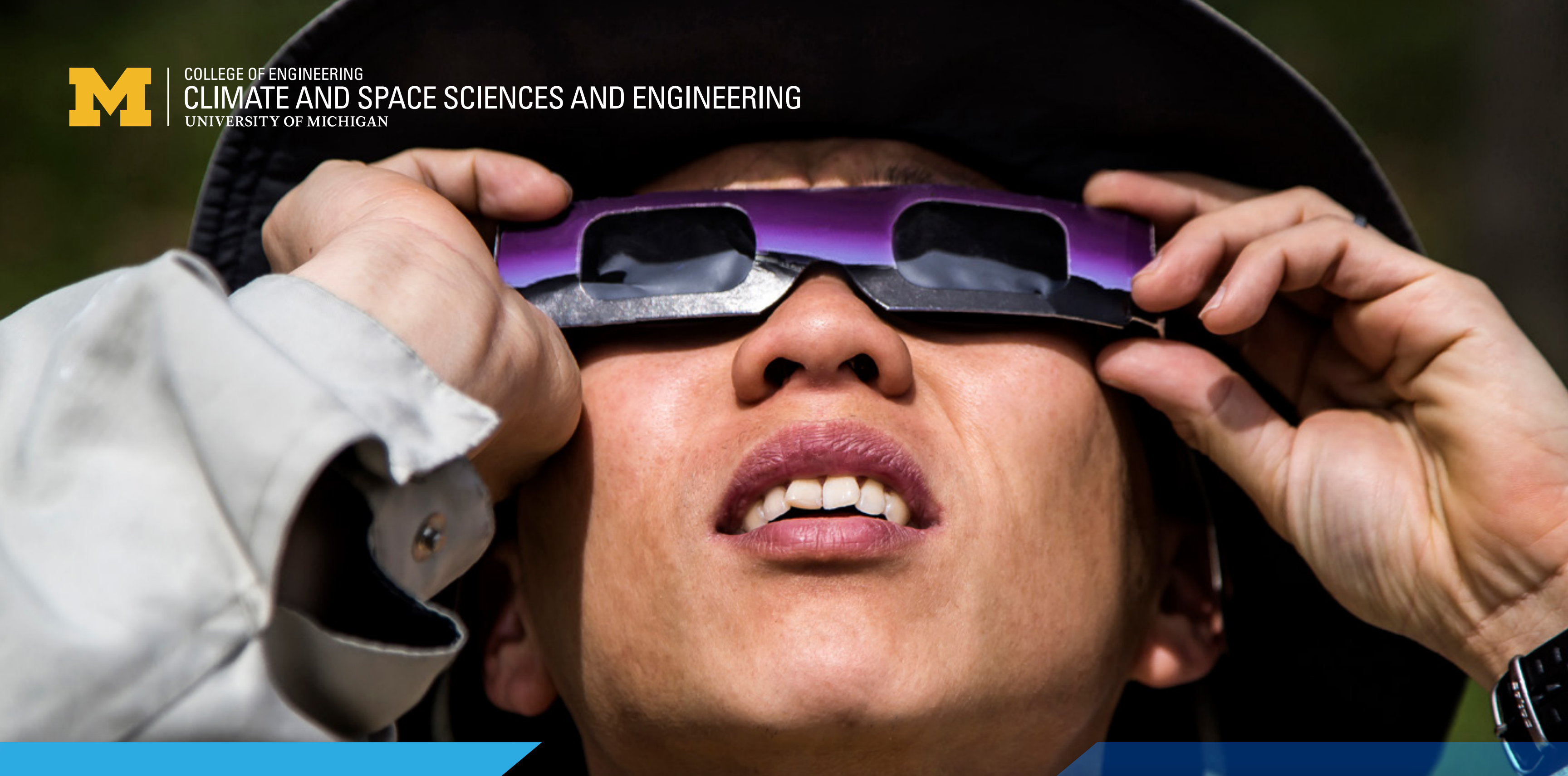
COLLEGE OF ENGINEERING
CLIMATE AND SPACE SCIENCES AND ENGINEERING
UNIVERSITY OF MICHIGAN



Discovery and Innovation for a Better World

Tuija Pulkkinen

Chair, Climate and Space Sciences and Engineering Department

Exploration, Research, and Serving the Common Good

Stars, planets, moons, comets, auroras and many other space phenomena have attracted our attention for millennia. Space exploration has given us detailed pictures of our Sun, our neighboring planets, their atmospheres and space environments, and the hostile radiation belts around our own planet. **The Space Physics Research Laboratory (SPRL),** established at the dawn of the Space Age at the **University of Michigan,** played a major role in these discoveries, and planted the seeds for what would become the department now known as **Climate and Space Sciences and Engineering (CLaSP).**

We focus on exploration and fundamentals. From concept development, design, and construction to operation of ground-based, airborne, and space-based instrumentation and systems. CLaSP develops cutting-edge numerical algorithms, machine learning methodologies, and models that describe the Earth and solar system in a variety of scales.

We proactively respond to societal needs. The reduced cost of access to space has facilitated the growth of novel services ranging from hurricane monitoring to space weather forecasts, and has led to a substantial increase in the downstream weather and space communication industries. Technology services we consider commonplace – communication, data transfer, and navigation – all rely on satellite services. CLaSP provides new knowledge and technologies, develops new services and mitigation/adaptation strategies, and educates graduates who will lead the transformation of the industries.

We train our students to address pressing challenges. Climate change, severe weather, rising sea levels, and space weather will require the fundamental scientific understanding gained at CLaSP to conceive of and apply practical solutions. Our new **Certificate Program on Climate Change Solutions** will prepare our graduates to work in a wide range of fields in academia, the public sector, and private industries.

The recently launched **University of Michigan Space Institute,** based at CLaSP, provides a place where space enthusiasts and space-related activities from across the U-M campuses can communicate, collaborate, and share information. Our alumni network, private sector, and governmental organization partners bring real-life problems to research in our classrooms.

The Climate and Space Sciences and Engineering department brings together faculty leaders in their fields, forward-looking observational and computational capabilities for research, leading-edge technology, and the next generation of student scientists.

Today is truly an exciting time to be a geoscientist!

OUR MISSION

From the Surface of the Earth to the Fringes of the Solar System

THE UNIVERSITY OF MICHIGAN COLLEGE OF ENGINEERING provides scientific and technological leadership to the people of the world. We seek to improve the quality of life by developing intellectually curious and socially conscious minds, creating collaborative solutions to societal problems, and promoting an inclusive and innovative community of service for the common good.

Our mission at Climate & Space is to provide scientific, technological and educational leadership in climate and space research to Michigan and the world.

- We use observations, modeling and theory to discover and explain phenomena in disciplines spanning from the Earth's surface to the outer reaches of our solar system and beyond.
- Our inclusive and innovative community inspires students to develop as intellectually curious, engaged citizens to tackle scientific and societal problems.
- We use the knowledge we generate to inform the public, stakeholders and policy makers.

SUN/HELIOSPHERE

1993: New Solar and Heliospheric Research Group provides foundation for space weather research

1995: Wind* spacecraft begins new era of solar wind observation with suite of leading-edge particle and field instrumentation

1997: ACE* spacecraft starts to provide severe solar storm warnings

2016: DSCOVR* satellite continues real-time solar wind monitoring

2018: Parker Solar Probe* launches to discover how solar storms are born near the Sun

2020: Solar Orbiter** launches to explore how the Sun shapes and controls the heliosphere

VENUS

2006: Venus Express* launches to probe the planet's atmosphere

MERCURY

2015: MESSENGER* reaches Mercury and discovers ice near its poles

2018: BepiColombo** launches, expected to arrive in 2025 when its two orbiters will start an in-depth study of the planet and its environment

MOON

2009: Lunar Reconnaissance Orbiter** identifies sites for future lunar mission

2023: (scheduled) Artemis Lunar Gateway** will provide logistical support for Lunar and deep-space exploration

EARTH

1914: Michigan establishes the first aeronautics degree program

1946: Space Physics Research Laboratory and High Altitude Laboratory founded

1957: "Rocket Panel" meets at Michigan to propose new space agency: NASA

1963–1968: Harm Buning teaches flight and orbital mechanics to all Apollo astronauts

2008–2019: Multiple CubeSat missions* explore weather and space phenomena and develop advanced technologies (RAX-1, RAX-2, MCubed-1, MCubed-2, GRIFEX, CADRE, TBEX-1, TBEX-2, QB50)

2016: Michigan-led CYGNSS* eight-satellite constellation mission launches to monitor hurricane intensity

MARS

2003: MarsExpress** studies the Martian atmosphere and environment

2004: Spirit** and Opportunity Rovers** characterize Martian rocks and uncover the history of Martian water

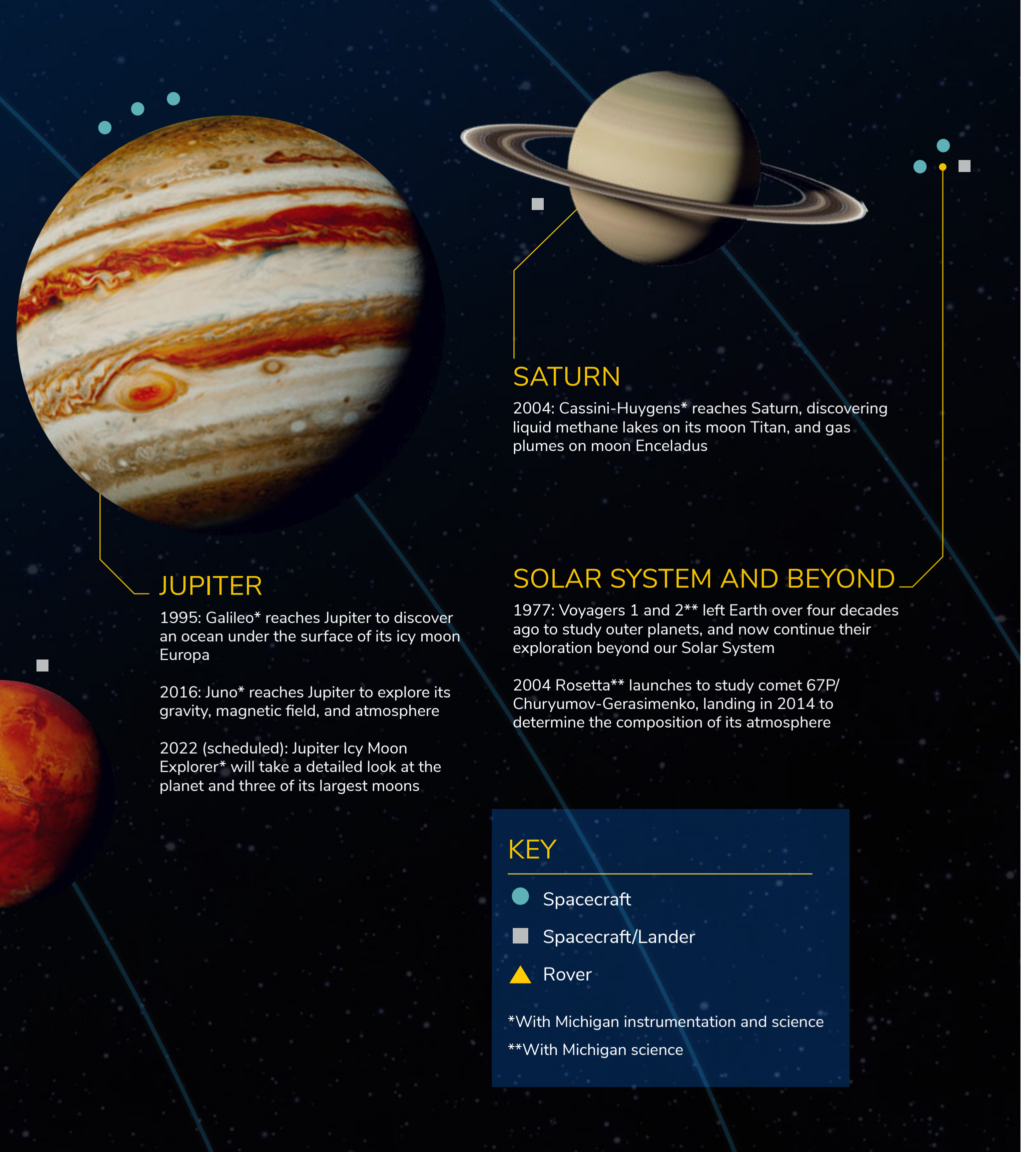
2005: Mars Reconnaissance Orbiter** begins monitoring Martian water

