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EXAMINING THE PRESIDENT'S FISCAL YEAR 2016 BUDGET REQUEST FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

MARCH 12, 2015

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ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

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EXAMINING THE PRESIDENT'S FISCAL YEAR 2016 BUDGET REQUEST FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THURSDAY, MARCH 12, 2015

U.S. SENATE,
SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 9:38 a.m. in room SR–253, Russell Senate Office Building, Hon. Ted Cruz, Chairman of the Subcommittee, presiding.

Present: Senators Cruz [presiding], Gardner, Blunt, Peters, and Nelson.

OPENING STATEMENT OF HON. TED CRUZ, U.S. SENATOR FROM TEXAS

Senator CRUZ. The hearing will come to order. Good morning, everyone, and welcome.

We gather here this morning not simply to examine the President's budget request but to begin to lay out a vision for the future of NASA and human exploration. As we begin the process of putting together a road map for the future of NASA, there is one vital question that this committee should examine: Should NASA focus primarily inwards or outwards beyond low-Earth orbit?

Since the end of the last administration we have seen a disproportionate increase in the amount of Federal funds that have been allocated to the Earth Science Program at the expense of and in comparison to exploration and space operations, planetary science, heliophysics and astrophysics, which I believe are all rooted in exploration and should be central to the core mission of NASA.

As I observed at our last hearing, the first priority for the space component of this subcommittee is to work to refocus NASA's energies on its core priority of exploring space. I know that that is a passion of the professionals at this fine institution. I see good signs that the current goals set out for human exploration are being achieved, as witnessed in December with the incredibly successful launch of the *Orion* EFT–1, and yesterday at Orbital ATK's solid rocket motor test in Utah, the engine that will power the space launch system into deep space.

But we need to use that momentum and get back to the hard sciences, to manned space exploration, and to the innovation that has been integral to the mission of NASA. We also need to provide

the men and women that work at NASA with clear and consistent long-term mission objectives so that they do not find themselves continually pouring time and energy into projects, only to see them swept up and carried away by the ever-changing winds of politics.

Science needs to drive NASA's mission, rather than the political winds of Washington. Short-changing these projects will surely have an adverse impact on encouraging our nation's best and brightest to continue to want to work with NASA.

As the Chairman of this Subcommittee, I am looking forward to being an outspoken champion not only for NASA and not only for the Johnson Space Center, but for everyone within the NASA family who plays a key role in advancing human exploration and promoting the hard sciences.

As former NASA astronaut, Dr. Mike Massimino, mentioned at our last hearing, young Americans are interested in space-related STEM careers and see themselves as future space entrepreneurs. It's critical that we begin to refocus the core priorities of NASA so that greater and exciting new opportunities can emerge and be realized. It is time for man once again to leave the safety of the harbor and to further explore the deep, uncharted waters of deep space.

I now recognize the Ranking Member, Senator Peters.

STATEMENT OF HON. GARY PETERS,
U.S. SENATOR FROM MICHIGAN

Senator PETERS. Thank you, Mr. Chairman. It's wonderful to serve with you on this committee, and I look forward to working with you in the years ahead.

This month we celebrate the 100th anniversary of the National Advisory Committee for Aeronautics, or NACA. Congress created NACA in 1915 because even though the Wright Brothers had invented powered flight in the U.S. in 1903, by the beginning of World War I the U.S. lagged behind Europe in aviation technology.

Within decades of NACA's creation, the U.S. was leading the world in aviation once again. We put the P51 Mustang in the sky, a fighter that proved so critical to the success of the Allies against Hitler. And later, in 1947, we were the envy of the world when Chuck Yeager's X–1 rocket plane broke the sound barrier.

But when the Soviet Union placed the first artificial satellite in orbit around the Earth, the U.S. was once again behind. Congress responded this time by folding the efforts of NACA into the newly established National Aeronautics and Space Administration, or NASA, in 1958.

By 1969, NASA put astronauts Neil Armstrong and Buzz Aldrin on the Moon, and in the decades following, NASA sent probes to explore the worlds of our solar system, built telescopes in space to peer to the edges of the universe, built a research outpost in space permanently tended by a crew of international astronauts, and made it possible to study the planet that we call home from space.

