THE STATE OF PLANETARY AND SPACE SCIENCES IN AFRICA

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Africa has an enormous potential to provide insights into planetary and space sciences, but it has remained largely untapped. Fostering a new generation of scientists promises far-reaching benefits.

The scientific and societal value of exploring our solar system and studying the meteorites that fall to Earth is widely accepted in today's scientific community. However, not all regions of the world have been able to assert themselves in this endeavor. Africa in particular is underrepresented in planetary and space sciences (see page 21).

Planetary and space science (PSS) research groups are now emerging in Africa (see Figure 1), but they remain scattered and underfunded. Here we review PSS programs in Africa and pinpoint ways to further elevate PSS.

PSS is a vast domain of research, so we have focused on the exploration of the solar system, the study of planetary material (meteorites), and global-scale processes affecting planets (e.g., impact cratering).

PSS in Southern Africa

Southern Africa has a strong PSS presence and the most advanced facilities on the continent, including the South African National Space Agency and the South African Astronomical Observatory (founded in 1820). The world's largest radio telescope project, the iconic Square Kilometre Array (SKA), is currently being built in the deserts of Australia and South Africa.

The SKA has strong government support, but the planetary sciences have no dedicated academic or research programs in southern Africa. Isolated groups work on specific

A view of the night sky from Egypt's Katameya Observatory, which has the largest telescope in the Arab world. Credit: Islam Hassan, CC BY-SA 2.0 (http://bit.ly/ccbysa2-0)