2007: Phoenix** examines ice cap with robotic arm

2011: Mars Science Laboratory** brings Curiosity Rover* to assess habitability on the Red Planet

2013: Maven** launches to study space weather on Mars

2018: MarCO Cubesats** launch to demonstrate new communication technology



A Climate & Space Tour of the Solar System

OUR DEPARTMENT HAS ITS ROOTS at the nation's oldest aerospace engineering program from the beginning of 1900's and the NASA-funded **Space Physics Research Laboratory** founded in 1948. Since then, the department has been part of a multitude of missions studying the Sun, Mercury, Venus, Moon, Mars, Jupiter, Saturn, the solar system, and beyond. Studies of our home planet cover ground-based, airborne and space-based observations of the atmosphere and space environment.

CLaSP history covers a large share of major national and international solar system exploration missions. New miniaturized technologies have shifted focus to CubeSat and microsatellite missions, which allows us to accomplish ambitious research goals with a fraction of the large mission budgets and in much faster timescales that are appealing both to research and education.

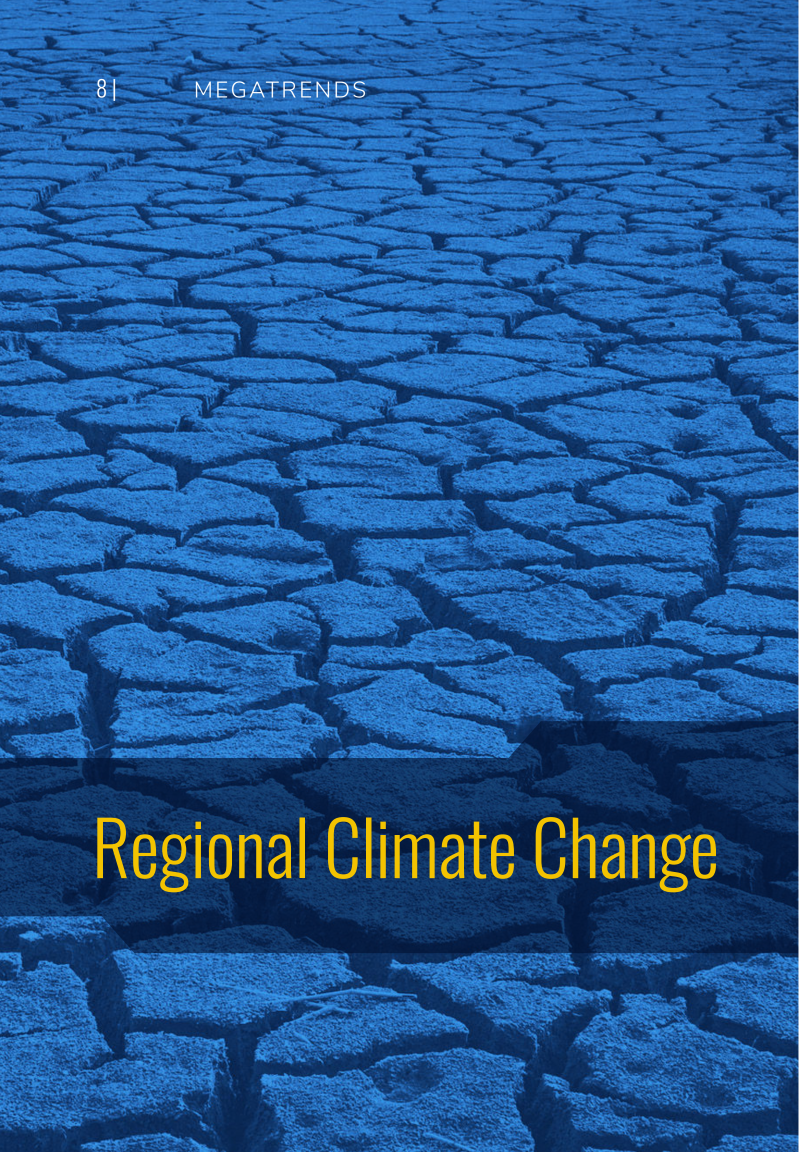
MEGATRENDS

THE IPCC REPORT ON GLOBAL WARMING (2019) concludes that the global climate has changed relative to the pre-industrial period. There is a wealth of evidence of changes already impacting organisms, ecosystems, and human well-being: temperatures are rising, drought and wildfires are starting to occur more frequently, rainfall patterns are shifting, glaciers and snow are melting, and the global mean sea level is rising. And these impacts treat our planet's regions in very different ways. To mitigate climate change, the global society needs to reduce or prevent the emissions linked to human activities.

A holistic approach to this grand challenge requires considerations and actions on several fronts:

- Monitoring and predicting changes in the global climate, in the mean and variability of its persistent properties including surface temperature, precipitation patterns, sea-level, ocean and ice sheet dynamics, ocean acidification, and frequency and occurrence of extreme weather events;
- Monitoring global increase of the surface temperature as a consequence of anthropogenic greenhouse gas emissions;
- Consideration of sustainability of the human activities without compromising the ability of future generations to meet their own needs;
- Mitigation of climate change impacts through implementation of policies to reduce greenhouse gas emission and enhance carbon sequestration. Technological solutions and innovations are needed for energy conservation, energy efficiency, and energy-efficient urban planning;
- Adaptation to climate change effects to reduce the vulnerability of natural and human systems.

Global Climate Change

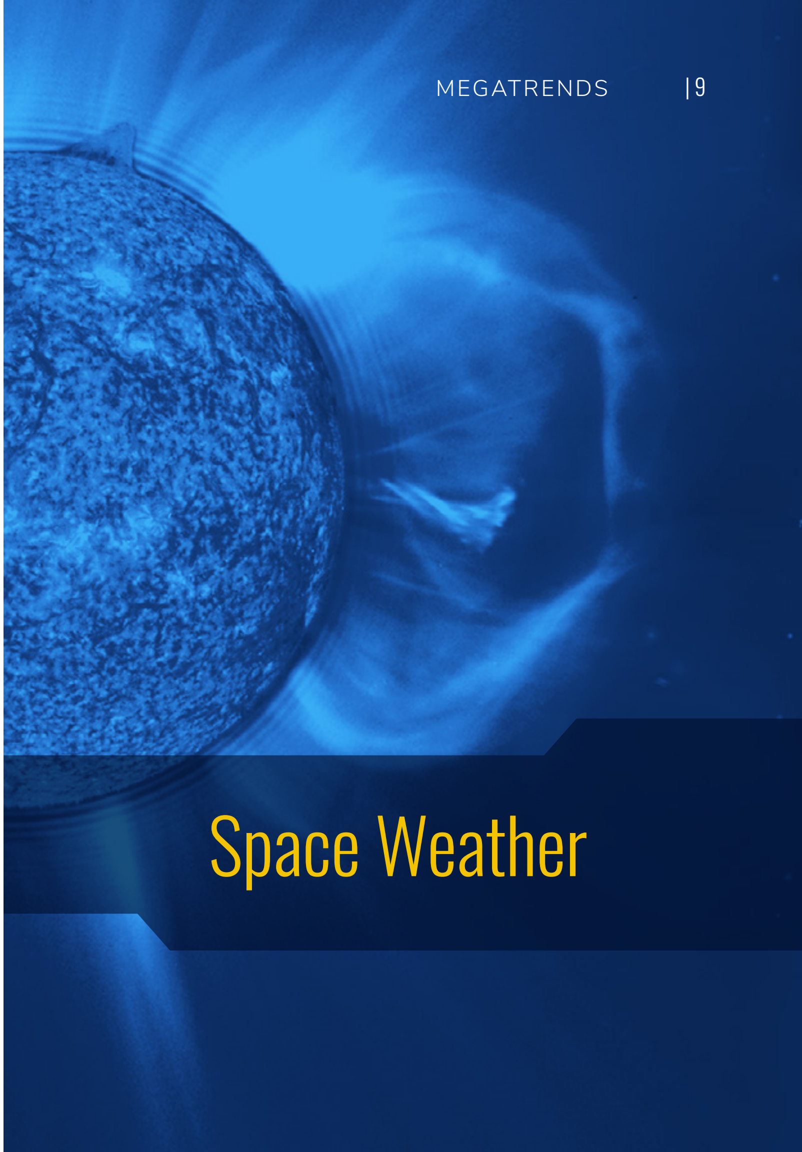


Regional Climate Change

CLIMATE CHANGE WILL impact the people, ecosystems, and infrastructure of the Great Lakes region as well as the lakes themselves. The **Fourth National Climate Assessment (2018)** predicts increases in extreme precipitation events, changes in growing seasons, and warming temperatures. While the regional effects are more difficult to predict, many of the impacts are already being observed:

- The polar regions warm more quickly, and the Ice cover decline opens new routes in the polar regions and lengthens the navigation season;
- Recent years have seen both record high and record low water levels in the Great Lakes, and the warming climate will cause changes in the range and distribution of some species, increases in invasive species and harmful blooms of algae, and declines in shoreline health;
- The increasing frequency of extreme weather events will directly impact communities through flooding, heat stress, and droughts in both urban and rural areas;
- The emissions in a warmer climate will impact regional air quality, affecting the health of millions of people.

