Statement of

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before the

Committee on Science
The U.S. House of Representatives
Hearing on
"NASA's Earth Science Program"

Chairman Boehlert, Ranking Minority Member, and members of the Committee:
Thank you for this opportunity to speak to you this morning on the issue of NASA's past, present, and future outlook for making contributions to the nation and the world in the area of Earth Sciences. My name is Marcia McNutt, and I currently serve as the President and CEO of the Monterey Bay Aquarium Research Institute, better known as MBARI. I am a past president of the American Geophysical Union, the largest professional society serving the geosciences. It has been more than a decade since my own research was funded by NASA, and NASA contributes only one percent of my institution's annual operating budget. I mention these facts merely to make the point that I have no financial incentive to provide you with anything other than my best advice.

Prioritizing Missions

First, you ask about prioritizing future missions. My own institution, MBARI, was founded and privately funded by David Packard to be a "NASA for the oceans", albeit on a much smaller scale. Like NASA, we constantly struggle at MBARI to balance our various missions. We must continue to explore the ocean in new dimensions while still conducting societally-relevant ocean research. We must apply emerging technologies to next-generation ocean systems without abandoning critical long-term time series.
There is no magic formula for making these hard choices. Tackling societally-relevant problems with near-term payback justifies the investment to today's taxpayers, while exploration lays the foundation for the societally-relevant research of the future and entrains the next generation. NASA is the only civilian agency that has the required capacity, tradition, and track record to vigorously pursue the technology development that will fuel tomorrow's discoveries. But at the same time, NASA has an obligation to maintain certain critical time series as long as the societal relevance is high, the rate of discoveries continues unabated, and the incremental cost is low as compared with the

cumulative prior investment. Unlike most S&T products, the value of time series only increases with age since inception. I have heard some argue that NASA could hand off wholesale areas of NASA research, such as the Earth sciences program, to another civilian agency in order to focus its efforts. Severed from the root of the technology program that feeds it, innovation in the program would eventually wither and die.

So how do we at MBARI maintain a balanced portfolio given these different, but essential missions? First, we determine what rough percentage of resources should be reserved for each mission area, and enforce the quota vigorously. The quotas are set so as to maintain critical mass and set a reasonable level of expectation in each program area such that the associated researchers can make long-term plans. If our overall budget grows, everything grows proportionally. If the overall budget shrinks, everything shrinks proportionally. Within those mission areas, projects compete with other like projects, but it would be unfair to pit exploration, for example, versus societally-relevant research because different criteria need to be used to measure their respective values.

Like NASA, my MBARI also undertakes high risk, long-lead time projects. Through experience, we have learned a few important lessons:

1. **Protect the rest of the research portfolio from being consumed by the large, long-term project by respecting the percentage quotas.** It is the rest of the research portfolio that helps to manage risk, retain balance, and nurture the seeds of the next big project.
2. **Structure the big project so that it provides science return at many incremental steps along the way**. We didn't have to discover this for ourselves at MBARI, because the Earth sciences community had already learned this lesson the hard way through the Mohole Project in the 1960s. The initial objective was to drill through the ocean crust into the underlying mantle rocks. The project proved to be so technically challenging and so mired in management missteps that after many years and many wasted millions of dollars it took an act of Congress to kill it. Out of the ashes of the Mohole Project arose the Deep Sea Drilling Project, now known as the Integrated Ocean Drilling Program. The Mohole's successor program had much more modest and achievable goals that kept the scientific community excited and engaged as remarkable discoveries were made in every ocean basin. The seafloor spreading hypothesis was confirmed. Climate records extending back more than 100 million years were recovered. And now, nearly 50 years after the Mohole Project was first conceived, we are finally on the brink of drilling into the oceanic upper mantle!
3. **If the project is really big, get lots of help.** We get help from institutions like Woods Hole and JPL for our biggest projects. The drilling program discussed above involved 23 different nations and is, in fact, held up as a model for international scientific cooperation.
4. **Get realistic cost and schedule estimates for the big project before undertaking it, including an assessment of the value of what will need to fall off your agenda if you pursue it.** And then make sure you can afford it. If you have structured the big project for incremental science return (see #2 above), then it won't matter if you don't achieve your goal right away because the discoveries

along the way will maintain the project's momentum, keep the research community engaged, and justify the investment.