Over the past century, the investments we have made in our civil aeronautics and space programs look pretty modest compared to the returns. Safe and reliable commercial air transportation, communication satellites, space-based imagery, and spinoff tech-

nologies from human spaceflight have provided our country extraordinary economic benefits.

The Apollo and Space Shuttle programs inspired generations of American students to pursue education in math, science, and engineering, many of whom went on to lead a revolution in computing and information technology. Just a few years back, I visited a high school in my home state of Michigan and I witnessed firsthand NASA's continued ability to inspire. All of the students were gathered in the gym to watch a large projector screen that connected them directly to U.S. astronauts on the International Space Station. And when the astronauts asked if any of the students planned to pursue degrees in the STEM fields, hundreds of hands shot up across the auditorium.

Today, it is simply impossible to imagine the world devoid of the scientific understanding that NASA has enabled us to achieve. Because of NASA, we know our planet is a fragile oasis in an unimaginably vast space. We know every point in the universe is speeding away from us at an accelerating pace, driven by some unseen force called dark energy. We know our galaxy is filled with billions and billions of planets, many of them possibly very much like our Earth. And we have seen actions and evidence of black holes, whose mind-bending physics remind us of how much we have to learn about the fundamental nature of space and time.

I see NASA's budget as a strategic portfolio of investments aimed at improving the well-being of our country and of our civilization. Like any portfolio, we must carefully choose our investments and remember that the balance of the overall portfolio is of the utmost importance. We must avoid false choices between robotic exploration, human exploration, the study of the universe, or the study of our home planet. We must avoid the temptation to view NASA's mission as a set of competing priorities. Rather, we should seek a set of complementary initiatives that will pay returns to our civilization for centuries to come.

I want to thank you, Administrator Bolden, for your service to our country and your appearance before the Subcommittee today. And I want to thank you, Chairman Cruz, for holding this hearing, and Ranking Member Nelson for everything you have done and continue to do for our space program and for the example that you set for this committee.

Although my position on this committee is new, my passion for science and technology is not, and I am truly excited about my opportunity to serve as Ranking Member for the Subcommittee, and I look forward to our discussion today. Thank you.

Senator CRUZ. Thank you very much.

I would offer the Ranking Member of the full committee, Senator Nelson, an opportunity to give a statement as well.

STATEMENT OF HON. BILL NELSON,
U.S. SENATOR FROM FLORIDA

Senator NELSON. Well, you're very gracious, Mr. Chairman, and I want to compliment you. At the last hearing I said even though the temperature outside was 10 degrees, that blossoms were breaking out all over Washington by virtue of the very supportive statements that you had made about NASA, of which you have contin-

ued those very supportive statements. I want you to know how much the NASA community and NASA family is appreciative of that support.

I want to point out that in some quarters it seems to be fashionable to say that Earth Science is not a part of the exploration program, and yet I would point out that tonight there is the launch of a mission called MMS. It has to do with a magnetosphere, and it will be a mission to gauge space weather—in other words, nuclear explosions from the surface of the sun—and how that affects our life here on Earth, GPS, various other satellites.

So Earth Science directly relates to everything that we're doing in exploration, and I would draw that distinction for folks who think that it's not fashionable that NASA be a part of Earth Science.

The other thing is that I want to compliment the Ranking Member, to see someone so enthusiastic as Senator Peters is, is indeed extremely gratifying.

And furthermore, I would like to congratulate the Administrator. He is now going on 7 years. His hair was dark when he started.

[Laughter.]

Senator NELSON. The fact that he's been able to get everybody in the harness over there at NASA, now without a deputy, although the nominee for deputy is sitting in the front row, and he has got everybody in the harness pulling in the right direction, all in the same direction, which is a significant accomplishment for the Administrator.

So I just wanted to pass around those compliments to you, to Senator Peters, and to the Administrator. Thank you.

Senator CRUZ. Well, thank you very much, Senator Nelson, and it has been a pleasure the last 2 years serving on this committee with you as the Chairman of the Subcommittee, and I'm looking forward to the next 2 years continuing to serve with you and with the new Ranking Member, Senator Peters.

We have a lot of work to do, and we are blessed to have a Subcommittee with some talented and dedicated members on both sides of the aisle who are committed to the core mission of NASA.

