Workshop: Design and Scientific Merit of the Variable Atmosphere Laboratory (VAL)

Center for Social Dynamics and Complexity (CSDC)
Arizona State University
Feb 23-24, 2008

I. Statement of objectives: This is a request for funds to discuss the scientific rationale for and design of a national facility to study the effects of atmospheric composition and climate on biological and earth processes (VAL, Variable Atmosphere Laboratory), tentatively to be located on the Arizona State University Polytechnic campus. We are proposing the creation of a large scale Variable Atmosphere Laboratory with multiple units (approximately 50 terrestrial and 20 aquatic "mini-worlds") in which atmospheric composition, temperature, humidity, UV radiation, atmospheric pressure and light cycle can be controlled. VAL would serve a wide variety of research fields, including geology, paleontology, ecology, plant physiology, animal physiology, astrobiology and environmental toxicology. Creation of VAL would provide the U.S. with the premier facility for experimental analysis of the effects of past and future climate change, and would be a critical step in rational planning for a sustainable earth.

II. Statement of need for workshop: The purpose of the workshop is to gather diverse, expert opinion on the design and construction of VAL, with a special emphasis on the identification of: 1) the most important scientific problems that cannot currently be addressed in a cost-effective manner without VAL, and 2) key design features necessary for the success of VAL. We have solicited substantial advice from outside experts for the current VAL Executive Summary. However, because of the breadth of fields encompassed by VAL, we strongly feel that the design and scientific rationale for VAL would be substantially improved by bringing experts from these diverse fields together. The workshop will be held at the Center for Social Dynamics and Complexity at Arizona State University.

III. Product: The product of the workshop will be a white paper, which we will submit to a general US science journal, and which will serve as the basis for proposals to fund construction of VAL. We expect that construction of VAL will eventually require significant support from multiple agencies; we are currently targeting: DOE, NASA, NIH, NOAA, EPA and NSF.

IV. Prior meetings on this topic: None

V. Workshop Organization

A. Workshop schedule
Feb. 23-24th, 2008

Day 1: Scientific Questions for VAL

8:00-9:00 AM: Group buffet breakfast (at CSDC)
9:00-10:00 AM: Introductions, sharing of expertise
10:00-noon: Review of Current Executive Summary for VAL
Noon-1:30: Group Buffet Lunch (at CSDC)
1:30-3:30 PM: Breakout groups to discuss scientific experiments for VAL
    Groups: Geology/Paleontology; Development/Physiology; Community Ecology; Astrobiology; Environmental Toxicology
3:30-5:00 PM: Large Group Discussion of VAL experiments
5:00-7:00 PM: Group Dinner at University Club

Day 2: Design of VAL
8:00-9:00 AM: Group buffet breakfast (at CSDC)
9:00-10:30 AM: What environmental variables should be regulated by VAL?
10:30-noon: How many and what size miniworlds?
Noon-1:30 PM: Group buffet lunch (at CSDC)
1:30-3:00 PM: What support facilities and personnel are required by VAL?
3:00-5:00 PM: Funding strategies for VAL: Next steps and plans for various levels of funding
5:00-6:00 PM Wrap Up
6:00-8:00 Dinner for Remaining Participants

Note: We have not confirmed these dates with all participants, and we will work to find the best date to ensure maximum participation after receiving notice about NSF funding.

B. Workshop participants

1. Organizers:
Dr. Jon Harrison, Professor, School of Life Sciences, Arizona State University
Dr. John VandenBrooks, Postdoctoral Fellow, School of Life Sciences, Arizona State University

2. Participants (most have been contacted by email and agreed to attend):
Arizona State University:
Dr. Ariel Anbar, Associate Professor, School of Earth and Space Exploration
Dr. Paul Davies, Professor, The Beyond Center
Dr. James Elser, Professor, School of Life Sciences
Dr. Jonathan Fink, Director, Global Institute for Sustainability
Dr. Nancy Grimm, Professor, School of Life Sciences
Dr. Paul Knauth, Professor, School of Earth and Space Exploration