Understanding the physical, chemical, and biological processes related to these changes are key to developing mitigation and adaptation strategies as well as reliable predictions for future evolution.



Space Weather

LARGE ELECTROMAGNETIC DISTURBANCES originating from the Sun have the potential to harm technological systems and humans in space and on ground. **The National Space Weather Strategy and Action Plan (2019)** of the National Science and Technology Council requests actions to enhance the Nation's preparedness for these **Space Weather events.**

The key objectives outlined in the report include enhancing security and protection of assets and operations; developing and disseminating accurate and timely space weather characterization and forecasts; and establishing plans and procedures for responding to and recovering from space weather events. Through such actions we can protect failure or malfunctions of satellites, communication and navigation systems, or outages in power distribution networks.

The new solar cycle is increasing in activity. At the same time, commercial satellites are up in the hundreds, and NASA has ambitious plans to increase human presence in Earth orbit, on the Moon, and even on Mars. Improved understanding, observations, forecasts, and models for space weather are critical to planning, execution, and decision-making for a diverse set of stakeholders from critical infrastructure operators to those securing the lives of the astronauts.

Humans in Space

THE INTERNATIONAL SPACE STATION (ISS) has hosted over 200 astronauts on Earth orbit since 1998. Ambitions to solidify human presence in space continue: the first commercial launch to the ISS has just taken place. The **NASA ARTEMIS** program intends to land the first woman and next man on the Moon by 2024 to explore opportunities for sustained presence on the Lunar surface. Inhabiting the Moon will act as a stepping stone for the next giant leap: sending astronauts to Mars.

Reliable access to space, landing on another planetary body, and sustaining life outside the Earth's shielding atmosphere and magnetosphere pose significant technological challenges. The success of any crewed program will build on a thorough scientific understanding of the target body – the Moon or Mars – gained through (robotic) planetary exploration mapping out the environmental conditions, including the local space weather both en route and on the surface.

NEW SPACE, THE globally emerging private spaceflight industry, has brought a remarkable shift from space activities by government agencies to private companies, and from few large-budget endeavors to a vast number of much less expensive projects.

The long-term goal is to create a vertical market enabling private space launches, space-based imagery, space tourism, telecommunication services, in-space manufacturing and resource harnessing, and cultural and educational activities related to space. Revenue will also be generated in the downstream sector through services, products, and applications making use of space-based technologies and assets. From agriculture and transport to healthcare and telecommunications, satellite communications and location-based services are transforming the way the modern society lives and operates.

Small satellites, particularly **CubeSats** building on standardized platforms, miniaturized instrumentation and shared launch opportunities have emerged in vast numbers and revolutionized both academic and commercial space activities. Spacecraft built by students in a university setting make scientific discoveries, and startup companies create novel services with relatively small capital investments.

A space-educated workforce is needed both as technology experts in the new industry as well as in the public sector developing the regulatory environment for the new industry to operate in.

New Space

Big Data

THE INCREASE IN data transmission capacity as well as numerical computing power have exploded the amount of data we have at our disposal. Big data is a new field emerging to analyze and extract information from data sets that are too complex to be treated by traditional techniques.

Machine learning-based algorithms are novel tools that automatically learn through experience. Through the use of specialized learning using training data sets, such algorithms are able to make predictions or decisions without being explicitly programmed to do so.

As the Earth and space science data sets and numerical simulations have grown, machine learning methods are actively being included in the analyses. Machine learning methods are used to augment and complement physics-based numerical simulations as well as treat large data sets (including imagery) to detect patterns that help in near-term predictions.

THE WAY WE OPERATE

Our Values

> "To be preeminent, you must lead, and in order to lead, you must be willing to take risks and be creative, transparent and collaborative. In other words, to achieve our vision, we must live our values."
>
> – Alec Gallimore, Dean of College of Engineering

OUR ACTIVITIES BUILD on the values developed together with the University of Michigan College of Engineering:

- Leadership and excellence
- Creativity, innovation and daring
- Diversity, equity and social impact
- Collegiality and collaboration
- Transparency and trustworthiness

Our Diversity Statement

DIVERSITY, EQUITY, AND INCLUSION activities in our department aim to draw in students, faculty and staff at all levels to develop an engaging and inclusive climate for everyone within the Climate & Space community.

While we continue to learn and grow as a community, our diversity statement reflects our commitment to developing broader participation in climate and space sciences - a challenge that the field faces both nationally and internationally.

CLaSP Diversity Statement

The teaching and research mission of the **Department of Climate and Space Sciences and Engineering** is enhanced by learning from and working with a diverse intellectual community within an environment of full inclusion – a supportive and welcoming workplace that values all individuals and their perspectives, contributions and ideas. We welcome members with diverse global experiences across all forms of dimensions and intersections, including race, ethnicity and national origins, gender and gender identity, sexuality, class and religion. We are especially committed to increasing the representation of those populations that are underrepresented in the Earth and Space Sciences. We are committed to attracting, recruiting and retaining a diverse population of faculty, undergraduate and graduate students, and staff. We work to identify and promote practices and structures that support inclusion, safety and diversity's development in our department's work through programs supported by our Diversity Ally, mentoring activities and our student organizations.

Improving Diversity

- **Grad-school Readiness Experience and After Training (G.R.E.A.T.) workshop.** We are working to build more diverse cohorts within the Climate and Space community by inviting and mentoring a diverse group of undergraduates from across the United States. Workshop participants attend a one-day workshop and learn about the graduate school experience, the application process, and how to translate their experience into opportunities in graduate school and beyond. We fully fund travel costs to and from the workshop to make participation as easy as possible.
- **Building relationships with minority-serving institutions.** Students from the Inter-American University of Puerto Rico and Cal State Los Angeles participate in our Program In Climate and Space Science Observation (PICASSO) Research Experience for Undergraduates (REU) program, which is sponsored by the National Science foundation. We are increasing funding to facilitate collaborations between students and faculty at these partner institutions, as well as building partnerships with tribal colleges and indigenous people within the Great Lakes region, recognizing that climate change is transforming all communities in Michigan.
- **Pathways to societal engagement in the climate and space sciences.** Climate change is one of the biggest challenges faced by our society, and we recently hosted a sequence of workshops focused on translating physical science research to societally relevant outcomes (November 2019, and March 2020). This program provides students with an opportunity to leverage Climate & Space research to potentially benefit communities facing climate change.

WE ARE VERY PROUD that our research covers the complete cycle from instrument development, to observations, models, and theory development. And we transfer all those aspects to our education and to the society at large.

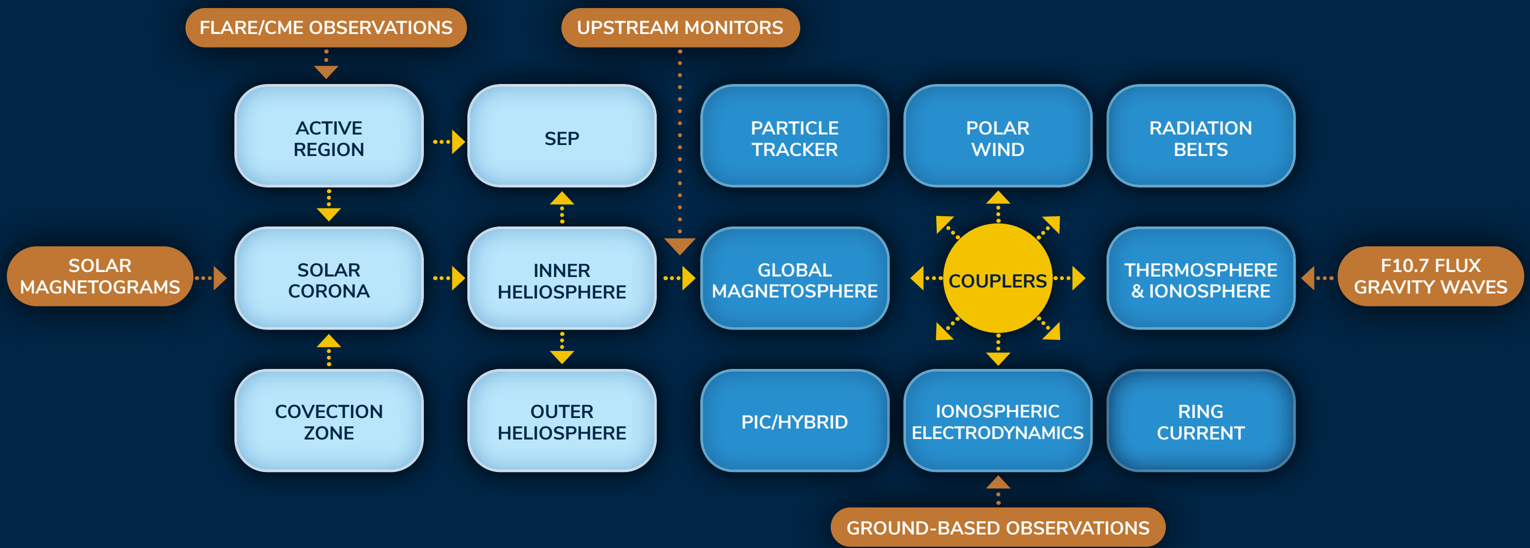
We develop measurement and instrument concepts, build instruments and systems, and make ground-based, airborne and space-based measurements. **The Space Physics Research Laboratory (SPRL)** with its highly experienced engineering team enables us to take significant responsibilities in national and international space missions.

We operate instruments, collect and process data, document and disseminate the results, and analyze and interpret the observations. We have the capacity to downlink data from satellites, and we currently operate the eight-satellite **Cyclone Global Navigation SatelliteSystem (CYGNSS)** mission that monitors hurricanes and soil moisture content from space.

We develop and validate models, and use those models for monitoring and predictions, as well as for understanding phenomena and processes. Our **Space Weather Modeling Framework (SWMF)** is a unique tool that couples multiple models from the Sun to the Earth's space environment. We are also active partners in national efforts to develop Earth System models.

We provide our data products and models for private weather and space weather service providers as well as public decision and policy makers. Throughout the cycle, we work with undergraduate and graduate students, transforming the results to ideas and technologies for companies, knowledge for the benefit of the society, and advancement of science.

The Complete Cycle



Space Weather Modeling: From Sun to Surface

The Space Weather Modeling Framework couples models of the Sun and the Heliosphere to a set of models describing the space environments of the Earth and other planets.

A specific Geospace combination of the models has been transitioned for operational use at the NOAA Space Weather Prediction Center in Boulder, CO.

As a NASA DRIVE (Diversity, Realize, Integrate, Venture, Educate) Science Center, **SOLSTICE (Solar Storms and Terrestrial Impacts Center)** focuses on merging novel machine learning methodologies with the numerical framework to improve on the quality and temporal range of the space weather predictions.

