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The Era of Big Data Comes to Oceanography

The late Jim Gray, who received the prestigious Turing Award in computer science and was a pioneer in the development of relational databases, proposed the "Fourth Paradigm" to describe the field of data-intensive science (Hey et al., 2009). In Jim's presentation to the National Research Council Computer Science and Telecommunications Board in 2007, he described the first three paradigms as *empirical* (relying on observations of nature), *theoretical* (relying on models), and *computational* (relying on computer simulations). The fourth paradigm was *data exploration*, which, in his view, combined theory, experiment, and simulation. Moreover, it relied on computational tools and processes to explore massive and diverse data sets.

Sometimes known as "big data" in the popular press, data-intensive science has broader implications than just massive data warehouses and power-hungry supercomputers. The rapid proliferation of data types and connectivity is leading to a "programmable world" with billions to trillions of real-time devices and sensors. Funding agencies and universities are trying to respond to this rapidly evolving world through endeavors such as EarthCube, a collaboration between the US National Science Foundation and Earth, atmosphere, ocean, computer, information, and social scientists, educators, data managers, and others (http://earthcube.ning.com). These are valuable and important efforts, but the pace of change makes it difficult to respond on the usual three-year grant cycle. Digital technologies are being radically personalized. We bring our own devices to work and to the field. We expect to be able to access a broad array of services and data from the cloud. We want to work, collaborate, and play anytime, anywhere. The days of centrally controlled networks and services are fading away. We don't need to come to the office to access our libraries, our laboratory instruments, or even our ocean-going instruments. Private data "aggregators" such as MarineExplore.org and OneOceanCorp.com are offering new services for ocean scientists and marine industries to explore a plethora of ocean data that rival what used to be held solely in government data warehouses. And it is not just our science. Education happens anywhere, not just in a one-hour lecture in a classroom.

These disruptive innovations are not limited to the digital world. The emergence of "additive manufacturing" (popularly known as 3D printing) brings together the digital and physical world. MakerBot (recently acquired by Stratasys) can bring 3D printing capabilities into anyone's lab (and home). When combined with the emergence of "open source hardware" (such as the Arduino microcontroller and the

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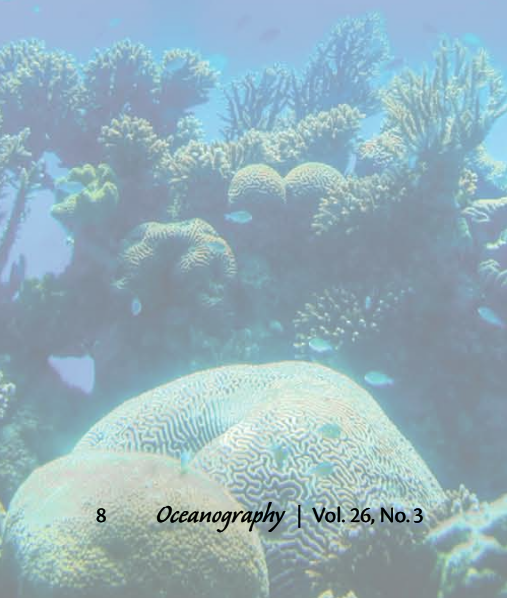

Open Hardware and Design Alliance), it is possible for individuals and small groups to enter the design and manufacturing business without the large amounts of financial capital that used to be required. Although the ocean presents unique challenges in terms of watertight housings, enormous pressures at depth, and low bandwidth communications, it is likely that we will see a transformation in ocean sensing in the coming years. Are these disruptive innovations for oceanography? I would argue that they have the potential to change the way we design observing systems, the way we collect data, and the way we collaborate. Walter Munk used to say that the twentieth century would be known as the "Century of Undersampling." The twenty-first may be different. Moreover, by lowering the cost of entry, data-intensive science and additive manufacturing might engage a broader range of students in oceanography. It is well known that experiential learning increases success and retention in science and engineering. We need to think that about these opportunities as well.

Mary Meeker and Liang Wu wrote in their 2013 review of Internet trends that Apple iPad growth has been three times faster than iPhone growth after their respective introductions (http://www.kpcb.com/insights/2013-internet-trends). Tablets now sell more units than desktops and laptops combined, only three years after their introduction. This has resulted in a dramatic shift in vendors. Moreover, we are now in the midst of two computing cycles: smartphones and tablets. And a third is on the way in the area of wearable/driveable/flyable computers. Will "swimmables" be next? Are we prepared and are we training our students to lead these disruptive innovations? Will our institutions, like HP and Dell, be displaced by new organizations? Will our predictions be way off target like *Barron's* magazine that had Jeff Bezos on the cover in 1999 as "Amazon.bomb?"

Sincerely,

Mark R. Abbott, TOS President

REFERENCE

Hey, T., S. Tansley, and K. Tolle, eds. 2009. *The Fourth Paradigm: Data-Intensive Scientific Discovery*. Microsoft Research, Redmond, WA, 252 pp. Available online at: http://research.microsoft.com/en-us/collaboration/fourthparadigm (accessed June 27, 2013).