Pacific hemispheres. The continental uplifted hemisphere is divided by the first overtone wave2 long πR into four tectonic sectors: two opposite uplifted – African and Asian and two opposite subsided – Eurasian and Indoceanic. The uplifting north-eastern Asian sector comprises northern relatively subsided Siberian subsector. Its relatively diminished radius (a loss of the angular momentum) is partially compensated by a dense atmosphere. In the cool northern conditions this compensation is in form of the Siberian High somewhat shifted to the west by the Coriolis force. This High is in a wave relation with other but weaker Highs in the northern hemisphere: North Africa, Azores, and North America. A chain of four smaller but persistent intermittent highs in the southern tropics stresses the wave nature of such structurizing. .



Kostogryz, Nadiia

Polarimetry and physics of atmospheric aerosol of the Earth

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Polarization measurements from satellites at λ> 300 nm is not efficient enough to study the physical characteristics of the aerosol Earth's atmosphere due to the inability to obtain data on the phase dependence, for example, the second Stokes parameter Q (α), which would correspond to the condition of the optical homogeneity of the atmosphere + surface and correctly split it atmospheric and surface components. This is due to the fact that in the case of Earth Q (α) is formed by the interaction of: 1) unpolarized solar radiation with the gas-aerosol medium and the surface; 2) radiation reflected by the surface (already polarized) to the atmosphere. If we neglect the latter, then the single scattering Q (α) details with latitude ψ and longitude L has the form $Q(\psi,L,\mu0,\mu,\alpha)=[(1-\beta(\psi,L))Qa(\psi,L,\alpha)+ \beta(\psi,L) Qg(\alpha)]^* [\omega\mu o/4(\mu0+\mu)]\{1-\exp[-\tau o(1/\mu0+1/\mu)]\}]+Qs(\psi,L,\mu0,\mu,\alpha) \exp[-\tau o(1/\mu0 + 1/\mu)]$, (1) where $\beta=\tau g/(\tau g+\tau a)$, the indices g, a and s - gas, aerosol and surface components, $\tau 0=\tau g+\tau a$ is optical depth, ω is the single scattering albedo μo and μ are the cosines of the angles of incidence and reflection of light. This type of Q (ψ, L, $\mu 0$, μ, α) is due not only to the well-known optical inhomogeneity of the surface and the difference of relief, but also to changes in the nature of aerosols over the details with different ψ, L. Obviously, the overlap, for example, the interval of phase angles $0 \leq \alpha \leq 90$ ° scanning method leads to the fact that the data for $\alpha = 0$ ° and 90 ° are related to the details, a distance greater than 1340 km at height of 670 km. Another situation is in the spectral range at λ <300 nm, where the ozone layer is completely absorbing cuts impact surface and the troposphere, i.e., the main sources of spatial heterogeneity of optical properties and their temporal changes. As a result, the value of Q (α) is formed to the upper layers of the atmosphere, and (1) reduces to $Q(\psi,L,\mu0,\mu,\alpha)=[(1-\beta(\psi,L))Qa(\psi,L,\alpha)+ \beta(\psi,L)\ Qg(\alpha)$ (2) Since the effective height of the ozone layer shows a pronounced latitude dependence, to obtain data on the phase dependence of Q (α) scan should be done in parallel to the plane of the equator. Possible longitude heterogeneity of optical properties manifested in the spread obtained from various revolutions spacecraft observational data that exceed the measurement error. Thus, polarimetry at λ <300 nm will determine the physical characteristics of stratospheric aerosol for different latitude belts and identify their temporal changes.

Kostogryz, Nadiya

THE METHOD OF COMPUTER ANALYSIS A VERTICAL STRUCTURE OF AEROSOL COMPONENT IN THE ATMOSPHERES OF THE GIANT PLANETS

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A program package to determine the nature of the change with depth of aerosol optical thickness or the ratio of aerosolic and gas components of optical thickness for the spectral absorption bands of atmospheric gases was been developed. Structurally, the program package consists of the units: determining an expansion coefficients xi of the scattering function in a series of Legendre polynomials and volumetric scattering coefficient $\sigma0$ for the polydisperse media with a specified refractive index and a function for the particle sizes distribution N(r); forming the interpolative array of calculated values for single scattering albedo ω and geometric albedo Ag in case of the semi-infinite homogeneous media with the parameters that have been determined in the previous unit; determining the values of the ω via comparing of calculated and observed values of the Ag for each measuring point in the investigated absorption band (including changes of the parameters of scattering function due to Rayleigh scattering); calculating of spectral values of effective optical depth τeff; finding the scattering τeff^s and absorbing τeff^v components of the τeff on the basis of spectral data ω and τeff; determining the amount of methane NL (in km-amagat) on the line of sight based at the data of τeff^v and then the atmospheric pressure p(NL) and the gas scattering component τg (λ0) of the optical depth at a wavelength λ0=887.2 nm; determining the aerosol component τa (λ,NL) according to the data of τeff^s (λ) and τg (λ,NL); building a graphical function of the pressure p for values of τa(λ) or τa(λ)/τg(λ) which was been converted at the wavelength λ0=887.2 nm. The program package was validated for analysis of spectrophotometric measurements of Jupiter's integrated disk for absorption bands of methane. The example of the results is shown in Figure 1..

www.mao.kiev.ua

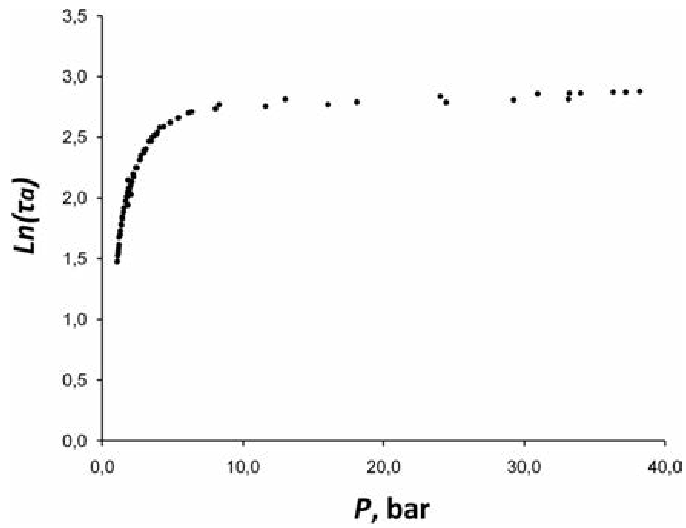

Figure 1. The dependence of the aerosol optical thickness on the pressure in the atmosphere of Jupiter (for absorption band of methane centered at 727.6 nm)

Leconte, Jeremy

A 3D point of view of the atmosphere of strongly irradiated terrestrial exoplanets: runaway greenhouse and climate bistability

Leconte, Jeremy[1]; Forget, Francois[1]; Wordsworth, Robin[2, 1]; Charnay, Benjamin[1]; Selsis, Franck[3]; Millour, Ehouarn[1]

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3. Laboratoire d'Astrophysique de Bordeaux, Bordeaux, France

Because current exoplanets detection methods are biased toward shorter period orbits, most planets discovered to date have a higher equilibrium temperature than the Earth. If water is available at the surface, water vapor can become a major constituent of the atmosphere of these planets, and lead to the so-called runaway or moist greenhouse climate instability that determines the inner edge of the traditional habitable zone. Modeling the climate of such hot, moist atmospheres is thus mandatory to understand the atmospheric properties of hot transiting terrestrial exoplanets for which observation should soon be available. So far, emphasis has been put on 1D radiative convective models, which cannot well predict the impact of clouds, or the non-linear effect of spatial inhomogeneities. In particular, while these single column models can provide reasonable answers for planets with a dense atmosphere or a rapid rotation which limit large scale temperature contrasts, only a three-dimensional model can treat properly the case of close-in exoplanets trapped in a spin-orbit resonance with a low obliquity. Indeed, this very peculiar radiative forcing can create a strong day-night side temperature contrast and a very efficient cold trap near the poles and on the night side (in the tidally locked case) that cannot be modeled in 1D. To study the processes determining the inner edge of the habitable zone in a wide variety of contexts, we used the new "generic" LMD GCM developed for exoplanet studies and which notably include a versatile radiative transfer code to simulate any atmospheric cocktail of gases, aerosols and clouds for which optical data exist. For the present work, we have implemented a new water cycle scheme with a more robust treatment of the cloud microphysics, precipitations and water vapor continuum opacity. This allows us to model hot atmospheres with an arbitrarily large amount of water vapor. Using this three-dimensional model, we will first give new estimates of the critical flux above which runaway greenhouse is triggered on an ocean-bearing world like the Earth. We will show that clouds have a stabilizing feedback on the climate and thus push the inner edge of the habitable zone closer to the star than usually inferred from 1D models. We will also discus the large uncertainties due to the microphysics of clouds. We will also show how the classical runaway greenhouse can be significantly delayed if water is present only in limited amount at the surface of a hot (land)planet with permanent cold traps. In particular, we will demonstrate that, depending on the flux received and on the atmospheric mass, a bistable climate regime can exist, with a "hot" state where all the water is vaporized, and a "cold" one where it is captured in the cold traps. Finally, we will discuss several processes that arise on Earth (ice flows and subsurface melting due to pressure and geothermal heating) that could hypothetically sustain liquid water on the surface of hot planets, such as Gl-581c, pushing further in the limits of the habitable zone.