With that, I'm very pleased to introduce and welcome the distinguished Administrator of NASA, the Honorable Charles Bolden.

STATEMENT OF HON. CHARLES F. BOLDEN, JR., ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. BOLDEN. Thank you very much, Mr. Chairman.

Mr. Chairman and Ranking Member Peters, I want to, first of all, on behalf of the entire NASA family, congratulate the two of you on your positions. I look forward to working with you.

It was interesting sitting here listening to everyone speak because I really appreciate the work that this committee has done through the years. It was here that the 2010 Authorization Act was crafted, and that is the present road map on which we work. So I commend the Committee and look forward to continuing to work with you all.

The President is proposing a Fiscal Year 2016 budget of $18.5B for us that builds on the 2015 appropriation and the significant in-

vestments that the Administration and the Congress have made in America's space program over the past 6 years.

Thanks to the hard work of our NASA team and partners all across America, we've made a lot of progress on our journey to Mars. In fact, we have now progressed farther on this path to sending humans to Mars than at any point in NASA's history, and this budget will keep us marching forward.

The support of this subcommittee and the Congress are essential to this journey. The International Space Station is a critical first step in this work. It's our springboard to the rest of the solar system, and we're committed to extending Space Station operations to at least 2024.

Thanks to the grit, determination, and American ingenuity, we have returned ISS cargo resupply missions to the United States, in-sourcing these jobs and creating a new private market in low-Earth orbit. Under a plan outlined by the Administration early in its term, we also have awarded two American companies, SpaceX and Boeing, fixed-price contracts to safely and cost-effectively transport our astronauts to the Space Station from U.S. soil. This will end our sole reliance on Russia. It's critical that we receive the funding requested for the 2016 budget so that we can meet our 2017 target date and stop writing checks to the Russian space agency.

Our newest, most powerful rocket ever developed, the Space Launch System, or SLS, has moved from formulation to development, something no other exploration-class vehicle has achieved since the agency built the Space Shuttle. The *Orion* spacecraft performed flawlessly on its first trip to space this past December. The SLS and Exploration Ground Systems are on track for launch capability readiness by November 2018, and the teams are hard at work on completing technical and design reviews for *Orion.*

Our budget also funds a robust science program with dozens of operating missions studying our solar system and the universe. New Horizons is preparing for its arrival at Pluto in July, and Dawn is now in orbit around the dwarf planet Ceres. Before we send humans to Mars, robots are paving the way. We are at work on a Mars Rover for 2020 and have begun planning a mission to explore Jupiter's fascinating moon Europa.

NASA is a leader in Earth Science, and our constantly expanding view of our planet from space is helping us better understand and prepare for these changes. NASA has 21 research missions studying Earth, and the last year alone we launched an unprecedented five more. We are at work on humanity's first voyage to our home star, a mission that will repeatedly pass through the Sun's outer atmosphere. Senator Nelson also mentioned a little bit earlier that we will launch the MMS mission tonight.

NASA's Hubble, Chandra and Kepler Space Telescopes explore the universe beyond our solar system. Hubble's successor, the James Webb Space Telescope, is taking shape right now out in Maryland, and the new mission is in development to extend Kepler's pioneering work in finding planets.

Technology drives science, exploration, and our journey deeper into the solar system and to Mars. With the President's request, NASA will continue to maintain a steady pipeline of technology to

ensure that we continue to lead the world in space exploration and scientific discovery.

NASA is also with you when you fly, and we're committed to transforming aviation by dramatically reducing its environmental impact, maintaining safety in more crowded skies, and paving the way toward revolutionary aircraft shapes and propulsion systems.

Mr. Chairman, America's space program is not just alive, it's thriving. The strong support we receive from this subcommittee and the entire Congress is making that happen, and I particularly appreciate the generous Fiscal Year 2015 appropriation.

As the President said in his State of the Union address, and I quote, "We are pushing out into the solar system not just to visit, but to stay, part of a reenergized space program that will send American astronauts to Mars," unquote. NASA looks forward to working with the Congress to make this vision a reality.

I would be pleased to respond to any questions you and the Committee may have.

