ENVISIONING VIRGINIA TECH

**BEYOND** BOUNDARIES

# Opportunity for a New Destination Area

# Global Systems Science

**White Paper Proposal**
**October 1, 2016**

Virginia Tech
*Invent the Future*

The GSS DA seeks to tackle emergent challenges to Earth Systems and achieve dynamic sustainability through a systems science, problem-oriented approach.

## Problem solving in an era of change: Achieving dynamic sustainability

We live in a time of rapid, human-driven change, the Anthropocene, in which humanity's impact on Earth systems is unparalleled (Figure 1). Growing population stress combined with progressive degradation of environmental systems and declining resource abundance are now rapidly changing the earth. The consequent threats to human, societal, and system resilience are not well understood and there is an urgent need to characterize and deconvolve the complexities and cross-scale interactions of these systems. There is ample evidence that some factors will have highly **nonlinear** responses to these increasing pressures, complicating our ability to predict future earth states. Thus, achieving **dynamic sustainability** will require an understanding of these interdependent factors, thresholds, and feedbacks. Given the importance of establishing this knowledge, it is remarkable that the threshold for rapid changes, or **tipping points,** is not yet well established for any large system.

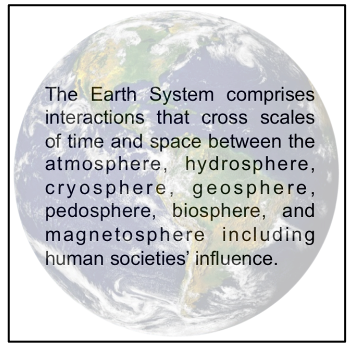


Figure 1. Definition of Earth Systems

An example of the evolving nature of pressures on global systems is seen in **Figure 2**. By plotting time (years) using a logarithmic scale alongside simplistic illustrations of the corresponding environments, one sees the accelerating rate of change that is occurring across **coupled biogeophysical and sociocultural systems**. These interacting dynamics will continue to evolve as **demands on resources grow and global systems change.** Until recently, most human impacts were on terrestrial systems, but increasing populations along coastlines worldwide, as well as construction and extractive technologies, are now rapidly changing marine environments. Coupled with progressive increases in temperature (colored bar) and changes in atmospheric composition and particle loading, every facet of the global system is in a **state of transition**.


Figure 2. Progressive degradation of terrestrial and marine systems is accelerating globally (image from McCauley et al., 2015, *Science*).

**Perturbations** to a physical or biological parameter in one system will **propagate** into other systems. The consequent dynamic, and often nonlinear, responses create challenges to deciphering and forecasting earth system functions. These complexities highlight the fundamental difficulty in achieving **sustainable solutions**. With earth systems in transition, any point where sustainability might be realized through interventive action must be expected to shift to some new unknown. This requires we create adaptive dynamic approaches to **sustainability**, an area of innovation well suited to systems science approaches.

The sheer complexity of global challenges at the nexus of natural and human environments warrants a critical reorientation of traditional problem-solving methods (Figure 3).