Lewis, Nikole K.

A Look Under the Hood of the SPARC/MITgcm: Recent Updates, Results, and Future Plans

Lewis, Nikole K.[1]; Showman, Adam P.[2]; Fortney, Jonathan J.[3]; Kataria, Tiffany[2]; Lian, Yuan[4]; Parmentier, Vivien[5]; Marley, Mark S.[6]; Campin, Jean-Michel[1]

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2. LPL, University of Arizona, Tucson, AZ, USA
3. Astronomy & Astrophysics, UCSC, Santa Cruz, CA, USA
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5. Observatoire de la Cote d'Azur, Universite de Nice-Sophia Antipolis, Nice, France
6. NASA/AMES, Moffett Field, CA, USA

The Substellar and Planetary Atmospheric Radiation and Circulation model (SPARC) was first used by Showman et al. (2009) to investigate the atmospheric circulation of the 'benchmark' extrasolar planets HD 209458b and HD 189733b. Since its initial inception, the SPARC/MITgcm model has been used to study the global three-dimensional atmospheric circulation of other prominent extrasolar planets such as GJ 436b (Lewis et al. 2010), HAT-P-2b (Lewis et al. 2013), and GJ 1214b (Kataria et al. 2013), explore the effects of time-variable forcing for planets on highly eccentric orbits (Kataria et al. 2013), make preliminary attempts at understanding three-dimensional mixing and cloud condensation in hot-Jupiter atmospheres (Parmentier et al. 2013), and understand regime transitions in hot exoplanet atmospheres (Showman et al. 2013). The SPARC/MITgcm model was created by coupling a non-gray radiative transfer scheme with the MITgcm dynamical core. Although at times computationally intensive, the SPARC model allows for the consistent treatment of radiative and advective timescales in exoplanet atmospheres and avoids the uncertainties associated with Newtonian relaxation schemes and two-band gray radiative transfer approaches. Here we discuss recent improvements to the SPARC/MITgcm model and its overall performance. Recent improvements to the SPARC/MITgcm model focus mainly on improving computational efficiency and stability and include updates to our radiative transfer scheme and the addition of a diffusive sponge layer at the top of the model atmosphere. We will discuss the performance of the SPARC/MITgcm model in the context of quantities such as global angular momentum, which we find the SPARC/MITgcm conserves to better than 0.1% under realistic exoplanet atmospheric conditions. Finally, we will overview planned future updates to the SPARC/MITgcm model. We currently have plans to more fully couple cloud condensation schemes to the SPARC/MITgcm to help explain albedo variations seen in recent Kepler observations. We will also more fully explore the effects of atmospheric composition assumptions such as C/O ratio and disequilibrium carbon and nitrogen chemistry on the global circulation patterns that develop in exoplanet atmosphere. Our current and future plans also include an exploration of atmospheres on earth-sized exoplanets (both hot and temperate) and how atmospheric circulation and clouds might affect the habitability of these potentially tidally locked worlds. Overall, the SPARC/MITgcm allows us to make robust predictions about the bulk advective, radiative, and chemical processes at work in exoplanet atmospheres. This will aid in the interpretation of current and future observations that will in turn help us to further refine the physical processes we incorporate into our models.

Liu, Junjun

Formation of Equatorial Superrotation and Multiple jets in Planetary Atmospheres

Liu, Junjun[1]; Schneider, Tapio[2, 1]

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2. Geological Institute, Swiss Federal Institute of Technology Zurich, Zurich, Switzerland

Equatorial superrotation and multiple jets are ubiquitous in the planetary atmospheres in our solar system and beyond. In the planetary atmospheres heated from below, equatorial superrotation can occur through convective generation of equatorial Rossby waves. Off-equatorial multiple jets can occur through the baroclinic instability induced by the differential solar heating. We use simulations with an idealized general circulation model (GCM) to explore systematically the relative roles of baroclinicity, heating from below, and bottom drag. Equatorial superrotation generally occurs when the heating from below is sufficiently strong. However, the threshold heating at which the transition to superrotation occurs increases as the baroclinicity or the bottom drag increases. The greater the baroclinicity, the stronger the angular momentum transport out of low latitudes by baroclinic eddies of extratropical origin. This competes with the angular momentum transport toward the equator by convectively generated Rossby waves and thus can inhibit a transition to superrotation. Equatorial bottom drag damps both the mean zonal flow and convectively generated Rossby waves, weakens the equatorward angular momentum transport. It can thus inhibit the transition to superrotation. The strengths of superrotating equatorial jets scale approximately with the square of their widths. In the off-equatorial region, baroclinic eddies induced by the differential solar radiation transport angular momentum out of retrograde jets and into prograde jets, which lead to the formation of multiple jets. The strength, width and spacing of the multiple jets are proportional to the energy containing eddy length scales. The eddy lengths vary weakly with latitude, and scale with the Rossby deformation radius and the Rhines scale. As the bottom drag decreases, both the eddy length and the eddy kinetic energy increase. Thus, the jets become stronger and wider, with increased interjet spacings. These results have broad implications for the formation of jets and superrotation in planetary atmospheres.

Mahtani, Deepak P.

Reanalysis of Warm Spitzer Full Orbit Light Curves of WASP-12 at 3.6μm and 4.5μm

Mahtani, Deepak P.[1]; Maxted, Pierre F.[1]

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Our current understanding of exoplanet atmospheres comes from observations taken using the Spitzer space telescope. The remaining working channels on Spitzer are at 3.6μm and 4.5μm. These channels are affected by systematic errors. The most well known of these is the IntraPixel Sensitivity variations, (IPSVs). This means that different parts of individual pixels are more or less sensitive to light that is incident upon them. It is possible to remove the IPSVs from the data. The systematic errors that affect Spitzer data are now the limiting factor in our analysis of exoplanet atmospheres at the 0.01% level. This is the level at which many interesting effects become apparent. Fully understanding these systematic errors will allow for the maximum amount of information to be gained from Spitzer data. We present here the first use of wavelets in the analysis of full orbit lightcurves. Wavelet analysis has been shown to be superior to standard exoplanet analyses because it nearly diagonalises the covariance matrix for model parameters. This means there are no correlations between model parameters. This allows more reliable uncertainties to be calculated. If one over estimates uncertainties then significant scientific findings will not be made. If one underestimates uncertainties then findings that have been quoted may not be real. This method allows the inclusion of red noise (correlated noise) with a 1/f power spectrum, which allows a better understanding of the effect of the systematic noise on the model parameters. We present a reanalysis of full orbit lightcurves of WASP-12b using wavelet analysis with the aim of determining if the previous null detection of ellipsoidal variations at 3.6μm and amplified variations at 4.5μm are real or are the result of systematic errors in the data. This is a very interesting system because the planet may be overfilling its Roche lobe and hence be accreting mass onto its host star. A better understanding of the atmosphere of WASP-12b will give a valuable insight into its formation, evolution and fate.

McGouldrick, Kevin

Microphysical Model of the Venus Clouds

McGouldrick, Kevin[1]

1. Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, CO, USA

Clouds play an important and likely variable role in the energy balance of a planetary atmosphere. On Earth, for example, the role of clouds and aerosols remains a key unknown in our current understanding of climate change. On Venus, if not for the massive greenhouse effect, the ubiquitous cloud deck would be sufficient to render the surface too cold to support liquid water. A subset of exoplanets are also likely to exhibit atmospheres and clouds of a variety of condensables that may be more finely determined through careful comparison of light curves and microphysical modelling. This work builds upon the results of McGouldrick and Toon (2007, 2008a, b) who had developed a microphysical model of the middle and lower cloud decks of Venus. This model attained good agreement with the observed characteristics of the Venus lower and middle cloud decks and found that vertical advection produced variations in cloud opacity that were consistent with the observed radiance inhomogeneities seen in near infrared wavelengths. However, that work treated the upper cloud as merely a boundary condition, providing volatiles (sulfuric acid and water) into the model domain. More recent work has been undertaken to extend the model domain to the upper cloud deck. Lacking a full treatment of all of the possible chemical pathways, this extension of the model requires a parameterization of the photochemical production of sulfuric acid in the upper cloud region, and a thermochemical destruction of sulfuric acid in the sub-cloud region. We have begun to incorporate parameterizations of these processes into the model, in addition to other microphysical improvements such as the inclusion of a binary homogeneous nucleation scheme from the literature (Vehkamaki et al 2002).

