

Planetary Robotic Exploration and Opportunities for International Collaboration on Climate Change: A Comparative Climatology Case Study

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Introduction

This Comparative Climatology Case Study describes projects that together create an exciting structure for inclusive, international scientific research on a subject of global concern. These activities address several of the top IAA Summit priorities endorsed by the IAA Board of Trustees in Planetary Robotic Exploration:

PRE 2.1 - Develop Opportunities for International Collaboration: Expand efforts to work together to achieve the next leap in understanding of our Solar System and to pave the way for human exploration

PRE 2.3 Develop Opportunities for International Collaboration: Strive to make available opportunities for international collaboration such as through shared science teams and science instruments...

and in Climate Change:

CC 3.1 - Support Coordination and Sharing of Data: Reinforce the programmatic coordination of the Earth Science programs worldwide..

CC 3.2 - Encourage Technology Development: Support the development of technologies, derived sensors, and scientific modeling...

CC 3.5 - Encourage Technology Development: Foster space technology efforts and demonstration projects, to enable offsetting of space technologies that have a potential for long-term development of green systems and/or alternative energies

In recent years our understanding of several key aspects of climate change have proved to be challenging – including the understanding of the role of the Sun’s variability on climate¹, and the role of cosmic rays on clouds². These topics were addressed in a recent conference on comparative climatology in June 2012, where discussions centered on how other planets can serve as natural laboratories for validation of various theories. Recent developments in discovering Earth-like planets around other stars, and the search for life to address the question, “Are we alone?” also provide a sound rationale for robotic planetary exploration to exploit our nearby solar system neighbors as planetary laboratories.

This Comparative Climatology Case Study is a three year project to develop an international program of scientific research and technology focused on comparing the climates of Earth, Venus, Mars, and Titan. Awareness of the Earth’s changing climate is worldwide, and opportunities for research and development are not limited to spacefaring nations. Broadband internet and adequate computer infrastructure are all that are required to work with planetary and climate data and do original research in comparative climatology. Building and flying small Earth and planetary remote sensing instruments is a good way for nations or without direct access to space to acquire new climatological data. Ultimately, we envision, a multi-national collaboration to develop and fly an interplanetary mission in search of new answers to climate change.

Background

It is natural to question what crucial differences resulted in a frozen, dry Mars and a Venus hot house, while Earth has had oceans for most of its existence. Climate response to changes in forcing involves interconnected feedbacks over a wide range of time scales. Predictions about the future

¹ [The Effects of Solar Variability on Earth’s Climate: A Workshop Report](#), Space Studies Board (SSB), National Academies Press, 2012

² Pachauri, R. K., Reisinger, A., [Fourth Assessment Report of the Intergovernmental Panel on Climate Change](#). Intergovernmental Panel on Climate Change, Geneva, 2007, pp. 104.

environment that humans will live in are based on complex numerical models that account for the forcing, responses, and feedbacks in the climate system. Venus and Mars represent real solutions to models of climate, the only available independent empirical data. Even Titan presents empirical data for one solution to climate system equations.

All three planets, Venus, Earth, Mars as well as Titan, have complex climate systems driven by periodic solar input and responding feedbacks with clouds, condensates, chemical cycles, and geology. Many of the smaller, rocky planets discovered around other stars likely have similarly complex climates. On Earth, Titan, early Mars, and perhaps early Venus, surface liquid is also a key part of the climate system. On each world, the climate forcing is different, and on each world the relative importance of individual physical processes and feedback mechanisms are unique.

Planets as Natural Laboratories for International Climate Change Research

The purpose of comparative climatology is to develop an understanding of the most fundamental rules that govern planetary climates. Foremost, the observation of similar processes on two or more planets permits a comparison of physical laws operating in different contexts. Mathematical models that simulate the chemistry and physics of climate can be verified and their limits understood by comparing the outcomes of numerical experiments for different planets. Where numerical models fail to explain observations, a comparison of the physics and chemistry operating under different conditions offers an opportunity to fundamentally improve the predictive power of these models.

Comparative climatology has the potential to improve the fundamental understanding and mathematical treatment of climate processes on Earth, Venus, Mars and Titan. However, it is also extremely useful for interpreting the growing data on planets around other stars. To the extent that improved understanding leads to a general theory of planetary climate, it will be possible to more accurately envision and model the atmospheres of terrestrial exoplanets. As the observational data become more accurate and diverse, it may eventually be possible to predict whether any given rocky planet around another star is habitable³.

Opportunities for International Collaboration

The revolution in Earth sciences, driven by space-based global data and the tools to use them means that innovative investigations can be made from anywhere on Earth, including in developing countries. The instruments that monitor the Earth come from a wide range of countries and consortia, who also share in the analysis and scientific interpretation of the data. The scientific instruments that are sent to explore other planets share much of the expertise and technology of Earth remote sensing instruments. Planetary science remote sensing instrument development is synergistic with ever more powerful techniques of Earth monitoring.