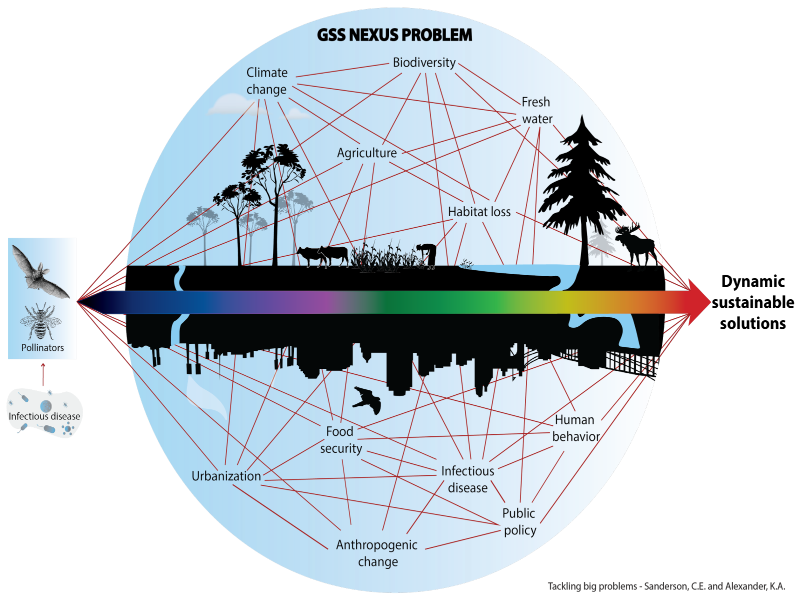


Figure 3. The GSS DA is designed to address nexus problems that occur across disciplines. A good example is the consequence of emerging infectious diseases affecting pollinator species. The cascading and coupled nature of interactions that occur across complex and divergent landscapes defy traditionally siloed problem-solving approaches. A systems science approach engages scale and discipline in novel ways.

We need new approaches and technologies to detect, characterize, and monitor **interdependent, cascading phenomena** that drive the emergence of critical threats to earth systems. A process-based understanding of these phenomena will provide the basis for designing **interventions** that are responsive and adaptive, realizing that solutions to emergent problems must be owned by the communities that they threaten.

The **Global Systems Science Destination Area (GSS DA)** is a transformative approach to problem solving (Figure 4) that harnesses the unique strengths of Virginia Tech together with its institutional culture and mandate for service.

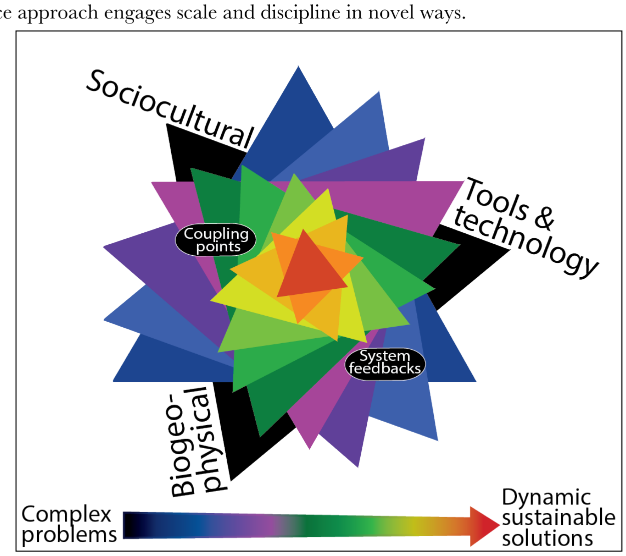


Figure 4. The Global Systems Science Destination Area is a problem-oriented approach that integrates the sociocultural, biophysical and technological frames reiteratively across the life course of complex problems.

## Virginia Tech Differentiators

Complex global challenges demand fully integrative approaches. As a land grant institution, Virginia Tech reaches beyond traditional disciplinary boundaries and **invents dynamic solutions for tomorrow's problems**. As a **comprehensive university**, Virginia Tech's programs in social sciences, humanities, and fine and performing arts provide a robust intellectual context for collaboration with innovative engineering and natural science-based approaches.

Successful **international and national Virginia Tech programs** bridge managed ecosystems, animal and plant communities, and the interface of sociocultural and biogeophysical systems. The University brings to bear substantial tools and technology infrastructure in the area of advanced modeling capabilities, high-performance computing, and advanced computing resources that may be used to develop state-of-the art predictive/forecasting models for the global environment. In addition, advanced sensors, both ground-based and space-based, will continue to be a more and more important part of GSS. The Colleges of Engineering, Science, and Natural Resources and Environment have outstanding potential for development of advanced materials, sensor development, and remote sensing techniques as well as advancing our understanding of the natural environment and human dimensions. The Virginia Tech Carilion Health Sciences, the Virginia-Maryland Veterinary School, and the College of Agriculture and Life Sciences foster cutting edge approaches to the management of human and animal health and emerging infectious disease, as well as other stresses at the interface of humans, animals, and the environment. The university also boasts traditional land-grant strengths in managed ecosystems and strong self-organization around extant, interdisciplinary grand challenges via research centers and investment institutes. Finally, as a comprehensive university, Virginia Tech has relatively untapped resources in the humanities, social sciences, and the arts in the Colleges of Liberal Arts and Human Sciences and Architecture and Urban Studies to contribute to creative problem solving.