Miguel, Yamila

Exploring Super-Earth Atmospheres

Miguel, Yamila[1]; Kaltenegger, Lisa[1]

1. Max Planck Institute for Astronomy, Heidelberg, Germany

The search for extrasolar planets has resulted in the discovery of super-Earths, planets with masses of ~10 Earth masses. Since no such planets exist in our solar system, their atmospheric composition and structure remains largely unknown. In this talk, we explore the possible atmospheric composition and structure for small exoplanets. These planets are interesting targets for future observations, therefore, addressing their atmospheric structure and composition is a major issue and the aim of our work. We explore the differences in the structure according to the observables semimajor axis and stellar type. We also explore three possible atmospheric compositions: hot rocky planets with outgassed atmopheres, planets with atmospheres dominated by H2O or CO2 and those with an atmosphere of solar composition.

Mitchell, Jonathan

Idealized seasonal cycles in a dry GCM and implications for atmospheric superrotation

Mitchell, Jonathan[1]; Vallis, Geoffrey[2]

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2. Princeton/GFDL, Princeton, NJ, USA

In previous work (Mitchell & Vallis 2010, MV10), we found the thermal Rossby number governs the transition from an Earth-like climatology of winds to a superrotating one, with the transition occurring for thermal Rossby numbers larger than unity. The atmospheres of Titan and Venus meet this criterion, however Titan also experiences a pronounced seasonal cycle. We examine the influence of an idealized seasonal cycle by introducing a non-dimensional parameter that (externally) controls the thermal inertia of the climate system. A large seasonal cycle prevents atmospheres with large thermal Rossby numbers from developing superrotation apparently by (1) cross-equatorial advection of low-angular-momentum air by the Hadley circulation and (2) the production of hemispherically asymmetric zonal winds. The latter may relate to a necessary condition for the global instability identified in MV10. Several other dynamical conditions are tested against superrotation in the simulations. The atmospheres of Earth, Mars and Titan are discussed in the context of these dynamical conditions, the Rossby numbers of their circulation, and the thermal inertias of their climates.

Moses, Julianne I.

Photochemistry and Transport-Induced Quenching on Hot-Jupiter Exoplanets

Moses, Julianne I.[1]; Visscher, Channon[2]

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2. Southwest Research Institute, Boulder, CO, USA

With 861 extrasolar planets identified as of February 2013 (http://exoplanet.eu/catalog/) and thousands more Kepler planetary candidates waiting to be confirmed, our solar system no longer seems so unique. Most of the exoplanets discovered to date are expected to have atmospheres of some kind, and the incredible diversity of the known exoplanet bulk physical attributes, orbital characteristics, and local irradiation environments guarantee equally diverse atmospheric properties. The characterization of exoplanet atmospheres is proceeding on two fronts: observational and theoretical. On the observational side, valuable information about atmospheric properties has been supplied by transit and eclipse observations of exoplanets orbiting very close to their host stars, as well as by spectral observations of young, hot, directly imaged exoplanets orbiting far from their host stars. On the theoretical side, physical and chemical properties of exoplanet atmospheres are predicted from a variety of radiative, chemical, dynamical, and evolutionary models. Comparison of models with observations then yields key information that illuminates the underlying mechanisms that drive atmospheric behavior and provides clues to how the planets formed and evolved. One theoretical tool that aids the interpretation of observations is a model that includes disequilibrium chemical processes like photochemistry and transport-induced quenching, as these processes can significantly alter the expected atmospheric composition. We will review our current understanding of disequilibrium chemistry on the so-called "hot Jupiters" and "hot Neptunes" for which we have the most information on atmospheric properties. In particular, we will discuss how the thermal structure, transport properties, and bulk metallicity and elemental abundance affect the atmospheric composition of close-in extrasolar giant planets; we will also review the current observational evidence for disequilibrium atmospheric compositions on exoplanets.

Moullet, Arielle

Exploring the diversity of atmospheres in the Solar System with the Atacama Large Millimeter Array (ALMA) and the K. Jansky Very Large Array (JVLA)

Moullet, Arielle[1]; Gurwell, Mark[2]; Butler, Bryan[4]; Lellouch, Emmanuel[3]; Moreno, Raphael[3]; Wootten, Alwyn[1]

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3. Observatoire de Paris, Paris, France
4. NRAO, Socorro, NM, USA

The new capabilities offered by ground-based (sub)millimeter and cm-wavelengths facilities now put this technique at the forefront of solar system atmospheric studies. Amongst molecules that are often present as minor components in planetary atmospheres, several display strong (sub)millimeter rotational lines (CO, HCN, HDO, SO_2,...) formed at altitudes above a few hundreds millibars. Modeling of the lines' profiles allows one to derive the temperature and molecular abundance vertical profiles in atmospheric regions that are rarely probed by other techniques. When a sufficient spatial resolution is reached, the combined retrieval of temperature, wind (through Doppler-shift mapping) and composition horizontal fields is a powerful tool to determine the global atmospheric structure, and to identify seasonal and diurnal cycles. Cm-wavelengths continuum observations evidence the thermal field and absorber distribution at deeper levels, down to a few tens of bars. (Sub)millimeter and cm-wavelengths observations are then essential to physically and chemically characterize the atmospheres of several solar system bodies, and eventually to constrain atmospheric processes that may be applicable to extrasolar atmospheres as well. This presentation provides an overview of the possibilities offered by (sub)mm and cm-wavelengths observations, in the context of the deployment of two groundbreaking instruments: the Atacama Large Millimeter Array (ALMA), a 64-element array nearing completion in Chile, that will eventually provide an unparalleled sensitivity for a large range of wavelengths, as well as an excellent spatial resolution; and the K. Jansky Very Large Array (JVLA), consisting in a major upgrade in frequency coverage, correlator capabilities and bandwidth of the VLA (New Mexico). A few topics illustrating the diversity of science cases that can be addressed with ALMA and JVLA, and that have already been investigated with various single-dish instruments and interferometers, will be developed: chemical characterization of tenuous atmospheres, determination of atmospheric wind regimes, thermal mapping of ice giants' tropospheres, and mapping of minor species in giant planets' upper atmospheres.

Nixon, Conor A.

The search for new trace species in the stratosphere of Titan using Cassini CIRS

Nixon, Conor A.[1]

1. Solar System Exploration Div., NASA Goddard Space Flight Ctr, Greenbelt, MD, USA

Saturn's largest moon Titan is one of the most enigmatic bodies in the solar system, with an atmosphere composed largely of nitrogen (~95%) and methane (~5%). The action of solar UV and magnetospheric charged particle bombardment initiates a rich photochemistry, creating a plethora of hydrocarbon and nitrile chemical species. The Voyager 1 encounter in 1980 was a watershed moment, unveiling for the first time true complexity of the atmospheric chemistry, principally through infrared spectroscopy that reveals the vibrational signatures of the molecules. Further advances were made by the Infrared Space Observatory (ISO), detecting the important molecules benzene (C_6H_6) and water (H_2O). The Cassini mission has been a different experience, with much of the new chemistry findings coming from the upper atmosphere, sensed through in situ techniques of mass spectrometry. Cassini also carries on board the Composite Infrared Spectrometer (CIRS), conceptual successor to the Voyager IRIS instrument. CIRS has so far detected no new molecules during ~9 years of studying Titan and more than 90 flyby encounters, although efforts to fully understand and model the dataset are still developing. This presentation describes the on-going search for new trace species in Titan's stratosphere with Cassini CIRS, and also upper limits that have been placed so far in cases of non-detections - including acetonitrile, ammonia, allene and others.