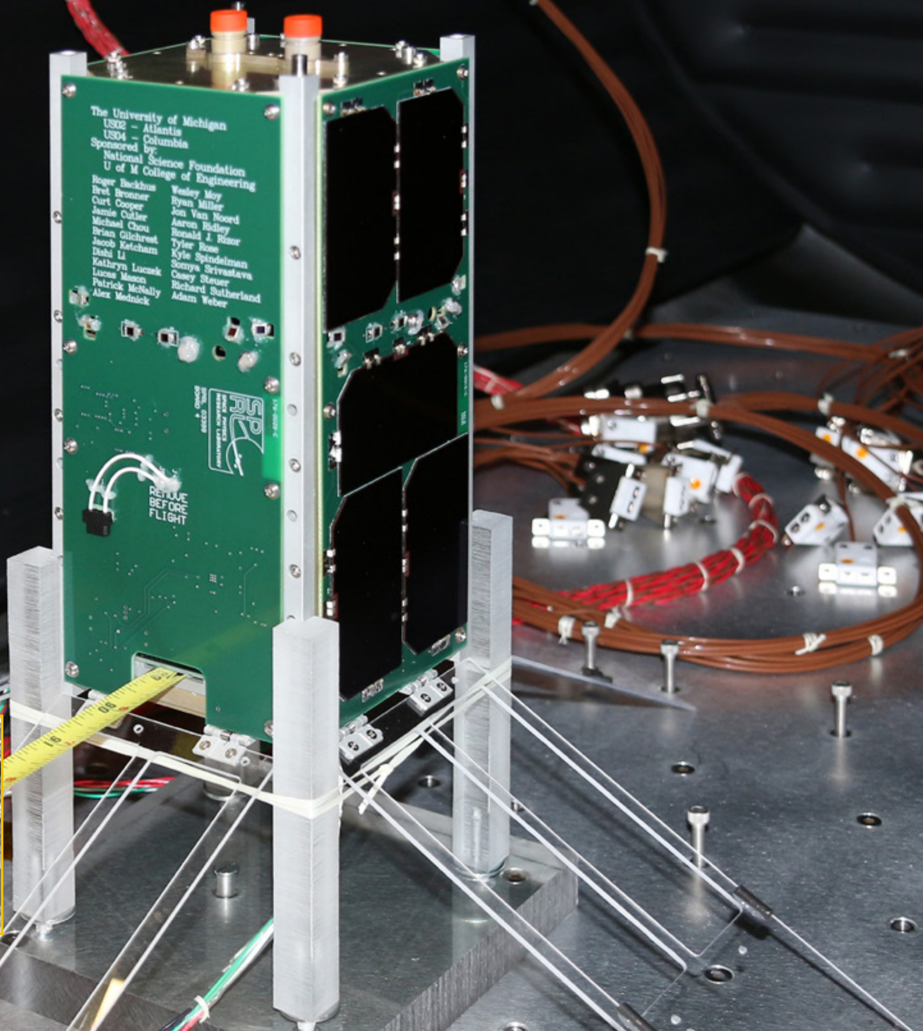
Scientific use of the framework covers geospace, as well as heliospheric and planetary bodies from the smallest planet, Mercury, to the gas giant, Jupiter, and its moons.

The Space Physics Research Laboratory

The **Space Physics Research Laboratory (SPRL)** operates in close collaboration with the department within the Climate & Space Research Building.

With an illustrious 70+ year history at the center of the American space flight program, the laboratory is one of only a handful of university centers able to conceive, design, construct, test, operate and analyze data from space flight instruments – a truly "end-to-end" activity.

The laboratory has expertise in electronics, remote-sensing, and computer systems, fabrication technology, as well as reliability and quality assurance. Instrumentation expertise ranges from in situ mass spectrometry, particles and fields to optical and microwave remote sensing.



CYGNSS: From Concept to Operations

The Cyclone Global Navigation Satellite System (CYGNSS) is a constellation of eight microsatellites flying in low Earth orbit. The satellites carry microwave antennas and receive GPS signals reflected from the surface.

Originally designed to track the life of tropical cyclones over the ocean, innovative data analysis methods now also yield signal over ground, allowing CYGNSS to track soil moisture in flooding areas and river basins.

The CYGNSS mission, designed and operated by Climate & Space, was selected as the first NASA Earth Venture Mission.

The department's **Spaceflight Operations Center (SOC)** downlinks and processes CYGNSS data for distribution to the scientific community.

Multidisciplinarity

CLASP RESEARCH AND EDUCATION are inherently multidisciplinary due to the complex nature of the processes and phenomena we study.

Our research is increasingly taking a **Systems Science** approach, considering interactions and feedbacks between the atmosphere, hydrosphere, cryosphere, biosphere, the ionosphere, magnetosphere, and the Sun and heliosphere. This includes physical and chemical processes as well as the impact of humans and societies on these components. And all of this in global, regional and local scales, from large-scale to microscale processes, and from time scales ranging from seconds to decades and millennia.

Our experimental research involves a strong interaction between science and engineering, with advances in technology facilitating novel measurements and techniques and observational needs driving the development of engineering solutions.

Certificate Program for Climate Change Solutions

The past decade has seen a growing student interest in developing solutions for the greatest challenge of the century: the global climate change. To support our students in different fields who would like to become leaders in this area, we have developed an engineering and physical science curriculum in the format of a certificate program. The Climate Change Solutions certificate program provides the University's graduate students an opportunity to develop skills that allow them to:

- Communicate about the climate system using mathematical, verbal, and visual means;
- Explain and demonstrate how changing climate impacts society;
- Evaluate and assess the relative impact, strengths and weaknesses of possible energy systems; and
- Evaluate resilience needs and determine the sufficiency of engineering, policy, and planning solutions.

We will launch the program in Fall 2020 in the College of Engineering in partnership with the School for Environment and Sustainability (SEAS).

The University of Michigan Space Institute

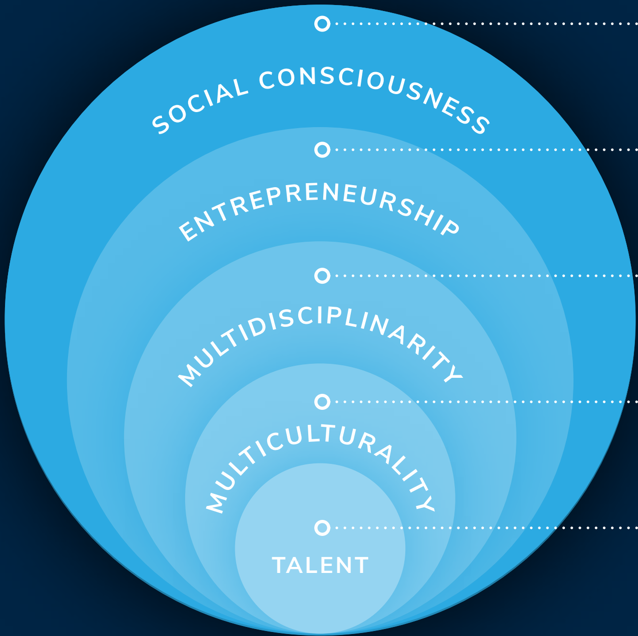
The University of Michigan Space Institute, launched in Fall 2019, is the University's focal point of space-related research, allowing faculty to collaborate with colleagues from a broad range of backgrounds. The Space Institute encompasses research from space, designing systems to operate in space, and research on living in space. With an emphasis on education, the Space Institute will serve as a common entity for connecting students with space-related courses, space-focused student groups, and faculty offering space research experiences and career-enhancing opportunities.

The Space Institute prime drivers are **Climate & Space, Astronomy,** and **Aerospace Engineering,** but the affiliate list spans every department in the College of Engineering, and several in the College of Literature, Science, and the Arts. Further participation is sought from Medicine, Kinesiology, Business, Law, and Public Policy.

The Space Institute will advance our leadership in space activities scientifically (including fundamental and applied research), technically (via engineering and project synergies), socially (emphasizing society's reliance on space), and commercially (through innovations, innovators, workforce education and corporate partnerships).

UNIVERSITY OF MICHIGAN
SPACE INSTITUTE

EDUCATION



MENTORED RESEARCH, CREATIVE EXPERIENCES

- Student-led activities (BLiSS)
- Experimental summer programs(Greenland)

CULTURAL ACCEPTANCE OF ENGINEERING SOLUTIONS

- International research projects
- Observational campaigns

SYSTEMS SOLUTIONS

- Systems engineering in industrial collaboration
- Earth system and space weather system modeling

VIABLE BUSINESS MODELS, SOLUTION IMPLEMENTATION

- Project-based courses with industry participation
- Sustainable energy solutions

SERVING PEOPLE AND SOCIETY

- Climate change mitigation and adaptation strategies
- Impacts of space-faring society

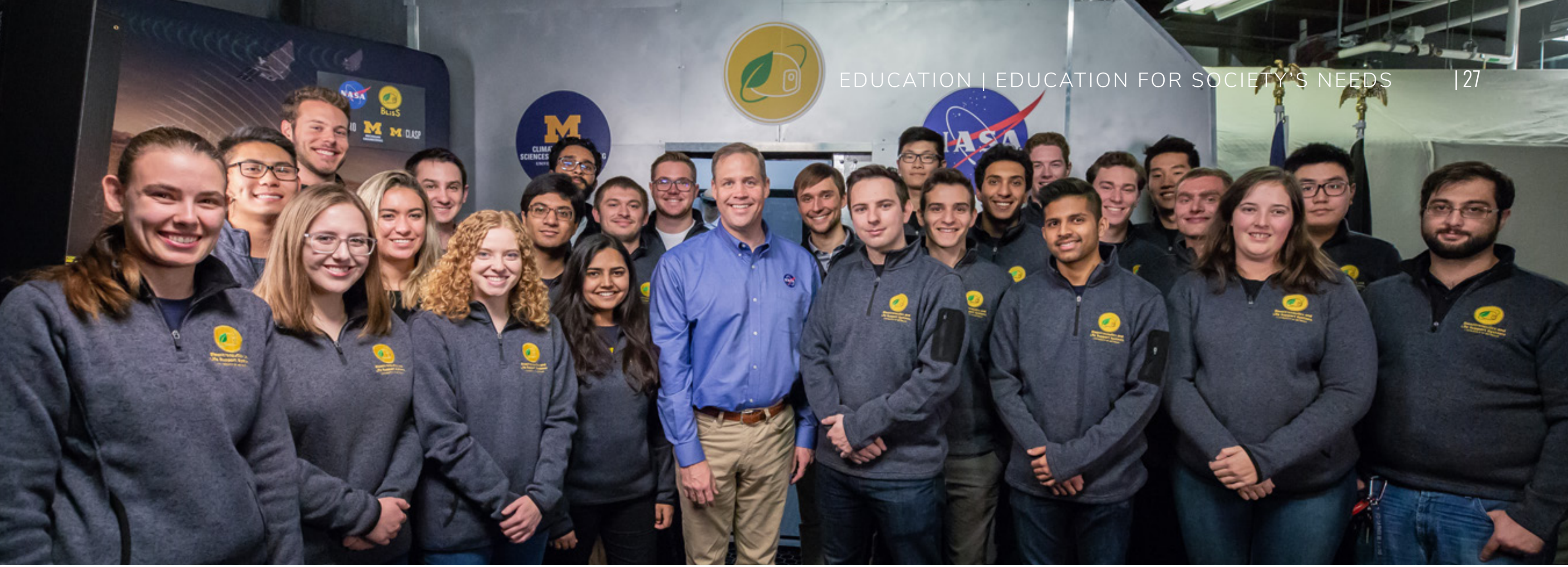
Education for Society's Needs

We seek to increase the scientific, technological and innovative capacity of society at large. We educate climate-conscious and space-savvy workers for private sector, public organizations and policy making venues. We involve all of our students in our cutting-edge research program engaging them in the processes of innovation and discovery.