[The prepared statement of Mr. Bolden follows:]

PREPARED STATEMENT OF HON. CHARLES F. BOLDEN, JR., ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman and Members of the Subcommittee, I am pleased to have this opportunity to discuss NASA's FY 2016 budget request. The President is proposing an FY 2016 budget of $18.5 billion for NASA, building on the significant investments the Administration has made in America's space program over the past six years, enabled through the strong and consistent support by this Committee and the Congress. This request will allow NASA to continue to lead the world in space through a balanced program of exploration, science, technology, and aeronautics research. NASA is an outstanding investment for our Nation not only because we uncover new knowledge, but because we raise the bar of human achievement, inspiring the next generation of scientists, engineers and astronauts.

The FY 2016 request includes $4,505.9 million for Exploration with $2,862.9 million for Exploration Systems Development, $1,243.8 million for Commercial Space Flight, and $399.2 million for Exploration Research and Development. This funding, with critical investment from each of NASA's mission directorates, supports NASA's plans to, as the President said in his State of the Union speech, continue our journey to Mars and push "out into the solar system not just to visit, but to stay[.]" NASA has made tremendous progress on this journey, and we will continue to progress, with building momentum, through the years to come.

As part of our strategic, stepping stone approach to deep-space explorations, NASA is facilitating the development of a U.S. commercial crew transportation capability with the goal of launching NASA astronauts from American soil in the next couple of years. This initiative to facilitate the success of U.S. industry to provide crew transportation to low Earth orbit will end our sole reliance on Russia and ensure that we have safe, reliable and cost-effective access to the ISS and low-Earth orbit. Commercial Products Contracts allowed potential providers to better understand and align with NASA human spaceflight requirements and gave NASA early insight into vehicle designs and approaches. NASA has now entered the development and certification phase with the award of two FAR-based, fixed-price Commercial Crew Transportation Capability (CCtCap) contracts to American companies to transport our Astronauts to and from the ISS. SpaceX and Boeing have laid out milestones with the goal of certified commercial crew capability in 2017. The contractors are committed and at work. Our approach has emphasized competition and redundancy to ensure that NASA's human safety and certification requirements are met, we achieve the best value for the American taxpayer, and we end our sole reliance on Russia for transportation services. Now, we need the funding necessary to execute this plan to completion. With continued support from the Congress, crews will again launch to the ISS from American soil by 2017.

Technology drives science, exploration and economic opportunity. NASA will continue to maintain a steady pipeline of technology to ensure that we continue to lead the world in space capabilities. NASA's FY 2016 request includes $724.8 million for Space Technology, to conduct rapid development and infusion of transformative

space technologies that enable NASA's missions and advance our country's dynamic aerospace industry services. Over the next two years, NASA will execute several in-space demonstrations including: a deep space atomic clock for advanced navigation, green propellant and four small spacecraft demonstrating pioneering new technologies. This summer, NASA plans to again test our Low Density Supersonic Decelerator off the coast of Hawaii to continue proving in flight the new technologies critical for landing larger payloads on the surface of the Red Planet. Informed by the results of FY 2014 testing of solar array and thruster designs, NASA continues development of a high-powered solar electric propulsion capability to enable future exploration missions and meet needs of U.S. aerospace industry. We will continue to progress toward a 2019 demonstration of space-to-ground laser communications, a capability that both American industry and NASA mission teams are eager to explore and harness. But the most exciting piece of our technology investments is the broad portfolio of research grants and other early stage investments, where the new technologies that will change the way we operate in space have a chance to move from ideas to components, to demonstrations of new systems and capabilities. These early stage investments are building stronger links between NASA and academia, and providing unique opportunities for the NASA workforce to innovate.

In December, NASA completed the first orbital test flight of the *Orion* crew vehicle, including a successful high speed reentry through the atmosphere. The Exploration Flight Test 1 (EFT–1) mission of *Orion* was nearly flawless. For the first time in a generation, a deep-space U.S. exploration vehicle has splashed down in the Pacific, and what we are learning from this test gives us increasing confidence in the systems we are designing.