Climate Change: Sharing of Data and Technology Development

As a subject of study, comparative climatology presents an opportunity to engage many countries and science agencies in a collaborative effort to understand our world in the context of the many other worlds in the cosmos. Scientific collaboration between scientists who use planetary science databases such as NASA's Planetary Data System (PDS)⁴ and ESA's Planetary Science Archive (PSA)⁵, and their peers in developing countries would enable high-impact, low-cost scientific investigations in comparative climatology. This is particularly relevant for countries without their own space agencies, who can thus be fully engaged in climate science and space exploration without their own space infrastructure. Where new scientific data are needed, international joint missions to Earth orbit and other planets

³ Lammer, H., 2013. [Origin and Evolution of Planetary Atmospheres](#). Springer, Heidelberg.

⁴ <http://pds.nasa.gov/>

⁵ <http://www.rssd.esa.int/index.php?project=PSA>

would provide the opportunity for these disparate communities to build and fly their own instruments and hardware and provide important ground control data.

What can Comparative Climatology Contribute to Climate Change Understanding?

The *Comparative Climatology of Terrestrial Planets*⁶ conference (June 25-28, 2012 in Boulder, Colorado), was attended by more than 120 scientists from many countries. The purpose of the conference was to identify and explore physical and chemical climate processes that are shared among rocky planets with atmospheres, in order to advance scientific progress through detailed comparisons. To this end, invited speakers and poster contributors were asked to present results on investigations that rely on comparisons between Earth, Mars, Venus, Titan, and terrestrial planets around other stars. The speakers highlighted similarities and contrasts between the environments of the terrestrial planets Venus, Earth, Mars, and Titan and what synergies exist between investigations of their climates. An edited volume, *Comparative Climatology of Terrestrial Planets*⁷, is being published by the University of Arizona Press' Space Science Series, and will become available in the autumn of 2013. The conference sponsored a public panel discussion, *Climate Change on Earth and Other Planets*⁸, drawing 650 participants to engage with Dr. James Hansen of the Goddard Institute of Space Studies and four other scientists on future climate and comparisons with other worlds.

A follow up *Comparative Climatology Symposium*⁹, was held on May 7, 2013 at NASA Headquarters in Washington, DC. Talks were presented on the results of the June 2012 Comparative Climatology of Terrestrial Planets conference, current Earth climate models, Earth observation, past and current Venus missions, observational studies of terrestrial planets and the influence of the Sun on climate. The symposium concluded with a NASA Science Mission Directorate Directors panel discussion and Q/A that discussed collaborations among the four divisions within the Science Mission Directorate and international agencies. The role of Venus and the opportunities for advancing two of the most difficult questions about Earth's climate (solar variability and cosmic rays) by a coordinated, systematic exploration of Venus were evident in the discussions in this symposium.

Significant efforts in the past decades have been undertaken by NASA, ESA, RSA, JAXA, and other countries to explore the neighbors of our solar system. Evolving partly from these programs, enhanced Earth observations and discussions are underway to facilitate dedicated internationally coordinated climate observations. For Mars, the ESA-NASA collaborations have been on-going, and Russia is presently also involved. The Indian Space Research Organization (ISRO)¹⁰ is launching the spacecraft *Mangalyaan* to Mars in late 2013. The current budget projections for most space agencies make it very challenging to explore Titan in the coming two decades. In this respect Venus is unique, due not only to its proximity and the short cruise time to the planet, but because of the numerous questions that still remain unaddressed, that are far more relevant to understanding future climate change on Earth.

How Comparative Climatology Can Help Achieve IAA Objectives

This case study will consist of some of the following activities, based on feedback from the IAA Board of Trustees in Planetary Robotic Exploration.

1. Form and support an *ad hoc* International CCTP steering committee.

⁶ <http://www.lpi.usra.edu/meetings/climatology2012/>

⁷ <http://www.uapress.arizona.edu/Books/bid2437.htm>

⁸ <http://www.youtube.com/watch?v=CVcoEP8z2Q0&feature=youtu.be>

⁹ <http://astrobiology.com/2013/05/comparative-climatology-symposium-new-approaches-to-climate-research.html>

<http://www.lpi.usra.edu/vexag/meetings/ComparativeClimatology/presentations/>

¹⁰ <http://www.isro.org/>

2. CCTP steering committee will work with NASA Analysis Groups (AGs), COSPAR, and IAA organizational elements.

3. A key recommendation relevant to meeting the IAA objectives from the international assembly of scientists at the CCTP conference was that there is a need for long-term, continuous, observations/measurements of the solar system's terrestrial planets. Climate is a planetary-wide phenomenon, and a deeper understanding is possible by continuously observing the other examples in the solar system. CCTP can move forward with NASA's continuing support for planetary observations using orbiting telescopes, high altitude balloons, and sounding rockets.