Ojha, Sunal

Monitoring spatial and temporal snow cover variability in three major basins from Himalayas

Ojha, Sunal[1]

1. Nepal Electricity Authority, Ministry of Energy, Kathmandu, Bagmati, Nepal

Satellite remote sensing is an effective tool for monitoring snow covered area. However, complex terrain and heterogeneous land cover and the presence of clouds, impose challenges to snow cover mapping. This research analyzes snow cover and glaciers with a perspective of climate change in Himalayan Regions using remote sensing techniques. The remote sensing snow cover data from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite from 2000 to 2010 have been used to analyze some climate change indicators. In particular, the variability in the maximum snow extent with elevations, its temporal variability (8-day, monthly, seasonal and annual), its variation trend and its relation with temperature have been analyzed. The snow products used in this study are the maximum snow extent and fractional snow covers, which come in 8-day temporal and 500m and 0.05 degree spatial resolutions respectively. The results showed a tremendous potential of the MODIS snow product for studying the spatial and temporal variability of snow as well as the study of climate change impact in large and inaccessible regions like the Himalayas. The snow area extent (SAE) (%) time series exhibits similar patterns during seven hydrological years, even though there are some deviations in the accumulation and melt periods. The analysis showed relatively well inverse relation between the daily mean temperature and SAE during the melting period. Some important trends of snow fall are also observed. In particular, the decreasing trend in January and increasing trend in late winter and early spring may be interpreted as a signal of a possible seasonal shift. However, it requires more years of data to verify this conclusion. Significant coverage of lake ice was found in lower elevation zone which is due to flat terrain in this zone. Key Words: Climate change, Himalayas, MODIS, remote sensing, snow, lake ice.

Osprey, Scott

Gravity-Wave Driven Circulations in the Earths Atmosphere

Osprey, Scott[1]; Read, Peter[1]

1. Department of Physics, University of Oxford, Oxford, United Kingdom

The large scale thermal structure of Earths atmosphere is controlled by: (1) the absorption of solar/terrestrial radiation by radiatively important gases like CO2 and ozone, and (2) adiabatic processes, such as dry convection and the circulations induced by breaking waves. Both diabatic and adiabatic processes can involve phenomena which are not directly resolvable in global climate models (GCMs), and so require parameterisation. The use of sophisticated parameterisations in Earth GCMs, has made a demonstrable impact on the ability of models to reproduce observed features in the atmosphere. Before the advent of spectral gravity wave (GW) parameterisations, GCMs suffered from conspicuous biases. One such bias, known as the cold-pole problem, included overly strong westerly winds in simulations of the wintertime polar night jet. This was also related to the under-representation of so called sudden stratospheric warming events in models. A further bias included the absence of a reversal of zonal mean zonal wind in the mesosphere: a climatological feature directly linked with the coldest occurring temperatures on earth - the summer polar mesosphere. A final common model deficiency relates to the quasibiennial oscillation: a phenomenon described by reversals in the direction of winds in the tropical stratosphere, occurring over a period of approximately 27 months. Before the development of modern GW parameterisations, GCMs could not spontaneously generate this phenomenon. We will discuss the impact of a modern spectral gravity parameterisation on the stratospheric circulation within a state of the art global climate model. We will also discuss how new satellite observations are helping to identify and quantify sources of GWs in the troposphere. We conclude by highlighting how future general circulation models used in the study of other planetary bodies would benefit from the inclusion of sophisticated GW parameterisations.

Payra, Swagata

A Comparative Analysis of Remote Sensing Observations Over Northwestern India

Payra, Swagata[1]; Soni, Manish[2]; Prakash, Divya[1]; Verma, Sunita[1]; Holben, Brent[3]

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2. Remote Sensing Division, Birla Institute of Technology Mesra, Extension Centre Jaipur, Jaipur, India
3. NASA Goddard Space Flight Center,, NASA, Greenbelt, MD, MD, USA

Atmospheric particles including mineral dust, biomass burning smoke, sulfates, sea salt and carbonaceous aerosol impact air quality and climate. Satellite based observations can provide detailed information for a large spatial area on the global and regional air quality. The satellite products however require a periodic comparison, validation and additional parameterization with frequent reliable ground-based observations made at or near the surface which are still lacking over the Indian subcontinent. Jaipur (Northwestern, India), a semi-arid region poses challenge for the satellite remote sensing of aerosols. The present work includes an extensive first comparative evaluation on satellite retrieved aerosol optical thickness (AOT) from the MODerate resolution Imagining Spectroradiometer (MODIS) and a handheld sun photometer (MICROTOP – II) over Jaipur. The ground based observations with a time difference within ± 30 minutes of MODIS Satellite scan are taken for validation purpose. The mean values of the collocated spatial and temporal ensemble are used for correlation between MICROTOP and MODIS aerosol products. The correlation is determined for different seasons at varying wavelengths. The comparison between MODIS and MICROTOP AOT shows good correlation for wavelength range in 440 nm, 550 and 670 nm.

Polichtchouk, Inna

Intercomparison of General Circulation Models for Hot Extrasolar Planets

Polichtchouk, Inna[1]; Cho, James Y.[1]

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We compare five general circulation models (GCMs), which have been recently used to study hot extrasolar planet atmospheres, under three test cases useful for assessing model convergence and accuracy. The models considered all solve the traditional primitive equations, but employ different numerical algorithms or grids. The test cases are chosen to cleanly address specific aspects of the behaviours typically reported in hot extrasolar planet simulations: 1) steady-state, 2) non-linearly evolving baroclinic wave and 3) response to fast thermal relaxation. When initialised with a steady jet, all models maintain the steadiness – except MITgcm in cubed-sphere grid. A very good agreement is obtained for a baroclinic wave evolving from an initial instability in spectral models only (see Figure 1). However, exact numerical convergence is not achieved across the spectral models: amplitudes and phases are observably different. When subject to a typical 'hot-Jupiter'-like forcing, all five models show quantitatively different behaviour – although qualitatively similar, time-variable, quadrupole-dominated flows are produced. Overall, in the tests considered here, spectral models in pressure coordinate (BOB and PEQMOD) perform the best and MITgcm in cubed-sphere grid with Shapiro filter performs the worst.

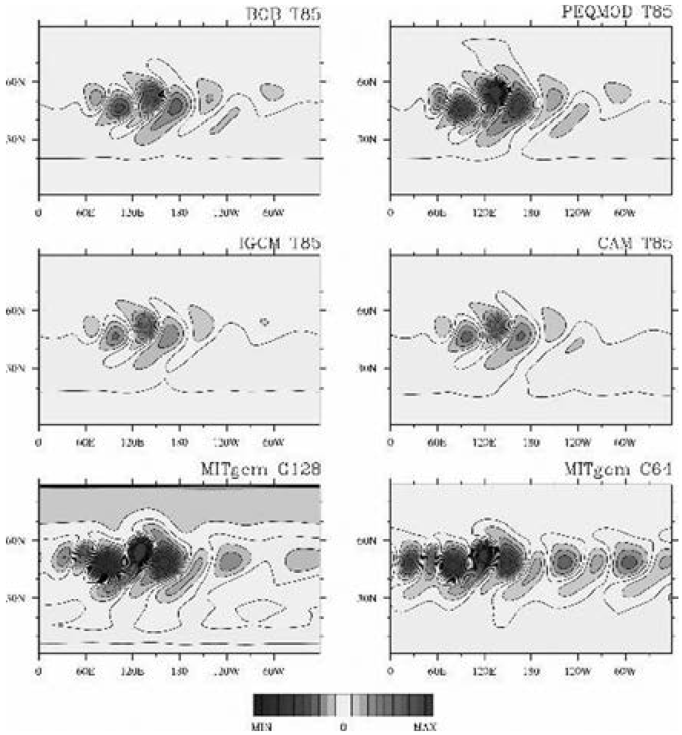

Figure 1. Cylindrical equidistant view, centred on the equator, of relative vorticity field at 10 planetary rotations from different models for baroclinic wave test case. From left to right and top to bottom the models are: BOB, PEQMOD, IGCM, CAM, MITgcm (latitude-longitude grid) and MITgcm (cubed-sphere grid).The resolution is the highest tested in all the cores, except in BOB; it is the second highest. The fields shown are from the bottom vertical level (~975 hPa). Maximum and minimum values for all the cores are ± 5×10^{-6} s^{-1}, with contour interval 5×10^{-7} s^{-1}. Good agreement is achieved in spectral models (top and middle row).

Radigan, Jacqueline

Observations of cloud and weather phenomena in the atmospheres of cool brown dwarfs

Radigan, Jacqueline[1]; Jayawardhana, Ray[2]; Lafrenière, David[3]; Artigau, Etienne[3]; Marley, Mark[4]; Cowan, Nick[5]; Apai, Daniel[6]; Buenzli, Esther[6]

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The past decade and a half has seen the discovery of over 1000 free floating brown dwarfs in the solar neighborhood. With temperatures ranging from ~2200 to 300 K they represent the coolest atmospheres available to direct and detailed study outside of our solar system, and have the added benefit of being much easier to observe than exoplanets, whose signals are washed out by the presence of their host stars. From an atmospheric science perspective, brown dwarfs are higher surface gravity analogs of extrasolar giant planets, and share important similarities such as overlapping temperatures, a rich molecular chemistry, condensate clouds, and rapid rotation. Recent observations of cool brown dwarfs in the time-domain (e.g. Artigau et al. 2009, Radigan et al. 2012) have revealed large-amplitude variability at near-infrared wavelengths for a subset of objects spanning the transition between cloudy L-dwarf and clear T-dwarf spectral types (~1200 K). This quasi-periodic variability of transition brown dwarfs is indicative of heterogeneous cloud features and evolving weather patterns in their atmospheres. I will review recent work and discuss how the newfound population of variable brown dwarfs with patchy clouds provides an unprecedented opportunity to probe cloud structure and dynamics of cool substellar atmospheres in the non-irradiated, rapidly rotating regime.

