Geographic Exploration of Digital Earth

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ABSTRACT: Geographic exploration remains imperative in the age of Digital Earth. Indeed, exploration is more demanding than ever as we probe places that are deeper (oceans floors, caves, inner Earth) and higher (atmosphere, planetary bodies), search for tangible evidence of historic and pre-historic landscapes, and seek new geographic understanding of complex earth processes. A review of exploration in the 20th Century and earlier times reveals that the movement toward remote exploration started even before the last terrestrial frontiers were breached. The author urges a vigorous policy of explora-tion for AquaterraBthe distinctive coastal and littoral zone that was inundated and exposed repeatedly during the Pleistocene ice ages and now rims all the World Ocean to a depth of 125 meters and to a height of 5 meters above current sea level. The exploration of Aquaterra will be a technological challenge unlike any before on earth as Digital Earth becomes the macroscope through which we view the whole, as well as the microscope through which we examine each piece. No one in our lifetime will see Aquaterra, as a whole, except through the lens of Digital Earth.
KEY WORDS Digital Earth, Exploration, Geographic Frontiers, Aquaterra, Oceans

Introduction

I commend the conveners of this symposium, United States Vice President Albert Gore, Mike Goodchild, Tim Foresman, and others around the world who have created and championed the concept of Digital Earth. The name itself evokes the image of a complete representation of the earth in a more realistic, comprehensive, integrated, and manipulable form than traditional globes and global models. It is almost as if we could take this wonderful world and hold it in our hands, watch it spin, and scrutinize any part of it to our hearts content.

Indeed, when implemented, Digital Earth will allow analysts and decision makers to view a spinning globe; select and zoom to any place (eg., continent, region, country, city, or point); and instantaneously access crucial information about that place. For those who prefer visualization or virtual reality, it will be possible to fly-through or walk-through any landscape on earth at any reasonable scale, and the definition of what is reasonable grows finer every year. For those who need to conduct geographic and other scientific analyses, it will be possible to model the atmosphere, oceans, terrestrial surface, and inner Earth at any reasonable scale. We will be able view and study the earth realistically with satellites orbiting, atmospheric conditions changing, and surfaces selected for the purpose at hand. The time scale can vary, too, as clouds form, nations evolve, or continents drift.

The technical challenges will be enormous. Fundamental technology development will include improved graphics, visualization, image processing, spatial data structures, computer cartography, and support of global and regional modeling. Geo-visualization and 4-D simulation will require parallel-processing, high-performance (tera-flop) computing architectures and advanced (100+ tera-byte) storage systems. Even the most powerful computers and storage devices will require optimization of software functions and maximal data compression. A new class of space/time/entity/process (STEP) linkage systems must be invented for representing and analyzing spatial phenomena across fields as diverse as medicine, biology, engineering, and physics. The resulting system will be a substantial improvement over current global models and will set the standard for the next generation of geographic technology. It will differ from current technology in that it will be supported with an extensive, high-resolution data collection; will overcome significant barriers to the integration of disparate types of geographic data (including both raster and vector data); and will be designed to facilitate modeling and other types of analyses as

well as visualization, virtual reality, and cartographic display.

Digital Earth will be especially useful in support of scientific research on major global issues such as (a) the search for causal mechanisms in continental drift and plate tectonics and (b) the attempt to understand climate change and its impacts on human systems (eg. redistribution of agricultural production, income, and energy demand). Yet, it will be equally well suited for detailed analyses of land cover change (eg. forests, wetlands, deserts); sources and effects of atmospheric pollution; energy assessment and planning; emergency management; commercial and military logistics; epidemiology; regional economics; and resource management.

2. The Ageold Quest to Explore The Earth S Frontiers

Now that our spirits have soared with unbounded possibilities, let's settle back to plain old analog earth in its present state of affairs, and ask ourselves what's missing. Other speakers surely will address the satellites and sensors that are needed to acquire imagery at finer spatial resolution, greater spectral definition, and improved temporal frequency. Others will address computational and analytical needs. Perhaps someone will address information that cannot be acquired through remote sensing and thus requires field investigation or other traditional data collection. I, too, am concerned about these matters, and my colleagues at Oak Ridge National Laboratory (ORNL) are working diligently to solve those for which we have funding and expertise. But there is a greater societal issue that speaks to human aspirations in the coming millennium and to which I address my remarks today: Is geographic exploration still necessary in the age of Digital Earth?

The rhetoric of geographic information science, including Digital Earth, often implies that future knowledge will be generated, not from exploration of the unknown but from better representation, integration, and analysis of what is already known. More broadly, there is a tacit societal presumption that the Age of Exploration has ended once and for all, that there is, in essence, nothing left to discover. Science itself has become a plodding quest for incremental knowledge in which quantum discoveries are unexpected and often unwelcome. No wonder the public has lost interest in what we learn, and support for scientific research is on the decline.