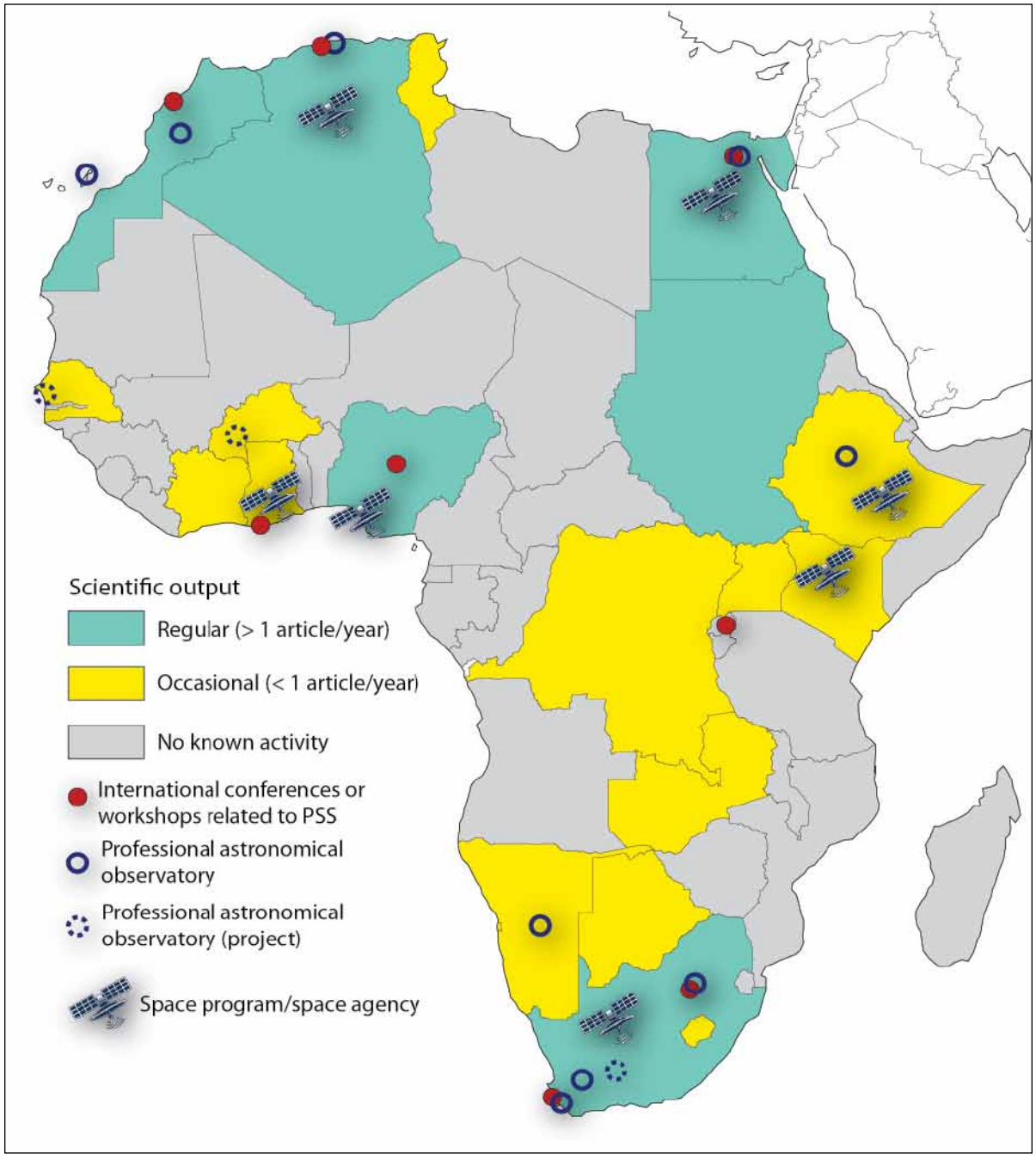

Fig. 1. Map illustrating the emerging activities in planetary and space sciences in Africa. Color codes represent results from a preliminary scan of published journals. The use of "project" here means that plans are in place to build facilities. Credit: David Baratoux

projects, such as meteorite and impact cratering studies, stellar occultations, asteroid detection and characterization, and lunar laser ranging.

Efforts in North Africa

In North Africa, Morocco has gained visibility in meteoritics and impact studies [e.g., *Chennaoui Aoudjehane et al.*, 2016] with the organization of international conferences, outreach programs (e.g., Space Bus Morocco), and frequent radio and TV appearances. The Ibn Battuta Center in Marrakesh is testing instruments and subsystems related to Martian exploration. In addition, a group of astronomers at Cadi Ayyad University (Marrakesh) has established the first astronomical observatory in the Atlas Mountains of Morocco [*Benkhaldoun et al.*, 2005].

The Algerian state has also endeavored to promote PSS through higher education reforms and development of its research infrastructure. Ongoing research is focused mainly on meteorites and impact craters and involves international collaboration [e.g., *Lamali et al.*, 2016;

A group of researchers mounts a device called the Sutherland High-speed Optical Camera (SHOC) on the 74-inch (~188-centimeter) telescope at the South African Astronomical Observatory near Sutherland, South Africa. The instrument observes stellar occultations by small bodies in the outer solar system. The project is fully funded by the South African government. Credit: Amanda Sickafoose

Sahoui et al., 2016]. Professional–amateur collaborations are common in Algeria [*Mimouni*, 2011]; events to foster such collaborations include, among other things, preparatory training courses and astronomical observations of recent asteroid occultations.

In addition, the Arabian Geosciences Union launched a section on planetary science and astrobiology in 2015 for PSS scientists across northern Africa and the Middle East.

East Africa PSS Programs

Remote sensing techniques are the cornerstone of PSS; knowledge of these techniques allows researchers to develop skills that are widely applicable in Earth, environmental, and atmospheric sciences. Recognizing this, Egypt has established a National Authority for Remote Sensing and Space Sciences (NARSS), which focuses on acquiring technical knowledge and capabilities to build small research and remote sensing satellites. NARSS also addresses environmental management and resource exploration.

Currently, the Egyptian government is establishing the Egyptian Space Agency in collaboration with China. The National Research Institute of Astronomy and Geophysics in Egypt operates the Katameya Observatory, which has the largest telescope in the Arab world. The institute also is planning to build an observatory on top of Mount Sinai.

The Egyptian Geological Museum in Cairo houses a small meteorite collection, including a specimen of the Nakhla Martian meteorite, which fell to Egypt in 1911. The exhibition is open to the public. In addition, Egypt has started a program for promoting science, technology, engineering, and mathematics (STEM) by establishing 11 STEM schools distributed across the country.

Ethiopia's vision for its space program is to focus its priorities toward serving local needs such as communication and agriculture. Ethiopia is home to the privately funded Entoto Observatory and Research Center, which is located on top of 3200-meter-high Mount Entoto, near Addis Ababa.

Kenya is taking advantage of its equatorial position to efficiently launch satellites. Its capital Nairobi also hosts a regional SERVIR facility for eastern and southern Africa; SERVIR is a joint venture by NASA and the U.S. Agency for International Development that supports satellite-based

A Landsat view of the Aouelloul impact crater in Mauritania. The crater is 390 meters in diameter and formed when a meteorite struck 3 million years ago. Mauritania and other West African countries hold several confirmed or potential impact structures that are awaiting initial or more detailed field studies. Credit: USGS/NASA

Earth monitoring and modeling in developing nations around the world.