External:
Dr. David Beerling, Professor of Paleoclimatology, University of Sheffield, UK
Dr. Robert Berner, Professor of Geology and Geophysics, Yale University
Dr. Jeffrey Graham, Research Physiologist, Scripps Institution of Oceanography
Dr. Ray Huey, Professor of Evolutionary Physiology, University of Washington
Dr. James Lee, Associate Professor of Biochemistry and Molecular Biology, Mayo Clinic, Phoenix, AZ
Dr. Pam Matson, Dean, School of Earth Sciences, Stanford University
Dr. Ian Miller, Assistant Curator/Postdoctoral Fellow, Denver Museum of Nature and Science
Dr. Russell Monson, Professor of Biology, University of Colorado
Dr. Günter Oberdörster, Professor of Environmental Medicine, University of Rochester
Dr. Jacques Roy, CNRS (Ecotron), France
Dr. Christine Wiedinmyer, National Center for Atmospheric Research
Dr. Peter Ward, Professor of Earth and Space Sciences/Biology, University of Washington

C. Workshop Location and Hosting

The workshop will be hosted by the Center for Social Dynamics and Complexity (CSDC) at Arizona State University (ASU), located on the fourth floor of the ISTB1 building. Lyn Mowafy, CSDC coordinator, will help with logistics of the workshop including travel arrangements and food. The CSDC has a 350 nsf of meeting room, with table and chair space for up to 40, Proxima projector and screen, wireless internet, and several smaller meeting spaces. Breakfasts and lunches will be catered and provided as a buffet. The buffet breakfast is a great way to get people there on time and get people talking. The working buffet lunch keeps people together and makes for an efficient use of time. Thursday night we will walk to the ASU University Club for dinner.

D. Workshop Product/Public Dissemination

The goal of the workshop is to produce a white paper that will stand as a “call for funding” for a national facility for experimental studies of the effects of atmospheric composition on biological and geological processes. The starting place for this white paper is the Executive Summary that follows. This was generated primarily by the organizers, with substantial feedback from many of the listed participants. Breakout groups at workshop will be charged with generating lists of specific experiments that can be addressed by VAL, and identifying the desired ranges of control for specific environmental parameters. The white paper will be submitted to a general science journal, such as Bioscience. We will create a website for VAL, posting the results of the workshop, and allowing a forum to collect comments from people around the world.

VI. Statement of Need and Initial Design Plan for a Variable Atmosphere Laboratory (VAL)

A. Scientific Justification

Our understanding of the effects of climate change on the earth’s biotas and human health is crucial to our efforts to maintain a sustainable planet. The changing composition of the earth’s atmosphere is a major control on both biology and earth processes (Adger et al. 2007). Rising CO_2 levels, increased UV radiation, elevation in trace pollutants, and changing global temperatures have profound effects on the earth’s plants, animals, microbes and inorganic materials, including earlier timing of spring events, poleward shifts in organismal range limits, and increases in abundances of high-latitude/altitude organisms (Adger et al. 2007). Currently, research on such effects is limited to small and short-term laboratory or difficult-to-control and replicate field experiments. We propose the creation of a large scale Variable Atmosphere Laboratory (VAL) with multiple units (approximately 50 terrestrial and 20 aquatic “mini-worlds”) in which atmospheric composition, temperature, humidity, UV radiation, atmospheric pressure and light cycle can be controlled. Creation of VAL would provide the U.S.A. with the premier facility for experimental analysis of the effects of past, current, and future climate change, and would provide critical information for policy makers.

Major research facilities are expensive, and can only be justified if they will strongly advance multiple fields of science, and be adaptable for testing hypotheses that have yet to be conceived. One of the biggest advantages of VAL will be its flexibility. The “miniworlds” will be generic “plug and play” units that can be adapted to any set of environmental conditions of interest to the investigator. The standard “miniworld” (either terrestrial or aquatic) will be able to control oxygen, CO_2, nitrogen, temperature, humidity, light, and UV radiation. Additionally, gas distribution systems will allow investigator-specific investigation of a wide range of minor gases, such as common trace gas pollutants (e.g. ozone, sulfur gases, methane, and nitroxes). This generic design will allow VAL to address fundamental questions in biology, geology, paleontology, astrobiology and environmental medicine.

1. Impact of Climate Change on Modern Organismal Physiology and Communities

How will the well-documented on-going changes in CO_2, temperature and atmospheric pollutants affect our world? The most obvious scientific application for VAL is the study of the impact of global climate change on multiple biological levels. The interactive stresses of temperature change, water stress, and trace pollutants on organisms are hypothesized to be potentially critical to the magnitude of the effect (Adger et al. 2007) but we lack the facilities to experimentally evaluate such interactions with experiments able to be replicated. With VAL, developmental and comparative physiological studies can be carried out on organisms ranging from microbes to plants to animals. While individual investigator experiments have allowed study of such processes for small organisms, it is currently very difficult and expensive to conduct such research on larger species or with multiple interacting factors as occurs in nature.