## Core Methodology

The core methodology of the GSS DA is a problem-based approach that integrates three overarching areas of inquiry (Figure 3). The **biogeophysical** sciences combine knowledge from microbial communities to the highest trophic levels, across continental, oceanic, and atmospheric environments. The biogeophysical component is governed by the basic principles of physics, chemistry, and geoscience. The **sociocultural** realm encompasses not only the social and health sciences but also consideration of human expression and experience through the humanities and the arts. Full integration of sociocultural approaches into global systems science is a paradigm-shifting approach to critical problems. **Technology and tools** are integrated across the problem life course in a manner that is responsive to the demands of individual problems.

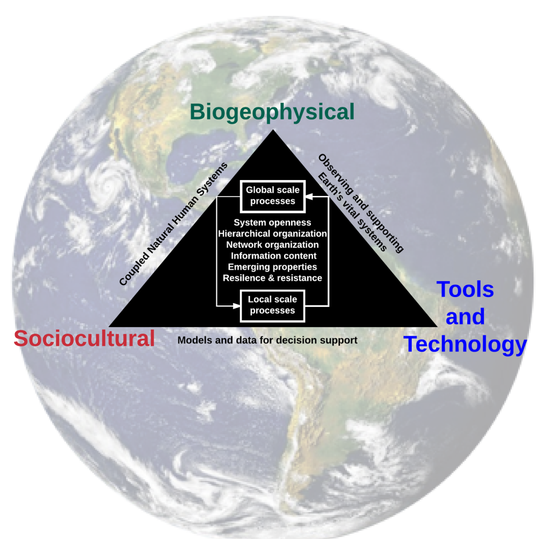


Figure 3. The Global Systems Science Destination Area employs a problem-based, systems science approach that integrates three overarching areas of inquiry.

Critical problems in global systems demand complex, team-based, interdisciplinary approaches. A primary advantage of this approach is that the makeup of interdisciplinary teams follows the specific nature of the problem being addressed. Further, resource impacts can be identified and addressed appropriately. In the case of infectious disease, transmission is a downstream problem that can be characterized and studied as a specific kind of consequence of critical global systems problems. In addition to bringing in new people and the synergies that come with new collaborations, GSS will draw on existing and emerging expertise in these topics. This process will allow the destination area to develop organically and scale up to additional programs to address a transforming problem landscape.

## Critical Global Challenges

Problems facing society today are unlikely to be those of tomorrow's generation. A fundamental element of the GSS DA is the notion that we need to become **future-ready** in problem solving. This DA is focused upon critical problems that cross the nexus of natural and human systems and were identified by a two-step process. The first stage began with extensive documentation of the significant global systems expertise at Virginia Tech. This information was obtained from faculty surveys, notes from GSS visioning exercises, the Beyond Boundaries event at the NCR, Town Hall events, and other reports. This information was mapped onto the key threats global and regional earth systems that were identified by a prominent international group of scientists (for example, Steffen et al. 2015, McCauley et al. 2015). Through this process, **nine critical areas** were identified where Virginia Tech is already positioned with significant expertise and visibility both nationally and internationally (Table 1).

| Critical Problems at the Nexus in Global Systems | Resource(s) Impacted |
|---|---|
| Sea level rise and human pressures on the land-sea interface | Coastal environments (land, animal, plant diversity) |
| Progressive soil degradation, changing soil ecosystems, supply | Soils, agricultural and natural systems |
| Pressures on forest ecosystems and watersheds (surface, aquifer) | Land systems, land use |
| Meeting demands for raw materials: Environmental, social and economic consequences | Minerals, energy, metal and systems, water |
| Abundance and quality of fresh waters | Water— surface and subsurface |
| Defaunation and biosphere integrity<br>*Chordates, Arthropods, Primary producers* | Natural animal and plant diversity |
| Supply and integrity of food | Wild food, crops, and livestock |
| Degradation of ozone and aerosol loading | Atmosphere |
| Transmission of infectious disease with changes in global ecology | Domestic/wild animals, and plants (human impacts) |

Table 1. Critical problems facing the global earth system where Virginia Tech investments will lead to national/international impacts. In practice, these are interlocking issues and collaborations amongst these groups and other DAs bring synergy to the whole.