NASA's Greatest Achievements in the Earth Sciences

You also asked me to list some of NASA's greatest achievements in the Earth Sciences from the past few decades. There are so many – the discovery of the ozone hole, the direct measurement of plate tectonic drift from space, the detection of post-seismic crustal deformation that influences the pattern of future earthquakes using Synthetic Aperture Radar, …. The list goes on. Knowing that you will be hearing from Drs. Solomon and Killeen on the accomplishments in the area of solid Earth and atmosphere, respectively, I'll concentrate on the oceans.

Certainly one of the most unexpected surprises was the contribution of satellite altimetry to so many areas of ocean sciences. NASA pioneered the technology for measuring sea surface height from 800-km altitude in space to 10 centimeter accuracy nearly 30 years ago. The technique was so successful for measuring sea level, waves, currents, tides, and air moisture, and for mapping the topography of seafloor using its gravitational effect on the shape of the ocean surface, that a number of other agencies both foreign and domestic launched follow-on altimeter missions. NASA continues to operate altimeters from space today, and each generation improves in its accuracy and scientific return.

Figure 1 shows one dramatic comparison of our knowledge of the ocean floor topography before and after the availability of satellite altimetry data. I recall 14 years ago serving as chief scientist on an oceanographic expedition to the South Pacific. One night we were steaming full speed ahead, when I called to the bridge from the main lab to say that based on my processing of the satellite altimetry data, we were headed straight towards a major undersea volcano that might have a very shallow summit. The mate on watch responded that nothing was marked on the navigational charts in the vicinity, but he agreed to slow down anyway. Less than 10 minutes later I heard a seaman yell out in the moonlight: "Breakers at 100 yards and closing!" Because the mate had already backed down on the engines, the ship was able to turn before crashing into the reef.