The National Academy of Engineering Grand Challenges Scholars Program (2017, 2019) reflects recognition that there are basic competencies that students must achieve to prepare them to address the global challenges. Climate & Space students gain these capacities through our interdisciplinary, research-based and hands-on learning experience.

Experience Expedition: Greenland

In 2019, Climate & Space organized the Greenland Expedition for Undergraduate Research, commemorating the first Michigan expedition to Greenland in 1926. Research during the 10-day visit to Greenland included sophisticated techniques such as drones to map the conditions on and near the second-largest ice sheet on the planet. From the base camp, the expedition ventured out over the tundra to conduct experiments near the ice sheet. The students also visited the Summit Camp, a year-round research station at the apex of the Greenland Ice Sheet, where scientists collect ice cores to determine past climates. The education and research during the expedition highlighted the importance of Greenland as the "canary in the coalmine" for global warming.



BLiSS: Student-Led Activities

Michigan **Bioastronautics and Life Support Systems (BLiSS)** is a student-run research team to design, build and test deep-space habitat prototype technology. The team, comprised of both undergraduate and graduate students was founded in 2015, and currently maintains an experimental habitat at the Climate & Space building.

The BLiSS team has received several grants to "strengthen NASA's deep space exploration capabilities, including habitation systems needed for an extended human presence beyond Earth's orbit."

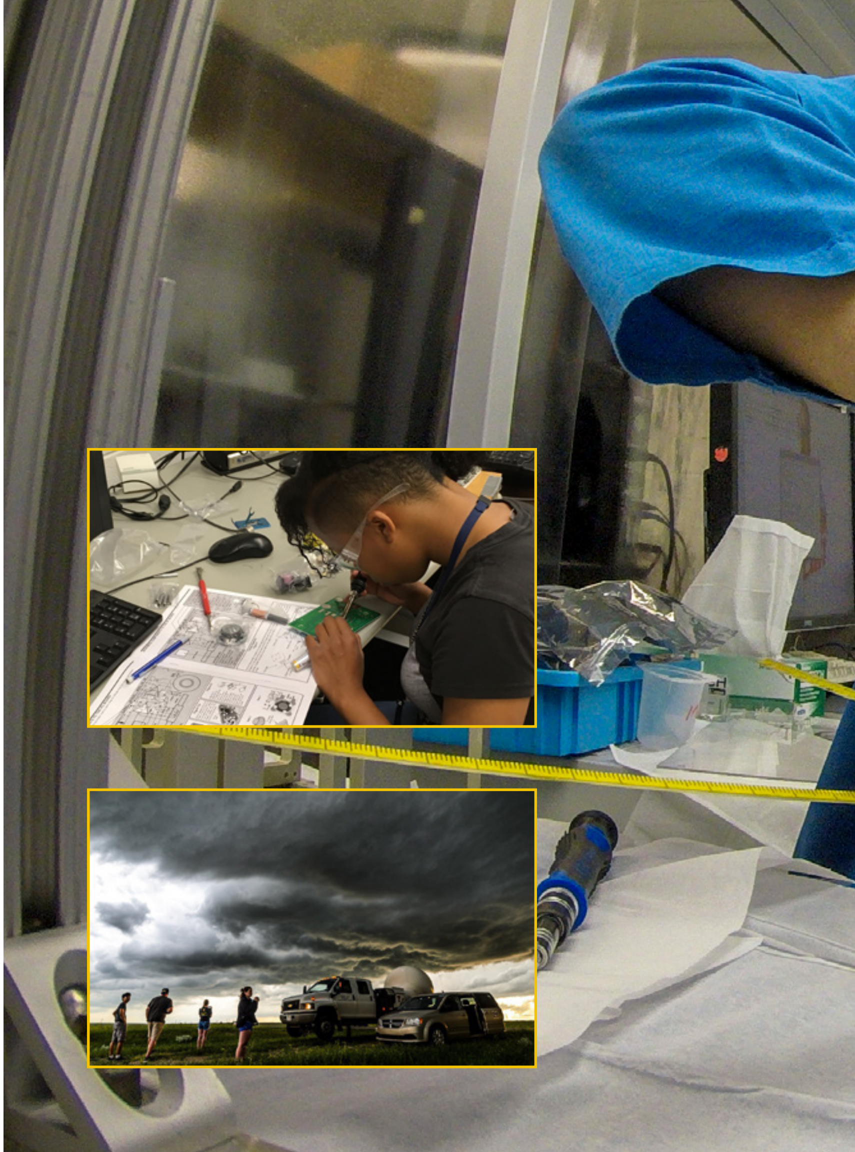
Recent projects include the **Mars Habitat Commonality,** in which students created a habitation system that shares common features with in-space and surface habitat designs, and a **3-D Printed Plant Growth Substrate** in which students designed and built a substrate prototype to help achieve effective plant growth in a microgravity environment.

In Fall 2019, NASA Administrator Jim Bridenstine visited the BLiSS Mars Habitat, and gave a press conference there together with Dean Alec Gallimore.

Student Experience

We offer unique opportunities for hands-on learning through dynamic classroom experiences, expeditions, fieldwork, and summer research programs.

- **Research Experience for Undergraduates (REU):** Our REU site program is called Program in Climate and Space Science Observation (PICASSO), and is funded by a grant from the National Science Foundation.
- **Tornado Camp:** An annual storm-chasing excursion operated in partnership with Texas Tech University to follow and study tornadoes and severe weather in "Tornado Alley" on the plains of Texas, Kansas, and Oklahoma.
- **Space Mission Design and Implementation on a High-Altitude Balloon:** This class teaches students how to design, build, test and deploy a small-satellite, deployed on a high-altitude balloon.
- **ArtsEngine/ Moldwin Prize:** A cross-collaborative initiative aimed at bringing North Campus Arts students into Prof. Mark Moldwin's scientific laboratory.



Dan Welling

Vania Jordanova

Building the 21st Century Academia

As a research-intensive department, we place a high priority on fostering an environment that enables faculty to do their best work. Many of our faculty alumni go on to become nationally and internationally recognized scholars, and leaders in their respective fields.

Dan Welling, Assistant Professor at University of Texas at Arlington. Principal Investigator of NASA Heliophysics DRIVE Science Center at UTA.

Vania Jordanova, Scientist at Los Alamos National Laboratory, Principal Investigator on the Space Hazards Induced near Earth by Large Dynamic Storms (SHIELDS) research program.

Manish Mehta, Aerothermodynamics Subject Matter Expert at NASA Marshall Space Flight Center for the Space Launch System (SLS) and lander technologies.

Manish Mehta

Jasper Kok

Paul Ullrich

Kevin Reed

Jasper Kok, Associate Professor at UCLAS. Expert on dust transport in terrestrial Climate Models, as well the atmospheres of Mars and Saturn's Moon, Titan.

Paul Ullrich, Associate Professor at University of California, Davis. Expert on Climate Models and Global Change.

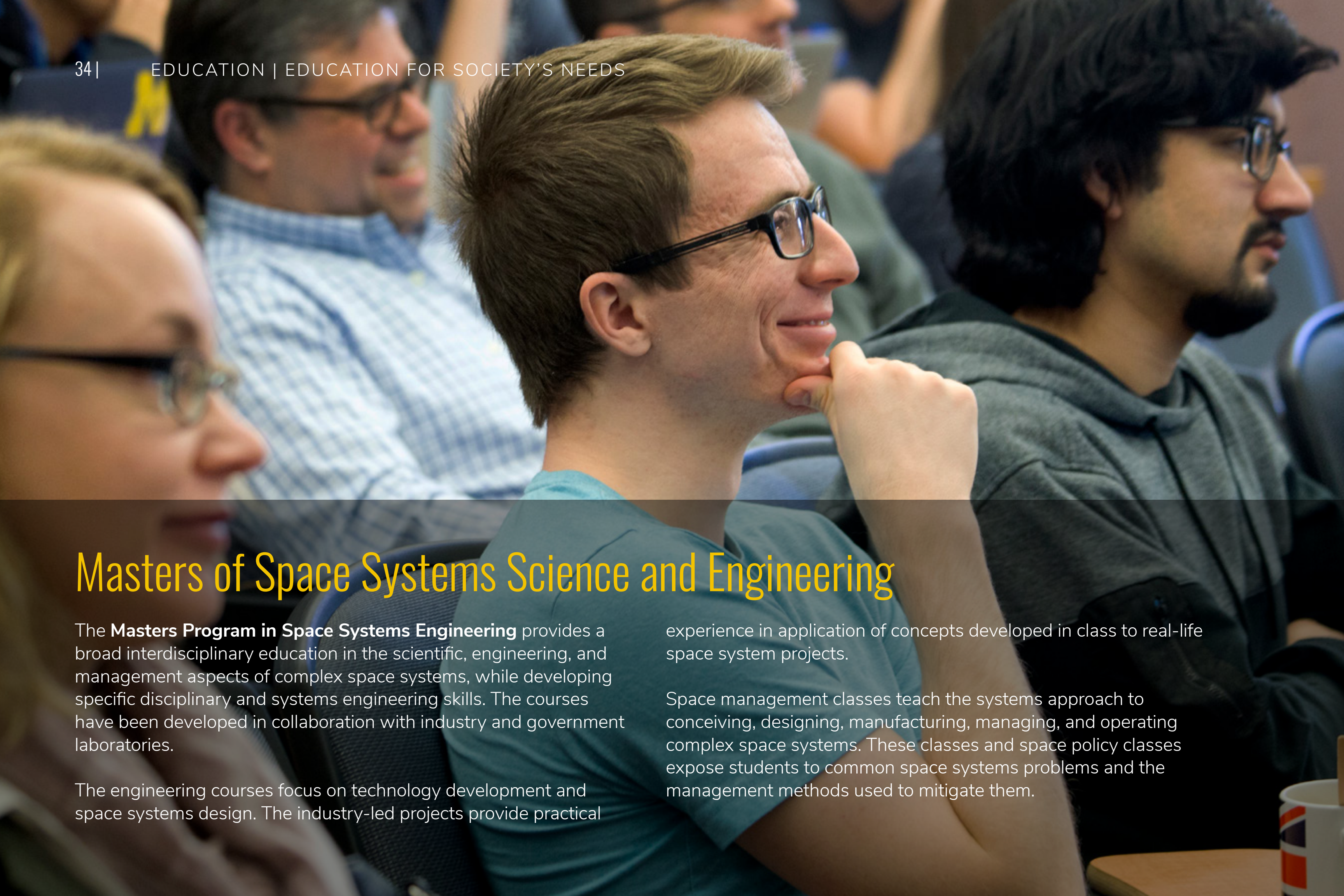
Kevin Reed, Associate Professor at Stony Brook University. Expert on Extreme Weather Events and Climate Change Impacts.