Acclimation and adaptation responses of organisms are likely to be very important in the resilience of ecosystems to climate change (Angilletta et al. 2007; Bradshaw and Holzapfel 2006); however, our facilities to examine such responses are limited. Evolutionary biologists will be able to conduct multi-generational studies with short-generation species (e.g. microbes, algae, *Daphnia*, fruit flies, mice, lizards, and amphibians) to experimentally address how atmospheric changes may cause evolutionary changes in the earth's biota. Community ecologists will be able to conduct repeatable studies of the effect of interactive environmental variables on small-scale communities such as soil ecosystems, pond, and grassland communities. Additionally, VAL will offer an ideal facility for the study of carbon cycling and sequestration and the impacts of a changing environment on these processes.

2. Paleontological and Geological Sciences

Interpretation of the future requires understanding of the past. Many links between climate change and evolution have been suggested almost since the inception of evolutionary theory. For example, atmospheric oxygen variation has been suggested as a cause for multiple evolutionary events, including historical insect and vertebrate gigantism, extinctions, and the fixation of evolutionary novelties (for a review, see Berner et al., 2007). Historical changes in temperature and carbon dioxide levels have long been used to explain evolutionary patterns such as extinctions (i.e. Knoll et al., 2007), body size changes (Hunt and Roy, 2006), and ecological reorganization, including the recent ice age cycles. More recently, changing ozone layer levels have been linked to increased mutation rates in the early Triassic (Beerling, et al. 2007). However, experimental evaluation of these hypotheses has been difficult. VAL will provide an excellent method of testing the single-and multiple-generation effects of such environmental and atmospheric variation on organisms, and will allow our scientific investigations of these critical questions to move from correlational to experimental. For instance, one could recreate a set of climatic and atmospheric conditions from a given time (i.e. Carboniferous or Campanian) and examine the impact on modern physiology and development. This is a critical step in understanding the possible impacts that modern climate change will have on our continually changing planet.

In addition to evolutionary studies, physical and chemical geological processes have been historically difficult to study on the bench top and in vials. The effects of the climate and atmosphere on weathering, our understanding of changing global atmospheric and rock cycles, and the interaction of geologic processes and the environment are all questions that are of specific interest to our understanding of how geological processes have changed through time. VAL will be able to recreate hypothesized early earth atmospheres – high temperature, low oxygen, high carbon dioxide – and geologists can use these conditions to understand how earth processes evolved during the early periods in the earth's evolution. Climate changes occurring today will also impact geological processes, with important feedbacks on world climate and environment. VAL will offer geologists and soil scientists an experimental platform to run larger, long-term studies of these important and complex processes, which is not currently possible.

3. Astrobiology and the Beginning of Life

VAL will provide an experimental facility ideally suited to astrobiologists trying to answer questions about what conditions allow for the evolution of life both on earth and extraterrestrially. The three major questions of interest to astrobiology as put forth by Fridlund (2000) are: 1) Are we alone in the Universe? 2) How unique is the Earth as a planet? 3) How unique is life in the Universe? In answer to these questions, at a recent meeting of the American Astronomical Society, it was reported that 236 planets from other solar systems or "exoplanets" have been identified. Recent technological developments have allowed scientists to calculate the atmospheric composition of these planets through the use of a variety of spectrometers (Coustenis et al., 2006; Grenfell et al., 2007). While we can begin to measure these atmospheres, the question still remains whether they are suitable to the evolution and sustainability of life (Grenfell et al., 2007). VAL will allow for the creation of these extraterrestrial atmospheres and conditions for studies on their impacts on a variety of organisms from bacteria to plants to animals. By utilizing VAL, scientists will be able to move closer to answering these three major questions.

VAL will also be able to simulate conditions of the early earth to allow for the study of their impact on the initial evolution of life on earth. The question of under what conditions and how did life originally evolve are central to the study of the early earth. Also, as the atmosphere evolved through the Archean and up to the explosion of life in the Cambrian, it would have had wide ranging effects on early life processes (Canfield, 2006). By being able to create a variety of hypothesized early earth conditions, we will be able to gain insights into the initial and continued evolution of life and what role the environment played in this process

Additionally, VAL provides a medium for the study of long-term effects of living under controlled atmospheres which could be useful for furthering space exploration and analysis on building infrastructure on other planets, on the moon, or in orbit around the earth.