Just as we have recently tested *Orion* by sending it on a shorter version of its future missions, we are continuously testing and experimenting on the International Space Station (ISS) in preparation for long-term missions in deep space. The Administration has committed to extending operation of the International Space Station to at least 2024. The FY 2016 request includes $4,003.7 million for Space Operations, including $3,105.6 million for ISS. Two commercial providers are now under contract to supply cargo to this critical asset, making the extension possible and giving us increasing confidence in our long-term strategy. This month, NASA will launch astronaut Scott Kelly on a one-year mission aboard the ISS to learn more about how to live and work in space for the long term. We will compare his vital signs to those of his twin brother, Mark, here on Earth in a first-ever experiment using identical twins to learn more about the effects of living in space. This is just one example of the vital knowledge and technology that our outpost in space will provide over the coming decade. The Space Station is the cornerstone of our exploration strategy, a nearby outpost in space where humanity is taking its early steps on its journey into the solar system.

For the next step on the journey, NASA is developing the required deep-space exploration infrastructure while we plan for the earliest missions. NASA has established Agency Baseline Commitments for the Space Launch System (SLS) and Exploration Ground Systems (EGS), each of which supports a launch capability readiness date for Exploration Mission 1 (EM–1) of November 2018. EM–1 is the first mission for SLS and *Orion.* NASA remains on schedule for this EM–1 launch readiness date for SLS and EGS. Baseline cost and schedule for *Orion* are now being developed. NASA's budget request provides the funding needed to keep SLS, *Orion,* and EGS on track. NASA will determine the integrated launch date for the EM–1 mission after all critical design reviews are complete, later this year. SLS and *Orion* are critical to human spaceflight beyond low-Earth orbit as part of an evolvable, sustainable, and affordable exploration program.

The journey to Mars runs through cis-lunar space. NASA's initial deep-space mission will launch to a "Distant Retrograde Orbit" around the Moon. NASA will use this region of space to test and demonstrate operation of human-rated vehicles *farther from Earth than ever before.* In late 2020, NASA plans to launch an advanced solar electric propulsion based spacecraft to redirect a small asteroid or a boulder from a larger asteroid to lunar orbit. In 2025, launched by SLS, *Orion* will carry a two person crew on a 25–28 day mission to rendezvous with the asteroid in cis-lunar space. *Orion* will dock with the robotic spacecraft attached to the asteroid in lunar orbit for about five days. NASA's planning leverages development efforts from existing programs across NASA mission directorates, and provides a critical opportunity to exercise our emerging deep space exploration capabilities.

As NASA strives to achieve the dream of sending humans to Mars, it is important to remember we are already there. For 40 years, increasingly advanced robotic explorers have studied the Red Planet. This has dramatically increased our scientific knowledge and helped pave the way for astronauts to travel there. Our latest Mars spacecraft, MAVEN (Mars Atmosphere and Volatile EvolutioN), arrived last Sep-

tember to study the upper atmosphere and joined a fleet of orbiters and rovers on the surface. Next year, we will send the InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) lander to study the planet's deep interior. In 2020, a new rover, building on the incredible success of Curiosity, will help us prepare for the arrival of humans at Mars. The Mars 2020 rover will address the highest priority Mars science objectives recommended by the Planetary Decadal Survey and will carry exploration technology investigations to help plan future human missions.

Mars is a key destination, but only one point on humanity's journey of discovery. Ours is a journey of understanding reaching through our Earth system, across our solar system, and beyond, deep into the universe. The FY 2016 budget request includes $5,288.6 million for Science to continue that mission, with $1,947.3 million for Earth Science, $1,361.2 million for Planetary Science, $709.1 million for Astrophysics, $620.0 million for the James Webb Space Telescope, and $651.0 million for Heliophysics.

NASA's Planetary Science program continues to expand our knowledge of the solar system, with spacecraft in place from the innermost planet to the very edge of our sun's influence. After nine years and three billion miles of travel, the New Horizons spacecraft awakened and began to prepare for its arrival in the Pluto system in July. Right now, Dawn is approaching the dwarf planet Ceres. Juno is speeding toward Jupiter where it will not only send back unprecedented data from a first ever polar orbit of our giant neighbor, but will also demonstrate how solar power can work at great distances from the sun. With the FY 2016 request, NASA will continue development of a robotic asteroid rendezvous and sample return mission, dubbed OSIRIS–REx, planned for launch in 2016. OSIRIS–REx will approach the near-Earth Asteroid Bennu, map the asteroid, and collect a sample for return to Earth in 2023. Looking further to the future, NASA is planning a mission to explore Jupiter's fascinating moon Europa, selecting instruments this spring and moving toward the next phase of our work.