PSS in West Africa

In West Africa, Nigeria's National Space Research and Development Agency (NASRDA) focuses on environmental management, resource exploration, communication, and defense projects.

The Ghana Space Science and Technology Centre, with current projects in radio astronomy, was established in 2012. This summer, Ghana launched its first satellite (Ghana-Sat-1) into space from the International Space Station.

The University of Ghana in Accra offers courses in geochemistry, including one that focuses on cosmochemistry. A network of international collaborations among Ghana, Europe, and North America was established around the time of the International Continental Scientific Drilling Program project at the Bosumtwi impact crater in Ghana in 2004. This collaboration resulted in several local scientists receiving advanced degrees overseas before returning to Ghana, and the program stimulated Ghanaian ecotourism [e.g., *Boamah and Koeberl*, 2007].

The Senegalese Association for the Promotion of Astronomy is very active in public outreach and has its own Space Bus program. PSS is virtually nonexistent in central Africa, but basic planetary sciences may be taught locally at the undergraduate level.

A Look to the Future

Recent strides in fostering PSS across Africa illustrate the key role played by a few dedicated individuals, particularly when they are supported by political will favoring the training and academic recruitment of a knowledgeable young generation. Such political will anticipates a return on investment: In Africa, as in the rest of the world, government investment in research and education is motivated by projected social and economic benefits.

Wider sharing of knowledge may have positive impacts on the private sector; facilitated access to space-based geostrategic data may attract investment in mineral resources as well as infrastructure development. Increasing innovation and patents with economic spin-offs requires an increasing number of professionals with engineering skills. The wider use of satellite data can assist in finding solutions to environmental, agricultural, and health issues (e.g., desertification, deforesta-

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Africa Initiative for Planetary and Space Sciences

Imagine a group of academic subjects that could help Africa to inspire youngsters, spur innovation, develop local economies, solve pressing problems, and even foster regional peaceful coexistence. Can such a panacea exist?

We strongly feel that it can. The subjects? Planetary and space sciences (PSS). In many areas of the world, investment in planetary and space science kick-started a wave of technological development and interest in science that propelled countries forward. A survey of almost 800 researchers who published in *Nature* between 2005 and 2008 revealed that half of them were inspired by the Apollo missions to pursue science—and not just astronomy or planetary sciences [*Monastersky,* 2009].

To elevate planetary and space science across the entire African continent, we propose the Africa Initiative for Planetary and Space Sciences (AFIPS; https://africapss.org/), an idea that stemmed from a panel discussion during the planetary science sessions of the 35th International Geological Congress (IGC) in Cape Town, South Africa, in 2016. Here we list a series of recommendations for expanding and structuring PSS across Africa.

Why Focus on PSS in Africa?

Unlike their counterparts in North America, Europe, and Asia, African nations do not have large, dedicated PSS programs that have international visibility. If scientific output can be measured in publications, Africa produces less than 1% of the world output in PSS, despite having more than 15% of the world's population (see Figure 1 at http://bit.ly/Eos-AfricaInitiativePSS).

What factors cause this low rate? Most glaringly, several countries lack a critical mass of requisite experts in science, technology, engineering, and mathematics (STEM) subjects. In addition, there's a widespread misperception that funding fundamental science costs society a lot but has little or only long-term societal impact. Such thinking limits national or international investment in PSS in African countries, from primary school through university research.

But overcoming this obstacle offers many opportunities. PSS teams often involve physicists, chemists, geologists, biologists, and engineers working on a common problem. This multidisciplinary aspect serves as a template for tackling pressing issues in our modern world.

What's more, expanding PSS may help to address several of the United Nations' Sustainable Development Goals that have already captured the interest of African governments: quality education, economic growth, reducing inequalities, climate, and peace.

PSS focuses on universal questions, such as the origin of life and the evolution and habitability of planets. Facts gained through science also help to fight against obscurantist tendencies. The subjects inspire people to think of the world as a single planet, not as a collection of countries. This favors international and intra-African cultural exchanges, which may contribute to peace alongside economic and social development.

What Does Africa Need to Foster PSS Education?

Students at most African high schools are not exposed to basic knowledge in astronomy and space science. We recommend a continent-wide effort to enhance teaching programs to fill these gaps.

