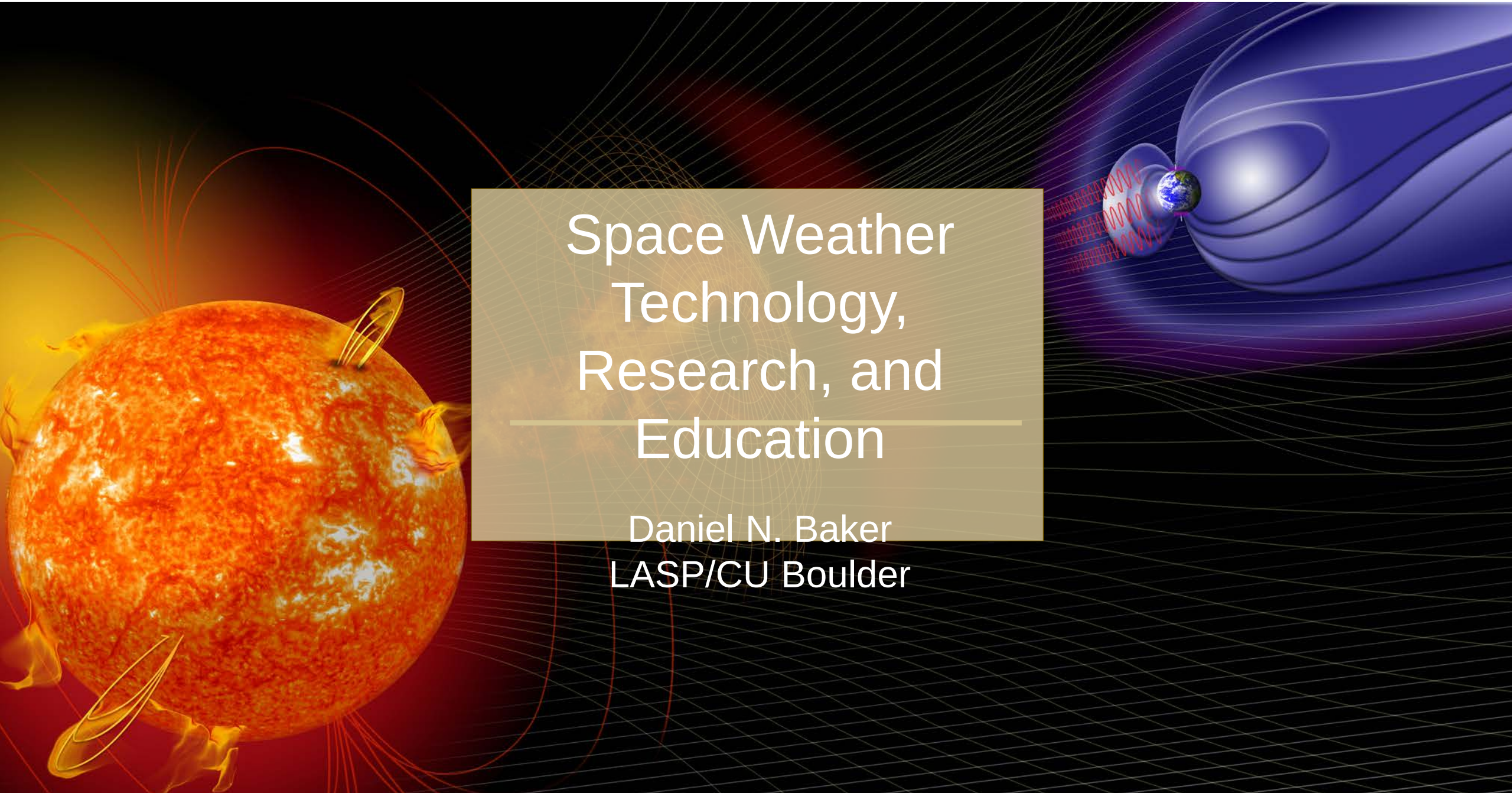

Space Weather Technology, Research, and Education

Daniel N. Baker
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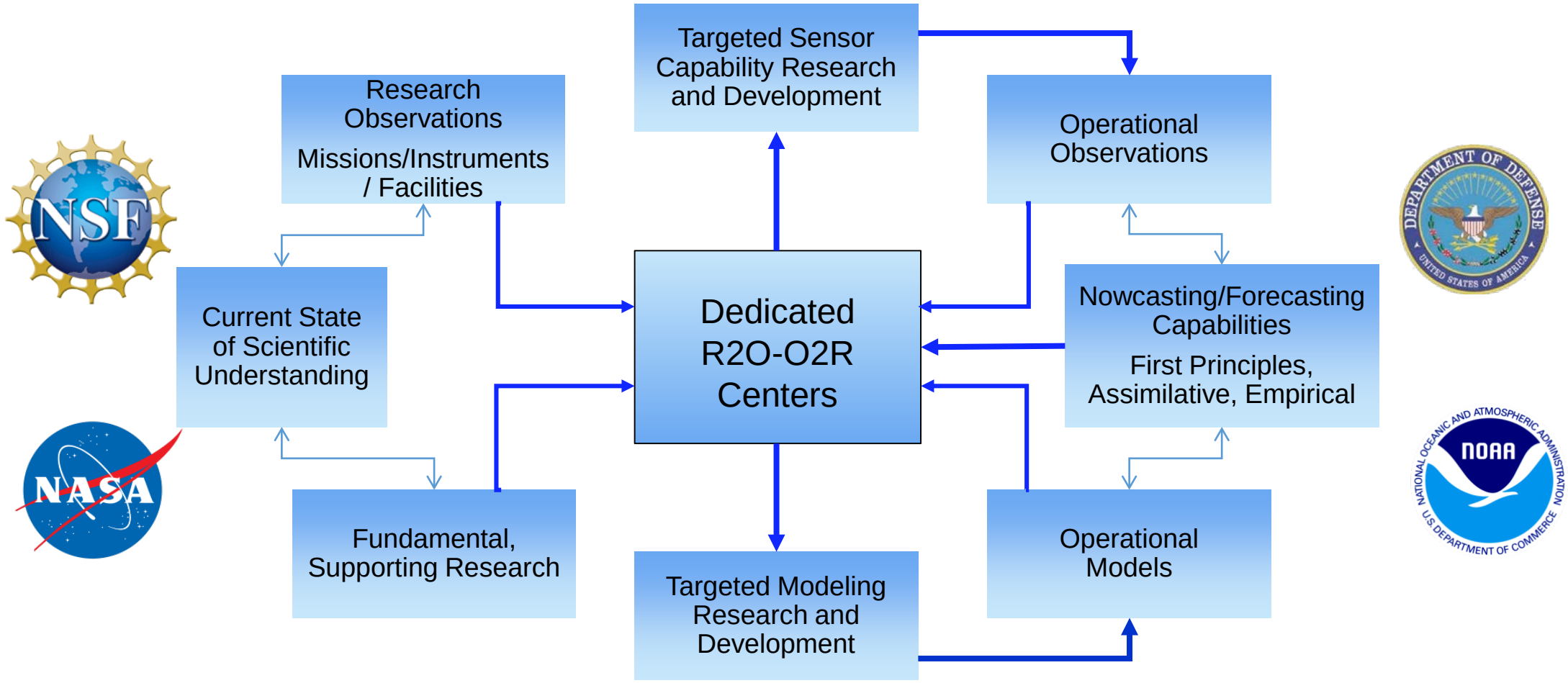
Problem Statement(s)

1. **Space weather (SWx) forecasting is not accurate, reliable, or timely enough to allow mitigating actions by users of the information.**
    - 24-hour solar forecasting is barely better than climatology (average rate forecast).
    - Radiation events remain a mystery: some very large eruptions cause events, some don't.
    - Current error in geomagnetic storm forecasts = ±6—12 hours.
2. **Transition of new research models, mission data, and tools to operational forecasting is inefficient. "R2O problem"**
    - Full-physics satellite drag models + vehicle gas dynamics simulations.
    - Van Allen Probes radiation belt data.
    - Application of artificial intelligence to space weather prediction.
3. **Researchers are unaware of the requirements (and shortcomings) of operational models and tools and cannot help. "O2R problem"**

Addressing the R2O and O2R Problems



Space Weather Testbeds

Enabling SWx O2R

Operational Model Copies

NRT Operational Data

SWx Data Portal and Archive

Data Improvements

Model Improvements

Tool Innovations

Operationally Validated Result

Required Education Program

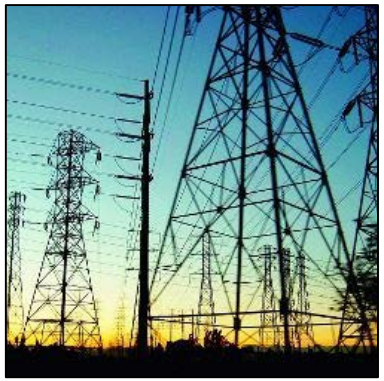
Undergraduate, Graduate, & Professional Curricula