We specifically propose to use Venus as a test case to study climate evolution. Venus, the first planet to be visited by a spacecraft 50 years ago, remains the logical point of entry for new participants in planetary exploration. We will establish an International Joint Venus Program to make scientific connections between the exploration of Venus and the climate evolution of our own planet. A spacecraft mission to Venus is an ideal opportunity for developing space agencies to participate in the quest to understand climate. A robotic mission to Venus provides an excellent platform for deploying remote sensing instruments. An international collaboration between space agencies and industrial partners to build and fly scientific instruments for Venus would allow many countries to participate. Contributions from countries would enable them to put their best technologies forward at relatively low cost and risk. The scientific opportunities of a mission to Venus are unique. More than any other planet, data on its atmosphere and geology have direct relevance to the functioning of our home world. The scientific data shared from a joint collaborative mission would enable an understanding of how Venus formed, and how the many processes that drive its climate interact.

At present Venus presents an excellent case for validating (i) the connection between solar variability and climate, (ii) a more general understanding of how climate feedbacks work, and (iii) the role of cosmic rays and clouds (which in turn affect the climate), as compared to Earth, and (iv) understanding the origin and evolution of terrestrial planets. Venus presents these scientific opportunities due to its properties:

- a. No seasons due to near orthogonal spin axis with respect to its orbit and slow spin period
- b. No hydrologic cycle due to absence of liquid/solid water on the surface
- c. No significant albedo changes due to vegetation and clouds as Venus presents a 100% cloud cover globally with only albedo changes in ultraviolet
- d. A powerful carbon dioxide greenhouse climate that is affected by cloud processes, atmospheric circulation, volcanism, and geochemistry at the surface.

The Venus Exploration Analysis Group (VEXAG)¹¹ was chartered by NASA in 2005 and has attracted the participation of the international scientific community. It has discussed science questions and priorities regarding Venus exploration which led NASA to charter the 2009 study of the large Design Reference Mission¹² to Venus to be launched within the decade (2013-2022). More recently, the US National Academies Decadal Survey of Planetary Science recommended the Venus Climate Mission¹³ as a scaled-down version of the Design Reference Mission.

Current NASA priorities make it unlikely that this mission will be realized within the decade without international collaboration. The international interest in missions to Venus is demonstrated by the European Space Agency currently operating *Venus Express* mission and the Japanese Aerospace

¹¹ www.lpi.usra.edu/vexag

¹² <http://vfm.jpl.nasa.gov/>

¹³ <http://www.lpi.usra.edu/vexag/augSept11/presentations/ClimateMission.pdf>

Exploration Agency's (JAXA) *Akatsuki* (Venus Climate Orbiter) which is now attempting to catch up with Venus in 2015 for orbit insertion to begin observations, and the RSA Venera-D projected to launch in approximately 2023. The Indian Space Research Organization (ISRO) has also shown a nascent interest in a mission to Venus. A coordinated international effort to explore Venus with IAA's support can be extremely productive. A first step should be to establish a standard protocol for relay communications between spacecraft from different nations.

4. The International Venus Exploration Working Group (IVEWG) was formed during the COSPAR 2012 Assembly as a grass roots effort of scientists interested in exploring Venus to answer the major science questions through internationally coordinated missions. IAA endorsement and support of this group by encouraging formal agency participation will facilitate the coordination of the efforts by the international space agencies. This science theme would benefit from a multilateral cooperative dialogue between space Agencies to maximize the science result and impact of society.

5. Investigate the establishment of small interdisciplinary working groups with 10-15 investigators. A relevant model is the Swiss International Space Science Institute (ISSI). This ISSI program mainly funds travel to meetings for team members with individual science funded through existing programs.

6. Create an Interplanetary Climate Model Inter-comparison Program (ICMIP) for comparing model results and for helping create a modular infrastructure for modeling planetary climates with a unified interface.

7. Engagement of non-space faring nations: There is a role for non-spacefaring nations in the long-term, continuous, observations/measurements of solar system terrestrial planets. CCTP can move forward with space agencies' continuing support for any institution interested in this research to participate via observations of solar system planets using orbiting telescopes, in situ measurements for confirmation of remote sensing data, high altitude balloons, sounding rockets, CubeSats or small satellites, the use of existing planetary data sets, and ground based observatories. Comprehensive space mission databases such as NASA's Planetary Data System and ESA's Planetary Science Archive are the primary tools for doing space research in the U.S. and Europe. Protocols to engage non-space faring nations in the analysis and interpretation of space mission data need to be developed and require little more than high-speed data infrastructure. Simple workshops led by scientists who use these databases should be held in participating countries to facilitate CCTP research worldwide.