Next, undergraduate students should be familiarized with the origin of Earth and other planets. The introduction to PSS should be the occasion to learn about the scientific value of the African impact cratering record and the wealth of scientific information gleaned from the numerous meteorites collected on the African continent.

Basic courses should include stimulating practical work, such as the analysis of planetary data and the examination of meteorites. Such practical courses require the creation and curation of meteorite collections in African museums.

From these courses should emerge opportunities to study space exploration techniques and become familiar with sensors used to analyze the surface and interior of planets. Pathways to research programs offered by major space agencies should also be cultivated.

To consolidate resources, the few African universities that already have emerging PSS groups are encouraged to commit to close interaction with key neighboring and overseas partners (universities and funding and space agencies). African students commonly move between countries and universities with diverse curricula, and these PSS programs may attract highly motivated students from neighboring countries.

Filling This Need: The Africa Initiative for Planetary and Space Sciences

We propose initial investment for a 5-year program that prioritizes M.Sc. and Ph.D. scholarships, temporary study-abroad fellowships for M.Sc. and Ph.D. candidates, and visits of junior (volunteering Ph.D. students) and senior researchers to Africa for transfer of knowledge. After a fourth-year review, the program could be renewed for another 5 years, with the longer-term goal of building a 20-year plan.

Initially, students receiving fellowships should be selected in countries with emerging groups in PSS, and the research topics should be defined in relation to local expertise and scientific priorities. The program must be advertised to ensure that the local population and political authorities are able to grasp the outcomes of new groups of pioneering academics who will be moving Africa ahead.

The definition of research projects under this new effort should be based on local expertise and strengths.

Tapping into Africa's Wealth of Geological History

The African geological record offers fertile ground for understanding processes on other planets. AFIPS could tap into this record.

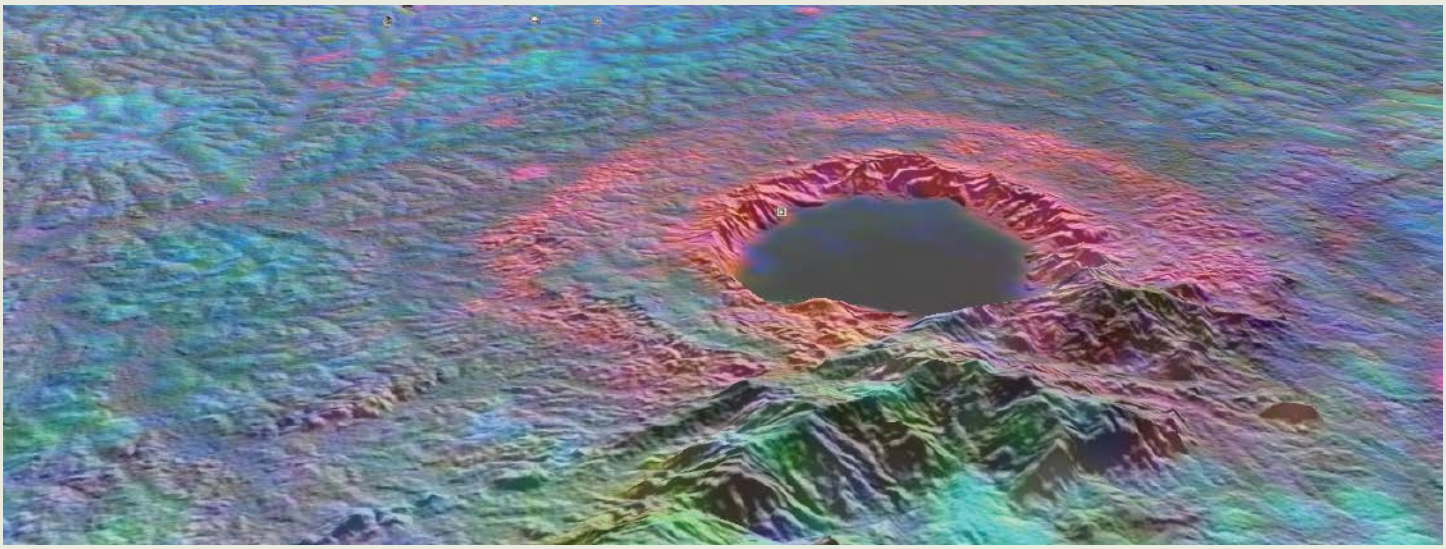
For example, planetary scientists have explored dry lakes in the Egyptian Western Desert to understand alteration signatures in the arid environment of Mars. Other planetary analogues include large meteorite impact structures, such as the Vredefort Dome in South Africa and the Bosumtwi impact crater in Ghana, and the active volcanoes and hydrothermal systems of the East African Rift. African deserts, in particular, the Sahara, are among the best places in the world to collect meteorites

The African geological record extends for more than 3.5 billion years, with cratonic nuclei distributed throughout the continent, offering clues to understanding the coupled evolution of the interior, surface, atmosphere, and life on a habitable planet.