The synthesis process in Table 1 shows the tremendous scope of expertise that we enjoy at Virginia Tech. To our knowledge, this type of compilation is the first of its kind for the university, particularly as it relates to problems in the Global Systems Science areas. The breadth and sheer number of areas reflect decades of investments across colleges and the resulting national and international accomplishments of VT faculty. Given that this expertise is currently scattered all over campus, with faculty often geographically and informationally isolated, it is little wonder that VT is often referred to as "the best kept secret."

Investments in GSS will provide two tiers of synergy to greatly increase VT visibility and reputation as an international destination in Global Systems Science. On the first tier, hiring faculty who bring currently missing expertise will significantly enhance the ability of research groups to become **nationally and internationally competitive** for big projects. Second, all of the issues in Table 1 are interlocking; as a result, additional collaborations between problem-focused groups with already complete palettes of expertise will bring increased synergy to the endeavor. In short, focused investments in specific areas are the most cost-effective means of sharply increasing VT recognition in Global Systems Science.

**GSS DA will catalyze growth of the University's Funding Base**

Problem areas represented in Table 1 are critical areas of opportunity for **growth of research funding** from both competitive and noncompetitive sources. Most importantly, GSS offers an opportunity to **expand** our current funding base to access underutilized sources of research support. Across the international and national public-policy continuum, there is increasing urgency to solve global resource, climate, and population stress challenges that operate across scales. These same issues resonate with Virginia Tech's strong alumni base. The GSS DA focus opens a programmatic window to access novel sectors of support associated with the **international and national development domains.** The GSS DA is also well suited to engage in **public-private partnerships**, a growing mechanism for nations from lower and middle-income economies to engage technically rich, non-state actors in development planning and implementation. Further, we anticipate that innovations in technology and tools will lead to growth and novel partnerships between **research and industry.**

**Resonance with the Commonwealth of Virginia**

It is noteworthy, that many of the issues in Table 1 are also of great concern to **government leaders in Virginia**. For example, more than 60% of the state population lives in the coastal region of Virginia. This number is predicted to grow to more than 75% by 2025. Recurrent flooding that threatens environmental quality as well as infrastructure security occurs almost weekly, in tandem with ongoing sea level rise. Legislators are beginning to recognize that they must **invest in their best universities** to understand and manage these effects. They also recognize the need for an **educated workforce** with advanced knowledge of coastal environmental science and coastal engineering to continue to monitor and respond to sea level changes.

Legislative urgencies are exacerbated by the increased relevance of large port facilities in the global economy, as well as continued importance of military installations in this region. For example, the harbor at the Port of Virginia is one of only three locations on the US Atlantic Coast that is sufficiently deep to receive the new Panamax container ships from Asia (Kenney, 2016). In addition to bringing a tremendous new wave of economic growth, accommodating these large vessels will further increase water and other environmental pressures on the region. Similar cases can be made for each of the critical areas in Table 1. For each, population and environmental stressors, combined with economic importance across multiple sectors, make global system science issues a **high priority for the Virginia legislature**.

## Systems Thinking Curricula: Undergraduate and Graduate Education

The global practitioner of the future will need to be able to identify, address, and solve complex global challenges. Educating students in well-rounded, interdisciplinary, team-based systems thinking is an integral part of the educational mission of the comprehensive, global, land-grant university of the 21st century. All students at Virginia Tech should be able to take basic courses in **systems thinking**, an approach that embraces complexity, crosses disciplinary boundaries, and encourages nimble and innovative approaches to intractable problems.