The most important planet we study is the one on which we live—Earth. Today, 21 NASA-developed research missions orbit Earth and provide a quantitative understanding of our complex planet, its origins and its future. In the last year, we have launched an unprecedented five Earth Science missions, starting with the Global Precipitation Measurement Core Observatory (GPM) that already has observed Hurricane Arthur's brush of the East Coast last July. The Soil Moisture Active Passive (SMAP) mission, launched in January, will give us for the first time ever, a picture of soil moisture on a global scale, allowing scientists to monitor droughts and predict flooding caused by severe rainfall or snowmelt. New research missions in formulation include PACE, the Pre-Aerosol, Clouds and ocean Ecosystem continuity mission, that observes ocean color, aerosols, and clouds; NISAR, the NASA–ISRO Synthetic Aperture Radar mission, being developed in partnership with the Indian Space Research Organization to measure complex processes such as ecosystem disturbances and ice-sheet collapse; and CLARREO, the Climate Absolute Radiance and Refractivity Observatory Pathfinder that will begin pre-formulation this fiscal year.

The Landsat series of satellites is a cornerstone of our Earth observing capability. The world relies on Landsat data to detect and measure land cover/land use change, the health of ecosystems, and water availability. The President's FY 2016 request recognizes Landsat's critical importance and sets out a multi-decadal plan for an Earth-observing architecture that ensures data continuity and reliability. The Sustainable Land Imaging program partnership with the Department of the Interior's U.S. Geological Survey will include flight of a thermal-infrared free flyer and an upgraded Landsat-9 mission, while infusing new technological developments for future missions and ensuring consistency with the existing 42-year Landsat data record.

Twenty-five years ago this April NASA deployed the Hubble Space Telescope. Hubble is still doing amazing science, and the last textbook that will have to be revised because of its discoveries has not yet been written. In just slightly over three years, NASA plans to launch the James Webb Space Telescope (JWST), Hubble's successor, and continue to reveal the unknown with the largest observatory ever put into space. This amazing telescope is taking shape right now in suburban Maryland, where this year the mirrors will be installed on the telescope backplane. The "heart" of the telescope that holds its instruments successfully completed a nearly four-month test in a cryogenic thermal vacuum chamber. NASA's Astrophysics program operating missions include the Hubble, Chandra, Spitzer, and Kepler telescopes, the Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory, and other missions that together comprise an unrivaled resource for the study of our universe. With the FY 2016 request, NASA will continue development of the Transiting Exoplanet Survey Satellite (TESS). TESS will extend the pioneering work of the Kepler Space Telescope, which showed us that virtually every star in

the sky has a planetary system. TESS launches in 2018 and will discover rocky exoplanets orbiting the nearest and brightest stars in the sky in time for Webb to conduct follow-up observations. NASA will also continue pre-formulation of the Wide-Field Infrared Survey Telescope (WFIRST), the top priority for large-scale missions of the most recent National Academy of Science Decadal Survey in Astronomy and Astrophysics.

Just as the most important planet that we study is the Earth, the most important star that we study is our own. NASA's Heliophysics Program is monitoring the Sun, near-Earth space, and the space environment throughout our solar system, with 29 spacecraft making up 18 missions. These missions work toward one goal: to better understand the sun and its interactions with the Earth and solar system, including space weather. The FY 2016 request supports development of NASA's Solar Probe Plus (SPP) mission, planned for launch in 2018. SPP will be humanity's first voyage to our home star and will repeatedly pass through the Sun's hot outer atmosphere. NASA will also begin science operations of the Magnetospheric Multiscale (MMS) mission to investigate how magnetic fields around Earth connect and disconnect, explosively releasing tremendous amounts of energy in a process called magnetic reconnection.