Science for Society

A key thread for AFIPS will be to harness PSS to help society. This involves not only pure research but also applied studies and conservation efforts.

Africa hosts 20 confirmed meteorite impact structures, including the largest and oldest on Earth (Vredefort, 2.02 billion years old). These structures, and specific sites therein, must be



False-color aerial view of Ghana's Bosumtwi impact structure showing surface enrichments of potassium (red), thorium (green), and uranium (blue) superimposed on a shaded relief image. The crater is about 10.5 kilometers in diameter and formed when a meteorite struck about 1 million years ago. Researchers hope to use geologic features like Bosumtwi to inspire the public and industries to become invested in PSS. Credit: David Baratoux/Geological Survey Department of Ghana

protected. AFIPS could be structured to show leadership in their conservation.

We also hope that through AFIPS, more African nations could take advantage of the clear night sky for observation of meteorite falls and of the dry conditions over a significant part of the continent for the preservation of ancient falls. We strongly feel that the curation of African meteorites in African museums for educational purposes will foster sustainable scientific and economic (tourism) development on local and regional levels, as well as contribute to education of the wider public.

We recommend that a regulatory framework be coordinated at the regional scale for efficient preservation of meteorites for scientific studies. It is our hope that through education efforts related to AFIPS, such coordination can be fostered.

Projects with implications for pressing issues (e.g., climate change and space environment) or a connection with industry will also be targeted by AFIPS. For instance, the study of shock deformation effects in natural impactites may serve the space industry, as it is related to the effects of impacts on man-made systems by micrometeorites.

Forging Partnerships

Academic staff training in PSS is a long-term effort. Here the Africa Initiative could mirror project frameworks of other science efforts in Africa. For example, Africa Array, a research and training program dedicated to continent-wide geophysics training that is run jointly by African and North American partners, is midway through a 20-year plan. The Africa Initiative requires a similar timescale.

Our initiative will build on the grassroots networks of African researchers, for example, the African Network of Earth Science Institutions, the African Academy of Sciences, the Geological Society of Africa, the West African Exploration Initiative (WAXI; see *Jessell et al.* [2016]), and the Young Earth Scientists Network.

African networks may partner with geoscience societies. For instance, Europlanet, an organization with substantial experience in engaging policy makers and European citizens with planetary science, is already working with African partners to create a coordinated outreach strategy for activities related to the Danakil region in Ethiopia (as a planetary analogue site). Efforts in the Africa Initiative could follow this and other similar examples.

African institutions must be made more aware of the resources readily available to them. These include data released by NASA and European Space Agency planetary missions along with tools and tutorials on how to process the data. The rise of open-access journals offers African researchers greater access to the scientific literature, which will help future researchers on the continent.

Endorsing the Africa Initiative for Planetary and Space Sciences

It is our conviction that the exclusion of one fifth of the world's population from taking part in the fascinating discoveries about our solar system impoverishes global science. The identified benefits for African society as a whole justify investment in continent-wide research and education programs in PSS. This call is also timely considering the 31 January 2016 adoption by the African Union of the African Space Policy and Strategy, which raises awareness of the central role of space science and technology in Africa's socioeconomic development.

We declare our commitment to the development and expansion of PSS in Africa. Our effort will be focused on fund-raising and elaboration of international collaborative programs, coordination at the institutional level, training M.Sc. and Ph.D. students, organization of workshops and PSS sessions at Africa-based conferences, communication, and public outreach. Already, 19 international organizations, including AGU, and 257 scientists around the world have endorsed the initiative.

We will attempt to mobilize domestic resources for the implementation of this policy and strategy. We are looking for a broader endorsement from the international PSS community and from key stakeholders on the African continent. Individuals and national or international organizations who would like to support this initiative are invited to sign up on our website: https://africapss.org/.

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Editor's Note: The authors of this sidebar are those who wrote the feature article "The State of Planetary and Space Sciences in Africa" (see page 16).