4. Pathogenesis of Environmentally-induced Lung Disease

The incidences of respiratory diseases such as asthma and COPD are at epidemic levels among the peoples of industrialized countries (see for example Cookson and Moffatt, 1997). Hypotheses for this proliferation have focused on exacerbating factors, such as air pollution, early exposure to "trigger" antigens (e.g., dust mites, cockroaches), tobacco/chemical exposure, and increases in the amount of time spent inside versus outside (McBride 1988; Platt-Mills et al. 1998). Moreover, high-density urban environments have been identified as predisposing factors contributing to the rise and prevalence of respiratory disease (Wang and Forsyth 1998). Despite intense study of patient populations, the unique circumstances that dictate why one person's responses lead to lung pathology when others do not are still obscure. What is clearly obvious, however, are the growing costs associated with the care and treatment of respiratory patients.

The statistics associated with asthma and COPD are particularly insightful (http://www.aaaai.org/media/resources/media_kit/asthma_statistics.stm American Academy of Allergy, Asthma and Immunology): 1) Since 1980, the prevalence of asthma in the U.S. has increased >50% overall and >80% among those under 18, 2) COPD represents the 4th leading cause of deaths in the United States, 3) Asthma is now the most common serious chronic disease of childhood, affecting nearly 1 child in 20, 4) Increases in the incidence of both COPD and asthma, as well as respiratory disease related deaths, are growing even faster among ethnic minorities; for example, while the death rates from respiratory diseases among Caucasians has doubled since 1980, African-Americans are four to six times more likely to die from respiratory diseases than Caucasians, 5) Asthma alone is the cause of between 3-6 million physician visits per year and accounts for 1 in 6 non-accident related emergency room visits, and 6) Estimates (in dollars) of the treatment and care of patients with respiratory diseases, including direct (e.g., medications, emergency room use, hospitalization, and death) and indirect (e.g., loss of days at work and school) expenditures, now exceeds tens of billions of dollars annually.

These statistics highlight the enormity of the problems associated with this lung disease. Furthermore, they underscore a need for continued research efforts to understand the fundamental causes of this disease, including the potential role(s) played by airborne environmental toxins (e.g., ozone and nitrogen/sulfur oxides) and particulate matter (e.g., diesel exhaust particles) as contributors to lung disease (Bernstein 2004).

Current studies of pollutant effects on animal models of lung disease are mostly limited to examination of single pollutants over short time periods, while in reality humans are exposed to multiple pollutants over long periods during which pollutants often peak regularly at certain times of day. Developmental studies of the effects of air pollutants with animal model systems will allow determination of the pathological mechanisms involved, interactions between various gases, and the genetic diversity responsible for variation in responses. VAL will provide an important facility for investigating the effects of variable levels of trace pollutants on the major animal models (e.g. mice, rats) that provide the bases for understanding human pathological responses,

5. Comparison to Other Approaches to Understand Effects of Environmental Change

VAL will complement and extend existing facilities and programs for studying the effect of atmospheric composition and global change on organisms and communities. The recently initiated NEON, Inc. program funded by NSF provides a mechanism to monitor changes in ecosystem and community function across the U.S.A., and allows comparisons across communities and regions. Field-based manipulative studies such as FACE sites (free-air CO_2 enrichment) and the Jasper Ridge Global change experiment (which allows heating as well as manipulation of watering levels and fertilizers) allow examination of atmospheric effects on intact communities. However, producing many types of controlled manipulations of such intact communities will be prohibitively expensive (e.g. significant changes in oxygen or cooling, testing interactions of various trace gases), and such field experiments are not practical for most animals. VAL would also complement current single-PI studies in environmental rooms and greenhouses that have been used for many small-scale studies of plants in pots, microbes and insects. While these studies have been, and will continue to be useful, the costs of the infrastructure to produce controllable environmental variation on a scale suitable for small communities and most vertebrates are beyond those of most single investigators. VAL would thus provide an economical solution to these issues, and a shared resource for investigators in many fields for studying the effects of climate change on organisms on an intermediate scale. The design will allow for modification of the interiors for the specifications that an individual research project requires, while providing the expensive shared infrastructure to regulate major atmospheric conditions. This facility would encourage multi-disciplinary research and the collaboration between scientists in a diverse array of fields, which is essential for a developing a complete picture of the impacts of environmental change.