8. Inspire the next generation of scientist explorers from all countries by finding innovative educational opportunities. Exploit unique opportunities in comparative climatology to interest and excite the public and students from a different perspective. Examples are

(i) [FameLab](http://www.famelab.org/)¹⁴, an international program of competitions designed to inspire and motivate young scientists and engineers to actively engage the public and share their enthusiasm for science.

(ii) Earth & Planetary science summer school programs from all interested nations. An excellent example is the Jet Propulsion Laboratory's [Planetary Science Summer School](https://pscischool.jpl.nasa.gov/)¹⁵, which is in its 25th year.

(iii) Engage citizen-scientists in data processing and analysis. One example is a group at the Denver Museum of Nature & Science that is analyzing hundreds of thousands of images of Venus, calculating wind velocities and reporting their results¹⁶ (Fig. 1). [The group's Wiki page](#)¹⁷ is used to organize activity and data processing and storage.

¹⁴ <http://www.famelab.org/>

¹⁵ <https://pscischool.jpl.nasa.gov/>

¹⁶ Bullock, M. A., et al. *Astronomical Society of the Pacific, Boulder, Colorado, 2010.*

(iv) Crowd-sources data analysis. Citizen scientists have been called upon to help classify galaxies in the highly successful [Galaxy Zoo](http://www.galaxyzoo.org/)¹⁸ program.

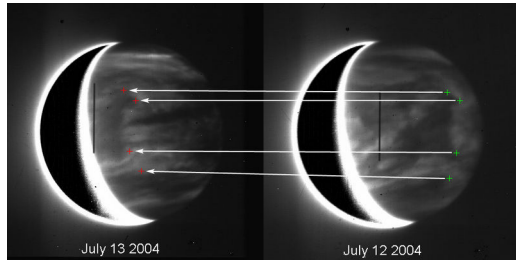


Figure 1. Citizen-scientists at the Denver Museum of Nature & Science analyze infrared images of Venus from NASA's Infrared Telescope Facility. The large data base of images is used to calculate wind velocities at the Venus cloud base.

9. The lowest-cost access to space is with the successful CubeSat program. Participant countries can conceive of, design, and build small sensor payloads. Launch costs are mitigated by 'piggy-backing' on larger payloads. CubeSat is a standardized spacecraft, 10 cm per side that can accommodate a 1.33 kg miniaturized payload. To date, most cubesat projects have originated at US and European universities. Figure 2 shows the Norwegian CubeSat, NCube. CubeSats are an ideal entry to space for countries that do not yet have space programs, but wish to engage in scientific climate research.

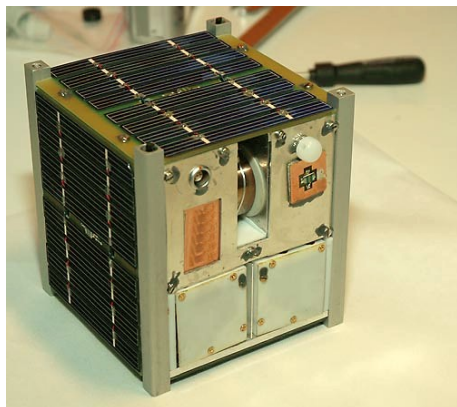


Figure 2. The Norwegian CubeSat, NCube

10. For an international consortium interested in collaborative comparative climatology research, the concept of CubeSat could be extended to a 'Planet Cubesat'. That is, an international project to build a low-cost planetary mission with off-the-shelf parts and state of the art sensors and fly it to Venus.

11. Publish a report of findings and key cross-cutting science questions in comparative climatology as part of the IAA Study on this subject.

Conclusion

Currently there is no paradigm that describes the origin and early evolution of terrestrial planets. Very large gaps in understanding the relative roles of impacts, cometary delivery, the solar nebula, and the intense radiation from the early Sun remain. Similarly, there is an incomplete understanding of how the Earth's climate will behave when greenhouse gases increase many times their current abundance, or increase on very short time scales relative to the historical record. At some point, models diverge because of small differences in the way responses and feedbacks are calculated, and it isn't possible to connect the dots from the Earth we know today and Venus in its present state. A coordinated international study of the Venus climate will provide an empirical test case needed to advance our understanding of Earth's climate and climates of terrestrial planets in general.

The Comparative Climatology Case study will bring together a broad spectrum of international researchers focused on comparing the climates of Earth, Venus, Mars and Titan. Venus has been chosen for special attention because of its proximity to the Earth, unique properties including a powerful greenhouse effect and rich opportunities for novel investigations. Venus is particularly attractive from

¹⁷ http://wiki.boulder.swri.edu/mediawiki/index.php/Venus_Winds_Wiki

¹⁸ <http://www.galaxyzoo.org/>

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the standpoint of engaging new players in planetary exploration and particularly the involvement of the non-space faring nations in acquisition of real planetary data.