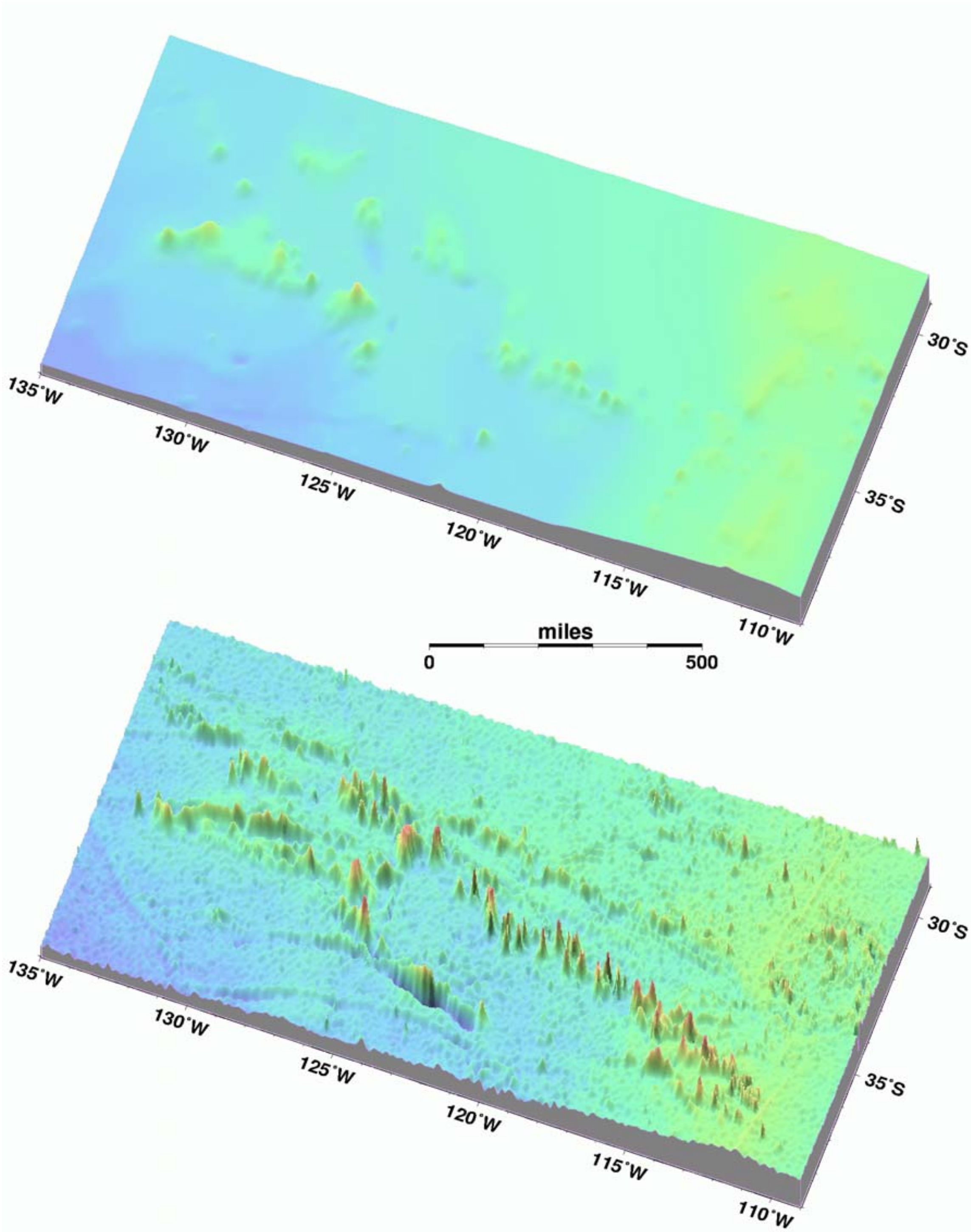

Figure 1. Comparison of our best available information on the bathymetry of the ocean basins in the South Pacific before (above) and after (below) the use of satellite altimetry to estimate the shape of the solid seafloor. These improved images have found many practical applications, such as providing safer navigation for ships and submarines, finding new productive fishing grounds, assessing volcanic and earthquake hazards, and improving general understanding of the geologic history and structure of the ocean basins. Source: http://www.ngdc.noaa.gov/mgg/image/seafloor.html

As a second, very different example, I will briefly mention NASA's development of instruments to measure ocean color to monitor the concentration of microscopic plants in the upper ocean. These small plants, called phytoplankton, are responsible for producing about half of the oxygen that we breathe and are the fundamental basis for nearly all of the oceanic food chain. One teaspoon of seawater can contain as many as a million of these fast-growing plants. NASA satellites have monitored the temporal changes in the concentrations of these minute plants from 700 km in space for a little more than two decades. This image of ocean color around Tasmania south of Australia was acquired by the SeaWIFS satellite in just about 1 minute. It would have taken 10 years of non-stop operations of an oceanographic ship to acquire the same amount of information, and all of the dynamic details, such as the effect of eddies and currents on the distributions, would have been smeared out beyond recognition. These satellite data have shown the changing productivity of the oceans in response to El Niños, reduction in polar ice extent, intensity of seasonal upwelling, and purposeful iron fertilization of the oceans. Such monitoring of the biological changes in the ocean help us to understand the consequences of both natural and man-made changes to the physical and chemical environment in which these plants survive.