The need for such centralized, reproducible systems for studying effects of climate change is increasingly being recognized at the international level. In France, the CNRS and the Languedoc-Roussillon region are funding a facility (scheduled to open in 2007) they call the Ecotron that will contain 12 macrocosms similar in size to those proposed here (http://www.ecotron.cnrs.fr/html/en/contexte/contextescient.htm). In addition, the Ecotron facility will have 12 one m^3 microcosms. VAL will allow regulation of more parameters (light intensity, oxygen, and trace gases) and more replication, and thus would be able to serve more researchers and address a wider array of questions than the Ecotron. Within the U.S.A., the most famous facility for producing a controlled environment for ecological communities is

Biosphere 2, which is in continued use for ecological research (http://www.b2science.com/). However, as Biosphere 2 remains an “n of 1” facility, it will not serve the needs of experimental science.

B. Proposed Design

VAL will provide a laboratory facility for researchers from the U.S. and around the world to conduct research critical to understanding our planet’s past and future. VAL will consist of multiple units (henceforth, miniworlds) capable of rearing plants, animals, and small communities under controlled environmental and atmospheric conditions. Ideally, each miniworld would be capable of controlling seven major environmental variables: oxygen, nitrogen, carbon dioxide, temperature, humidity, total solar irradiance, and ultraviolet irradiance. In addition, a subset of chambers will have the capacity to regulate total barometric pressure, and each chamber will have the capability to add regulation of other specific gases of interest (e.g. ozone, methane, ammonia). Most investigators will utilize VAL by coming to VAL with their organisms, setting up multiple miniworlds as needed for their experiments, and returning at intervals to collect data on their organisms. Therefore, VAL will also require general laboratory and office space; a design similar to a well-equipped field station or a major national laboratory. Investigator on-site housing may also be required, depending on the final location. Additionally, we are proposing to install a live camera system that can be viewed over the internet so that in addition to the onsite care, researchers will be able to observe their experiments from off location.

1. Miniworld Design: Each miniworld will be a relatively air-tight environmental room, with its own environmental control system. The majority of miniworlds will be identical and the size of a small room (approximately 75 m^3); a smaller fraction will be larger (approximately 150 m^3) for larger organisms and community studies. Inner walls will be coated with fiberglass to allow ease of cleaning/disinfection. Entrance will be through an ante-room (approximately 8 m^3) equipped with two near-air tight doors and a system for flushing the anteroom to the conditions of the miniworld. For many atmospheres, it will be necessary to investigators to utilize a SCUBA-type breathing apparatus, which will be provided by VAL. Water (fresh and saltwater) will be available within each miniworld on tap. VAL will maintain a large supply of tables, aquaria, pots, cages, and other equipment for growth of plants and animals in a space-efficient manner. In addition, twenty 250 L aquatic miniworlds will be available with recirculating water systems for examination of atmospheric conditions on small aquatic communities. The interiors will be built with maximum flexibility in mind, allowing for a variety of setup conditions including soil makeup and depth, sub-areas within the larger framework, and any other conditions an individual investigator might require. The following variables will be controllable in all miniworlds ([x-x N] indicates the range possible relative to current normal sea level conditions):

Oxygen: 5-95 kPa [0.2-5 N]
Nitrogen: 5-95 kPa [0.05 – 1.2 N]
CO_2: 0-2 kPa [0 – 5000 N]
Temperature: 5-45°C (subset of units to be designed to reach extreme high and low temps)
Humidity: 0-95%
Light: 0 to 1500 watts m^{-2} (solar simulators [0 – 1 N], timed to control photoperiod)
Ultraviolet radiation: 0-5 watts m^{-2} [0 – 5 N] (solar spectrum mimic)
Trace Gas Control: 0-2 kPa

2. Gas delivery systems: VAL is made possible by an on-site gaseous oxygen, nitrogen and carbon dioxide production facilities. The economies of scale for industrial gas production greatly reduces the cost of having similar smaller units built by investigators at their own institutions, and is the primary reason for creation of a national facility. Air is liquefied by cooling and oxygen, nitrogen and carbon dioxide are separated by fractionation due to their different boiling points, with microfilters used for purification. Gases are stored in bulk as liquids, with the user drawing from the gas space. Many companies (e.g. Air Liquide, Universal Industrial Gases, BOC Edwards) produce industrial facilities with outputs in the range of that required for this facility for use in a variety of industries (e.g. food, semiconductors). Our current estimates are that VAL would require 4 tons of oxygen/day, 10 tons nitrogen/day and 0.04 tons of carbon dioxide/day. A major advantage of this method of gas generation is that it pulls the gases from the atmosphere and then releases them back to the atmosphere, so there is no net change in the external atmospheric composition (i.e. it does not release newly created carbon dioxide to the atmosphere). Each miniworld will also have a setup for the delivery of trace gases to the unit, but each trace gas will have to be supplied for the duration of a given experiment and will not be generated on site.