Career Paths From Climate & Space

The graduate and undergraduate programs at Michigan Engineering are among the highest ranked in the nation. Our goal is to ensure that every student benefits from a world-class educational experience. We are committed to preparing our students to become tomorrow's leaders.

- Sam Basile, MEng, Applied Climate '14; PhD, Climate and Space Sciences and Engineering '19. ***National Climate Assessment, Senior Staff Scientist.***
- Kiko Dontchev, MEng, Space Engineering '10. SpaceX, ***Director, Dragon Ground and Launch Operations.***
- Matt Irish, MEng '18. ***National Renewable Energy Laboratory, Electricity Markets Engineer.***
- Emily Judd, MS, Climate and Space Sciences and Engineering '18; MEng Space Engineering '19. ***NASA Langley Research Center, Aerospace Engineer.***
- Anny Lin, MEng, Space Engineering '19. ***Northrop-Grumman, FTL (Future Technical Leader) Systems Engineer.***
- Joe Mancewicz, MS, Atmospheric & Space Sciences '96 ***NVIDIA, Senior Software Engineer. Two-time Academy Award winner.***
- Emily Upton, BSE, Earth Systems Sciences & Engineering '17; MEng, Applied Climate '18. ***DTE Energy, Associate Engineer.***


ERATIONS CENTER



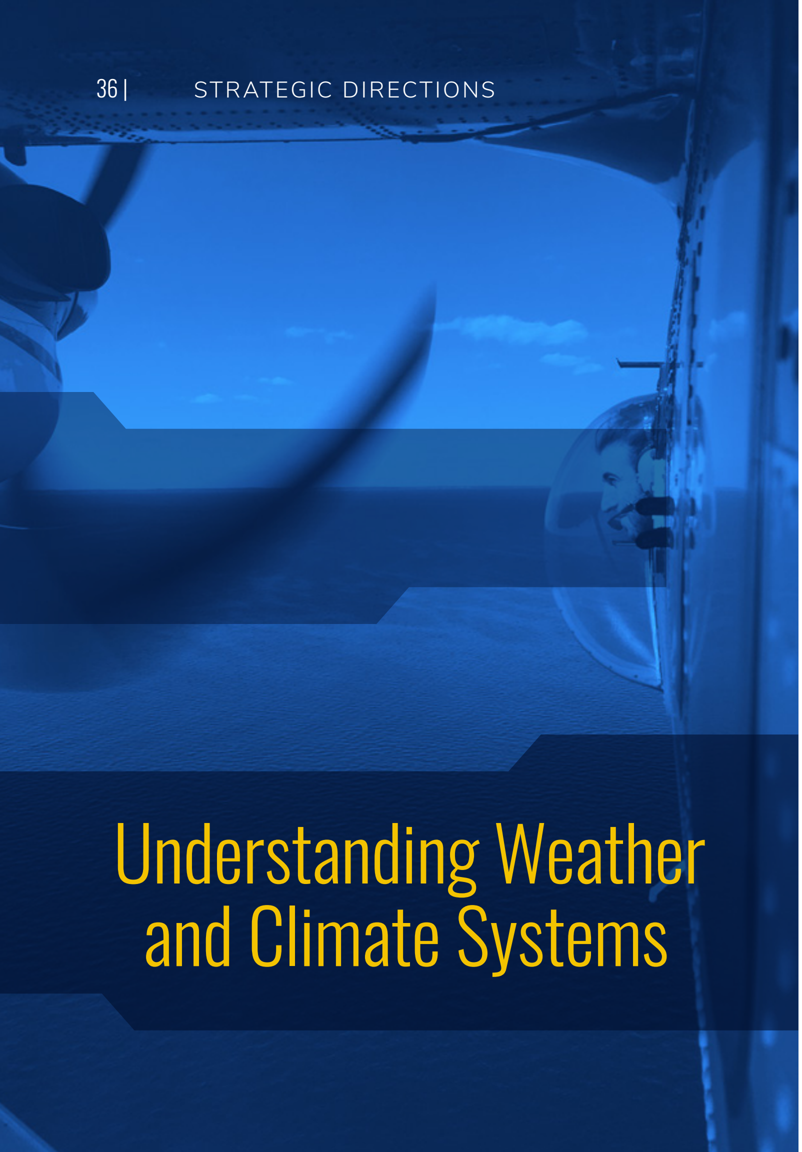
Masters of Space Systems Science and Engineering

The **Masters Program in Space Systems Engineering** provides a broad interdisciplinary education in the scientific, engineering, and management aspects of complex space systems, while developing specific disciplinary and systems engineering skills. The courses have been developed in collaboration with industry and government laboratories.

The engineering courses focus on technology development and space systems design. The industry-led projects provide practical experience in application of concepts developed in class to real-life space system projects.

Space management classes teach the systems approach to conceiving, designing, manufacturing, managing, and operating complex space systems. These classes and space policy classes expose students to common space systems problems and the management methods used to mitigate them.

STRATEGIC DIRECTIONS



Understanding Weather and Climate Systems

Challenge

We need detailed and accurate understanding on how the changing climate will impact the environment and society on both global and local scales in order to take optimal mitigation and adaptation actions.

Our Contribution

We characterize environmental change in local and global scales. We observe, model, and project the impacts of extreme weather and climate on society. We foster the process understanding of weather and climate phenomena, and we develop innovative observations and models of the Earth system.

Our new endeavors tackle extreme weather both through next steps in data science and machine learning in the context of Earth System Models, and by developing the next-generation instrumentation for hurricane monitoring to follow the highly successful CYGNSS satellite mission.