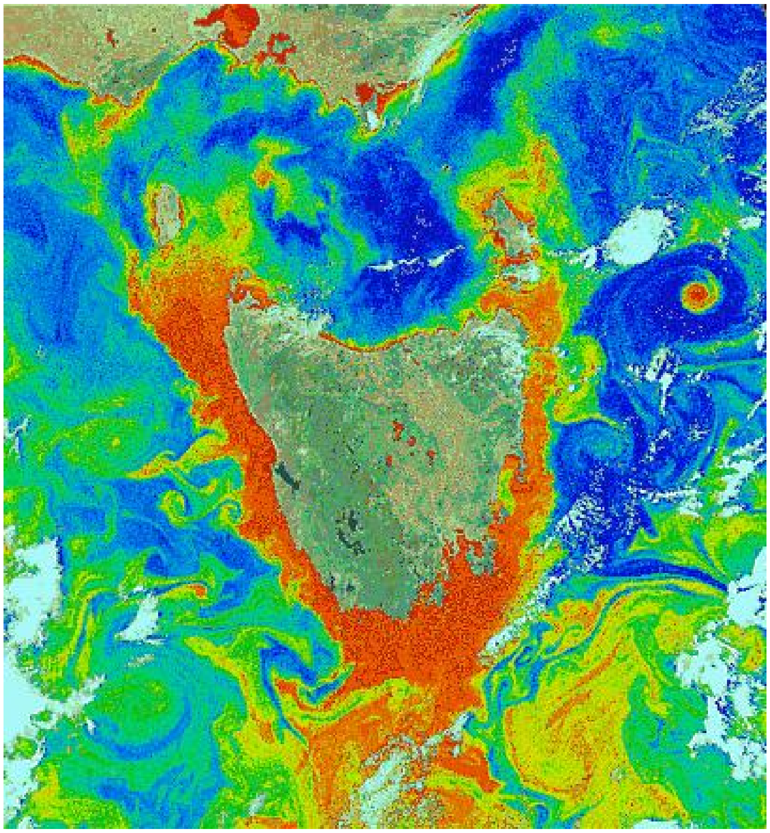

Figure 2. SeaWIFS imagine of chlorophyll concentrations in the surface waters around the island of Tasmania just south of Australia. Source: http://oceancolor.gsfc.nasa.gov/SeaWiFS/TEACHERS/sanctuary_2.html

Highest Priority Unanswered Questions

In your second question, you asked me to list the highest priority unanswered questions in Earth Sciences that can be addressed from space. Again, I will choose an ocean example. Within the last decade, reconstruction of past climate records from sparse data have demonstrated that the Pacific ocean temperature and productivity of fisheries all change in lock step to a climate rhythm that waxes and wanes over decadal time scales Figure 3). This temperature variation, called the Pacific Decadal Oscillation or PDO, involves temperature changes of just one to two degrees and has also been well correlated with changes in sea level recorded by satellite altimeters. The figure below shows that the "cool" phase of the PDO that ruled the Pacific in the early 1960's corresponded to the crash in the sardine fishery in my own hometown, Monterey, CA. Landings of sardines fell from 3.6 million metric tons in the 1930's to less than 10,000 metric tons by 1965. During that same time, the anchovy fishery offshore Peru became the biggest single-species fishery in the world. In the mid-1970's, the regime shifted, and the Peruvian anchovy fishery crashed. The most recent regime shift which coincided with the 1997-98 El Niño was captured by a number of satellite sensors: sea level (as measured by altimetry), ocean temperature, and ocean plant production (as measured by ocean color) all shifted together back into the cool (anchovy dominated) phase. So what forces cause the shift? What rhythms govern the time scale? We don't know, and its long life span (20-30 years between regime shifts) means that we must be patient. But much is at stake. The numbers of seabirds in Hawaii, monarch butterflies in Mexico, and salmon in Oregon all appear to vary at the pace of the PDO - despite the fact that the temperature variations are one to two degrees! We have only captured one shift with high-quality records, but the hope is that with patience we will understand how the system works, and hopefully avoid another fisheries crash like the one that devastated Monterey.