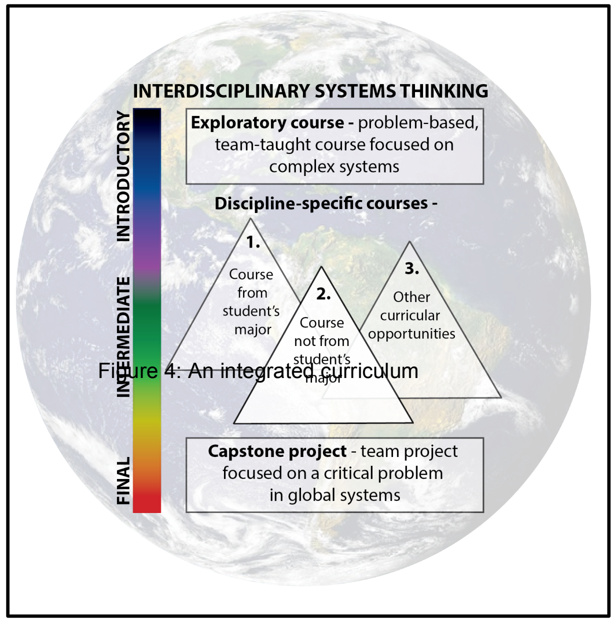

Figure 4: An integrated curriculum

The instructional component of GSS will prepare students to live in an increasingly diverse society by emphasizing relationships between the *ensemble* and the *individual*, *global complexity* and *local context*, and *technological capacity* and *human aspirations*. **Systems Thinking**, as the overriding conceptual framework of the curriculum, will guide students across the university in their experience of *networked information*, *knowledge*, and *practice*.

### Undergraduate Education

The umbrella undergraduate curriculum for the GSS destination area builds on existing, strong curricula in sustainable, food, and water, allowing students from these programs to enhance their experience through courses focused on systems thinking. All students at the university would be able engage the destination area coursework in systems thinking as it relates to their course of study and allows them to address identified global challenges, as the initial proposed curriculum includes four 3-credit-hour courses. Students in majors not usually associated with global systems science will be able to advance their understanding of global challenges and systems-thinking problem solving by engagement with this umbrella curriculum. Complementary curricular opportunities might involve study abroad, service learning, restricted electives, undergraduate research, Pathways courses, and other educational platforms specific to particular majors.

Students will participate directly in this destination area by taking an **introductory**, **interdisciplinary, team-taught and problem-based exploratory** course in **Systems Thinking**, grounded in systems science but taking advantage of significant resources in the liberal and performing arts and social sciences. Complex systems abound in all areas of study—

ensemble music performance, narrative forms, social networks, civil society, microbiome, etc. Incorporating varied disciplinary experiences with complexity and the kind of discipline-specific thinking that emerges from the specificity of those systems, this basic course in Systems Thinking will train students to work in interdisciplinary groups and to approach complex problems through frameworks informed by their experiences with systems theory across disciplines and domains.

**Intermediate-level courses in discipline-specific systems thinking** will deepen students understanding of the frameworks for analysis appropriate to their major course of study, as well as one other area. Students will take two of these courses so that they understand the systems paradigms of their own disciplines as well as those of one other at a significant level of sophistication. A **capstone experience** focused on a critical, grand challenge problem of global significance will bring together students from a variety of majors to work again in team-based, interdisciplinary problem solving.

### Graduate Education

Development of the Global System Science destination area will provide robust academic and real-world experiences for graduate students with respect to the nine identified critical global problems. Students will take advantage of existing synergies as well as developing new ones, including the relevant IGEPs like Remote Sensing, Interfaces of Global Change, Translational Plant Science, and Water INTERface. Interdisciplinary collaboration with graduate programs in humanities, social sciences, and the arts is crucial to realizing the integrative vision of GSS.