A recent review in The New Yorker (Hertzberg 1999) illustrates society's typical attitude toward geographic exploration. Hendrik Hertzberg belittled the National Geographic Society's new Adventure magazine, not for its writing or photography or style, but rather because, the exploration of unknown territory, conducted of necessity under conditions of extreme hardship is obsolete. That sounds like what Columbus contemporaries were saying in 1491, and it's simply not true. Yes, the nature of exploration has changed, but there is still much left to discover. In the earlier Age of Exploration it was a stunning accomplishment simply to observe a new landmass and report its existence. Today, exploration is more demanding than ever as we probe places that are deeper (oceans floors, caves, inner Earth) and higher (atmosphere, planetary bodies), search for tangible evidence of historic and pre-historic landscapes, and seek new geographic understanding of complex earth processes. Through technology, exploration can now be extended to places where humans cannot go, to phenomena that cannot be observed directly by human senses, and to macroscopic features so large they can be observed and investigated only through remote sensing, GIS, and advanced geo-visualization. In this new age, Digital Earth is an essential tool for discoveries that might not have been recognized before, even if the observations had been collected.

Recently, the Council of the American Geographical Society (AGS) voted to revitalize the Society's historic mission to support geographic exploration, and I was named Director of Exploration. In this new capacity, I have come face to face with society's initial skepticism. The bad news is that skepticism is pervasive. The good news is that most people quickly reconsider their views when the new nature of exploration is explained and a few examples of recent discoveries are offered.

3. 20th Century Exploration

We at the AGS have in our possession a wondrous globe that extols the history of geographic exploration in the 20th Century. It's called The Flier's and Explorers Globe or sometimes just The Fliers Globe, and it has belonged to the AGS since 1929. Its extraordinary value, lies in what's been scribbled and scrawled across its surface.

Picture, if you will, an antique globe with Charles Lindbergh's route etched across the Atlantic and signed in his own hand. How much would such a collectible bring at Sotheby's? How much more if Amelia Earhart also signed and marked her route as the first woman to fly across the Atlantic in 1932? Now, add Wiley Post, first man to fly solo around the world (1933), and Harold Gatty, who helped him set an around-the-world speed record shortly before Post and Will Rogers died on the same route. Add

Louise Boyd, the most accomplished of early women aviators. Add John Glenn, first person to orbit the earth (1962), with a photograph of President John Kennedy and Vice-President Lyndon Johnson watching him sign. Add astronauts Frank Borman and James Lovell.

That's why it's called The Fliers Globe, but what about explorers? Look north, and you'll find Robert Peary, president of the Society (1903 to 1907) and first person to reach the North Pole (1909). Look south, and you'll find Roald Amundsen, first to reach the South Pole (1911). Elsewhere, you ll find Fridtjof Nansen, who led a lengthy Arctic expedition (1893-1896), directed the League of Nations refugee relief effort after World War I, and won the Nobel Peace Prize in 1922; Richard Byrd who explored the Arctic and Antarctic regions and established the Little America research base in Antarctica; and Sir Hubert Wilkins, among the first to explore the Arctic by air. You'll even find Sir Edmund Hillary's signature on Mt. Everest and William Beebe's signature near Bermuda where he and Otis Barton set a depth record of 3,028 feet in the Bathysphere (1934).

The Fliers Globe contains these signatures and many others for a total of 62 individuals, and some names are repeated for more than one feat. The Fliers Globe is not a complete record of 20th Century exploration, however, for we somehow missed a few obvious candidates. Jacques Piccard and Don Walsh, for example, descended to the bottom of the ocean (35,800 ft.) in the Bathyscaphe in 1960, but their names do not appear over the Marianas Trench. Jacques Cousteau's name doesn't appear although he certainly qualified on the basis of many ocean explorations. Astronaut Neil Armstrong definitely should have signed when he returned from the moon in 1969. Cosmonaut Valentina Vladmirovna Tereshkova should have signed as the first woman in space in 1963. Some, like Cousteau, are lost forever, but the Society has begun a process to remedy as many oversights as possible.

Are we, in the age of Digital Earth, still accomplishing feats of comparable magnitude. I've asked friends and colleagues which modern explorers and aviators are worthy to sign. Robert Ballard has been suggested, as have Sylvia Earle and Graham Hawkes for their separate and joint accomplishments in deep ocean exploration. Dave Allured, Neil Backstrom, and Rick Bridges clearly qualify for discovering the world's deepest cave, Lechuguilla in New Mexico (1986). For aviation, Bertrand Piccard (son of Jacques Piccard) and Brian Jones have been suggested for their unprecedented circumnavigation of the earth by balloon earlier this year. It's comforting to know the quest continues in both arenas.

Two other candidates definitely would qualify as explorers, if only they were human. NASA's Mars Rover and Hubble Telescope have explored distant places in the old fashioned sense of being there and recording what they saw, albeit digitally and remotely. Herein lies a hint of things to come as being there becomes less important (and less effective) than probing and reporting what lies beyond our human grasp.