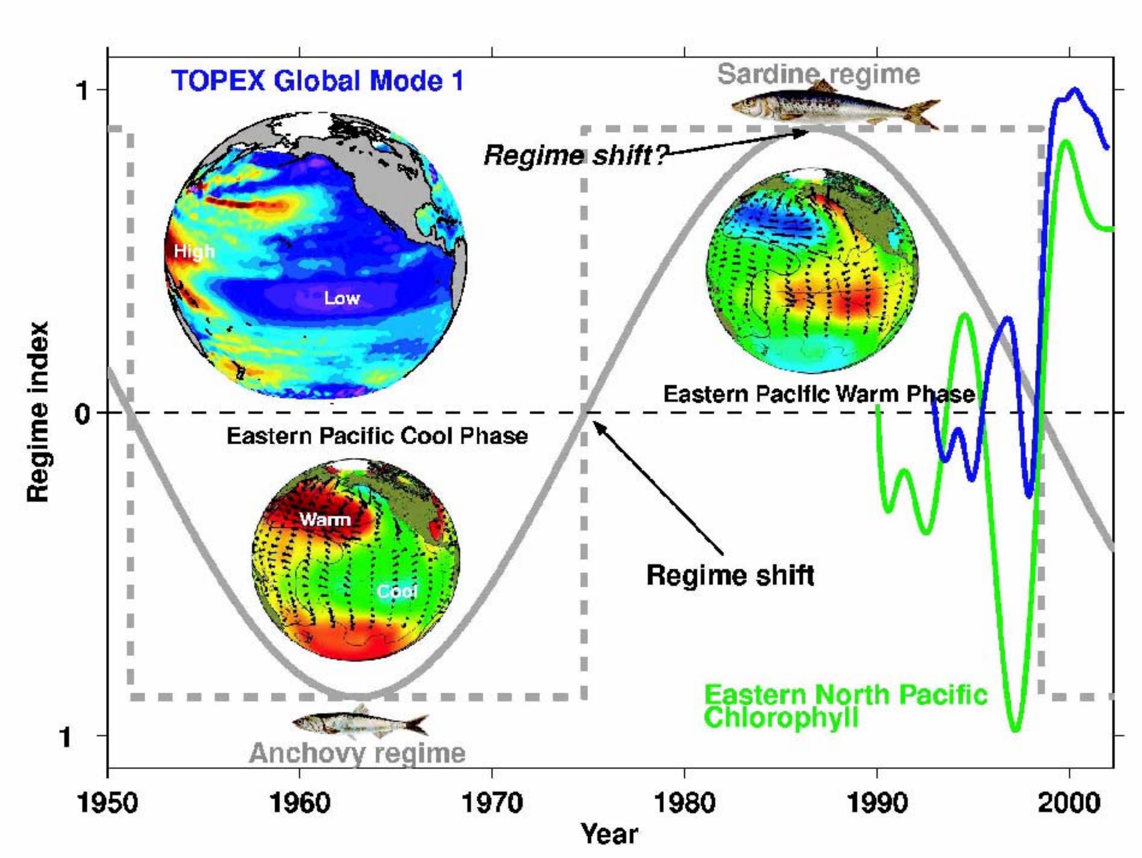

Figure 3. Illustration of the changing nature of the Pacific Decadal Oscillation (PDO). These variations of just one to two degrees in the Pacific ocean temperature pattern have a large effect on the productivity of fisheries. When the anchovy fishery off Peru in strong (the Eastern Pacific cool phase), the sardine fishery in Monterey is poor. Note the strong correlation between sea surface height from the TOPEX altimeter and the ocean temperature pattern as observed from space during the most recent cool phase. Even the microscopic plants in the upper ocean respond to the warm and cool phases. Figure published in Science (volume 299, pp. 219-221, 2003) and provided courtesy of Francisco Chavez, MBARI.

Future Prospects

In your fourth question, you asked me about the future of NASA's contributions to Earth Sciences. I hope that I have already made the point that there are exciting couplings emerging among the physical, chemical, and biological aspects of the ocean that point to a planetary metabolism that is best observed and most efficiently monitored from space. I have no doubt that upon further investigation, we will find that many changes in the land-based biosphere are also controlled by similar rhythms, just as scientists have been able to demonstrate the connection between the El Niño event in the eastern tropical Pacific and, for example, drought in South Africa. Understanding exactly what will happen before it happens is clearly a powerful position to be in, because it enables us to take actions that benefit from the regime shift, as opposed to those that suffer from it. I am personally very excited about the prospects of monitoring salinity directly from space, in order to get the second necessary component for understanding the thermo-haline circulation that transports so much of the planets' mass and energy. I see the potential for monitoring the planet's carbon cycle from space through both direct measurements and better modeling of the thermohaline circulation. For example, we estimate that the oceans take up a net 2,000 million metric tons of carbon dioxide from the atmosphere annually, but that number is the small difference between two very large numbers: 90,000 million tons of CO_2 taken up by ocean plants and other processes versus 88,000 million tons of CO_2 returned to the atmosphere from the ocean through the upwelling of deep ocean waters. Clearly our "balance of payments" (so to speak) in terms of the carbon budget is very sensitive to both the physical and biological states of the ocean, which in turn vary with both the El Niño and the PDO oscillations. There is so much to learn, and only when we have a better understanding of all of these cycles and where we are within them will we be able to make wise policies to protect and sustain our Earth environment.

Thank you very much for this opportunity to speak to you on these critically important issues.