## Investments requested to realize the GSS DA

**Faculty:** The GSS DA will require at least **five new faculty lines per problem area with a total of 45 new faculty lines** necessary to realize the aspiration embodied in this DA. It is envisioned that the GSS DA will have at least 100 dedicated faculty (new and existing lines) working in problem solving groups. To move this DA forward we must **invest in unique infrastructure** that will house systems science teams, creating productive problem spaces. This investment of infrastructure and faculty is fundamental to the success of GSS DA where novel faculty clusters and consequent interactions become central to innovation and growth.

**Infrastructure: Preliminary assessment of programming needs for the GSS building**
The **Global Systems Science (GSS) building** at Virginia Tech will be a preeminent systems science research and education facility. Truly a destination, the structure will be the headquarters of a world renowned group focused on solving critical regional and global problems facing the Earth system. **Funds** are requested to immediately begin programming the building. This will be a significant undertaking and should begin ASAP upon receiving the documents from each of the teams from the GSS problem areas that have been identified.

**Faculty offices** are needed for each participating faculty member (approximately 80-100 positions). Each of these will need an accessory office for a postdoc or visitor at ratio of one per two faculty. There are various models for how to arrange faculty offices. If they are organized as suites (which present advantages and disadvantages), a working assumption might be two large graduate student suites per faculty member. Suites could be organized around several central common work space areas that are set up for different types of purposes. For example, some would have large tables, another could be scale-up style, others could be set up as 'situation rooms' with extensive monitor coverage. Full integration of arts, humanities, and social science faculty with scientists should be a goal of office design.

**Administrative and technical staff offices** are needed to enable the building and its people to propel their mission forward. These spaces should be adjacent to common areas with forwardly designed administrative space.

**Conference rooms** for 10-20 people are also needed as well as smaller conference rooms geared towards distance collaboration. Extensive visualization is important for the GSS and needs, including 3d (sphere, cube and or cave would be helpful). Ex. A stand-alone HPC center (such as VBI).

**Bench/wet laboratories** are an extensive part of GSS studies and extensive 'flexible wall' style facilities would provide a high degree of flexibility with changing project/problem needs and ample hoods for chemical handling. Programming would have to determine the distribution of laboratory types.

**Physical (dry) laboratories.** Other types laboratories may be best served for physical studies. For example, microscopic investigations of sediments, soils, cores, tree samples, animal samples, or pollen.

**Staging areas and storage** for field equipment and preparation for expeditions is also necessary. This should have ready access to a loading dock. Storage space for valuable equipment is *always* under-programmed in the typical building and the GSS has the opportunity to get this right in a modern facility.

**Specialized function rooms.** These include multiple cold storage rooms, frozen storage rooms, walk-in environmental chambers with internal access to power and appropriate lighting, sound-proof rooms for interviewing, and multiple rooms appropriate for focus group meetings.

**Common space** is needed to promote group interactions to ensure that traditional silos are nonexistent. In addition to extensive conference areas, this is facilitated by a GSS cafeteria and access to signature hi tech seminar lecture halls for 100+. Perhaps related to the visualization labs would be a GSS-wide data immersion space akin to a mini theater with screens on all walls and 3D capability. Common space for undergraduate research and collaboration would also be beneficial. Hallways should have alcoves with plenty of wipe boards.

**Modern classrooms advancing beyond the scale-up model** will be created for undergraduate and graduate instruction. These will be strategically placed in the building allowing new connections to faculty problem spaces. We will create **integrated GSS learning spaces** to draw from the classroom environment, merging into hands-on activities that follow and engage faculty problem areas. Numbers and sizes will be determined in the programming and design phase. Additionally, Echo360-capable classrooms create global contexts for learning.

**Style.** Such a preeminent building needs a special statement that communicates its world-class objectives. For example, the lobby could be a central feature that crosses through all of the floors (ex. lobby) with a centerpiece emblematic of system science. This would communicate the nature of the tasks ahead to the outside world while also fostering connections and cross-pollination between the nine problem teams on a daily basis. Naturally, the GSS building should have 'green' status, invoking the principles of sustainability as known at this time.

**Program development funding**

Investments will be needed for workshops and invited speakers, graduate student support, seed funding for problem-group grant proposal development, large equipment, and travel grants.

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