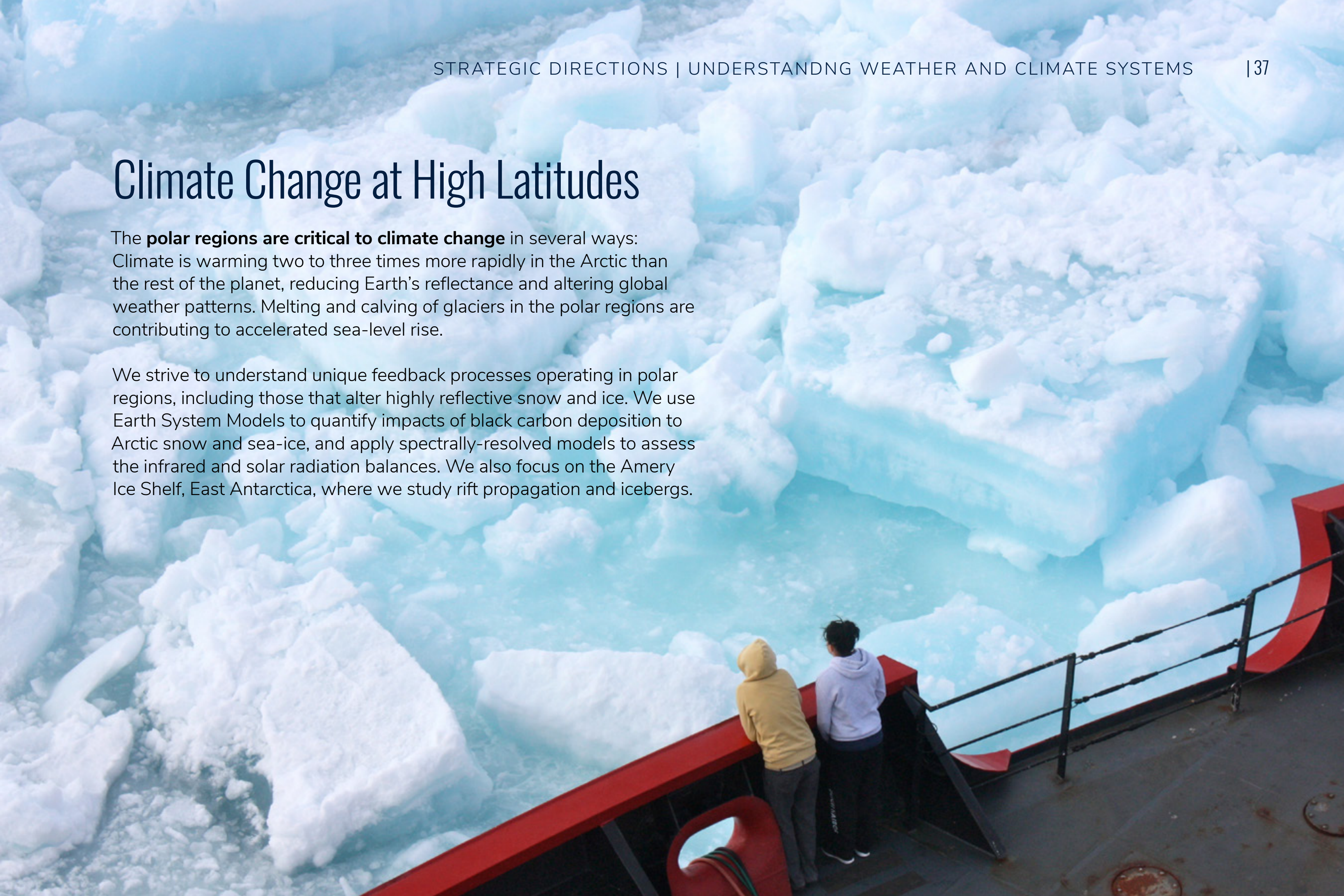
Broader Impact

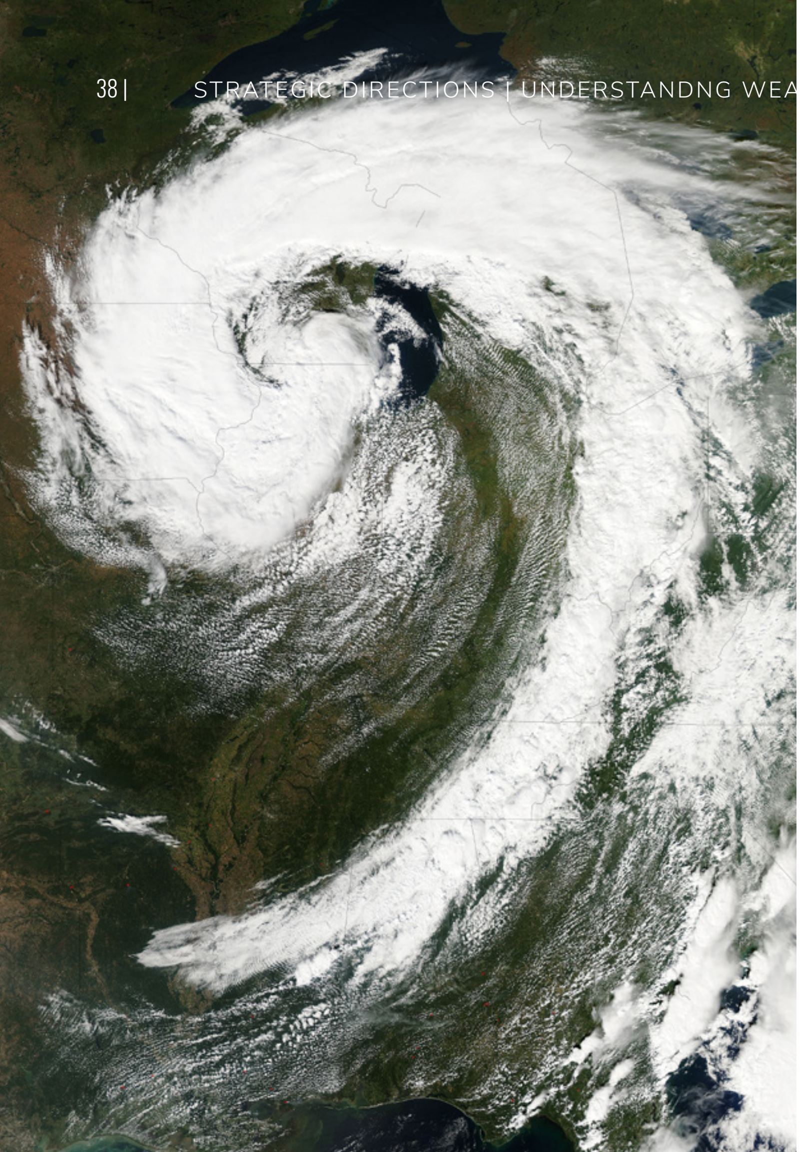
Our research advances weather and climate models, and our results are used to inform national and regional policy makers. We contribute to climate change solutions and guide mitigation and adaptation approaches. Our research-based interdisciplinary education trains the next generation of engaged citizens to tackle the challenges of climate change.

Climate Change at High Latitudes

The **polar regions are critical to climate change** in several ways: Climate is warming two to three times more rapidly in the Arctic than the rest of the planet, reducing Earth's reflectance and altering global weather patterns. Melting and calving of glaciers in the polar regions are contributing to accelerated sea-level rise.

We strive to understand unique feedback processes operating in polar regions, including those that alter highly reflective snow and ice. We use Earth System Models to quantify impacts of black carbon deposition to Arctic snow and sea-ice, and apply spectrally-resolved models to assess the infrared and solar radiation balances. We also focus on the Amery Ice Shelf, East Antarctica, where we study rift propagation and icebergs.





Earth System Predictions

Earth System Predictions span timescales from the daily weather, to subseasonal and seasonal timescales, to multiannual and multidecadal time periods. Weather Prediction Models are now extended to provide weather guidance for 3-4 weeks in advance. Earth System Models assess how the Earth system will respond to changing concentrations of greenhouse gases and other short-lived pollutants.

The longer-term climate assessments crucially depend on the physical representations of all Earth system components, including vegetation, oceans, ice sheets, and the atmosphere. On the weather timescale, the coupled ocean-atmosphere interactions are important for predictions of tropical cyclones. Modern research is thus transitioning to fully coupled modeling frameworks paired with data assimilation capabilities, which provide the initial state of the Earth system.

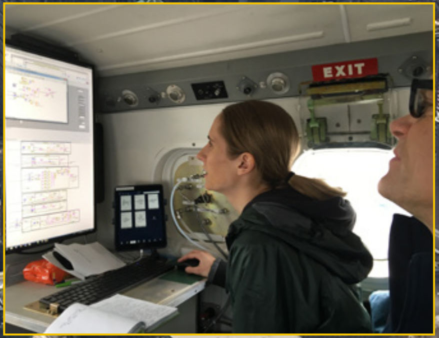
As part of a national community effort, we develop weather prediction and Earth system models across a wide range of spatial and temporal scales. We develop numerical methods to represent local and regional phenomena such as tropical and extratropical cyclones, or mesoscale convective systems within the global models. We also develop rigorous methodologies to compare the model outputs with observations to assess model performance on weather, seasonal, annual, and decadal time periods. These modeling tools are used to understand climate change questions such as future climate-carbon interactions or impacts of black carbon on the Arctic climate.

Changing Composition in the Earth's Atmosphere

Methane follows carbon dioxide as a major driver of climate change, but we have relatively poor understanding of what is controlling current levels and how future atmospheric methane will behave.

We lead development of new approaches to tackle the methane challenge, in particular through airborne and space-based observation campaigns. We address methane emissions from large cities, a previously neglected potential source. Survey flights along the U.S. East Coast revealed large emissions from urban natural gas systems, with leaks measured at nearly twice the estimates by the Environmental Protection Agency.

Work in Climate & Space sheds light on the unexpected and unexplained long-term trends in the global methane budget, identifies mitigation opportunities, and has already impacted legislation at the national and state levels.



Great Lakes Research

The Great Lakes contain about twenty percent of the world's surface fresh water, and represent an important economic, recreational, and cultural resource for the region. We investigate how this regional resource will respond and adapt to the changing climate. In addition, we advance the predictive capabilities for the Great Lakes region, and contribute to the coupling of the lakes to the atmosphere for use in NOAA's weather prediction models.

Recent years have seen record high water levels (e.g. in winter of 2020 on Lakes Erie and Superior), as well as record low water levels (e.g. in 2013 throughout the entire Great Lakes basin). High water levels cause shoreline erosion and flooding, while low water levels impact fishing, shipping, and recreation. Both effects impact the professional and personal lives of over 30 million people living in the region.

We work to understand the influence of climate change on both water quantity and quality, e.g. through formation and growth of the harmful blue green algal blooms. Together with community partners in water treatment and recreational fishing and beach management, we develop strategies to prevent the algal bloom formation and mitigate its effects on society. We couple the **National Oceanic and Atmospheric Administration's (NOAA)** newest Unified Forecast System to a combined ocean-ice model which has been adapted for the Great Lakes. This joint work with NOAA's **Great Lakes Environmental Research Laboratory** and the **National Weather Service / Weather Forecast Office Detroit** demonstrates that the lake atmosphere coupling improves lake-effect snow forecasts during the winter season.

Space Weather

Challenge

Forecasting the impact that space weather has on humans and infrastructure in space and on ground requires understanding how the Sun drives extreme conditions in the space environment.

Our Contribution

We develop, operate, and analyze data from space instruments to gain further understanding of the processes associated with space storms. We develop models to improve understanding of space weather drivers, and to support NOAA 24/7 prediction services. Our space weather research continues its strong experimental component through new space missions, including the recently selected **SunRISE** mission (scheduled for launch in 2023) focusing on the Sun, and the upcoming opportunities in the **Geospace Dynamics Constellation (GDC)** mission to study the Earth's upper atmosphere.

Broader Impact

Our research products help protect communication systems, technological infrastructures, and their operations on ground and in space. The models we develop enable robust engineering solutions to mitigate space weather effects. At the same time, the models can be used to protect human space explorers in Earth orbit and beyond thereby facilitating crewed space exploration. Our research-based, multidisciplinary education trains next generation of scientists to develop instruments, advance understanding, and improve quantitative forecasting.

The Sun and the Heliosphere

The Sun is the source of energy and the driver of space weather processes in space, in the upper atmosphere, and on the ground. As our closest star, we can study it in high detail to understand its stellar evolution and dynamical processes.

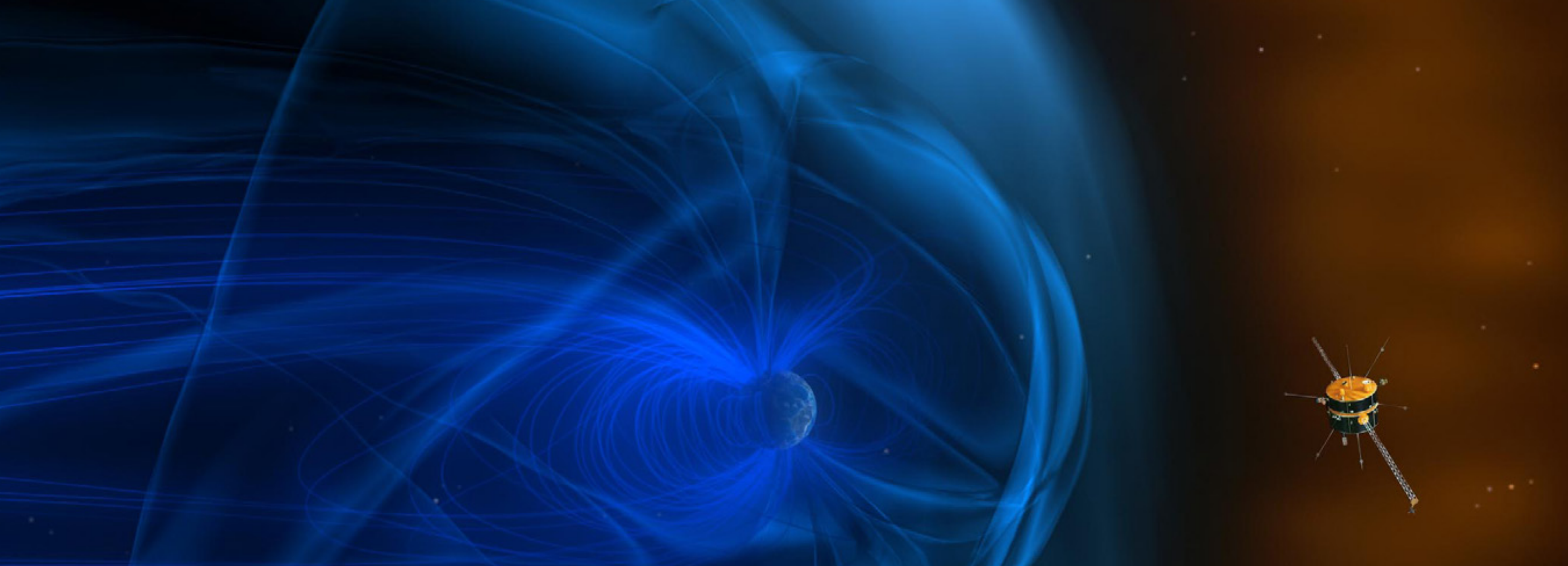
Our experimental solar physics research is expanding with the combination of **Parker Solar Probe** (launched 2018) reaching close proximity to the Sun; the **Solar Orbiter** (launched 2020) providing the first ever view of the Solar polar regions; the **Daniel K. Inouye Solar Telescope** (DKIST) observatory providing detailed spectrographic measurements of the solar surface; and the upcoming **SunRISE** mission to study energetic particles associated with space storms.