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tion, farming by satellite, and identification of factors controlling the spread of disease).

The knowledge gained and resources developed by current PSS efforts in Africa are only the beginning. As PSS grows in Africa, so too will its capacity to address the multiple challenges that this continent is facing for sustainable and inclusive economic growth.

Space Bus programs, such as this one in Senegal, promote planetary and space sciences to the general public. The bus follows an itinerary across the country and stops in several cities. At stops, interested people can gather to hear interactive talks and engage in hands-on activities related to telescopes, planets, and space exploration. Credit: Maram Kaire

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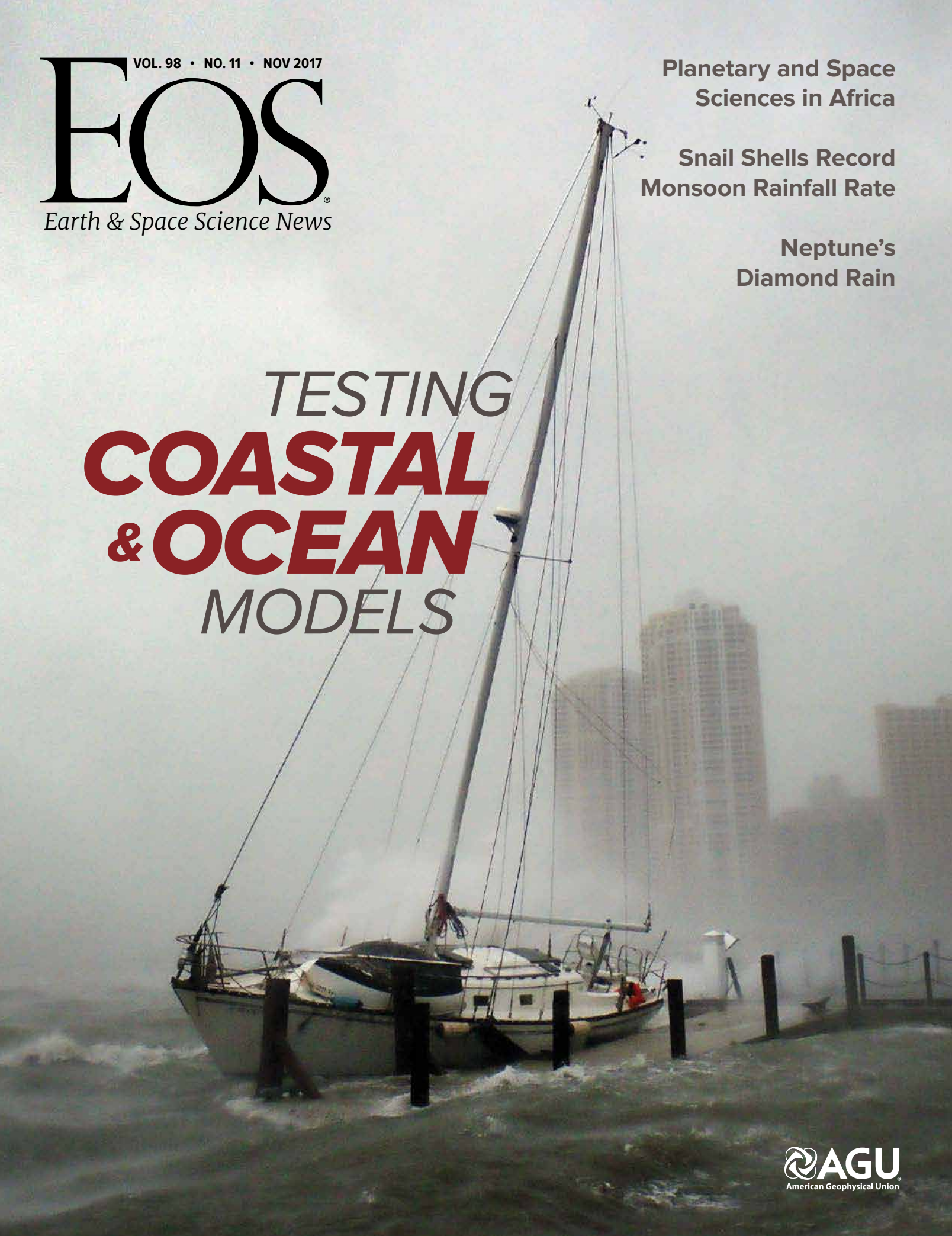

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