Ramirez, Ramses M.

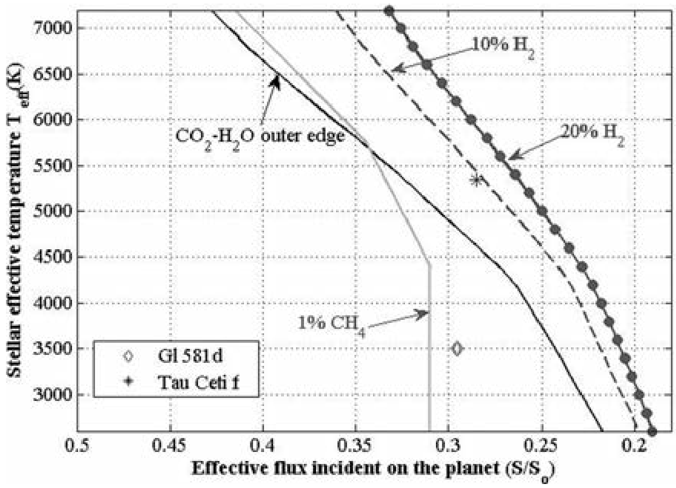
Habitable Zones around Main Sequence stars : Greenhouse and anti-greenhouse effects of H2 and CH4

Ramirez, Ramses M.[1]; Kopparapu, Ravi kumar[1]; Kasting, James F.[1]

1. Geosciences, Penn. State Univ., State College, PA, USA

Previous studies suggest that CH4 and/or H2 may be common gases for young habitable planets like early Earth (Pavlov et al., 2000;Wordsworth and Pierrehumbert, 2013). Examining the other planet within own solar system's habitable zone (HZ), early Mars' highly reduced mantle would have made H2 concentrations approaching 20% plausible, although 5-10% H2 would have sufficed to raise the mean surface temperature above the freezing point of water (Ramirez et al., 2013, in review). Thus, exoplanets similar to our early Earth or early Mars, may have CH4 and H2 concentrations of ~1% and 10-20%, respectively.Here, we extend our results for the traditional N2-CO2-H2O HZ (Kopparapu et al., 2013, in press) and assess the impact from the addition of 1% CH4 and 10-20% H2 to planetary atmospheres around main sequence stars. We have also derived new parameterizations that include CH4 and H2 in this expanded traditional liquid water HZ. Hydrogen has a powerful greenhouse effect, extending the outer edge of our solar system from ~1.7 to 1.82 AU and ~1.7 to 1.9 AU for 10% and 20% H2, respectively. The outer edges for all stellar types extend outward by similar proportions. In contrast, the strong anti-greenhouse of CH4 results in only a modest expansion of the outer edge (~ 0 - 2%) for stars of spectral classes F0 - ~G4, while shrinking it significantly (~5-20%) for K-M stars. Therefore, H2 may extend the outer edge to include planets located outside of the traditional liquid water HZ (i.e Tau Ceti f), while CH4 may make late star planets located within the traditional liquid water HZ (i.e. GL581d) too cold to support stable liquid water on their surfaces. If young habitable extrasolar planets started out H2-rich, the outer edge moves inward as these worlds evolve methanogens and consume H2 to form CH4. Pavlov et al. "Greenhouse Warming by CH4 in the Atmosphere of Early Earth" J. Geophys. Res. 105: 11,981-11,990 (2000) Kopparapu R., Ramirez, R., Kasting, J.F., et al., "Habitable Zones Around

Main Sequence Stars: New Estimates." Accepted to ApJ. (2013) Wordsworth, R., Pierrehumbert, R., "Hydrogen-Nitrogen Greenhouse Warming in Earth's Early Atmosphere" Science 4, 339, 6115, 64-67. (2013)



Stellar effective temperature versus the effective stellar flux incident on a planet. The corresponding locations for Gliese 581d and Tau Ceti f are shown for comparison. The traditional habitable zone(HZ) outer edge (black) is exposed to (a) 10% and 20% H2, respectively (purple), and (b) 1% CH4 (green). Although outside of the traditional CO2-H2O HZ, Tau Ceti f may exhibit stable liquid water on its surface with just 10% H2. In contrast, Gliese 581d may be unable to support stable liquid water, given just 1% CH4.

Rauscher, Emily

Evaluating the Influence of Magnetic Drag and Heating on Atmospheric Circulation Near the Photospheres of "Hot Jupiters"

Rauscher, Emily[1]

1. Astrophysical Sciences, Princeton University, Princeton, NJ, USA

Hot Jupiters are the most easily detected type of exoplanet: gas giant planets that orbit several stellar radii away from their host stars, with orbital periods of a few days. They are expected to be tidally locked into synchronous orbits, meaning that they should rotate much more slowly than our own Jupiter, and only one hemisphere is irradiated by the star. These properties, together with incident stellar fluxes ~10^4 times what Jupiter receives from our sun, mean that hot Jupiter atmospheres are very different from any found in the solar system. While much work has been done to develop circulation models appropriate for this new regime, there are still remaining issues that need to be addressed. One such example is the question of whether magnetic effects may significantly influence the photospheric properties of hot Jupiter atmospheres, where temperatures are high enough that there could be a weak level of thermal ionization (another difference from solar system atmospheres). As mostly-neutral atmospheric winds, at km/s speeds, blow embedded ions through the planet's magnetic field, the winds will experience a bulk Lorentz force drag, and induced currents will heat the atmosphere through ohmic dissipation. We have included an energetically and geometrically consistent treatment for these magnetic effects in our general circulation model. I will present results in which we compare models at different equilibrium temperatures and with a range of assumed planetary magnetic field strengths. We find that under some circumstances the magnetic effects may strongly influence hot Jupiter atmospheric circulation.

Rymer, Abigail M.

Negative Ions in the Solar System

Rymer, Abigail M.[1]; Westlake, Joseph[1]; Smith, Howard[1]; Fentzke, Jonathan[1]; Wellbrock, Anne[2]; Coates, Andrew[2]; Strohbehn, Kim[1]

1. JHU-APL, Columbia, MD, USA
2. MSSL-UCL, Dorking, United Kingdom

The NASA Cassini spacecraft has been in orbit at Saturn for 8 years, making 89 flybys of Saturn's largest moon 'Titan' and 19 flybys of the cryo-volcanically active icy satellite 'Enceladus', to date. One of the most surprising discoveries of the Cassini mission has been the abundance of negative ions and negatively charged dust present in the atmosphere of Titan and in the ice volcano plumes that emerge from the South pole of Enceladus. At Titan, negative ions are observed in the altitude range 950-1400 km with peak density typically a few 10s per cc and significant day/night variations. At Enceladus negative ions, nanograins and dust are seen below ~600 km altitude with a (mass dependent) density typically < 1 per cc. In the Earth's D-region the density of negative ions often dominates over the 'free' electron density below 80 km and on the nightside of Mars below ~30 km. In all these regions we have encountered the peculiar situation that ions become the dominant current carriers because electrons are less free to move. Fundamentally these "massive electrons" alter the dynamics of the ionospheres, and may be responsible for coagulation of aerosols at Titan and by extension the early Earth too. In this presentation we will discuss what is similar and what is different between the formation and physics of electron attachment in the Earth's ionosphere as compared to Mars, Titan and to the Enceladus plume ionosphere. We will also discuss how we can improve our understanding of negative ion physics, especially in the region 60 – 100 km at Earth, by utilizing emerging flight opportunities on sub-orbital vehicles.