Understanding how the solar wind is generated and accelerated, and how it propagates through interplanetary space will help in predicting what our host star has coming our way. The Space Weather Modeling Framework simulates all of these processes, benchmarking against, and helping in the interpretation of the observations.

The Upper Atmosphere and Geospace

The solar wind impact in the near-Earth space environment includes couplings and feedbacks, preconditioning and memory. We use ground-based magnetic measurements, auroral and radar observations to monitor the effects of space storms in the upper atmosphere. We employ a large network of Global Navigation Satellite System (GNSS) receivers to evaluate the upper atmosphere total electron content, which is a key parameter determining the level of disturbances expected in satellite communication signals. The upcoming **Geospace Dynamics Constellation** mission will address many details of the magnetosphere – ionosphere – thermosphere coupling.

The **Space Weather Modeling Framework** is well suited to model many of these processes, and the code can run in real time. Furthermore, we use machine learning methods to predict the upper atmosphere total electron content, which will help address ionospheric space weather and its possible impact on navigation and communication systems.



Operational Space Weather Forecasts

The **Geospace Model** extends from the solar wind driver to the impacts in the upper atmosphere and on ground, with specific modules describing the details of the inner magnetosphere and upper atmosphere and ionosphere. An operational version is continuously developed and provided to the NOAA Space Weather Prediction Center. Through NOAA, we provide services to stakeholders whose systems may be vulnerable to space weather hazards.

Challenge

In order to fully explore the possibility of existence of life on other planets or stellar systems, it is necessary to understand the conditions and processes at the Sun and the planets of both our own Solar System, as well as in other star systems.

Our Contribution

We develop space mission concepts, and build and operate space instruments. We develop data analysis techniques and models, which are used together to draw conclusions of the key processes and conditions in the heliosphere and other planetary systems.

Our planetary exploration continues with two missions probing the Jovian system, the **Europa Clipper** and **Jupiter Icy Moon Explorer,** especially targeting the existence of liquid water.

Broader Impact

Space exploration engages and excites the public, and offers an opportunity to convey the results of recent scientific and technological advances, thereby advancing public perception of science and engineering. The scientifically and technically challenging projects require advanced solutions that can have applications also in other environments and industries. Our students and scientists gain skills that facilitate discovery and innovation.

Space Exploration

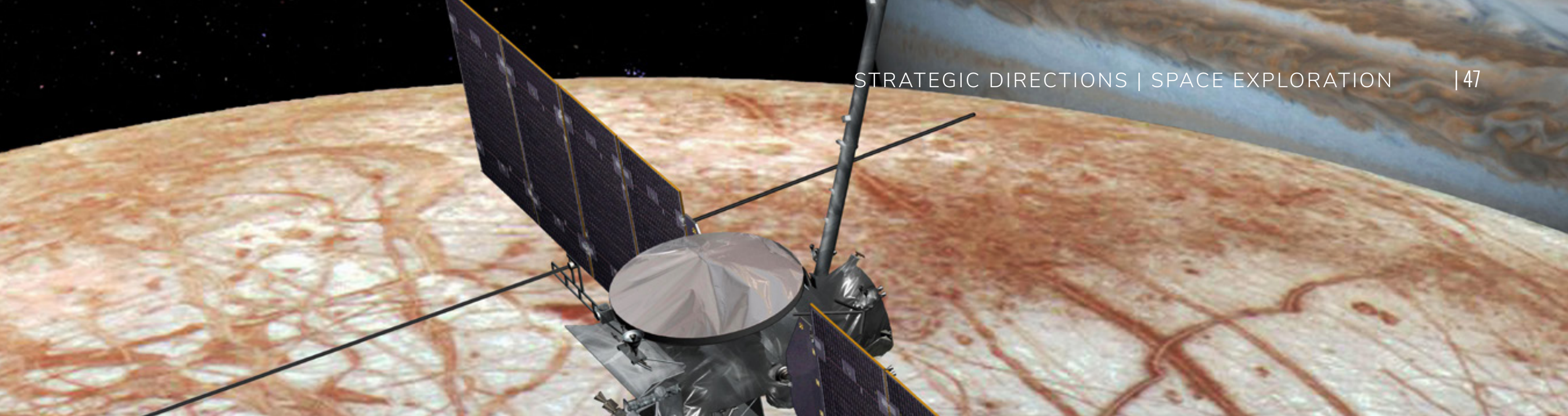
Rocky Planets

The inner solar system planets form an interesting combination for our comparative studies, as Mercury and Earth have magnetic fields while Mars and Venus do not. Venus and Earth have dense atmospheres, while the atmosphere of Mars is tenuous, and Mercury has none. It is often stated that Mars represents the primordial Earth, while Venus is the greenhouse effect taken to its extreme.

We are leaders in the science of Mercury's exosphere and magnetosphere created by the interaction of the solar wind and the planet's global magnetic field. Using our **Fast Imaging Plasma Spectrometer** and the magnetometer onboard the **MESSENGER** mission that orbited Mercury from 2011 to 2015, we showed that Mercury experiences the most intense and dynamic space weather in the Solar System due to its close proximity to the Sun. Our Mercury science work will continue with new measurements from the **BepiColombo** mission that will arrive at Mercury in 2025.

With the **Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging Plus (DAVINCI+)** mission team, we will lead the effort on the origin and evolution of the Venus atmosphere, which will shed light on terrestrial planet formation in our solar system and around other stars.

Mars is the closest planet to Earth and thus a natural target for research. We develop instruments and measurement techniques to explore the habitability potential of the planet, and study the atmosphere, surface, and soil as part of NASA's robotic exploration missions. Studies of our sister planet shed light on own planetary evolution, as well as the current states of all inner planets.



Icy Worlds

The moons of the gas giant planets Jupiter and Saturn offer an exciting opportunity to probe objects that may host liquid water and thus have potential for sustaining life. Climate & Space research focuses on the planetary space environments and their interaction with the moons, as well as conditions on the moons' surfaces and atmospheres.

Our earlier study of the Jovian moon Europa showed first evidence of active subsurface processes driving eruption of plumes from Europa's surface into space. The **Europa Clipper** mission (scheduled for launch in 2022) will explore the moon's ice shell and ocean, as well as the possibility of liquid water within or beneath the ice. Our magnetic sounding instrument is key to determining the ice shell thickness and ocean depth and salinity. We also develop models of the plasma interaction with Europa and its exosphere to characterize the plasma and magnetic environment surrounding the moon.

Ganymede, the largest moon in the solar system, has a strong internal magnetic field that creates a mini-magnetosphere around the moon. The upcoming **Jupiter ICy Moon Explorer (JUICE)** mission (scheduled for launch in 2023) will sample key regions of Ganymede's magnetosphere and interior structure, especially the sub-surface ocean. As part of the particle, magnetic, and wave instrument teams, we already develop models for the moon and its environment.

Tools for Discovery

Challenge

Paradigm shifting engineering is necessary to monitor and protect our planet and to explore the wide-ranging processes and far-reaches of the solar system. New data science tools, such as machine learning, are emerging and have the potential to transform our data analysis capabilities.

Our Contribution

We develop innovative engineering solutions for new instruments, space missions, and new methods for data analysis and modeling. We introduce new technologies to new space industry and to the broader society through technology transfer, and through industrial partnerships in our educational and research projects.

Broader Impact

Ambitious research has always been a technology driver, and the harsh conditions in remote areas such as the Arctic, Antarctic or the space environment drive automatization and autonomous/remote operation, reliability, durability, and miniaturization and embedded systems architecture. All of these technologies have significant applications in other industries and in the wider society. To meet the projected growth, the new space industry will require science and technology experts capable of developing new solutions for the industry and society at large.

Engineering Solutions

We develop new technologies for instruments, measurement systems, and spacecraft systems both for climate and space science applications. The instruments and space missions are often realized through large national or international collaborations, in which the time from design to operations can last from a few years to well over a decade. Despite the complexity, we involve our students in all activities, including mission design, data acquisition and analysis, and incorporating the results into models.

Climate & Space is one of only a few departments in the nation with the capability to realize complete space missions, ranging in size from the miniature CubeSats to large-scale planetary missions. To fully leverage the novel model-based engineering and 3-D prototype printing tools, we are planning to create a new makers' space for both researchers and students to facilitate ideation of next-generation instruments and spacecraft.

Our students build CubeSats and other small satellite missions, which have the advantage of a much shorter time span from planning to launch. The rapidly developing technologies now allow the use of advanced instrumentation that can bring valuable science results even from the smallest of satellites.

Modeling and Data Science

We are forerunners in developing physics-based, coupled multisystem models for both Earth System and Solar System science.

We advance Weather Prediction and Earth System Models and explore the coupling of the atmosphere to the biosphere, hydrosphere, and cryosphere from below, and to the ionosphere and magnetosphere from above. These models are developed as large community efforts coordinated by the **National Oceanic and Atmospheric Administration (NOAA)** and the **National Center for Atmospheric Research (NCAR),** and target scales ranging from local weather phenomena to the evolution of the climate over centuries and millennia.

The **Space Weather Modeling Framework** couples models of the Sun and the Heliosphere with a set of models describing the space environments of the Earth and other planets. The framework is among only a handful of space weather models capable of operational use, and even fewer that can describe the entire system from the Sun to the surface of the Earth.

We collaborate with data scientists to develop and apply powerful Machine Learning methodologies to space weather, as well as weather and climate predictions and problems. Our research advances physics guided and interpretable machine learning methods to make them robust, reliable, insightful, and less sensitive to noisy or missing data. Combining observations, theory, physics-based models, and machine learning methodologies provides a powerful tool to provide more accurate forecasts over longer timescales.

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As part of the U-M College of Engineering, Climate & Space combines science and engineering, offering an integrated view of Earth and space for climate studies, planetary science, instrumentation, and large-scale modeling.

Our students gain practical, hands-on experience that brings together science and engineering. They learn to think collaboratively, to focus on discovery, paradigm-shifting engineering solutions, risk-taking, and creativity. Our faculty bring their everyday research activities into the classroom, and include both undergraduate and graduate students as part of their research project teams.

Climate & Space students learn about entrepreneurial engineering in a teaching facility and idea accelerator, giving them a strong foundation to become the next generation of innovators and explorers serving the common good.

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