3. Estimating the number of units needed: The number and term of miniworld use is likely to vary greatly, and directors will need to gauge the trade-offs between use by more teams vs. use of more miniworlds to generate for powerful experimental designs. Some investigators will utilize a relatively large number of miniworlds (5-12) to investigate dosage effects or interactions of two variables over relatively short periods (months), while other investigators utilize fewer miniworlds for longer-term evolutionary or community change studies (up to 4-5 years). For ball-park estimates, we will assume that the average investigative team would use 5 miniworlds for six months. We are proposing a VAL with 50 75 m^3 terrestrial miniworlds, ten 150 m^3 terrestrial miniworlds, and 20 aquatic miniworlds, which by this ball park estimate could support research by about 25 investigative teams per year. Because of the cost of this facility, priority will go to proposals that utilize investigative teams to conduct multi-level (molecular to population) studies of environmental effects, but it will be important to allow smaller (e.g. graduate student) projects. All efforts to include encourage a diverse group of participants in the facility will be made.

Total miniworld space: 11250 nsf small miniworlds + 4500 nsf large miniworlds+2000 nsf for 20 aquatic miniworlds = 17,750 nsf

4. Estimating lab and office space needed: Use of VAL will vary widely among experiments, with some teams staying for an entire experiment, collecting data on a daily basis, with other teams coming for 1-2 weeks to set up an experiment and returning at yearly intervals. For a ball-park estimate, we estimate that an investigative team will be at VAL for 2 months per six month experiment; if 20 teams use VAL per year, lab and office space will be required for about 8 overlapping teams. Therefore, we suggest that VAL will require about 10,000 nsf of lab space adjacent to the miniworlds. This should be a general lab space, with some standard equipment provided (balances, mass spectrometry, gas chromatography, etc.); and benches available for unique equipment brought by the investigators. The goal is to have most equipment necessary on site.

In addition, the VAL director will have a 2000 nsf lab space, and construction of VAL should include setup costs of a lab for the director. Common office rooms should provide computers for use of about 20 (500 nsf: office cubes). Offices will be needed for the VAL director and postdocs (300 nsf total). There should also be a conference room (300 nsf), a storage room for equipment (300 nsf), and a supply/maintenance room (100 nsf).

Total support lab space: 1200 nsf
Total office/support space: 1500 nsf

5. Personnel: VAL will require a minimum of: an on-site director, an administrative assistant, a mechanic/custodian, and three animal/plant care technicians to monitor the growth chambers when investigators are gone. Additionally, three postdoctoral fellows would live on-site, and conduct experiments with the director and in collaboration with the investigating teams.

6. Location: We are proposing that VAL be located at the ASU Polytechnic campus. VAL fits well with the applied science focus of ASU Polytechnic. The available space and excellent guest housing for visitors to the site are a major plus.

7. Funding Plan: VAL is not designed to address any current call for proposals, but instead represents a “ground-up” concept. Funding of VAL will require that we generate excitement among our colleagues and funding agencies. We hope that construction of VAL will be funded by a combination of NSF, DOE, EPA, NASA, NOAA, and perhaps private donors. Ideally, operating costs of the facility (maintenance, gas generation, personnel) would be defrayed by ongoing support from these entities. Investigators would be required to fund their travel and housing costs, costs of their experimental organisms and any food required, and all extra scientific equipment and supplies needed. We anticipate that funding of VAL will occur in the following sequence: 1) this workshop to develop broad scientific rationale for VAL and to generate three scenarios for VAL depending on level of funding, 2) the solicitation of funding for architectural/engineering plans, and 3) the request of funding for the construction of the facility and operating budget.

C. Educational Outreach

Educational outreach will be an important component of VAL. School groups will be able to tour the facility, and web cams and web-based data systems will allow school groups to observe and participate in on-going experiments. Educating students and the general public on the impacts of global change will be a central theme of VAL. We propose to collaborate with several museums to design the first ever scientific exhibit on global climate change to be presented to the public (Denver Museum of Natural History, Arizona Science Center). There is a great deal of incorrect/untested information that has been presented as fact about global climate change, and more specifically on its impacts on biology and the environment. This facility offers the perfect opportunity to educate the public on the reality of the impacts of global climate change through lecture series, high school student involvement, and a strong volunteer program.