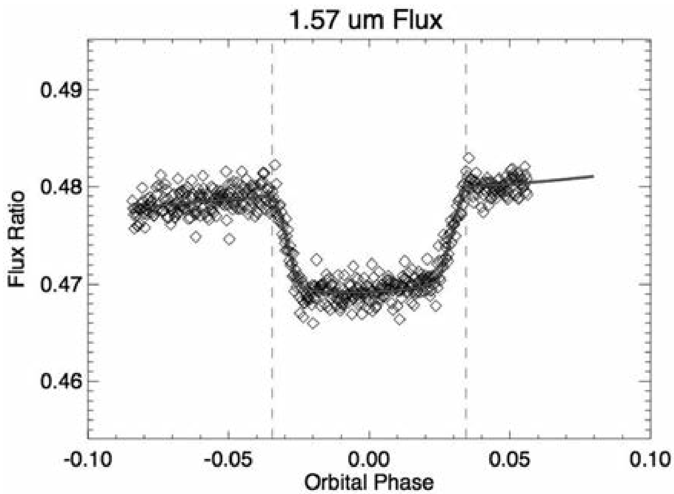
Schlawin, Everett

A Near-Infrared Transmission Spectrum of the Hot Jupiter Corot-1b

Schlawin, Everett[1]; Zhao, Ming[2]; Teske, Johanna[3]; Herter, Terry[1]

1. Astronomy, Cornell University, Ithaca, NY, USA
2. Astronomy & Astrophysics, Penn State, University Park, PA, USA
3. Astronomy, University of Arizona, Tucson, AZ, USA

The Hot Jupiter Corot-1b is an excellent test bed for models of extreme planetary atmospheres above 2000K due to its large radius, small surface gravity and nearby reference stars of similar spectral type. We present spectroscopic observations of the Hot Jupiter Corot-1b taken with the SpeX spectrograph on the Infrared Space Telescope Facility (IRTF) during 3 primary transits using a single reference star for calibration. Our observations give planet to star radius ratio uncertainties of order 0.1% or about 1 scale height for 0.3 micron bin sizes across a 0.8um to 2.4um wavelength region. Preliminary analysis of the time series shows consistency with previous space based measurements of the planet's radius and a relatively flat spectrum to within 1 scale height. Our results demonstrate the capability of ground-based surveys to spectroscopically characterize exoplanets that orbit stars fainter than a K magnitude of > 12.



Representative time series for the 0.306um wide wavelength region centered on 1.57um. The flux ratio is the flux of the planet host star divided by the reference star. The vertical dashed lines mark the ingress and egress of the planet on to the stellar disk. The solid line shows a best fit from the Mandel and Agol 2002 with a quadratic baseline.

Schneider, Tapio

Grand Challenges in Global Circulation Dynamics *(INVITED)*

Schneider, Tapio[1, 2]

1. Dept. of Earth Sciences, Swiss Federal Institute of Technology, Zurich, Switzerland
2. California Institute of Technology, Pasadena, CA, USA

This talk surveys what we know about the dynamics of global atmospheric circulations and what the remaining grand challenges are. The focus will be on Earth's atmosphere, with an eye toward general principles that are applicable to other planetary atmospheres. I will review issues in tropical dynamics (e.g., Hadley circulations and the role of convection in it) and what they can teach us about slowly rotating planetary atmospheres, as well as issues in extratropical dynamics (e.g., large-scale turbulence and jet formation) and what they can teach us about rapidly rotating planetary atmospheres.

http://www.clidyn.ethz.ch

Showman, Adam

Atmospheric Dynamics of Exoplanets *(INVITED)*

Showman, Adam[1]

1. Department of Planetary Sciences, Lunar & Planetary Laboratory, Tucson, AZ, USA

The discovery and characterization of exoplanets has raised fundamental questions about how the atmospheric circulation and climate of planets depends on incident stellar flux, planetary rotation rate and radius, and atmospheric mass and composition. I will survey fundamental processes governing the atmospheric dynamical regime and describe how they are expected to vary under the broad range of conditions relevant to exoplanets. Current observations are best for giant exoplanets (e.g., the hot Jupiters) and I will show how predictions emerging from theory and simulations can help to explain several aspects of these observations. I will also describe how the dynamics can play a role in affecting the habitability of the surfaces of terrestrial exoplanets. Links with the dynamics of solar system planets, both terrestrial and Jovian, will be emphasized.

Spiga, Aymeric

Convection, turbulence, waves: a comparative analysis of mesoscale processes on Mars and the Earth, and perspectives for other planetary environments

Spiga, Aymeric[1]; Forget, François[1]

1. LMD, Paris, France

Small-scale atmospheric processes offer fascinating perspectives for a comparative planetology approach. Not only those processes, left unresolved by Global Climate Models, have a key influence on the whole climate, but they also unveil key characteristics of planetary environments, and fundamental atmospheric dynamics. Here, using recent spacecraft observations, and dedicated mesoscale models and large-eddy simulations, we compare mesoscale and microscale phenomena on Mars and on the Earth. Mars appears as an intense and exotic counterpart to the Earth. Deep convective motions could occur in Martian local and regional dust storms. We name this phenomenon "rocket dust storm", or "conio-cumulonimbus", given the implied fast and powerful vertical transport. The supply of convective energy is provided by the absorption of incoming sunlight by dust particles, rather than by latent heating as in moist convection on Earth and other environments. Dust-driven deep convection on Mars has potentially strong implications for the Martian atmospheric physics and dynamics, but also provides a new example of the importance of deep convective processes in planetary atmospheres. Boundary layer convection, also named shallow convection on Earth, is actually not so shallow on Mars: daytime turbulent plumes can reach about one atmospheric scale height. While sensible forcing dominates the terrestrial planetary boundary layer, the daytime Martian boundary layer is primarily driven by radiative forcing. This radiative control explains why the convective boundary layer on Mars is deeper over elevated terrains than in lower plains despite similar surface temperatures, in striking contrast to the vast majority of terrestrial conditions. This also implies generalized definitions for mixing layer scaling, and challenges the Monin-Obukhov formulation for surface-atmosphere exchanges. While observations of clear-cut katabatic events are difficult on Earth, except over vast ice sheets, those intense downslope circulations are widespread on Mars. Their intensity and regularity can be witnessed through numerous aeolian signatures on the surface and thermal signatures in the steepest craters and volcanoes. Furthermore, similarly to the Loewe phenomena in terrestrial polar regions, katabatic jumps could form on the Martian polar caps and be responsible for the migration of ice over geological timescales. Gravity waves are ubiquitous in planetary atmospheres and key drivers to both regional and global climates. Extremely cold temperatures in the Martian mesosphere can be explained by the combined influence of thermal tides and gravity waves. Such cold pockets can be propitious to clouds formed by the condensation of CO2, the major component of the Martian atmosphere. Those clouds are exotic counterpart of thick polar stratospheric clouds on Earth, also formed by propagating gravity waves. Following this Mars vs. the Earth comparative study, we will examine the perspectives to apply our modeling approach to other planetary environments where mesoscale processes are at play: Venus, Titan, gas giants, ...

http://www.lmd.jussieu.fr/~aslmd

Stam, Daphne M.

Uncovering Exoplanets using Spectropolarimetry *(INVITED)*

Stam, Daphne M.[1]

1. Aerospace Engineering, Technical University Delft, Delft, Netherlands

After two decades of highly successful exoplanet detections, we know that almost every star in our neighborhood has a planet. The next step in exoplanet research is the characterization of the atmospheres and, if present, the surfaces of these planets. This will especially be interesting for planets in the habitable zones of their stars, where temperatures could be just right to allow liquid surface water, a prerequisite for life as we know it. Whether liquid water actually exists on a planet depends strongly on the atmospheric composition and thickness. Famous examples are Venus and Earth, with similar sizes, inner compositions and orbital radii, but wildly different surface conditions. The characterization of the atmospheres and/or surfaces of gaseous and/or solid exoplanets will allow a comparison with Solar System planets and open up a treasure trove of knowledge about the formation and evolution of planetary atmospheres and surfaces, thanks to the vast range of orbital distances, planet sizes and ages to be sampled. Characterization will also allow studying conditions for life and, ultimately, the existence of life around other stars. Some information about atmospheric properties has already been derived for a few close-in, hot exoplanets, whose thermal flux can be derived from measurements of the combined flux of the star and the planet. Characterization of the atmosphere and/or surface of exoplanets in orbits as wide as those of the Solar System planets, and in particular of Earth-like planets in habitable zones of Sun-like stars, is virtually impossible with transit observations. Spectropolarimetry appears to be a strong tool for the detection and the characterization of such exoplanets. Polarimetry helps detections, because direct starlight is usually unpolarized, while starlight that has been reflected by a planet is usually polarized. Polarimetry thus improves the contrast between stars and their planets, and confirms that the detected object is indeed a planet. I will focus on the power of polarimetry for characterizing Solar System planets and exoplanets. This application is known from the derivation of the Venus cloud properties from the planet's polarized phase function by Hansen & Hovenier in 1974. Using available observations of Solar System planets and calculated flux and polarization phase functions and spectra for different types of exoplanets, I will discuss the added value of polarimetry for exoplanet characterization as compared to flux observations, focussing on the retrieval of properties of clouds and hazes. Special attention will be given to the features in polarized phase functions that reveal the existence of liquid water clouds in the atmosphere (rainbows), even in the presence of ice clouds. Using satellite data of the cloud and surface coverage of the Earth, we will present calculated flux and polarization phase functions that should be observable from afar and compare them with the limited available data, such as from Earthshine observations. Finally, we will introduce LOUPE, a small spectropolarimeter designed to observe the Earth as if it were an exoplanet, from the Moon. LOUPE would provide much—needed spectropolarimetric data of a truly Earth-like planet.