4. Remote Exploration

The roots of remote exploration go back farther than one might think. As early as the 1860s, there was a serious scientific proposal to explore Africa by balloon. The geographically gifted young visionary failed to attract funding, however, and later yielded to a publisher's suggestion to rewrite the concept as science fiction. Thus, *Five Weeks in A Balloon* (Verne 1863), a fictional account of scientists using a balloon to explore Africa, became Jules Verne's first novel. Today, Verne (1828-1905) is famous for predicting airplanes, submarines, television, guided missiles, spacecraft, and satellites almost a century before their actual invention. Viewed as a geographer, he was well-grounded in the discipline and his subjects covered the same frontiers that challenge us today space, oceans, inner Earth.

In 1904, Professor William Morris Davis, a key founder of modern geography, wrote to the AGS urging the Society to fund two exploration projects. One was a traditional expedition to learn more about glaciation of the Andes Mountains. The other was a steamer voyage to collect kite soundings of the atmosphere over the tropical Atlantic Ocean. The latter is clearly analogous to the types of remote exploration that are conducted today in space, under the sea, or deep into the inner Earth. The move toward remote exploration thus began even before the last terrestrial frontiers were breached at the North Pole (1909) and South Pole (1911). Indeed, the movement actually began hundreds of years earlier if ocean depth soundings are considered in the same light.

5. Aquaterra, The Next Frontier

In January 1999, I called for the exploration of Aquaterra the distinctive coastal and littoral zone that was inundated and exposed repeatedly during the Pleistocene ice ages and now rims all the worlds oceans to a depth of about 125 meters and to a height of about 5 meters above current sea

level (Dobson 1999). In August 1999, the *Professional Geographer* (1999) published a special issue on the geography of ocean space. In that issue and elsewhere for several years, Dawn Wright has championed the use of geographic information systems (GIS) to represent and analyze oceans and associated geophysical phenomena. Clearly, there is interest among geographers in exploring the oceans just as we explored land areas during the Age of Exploration. I am firmly convinced that first Aquaterra and then the Deep Ocean must be viewed as the next final frontiers of Digital Earth.

Aquaterras defined space is a function of time, bounded by the highest and lowest sea levels of the past 120,000 years. This covers the four best documented cycles of rise and fall and also the entire span of time during which anatomically modern humans are known to have existed. Excellent data are available for the most recent sea level rise, based primarily on analysis of Barbados corals which indicate lows of -120 m at 17,000 years (Fairbanks 1989) and -125 m at 21,800 years (Peltier 1994). Earlier fluctuations are inferred from heavy oxygen isotope (^{18}O) concentrations in marine sediment cores (Stringer and Gamble 1993) and from the advance and retreat of glaciers.

A long term goal and major challenge of exploration must be to regionalize Aquaterra with reference to three-dimensional space and time. At any given moment, Aquaterra is either fully inundated during periods of maximum transgression as it nearly is today; fully exposed as it was during the maximum regression 21,800 years ago; or partially inundated and partially exposed. Regionalization, thus, depends on creating a reliable chart of dates and corresponding mean sea levels during the past 120,000 years. It is essential, however, to advance far beyond mere outline. Next, we must map and describe its physical geography, emphasizing the lands exposed at any given time. Where were Aquaterra's rivers and estuaries? Surely, they were focuses of biological activity and human settlement then as in later historic times. Where were its up lands? Surely, elevated areas would have served humans and animals alike as refuges from flooding, and the theoretical maximum local relief *within* Aquaterra is 130 m. Where were its distinctive landforms? Waterfalls twice as high as Niagara conceivably could have existed there and could have been valued in religious or secular ways, but no one has searched for them.

The exploration of Aquaterra will be a technological exploration unlike any before on earth, at least as challenging as space exploration of the moon and planets. Unlike the moon and Mars, there will be no direct viewing of the whole, because the field of view for each observation is so limited. Thus, Digital Earth will be the macroscope through which we view the whole, as well as the microscope through which we examine each piece. Geo-visualization will be paramount. No one in our lifetime will ever see Aquaterra, as a whole, except through the lens of Digital Earth.

6. A Call For Exploration

In 1903, Admiral Robert E. Peary, then president of the AGS, urged the Society to adopt an aggressive policy of polar exploration. We need a large and vigorous policy, he said. Of late years exploration has of necessity been a work of large details, opening the hearts of continents and pushing northward and southward, till today only the northern and southern apices of he earth still hide in the mists and gloom of the polar nights. If we wish to keep in the lead and be in at the death in the final geographical conquest of the world, our first efforts must be in those two directions, north and south. He urged the Council to purchase a ship and carry on original scientific investigations (explorations, surveying, hydrography, deep-sea dredging, etc.). (Wright 1952, p. 138) I urge the same for Aquaterra, a global feature so forgotten by mankind that Admiral Peary failed to mention it in his remarks. I address my call to the conveners of this symposium, the AGS, the National Aeronautical and Space Administrations (NASA) Digital Earth Program, the National Oceanic and Atmospheric Administration (NOAA), and anyone else who cares deeply about geographic exploration.

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