Focused SWx Science Topic Workshops

SWx Summer School Contributions

Academic SmallSat Programs

Operational Forecasting Focused Workshops



Infrastructure & Policy Makers Communications Programs

EDITORIAL

Space, still the final frontier

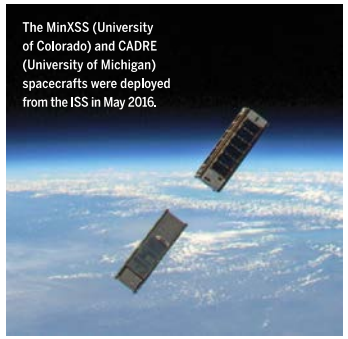
This week in Pasadena, California, the International Science Council will convene its Committee on Space Research (COSPAR) Scientific Assembly to promote the exchange of results, information, and opinions in space research. Since its creation 60 years ago, on the heels of the 1957 launch of Sputnik by the Soviet Union and of Explorer 1 by the United States in early 1958—events that marked the dawn of the space age—COSPAR has nurtured partnerships between nations pursuing space science. There is a new space age now—one with many more players and exciting technologies to harness. New capacity-building endeavors at universities worldwide are providing opportunities for involvement in space missions, both great and small.

At the height of the Cold War in the 1960s and 1970s, space science and human space exploration offered a channel for citizens from the East and West to communicate and share ideas. Space has continued to be a domain of collaboration and cooperation among nations. The International Space Station has been a symbol of this notion for the past 20 years, and it is expected to be used by many nations until 2028. By contrast, there have been recent trends toward increased militarization of space with more—not less—fractionalization among nations. As well, the commercial sector is becoming a key player in exploring resource mining, tourism, colonization, and national security operations in space. Thus, space is becoming an arena for technological shows of economic and military force. However, nations are realizing that the Outer Space Treaty of 1967 needs to be reexamined in light of today's new space race—a race that now includes many more nations. No one nation or group of nations has ever claimed sovereignty over the "high frontier" of space, and, simply put, this should never be allowed to happen.

The good news is that there is room to further expand interest in space research. In addition to the huge missions run by the U.S. National Aeronautics and Space Administration, the European Space Agency, or private entities like SpaceX, small space activities are burgeoning. Today, there are many academic space science programs around the world because of growing student interest in the relevant education and training. To create sustainable space programs at universities, capacity building is required that goes beyond space engineering. For example, the International Satellite Program in Research and Education (INSPIRE) grew out of courses at the University of Colorado to teach aspiring students not only about the design and development of small spacecraft, but also the outstanding science that can be accomplished with such missions. Since 2015, INSPIRE has brought together universities to both fund and develop real hands-on space missions. It now has member universities and institutes from over a dozen nations (predominantly in Asia). Together, these partners secure funding and contribute complementary technological know-how and resources to launch new small space missions. Four separate "smallsat" projects currently involve the University of Colorado at Boulder in the United States, Nanyang Technological University in Singapore, the Indian Institute of Space Science and Technology in India, and National Central University in Taiwan. For universities in developing nations, showing that one can design, build, launch, and operate a spacecraft that can contribute to new advances in Earth and planetary sciences demonstrates that one truly deserves a "seat" at the proverbial international table. Beginning on a small scale of cooperation on microsatellites could open doors to collaboration on bigger scientific and technical programs and opportunities, fortifying relationships that may one day play a key role in other diplomatic interactions.

As was true during the Cold War, there are still political differences on Earth, but in space we should together seek to push forward the frontiers of knowledge with a common sense of purpose and most certainly in a spirit of peaceful cooperation.

–Daniel N. Baker and Amal Chandran



The MinXSS (University of Colorado) and CADRE (University of Michigan) spacecrafts were deployed from the ISS in May 2016.

"There is a new space age now—one with many more players and exciting technologies to harness."

PHOTOS: (INSET) ESA/NASA; (RIGHT, TOP TO BOTTOM) PATRICK CAMPBELL/UNIVERSITY OF COLORADO; UNIVERSITY OF COLORADO AT BOULDER

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We can do much better.