Stangier, Toby

Direct Wind Measurements in the Atmospheres of Mars, Earth and Venus

Stangier, Toby[1]; Herrmann, Maren[1]; Sornig, Manuela[1, 2]; Sonnabend, Guido[1]

1. I.Physikalisches Institut, University of Cologne, Cologne, Germany
2. Planetary Research, Rheinisches Institut fuer Umweltforschung, Cologne, Germany

Introduction: Infrared heterodyne spectroscopy offers the capability to resolve single molecular transition features by providing ultra high resolving power of >107. Thus, it is a very sensitive tool to study the dynamics of planetary atmospheres. The Cologne Tuneable Heterodyne Infrared Spectrometer (THIS) enables ground-based measurements of those transitions and provides direct line-of-sight wind velocities from their Doppler shift [1]. It is capable to target a wide range of the mid-infrared regime (8-13μm). Method &

Observations: Non local thermodynamic equilibrium (non-LTE) emission of CO2 around 10 μm occurs due to solar radiation at low pressure levels in the mesospheres of Mars, Earth and Venus. On Mars, the 1 μbar level of the mesosphere can be found at approximately ˜80 km altitude, whereas on Venus it is located at around ˜110 km. By means of the precise frequency information of the CO2 emission, the Doppler shift can be directly deduced from the measured spectra and a statement on the predominant wind speeds can be given. Various observations of the dynamics in the Venusian and Martian atmosphere took place in recent years at the McMath-Pierce Solar Telescope on Kitt Peak, Arizona [2][3]. Wind speeds up to approximately 100 m/s on Mars and 150 m/s on Venus were measured with an accuracy of 10 m/s. On Earth, CO2 non-LTE emission can not be observed from the ground. Here, stratospheric Ozone can be probed to determine wind velocities at ˜32 km altitude using the sun as background emitter. First observations were performed in January 2010. Results: A great variability of the zonal wind velocity in the atmosphere of Mars was determined during the last 6 years. Mainly seasonal variability was expected and explained by general circulation models. On Venus the wind contributions need to be distinguished between the zonal super-rotational component and the sub-solar to anti-solar flow which is predominant in high altitudes. It was found, that the wind velocity decreased unexpectedly towards the equatorial region from its maximum in mid-latitudes of around 30 m/s. The sub-solar to anti-solar flow however reaches an expected maximum of 150 m/s at the terminator. Variability of a few 10 m/s was found on various time scales. The telluric ozone observation provided a wind field with a velocity of about 88 m/s with an east-west orientation. Outlook: Future observations of the dynamics in the atmospheres of Mars, Venus and Earth will be performed. Longtime investigations of the winds shall provide more information on the variability and help to understand the differences between our neighbor planets and us and to develop more sophisticated circulation models. References: [1] Sonnabend, G. et al.: Ultra high spectral resolution observations of planetary atmospheres using the Cologne tuneable heterodyne infrared spectrometer; JQSRT 109 (2008), 1016-1029 [2] Sornig, M. et al.: Venus upper atmosphere winds from ground-based heterodyne spectroscopy of CO2 at 10μm; PSS 56 (2008), 1399-1406 [3] Sonnabend, G. et al.: Mars mesospheric zonal wind around northern spring equinox from infrared heterodyne observations of CO2; ICARUS 217 (2012), 315-321

Thomson, Stephen

Jupiter's Unearthly Jets: A New Idealized Model

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The complex flows at cloud-top level on Jupiter, revealed through moving images and cloud-tracking, continue to challenge our understanding of fluiddynamical fundamentals. In particular, a long-standing mystery has been the straightness of Jupiter's zonal jets – even at high latitudes – quite unlike terrestrial strong jets with their typical long-wavelength meandering. Such meandering is also conspicuous in many idealized model studies of Jupiter's weather layer, such as those of Williams, Yoden, Yamada, Cho, Polvani, Showman, Li, Ingersoll, Huang, Scott, and others. The problem is addressed in two steps. The first is to take seriously the classic Ingersoll-Cuong, Dowling-Ingersoll and Stamp-Dowling scenarios, with deep zonal jets in the convection zone underlying the weather layer, recognizing that such flows can be stable by Arnol'd's second shear-stability criterion (A2-stable) even with reversed upper potential-vorticity gradients. The second step is to improve the realism of the small-scale stochastic forcing used to represent the effects of Jupiter's thunderstorms, by injecting small vortices in physical space. Past studies have tended either to work in spectral space or to inject anticyclones only (Li-Ingersoll-Huang, Showman). Here we recognize that the real thunderstorms are likely to generate cyclonic as well as anticyclonic potential-vorticity anomalies, but with unequal strengths, and, following Li, Ingersoll and Huang, are most likely to occur preferentially where the interface to the deep flow is coldest. We use a one-and-a-half layer quasigeostrophic model in a doubly-periodic beta-plane geometry, with an A2-stable jet configuration having reversed upper potential-vorticity gradients, following the work of Stamp and Dowling. The deep jets are represented, as usual, by a fixed quasi-topographic term in the model's potential-vorticity equation. Special attention is given to 'pulsed convection' scenarios that try to mimic the observed 'belt revivals', which suggest time-variability in the deep convection affecting the weather layer. Long model runs presently in progress suggest that such scenarios will attain statistically steady states over many pulsations, with no need for the artificial large-scale dissipation used in many idealized studies. The model appears to have promise as a way of explaining the jet straightness and of constraining possible values of Rossby deformation lengths for the real planet, as well as suggesting new guidelines for general circulation model studies.

Thrastarson, Heidar T.

General Circulation and Variability of Close-In Exoplanet Atmospheres

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Many exoplanets are on close-in orbits and are likely tidally synchronized. Scaling arguments and simulations indicate that this type of planets may occupy a regime where atmospheric flow structures (jets/vortices) are large, making their possible time variability crucial to observations (if they are coupled to the temperature field). Time variability affects assumptions when interpreting observations, but also offers an opportunity to extract additional information about the atmospheres from the time modulation of the signals. The goal of our study is to constrain the conditions under which time variability can be expected and understand mechanisms likely to cause or quench variability on tidally locked exoplanets. We use a general circulation model, solving the primitive equations with thermal relaxation. We have explored the parameter space relevant for tidally synchronized planets, using the mini-Neptune GJ1214b and the hot Jupiter HD209458b as reference planets. For a large range of conditions, robust features include a small number of jets and large-scale vortices. The vortices often exhibit time variability, associated with planetary scale waves, with corresponding variability in the position of relative hot and cold regions. These results make a strong case for mission concepts such as NASA's FINESSE and ESA's EChO, that emphasize repeated measurements of a given planet, enabling feedback between observations and modeling that can yield new insights for exoplanet atmospheres. Furthermore, it is already becoming possible to extract information about latitudinal as well as longitudinal structure of transiting exoplanet atmospheres, so knowledge about the extent of spatial and temporal variability can soon be within reach.

Titov, Dmitrij

A new view of Earth's sister: Insights following seven years of observation with Venus Express

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Since April 2006 ESA's Venus Express has been performing a global survey of the remarkably dense, cloudy, and dynamic atmosphere of our near neighbour. The mission delivers comprehensive data on the temperature structure, the atmospheric composition, the cloud morphology, the atmospheric dynamics and the escape processes. Vertical profiles of the atmospheric temperature show strong latitudinal trend in the mesosphere and upper troposphere correlated with changes in the cloud top structure and indicate convective instability in the main cloud deck at 50-60 km. Observations reveal significant latitudinal variations and temporal changes in the global cloud top morphology, which modulate the solar energy deposited in the atmosphere. The cloud top altitude varies from ~72 km in the low and middle latitudes to ~64 km in the polar region, correlated with decrease of the aerosol scale height from 4 ± 1.6 km to 1.7 ± 2.4 km, marking vast polar depression. UV imaging shows for the first time the middle latitudes and polar regions in unprecedented detail. Solar occultation observations and deep atmosphere spectroscopy in spectral transparency windows mapped distribution of the major trace gases H2O, SO2, CO, COS and their variations above and below the clouds, and so provided important input and validation for models of chemical cycles and dynamical transport. Tracking motions of cloud features provided the most complete characterization of the mean atmospheric circulation as well as its variability. Low and middle latitudes show an almost constant zonal wind speed of 90 +/-20 m/s at the cloud tops and vertical wind sheer of 2-3 m/s/km. Towards the pole, the wind speed drops quickly and the vertical shear vanishes. The meridional poleward wind ranges from 0 at equator to about 15 m/s in the middle latitudes. Comparison of the thermal wind field derived from temperature sounding to the cloud-tracked winds confirms the validity of cyclostrophic balance, at least in the latitude range from 30S to 70S. The observations are supported by development of General Circulation Models. Non-LTE infrared emissions in the lines of O2, NO, CO2, OH originating near the mesopause at 95-105 km were detected and mapped. The data show that the peak intensity occurs close to the anti-solar point, which is consistent with current models of the thermospheric circulation. For almost complete solar cycle Venus Express instruments continuously monitor induced magnetic field and plasma environment around the planet enabling assessment of the global escape rates of O, H, and He ions, that weakly depend on solar conditions and are surprisingly lower than those at Earth.

