The Need for a National Earth Science Micro-Satellite Program

1. ***What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?***

Here we address a key challenge of ***operations*** in the coming decade. We introduce this challenge by reviewing how we arrived at our current state.

NASA has correctly identified two big questions permeating all of Earth Science research. (1) What is the current state of the global Earth System, and (2) How is the global Earth system changing now as well as in the future? At the heart of these questions is the concept of a global Earth system, a holistic view of Earth’s lithosphere, hydrosphere, biosphere and atmosphere, and humanity’s role as embedded in this system. This concept of the Earth System is relatively new, originating and evolving within NASA’s Mission to Planet Earth in the 1980s, the Earth Observing System (EOS) of the 1990s and 2000s, and continuing into the present day. Conceptualizing the Earth as a system led to the creation of all-encompassing satellite missions with flagship satellites carrying multiple sensors, accompanied by focused PI-led instruments. At the same time, this effort led to a successful ground-based infrastructure to receive, process, analyze, interpret, and disseminate the information and science derived from these missions. The NASA concept of an Earth system has resulted in the resounding use of Terra and the A-Train data, a global community that expects free and easy access to web-based data, and modeling infrastructure that includes assimilation, sub-orbital validation assets and networks. Together, all facets have led to an explosion of scientific output leading to a better understanding of our planet and the forces acting upon it.

It is 2015 now. Where do we stand?

To continue the scientific momentum generated by EOS, it is imperative to continue and expand the vision of the Earth as a system and employ a wide array of coincident measurement-based missions. One solution is to continue obtaining a wide array of measurements with “big” (EOS-like) or even “moderate” (Venture class-like) missions. Flagship missions that combine several important sensors and look for synthesis between measurements are an excellent strategy to meeting many key scientific goals. Such strategy would be obvious if cost were no object. But cost is always a factor, and seems to be increasingly so. There is a limit to how many flagship missions can fit within budget, and with the specialization of research communities, someone is not going to get what they need. Since the need for measurements is nearly unlimited, the key challenge is to maximize global observations and keep within a budget. Long-term measurements (climate quantities) continue to be important, but one size really does not fit all research and operational needs.

The current Earth Science program of supplementing large flagship missions with lower cost, competitively selected Earth Venture missions, instruments and sub-orbital programs has been essential to provide the wide array of data needed.

**We propose here to add a “Micro” Satellite program to the mix in the range between 1 to 100kg size**. The idea would be to enhance flexibility, increase capability and keep costs down.

1. ***Why are these challenge/questions timely to address now especially with respect to readiness?***

Building a space-worthy instrument is hard, but creating one for *scientific* use (calibrations, stability, etc) is even more difficult. Creating one that can fit within the dimensions of a micro spacecraft requires another level of complexity. When the micro satellite and Cubesat programs began, the emphasis was on education and the instruments were essentially toys. The next generation of micro-satellites was able to provide useable scientific data on space science such as space weather. Now, we are entering an era when these instruments are being built for Earth science applications.

The first to see the potential of pointing micro-satellites at the Earth have been private ventures, like Google or Planet Labs. They are currently using fleets of satellites equipped with simple imagers to take qualitative pictures from space. This is only the beginning.

There is no question that NASA has been preparing for this opportunity through the Earth Science Technology Office (ESTO) and its InVEST program. This program has invested in several micro-satellite projects, and the first set is reaching conclusion and should be ready to hitchhike aboard launches of opportunity as early as 2016. The next set of projects will soon begin their 2-year period of design, construction and testing, becoming ready for launch as early as 2018. These projects are highly innovative proving that the technology exists to construct sought-after Earth-viewing space sensors in miniaturized form for a fraction of the cost. For example, we have personal experience in developing HARP, an Earth-viewing multi-angle, multi-wavelength imaging polarimeter. HARP is based on a concept called PACS that has been flown successfully on the NASA ER-2. HARP, however, has been miniaturized to be roughly 1/10 of PACS’ volume and weight while keeping the same requirements. The technology of miniaturization makes an Earth science micro-satellite program viable and timely.

The ESTO InVEST problem is termed ‘technology demonstration’. The problem with the ESTO InVEST program is that it stops at the technology demonstration. There is no mechanism for turning these measurements into science, including algorithm development and data dissemination. The current Venture Class program allows for some micro satellite component but it takes second sit on the larger size missions. We need a comprehensive Micro-Satellite program that calls for and support instrument and mission development from beginning to end.

**We envision an Earth science micro satellite program in which there is programmatic support for an infrastructure of common mission operations, downlink and data processing.**

Data would be public and archived in a common format with readers and tools made available to all users. The individual satellites, sensors and missions would be awarded competitively.

NASA knows how to do this. The Earth Venture sub-orbital program provides a template. An Earth Venture micro-satellite program would similarly encourage 5-year courses of study that would include the building and launching of one or more micro satellites, and the time and resources to produce and make scientific use of the data.

1. ***Why are space-based observations fundamental to addressing these challenges/ questions?***

Micro-satellites permit a view of the Earth unmatched by other existing or proposed platform. Sub-orbital measurements are essential components of addressing the Big Questions stated above, but they do not provide a global perspective. Micro-satellites provide a cost effective global picture and numerous possibilities for multi-platform and formations flying observations.

Unlike large flagship platforms or smaller Earth Venture missions, micro-satellites are conceived as components of a larger whole. They may be CubeSats (e.g. space-worthy technology of particular size dimensions), CapSats (e.g. laboratory instruments in special containers), or something else not already defined. They can fly in clusters or in formations, and can be launched sequentially to maintain a longer data record. These instruments are not well-suited to maintain Climate Data Records, but they are perfect for process-oriented studies, obtaining the observations that focus on specific Earth science unknowns or controversies such as the effect of aerosols in invigorating deep convection. Micro-satellite launches could be planned in conjunction with specific field experiments or Earth Venture Sub-orbital campaigns to add specific space-based support to the campaign. The use of relatively inexpensive satellites allows for multiple instruments in differing orbits, and could be used to measure the *global* diurnal cycle of various phenomena. This becomes essential as GEO orbits become filled with high capability sensors that produce excellent temporal information for a limited region. Micro satellites may become the glue that binds these regional data sets into a global whole.

In conclusion, we are proposing this solution to a key operational concern facing the future of a space-based Earth science, and that is how to maintain and expand EOS-level quality for future measurement-based science, at a price we can afford. A micro satellite program is a cost-effective complement to full-size satellites that together can maximize global observations.