Tyler, Robert

Resonant Tidal Excitation and Heating of Giant-Planet Atmospheres

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This poster will describe work in progress involving theoretical analyses and modeling of the deposition and dissipation of resonantly excited tidal energy in the atmospheres of giant planets. There are two classes of objectives in this work. The first involves the development of a generic description of the dependence of an atmosphere's tidal response on unknown parameters reflecting the range of conditions expected for giant planets, and the conditions for resonance. There have surely been previous studies concerning the tides in the atmospheres of the gas giants in Solar-System and exoplanet applications, but the needed description is far from complete, and in fact most of the tidal studies provided have involved various approximations that restrict the dynamics in such a way that important resonances expected from even Classical Tidal Theory are disallowed. The approach used here to provide the needed description is to isolate the elements of the tidal response calculation that are common to a whole class of scenarios from the other elements (e.g. parameter values) that vary and may typically even be unknown. Using the complete Laplace Tidal Equations, we then calculate the solution for the full set of tidal scenarios filling a parameter space with coordinates describing these parameters. There is then a full tidal solution associated with each position in this space and through examination of this solution space one may characterize the behavior of the whole tidal class considered. In one example, the total dissipation associated with each solution for a class of tides on Jupiter is shown as a function of two unknown parameters. Because some of the features, such as the narrow resonance peaks, extend across the diagram, one may make inferences about entry into resonant states even when parameters required for the calculation are uncertain. From this one might expect that tendencies toward either stratification or destratification (corresponding to upward or downward motion in the diagram) would lead to encounter with one or more resonant tidal states. If there are associated negative feedbacks on the tendency resulting from the enhanced tidal response, a stable location in the diagram is reached. If, on the other hand, the feedbacks are positive, the configuration will accelerate through the resonant state, leaving the chance of finding an atmosphere in this state unlikely. The second objective in the work underway is application-specific and includes the testing of two hypotheses: The first, which we may refer to as the "Lindzen Hypothesis," postulates that the steady banding (belts, zones, jets) on Jupiter are due to a rectification of periodic tidal forces raised by Io. The second is the postulation that the inflation of "hot-jupiter" extrasolar planets is due to resonant excitation of the atmosphere by tidal forces. The work conducted so far supports the Lindzen Hypothesis by first confirming the previously reported claims regarding the imprint of the Hough modes on banding (Ioannou and Lindzen, Astrophys. J., 406, 1993), and further provides self-consistent estimates of the tidal work and dissipation and shows that these rates are are significant.

Verma, Sunita

On the Sulfate Aerosols Representation in an Interactive Global Climate Chemistry Model

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The regional and global climate models are important tool for interpreting a specific aerosol component. To accurately represent the tropospheric chemistry of sulfate aerosols in a global climate chemistry model, a throughput consideration of multi-phase processes is essential i.e. the incorporation of a heterogeneous reaction system of aerosols (both gas phase and aqueous phase, predominating in cloud water), their subsequent transformation, dispersion and the mechanism for their eventual removal from the atmosphere. The existing chemistry transport models usually do not resolve the chemical species within the model domain and therefore neglect the effects associated with evolution of short-lived chemical species concentration with the evolving meteorology. This study in above perspective is a focused effort to incorporate tropospheric sulfate chemistry with internally resolved short-lived species in a three dimensional global circulation model LMDZ. The model provides a size-segregated, two-moment distribution of aerosols which undergo processes like nucleation, condensation, coagulation and interaction with clouds. The present study highlights the importance of chemistry-driven atmospheric transport models and discusses important results of online chemistry module, its subsequent incorporation and coupling with LMD-GCM.

Wang, Yixiong

Terrestrial Planetary Atmospheric Circulation Regimes in a Simplified GCM with Dual-band Radiative-transfer Scheme

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With the ever-increasing numbers of detections of exoplanets and the increasingly detailed, in-depth observations and studies of Solar System planets, we are indeed in an era when systematic and comparative studies of the commonalities and differences among planetary circulations are sorely needed. In this contribution, we present our numerical exploration of a parameter space constructed by three defining dimensionless parameters for terrestrial planetary circulations: a thermal Rossby number, the obliquity of the planetary rotation axis and a greenhouse parameter (which is defined as the ratio of atmospheric opacities of the infrared and visible wavelength bands). A simplified 3D GCM with dual-band semi-gray radiative transfer scheme is employed, which models an Earth-like atmosphere but with a relatively small number of tunable parameters and can be essentially viewed as a simplified but non-trivial prototype planetary atmosphere. A regime diagram encompassing our experiments is built using these dimensionless parameters as coordinates. By examining characteristic dynamic variables such as the number and intensity of jet streams, the strength and direction of the prevailing winds, Hadley cell width, heat transport efficiency and so on, we discover clear scaling trends and bifurcations as well as a great diversity of circulation structures out of even such a simple, idealised model. We discuss how this will help us to put Solar System planets and exoplanets into a much broader context of possible planetary circulation regimes. Some scenarios of tidally-locked planets are also modelled and studied alongside more generic, non-synchronous planets.

Westlake, Joseph H.

Energetic Neutral Atom Imaging for Probing Planetary Atmospheres

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Energetic Neutral Atoms (ENAs) are sensitive tracers of the interaction between energetic particles and neutral gasses, whether it be the interaction of magnetospheric ions with the Earth's upper atmosphere, the solar wind with Venus or Mars, or Saturn's magnetospheric ions with Titan's upper atmosphere. ENAs provide remote information about the atmospheric structure and energy deposition. Ion penetration into planetary atmospheres is a process that is widespread in our solar system and is likely also prevalent in exoplanetary systems, as it is a process that will occur wherever a neutral gas interacts with energetic ions. We present observations and lessons learned from ENA imaging at Earth, Mars, Venus, Saturn, and Titan as well as show the possibilities reached with future ENA imaging platforms like the recently selected JENI ENA imager on ESA's JUICE mission to Jupiter.

Young, Roland

Cassini observations reveal the regime of zonostrophic macroturbulence on Jupiter

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Zonostrophic macroturbulence is a paradigm where the kinetic energy associated with the zonal flow in a planetary atmosphere and the kinetic energy associated with the residual (non-zonal) flow are strongly separated in terms of their energy spectra. It is thought to be an important flow regime in the atmospheres of rapidly-rotating gas planets such as Jupiter. We have been studying the turbulent kinetic energy properties of Jupiter's atmosphere using data from the December 2000 Cassini flyby, comparing its properties with predictions made by zonostrophic theory. Using cloud tracking of brightness features in these images, we have been able to estimate the wind velocities near Jupiter's cloud tops from the flyby data. From our velocity fields we are able to estimate the kinetic energy spectra of both the zonal and non-zonal flow fields, and compare them against the properties of the zonostrophic flow regime. We were also able to compare our spectra against equivalent spectra derived from velocity fields produced independently by Choi & Showman (2011, Icarus, 216, 597-609). In both datasets the zonal spectrum is very steep and most of the kinetic energy resides in slowly evolving, alternating zonal (east-west) jets, while the residual spectrum obeys the Kolmogorov-Kraichnan law specific to two-dimensional turbulence in the inverse energy cascade range. The spectral data was used to estimate the inverse cascade rate and the zonostrophy index R_β for the first time. Although both datasets yielded somewhat different values, the ensuing values of R_β belong well within the range of zonostrophic turbulence. We infer that the large-scale circulation is maintained by an anisotropic inverse energy cascade. We discuss the method of cloud tracking as applied to planetary atmospheres in more general terms. Some aspects of the atmospheric circulation are accessible only through higher-order correlations requiring a 2D flow field, such as some characteristics of zonostrophic turbulence. We discuss how cloud tracking could be used for future comparative planetology within the Solar System.