NASA's Aeronautics research is making air travel cleaner, safer, and more efficient. Every U.S. aircraft and U.S. air traffic control tower has NASA-developed-technology on board. NASA's FY 2016 budget request includes $571.4 million for Aeronautics to fulfill the Agency's strategic research agenda, addressing the most critical challenges facing the aviation sector. NASA is improving safety and reducing development costs of new aviation technologies, developing integrated air traffic management tools to expand airspace capacity with more fuel-efficient flight planning and diminish delays, and researching next generation aircraft configurations, efficient engines, and low carbon propulsion systems such as hybrid electric technology systems. NASA is enabling the future of unmanned and autonomous flight by providing technical data and analysis to directly inform FAA rulemaking related to Unmanned Aircraft Systems (UAS), funding technology development to address emerging needs for UAS integration, and initiating fundamental research in autonomous systems for aviation. Also in FY16, NASA is initiating a series of flight demonstrations focused on environmental performance, and expanding our portfolio of rapid-turnover feasibility demonstrations to infuse new ideas into our research program. NASA's aeronautics research continues to play a vital leadership role to air travel and commerce by enabling game-changing technologies and innovation that allow the U.S. aviation industry to continue to grow and maintain its global leadership role. NASA is truly with you when you fly.

NASA's spacecraft are voyaging beyond the solar system, we are developing a mission to pass right through the Sun's atmosphere, and our spacecraft are exploring the planets in between. The venerable Hubble Space Telescope is looking back into deep time, Kepler is demonstrating the prevalence of planets around other stars, and the James Webb Space Telescope is on the way. An early version of *Orion* splashed down in the Pacific, Astronaut Mark Kelly is preparing for a one-year mission in space, and the Space Launch System is on track for a November 2018 launch capability. NASA is embracing its mission as never before. NASA looks forward to working with the Committee and the Congress to make this vision a reality.

Mr. Chairman, I would be pleased to respond to your questions and those of other Members of the Subcommittee.

ATTACHMENT

National Aeronautics and Space Administration

FY 2016 PRESIDENT'S BUDGET REQUEST SUMMARY

	Fiscal Year						
	Actual	Enacted	Request	Notional			
Budget Authority ($ in millions)	2014	2015	2016	2017	2018	2019	2020
NASA Total	17,646.5	18,010.2	18,529.1	18,807.0	19,089.2	19,375.5	19,666.1
Science	5,148.2	5,244.7	5,288.6	5,367.9	5,488.4	5,530.2	5,613.1
Earth Science	1,824.9	--	1,947.3	1,966.7	1,988.0	2,009.3	2,027.4
Planetary Science	1,345.7	--	1,361.2	1,420.2	1,458.1	1,502.4	1,527.8
Astrophysics	678.3	--	709.1	726.5	769.5	1,005.5	1,138.3
James Webb Space Telescope	658.2	645.4	620.0	569.4	534.9	305.0	197.5
Heliophysics	641.0	--	651.0	685.2	697.9	708.1	722.1
Aeronautics	566.0	651.0	571.4	580.0	588.7	597.5	606.4
Space Technology	576.0	596.0	724.8	735.7	746.7	757.9	769.3
Exploration	4,113.2	4,356.7	4,505.9	4,482.2	4,298.7	4,264.7	4,205.4
Exploration Systems Development	3,115.2	3,245.3	2,862.9	2,895.7	2,971.7	3,096.2	3,127.1
Commercial Spaceflight	696.0	805.0	1,243.8	1,184.8	731.9	173.1	1.1
Exploration Research and Development	302.0	306.4	399.2	401.7	595.1	995.4	1,077.2
Space Operations	3,774.0	3,827.8	4,003.7	4,191.2	4,504.9	4,670.8	4,864.3
International Space Station	2,964.1	--	3,105.6	3,273.9	3,641.0	3,826.0	4,038.3
Space and Flight Support	809.9	--	898.1	917.3	863.8	844.8	826.1
Education	116.6	119.0	88.9	90.2	91.6	93.0	94.4
Safety, Security, and Mission Services	2,793.0	2,758.9	2,843.1	2,885.7	2,929.1	2,973.0	3,017.5
Center Management and Operations	2,041.5	--	2,075.2	2,105.0	2,136.6	2,168.6	2,201.0
Agency Management and Operations	751.5	--	767.9	780.7	792.5	804.4	816.5
Construction and Environmental Compliance and Restoration	522.0	419.1	465.3	436.1	442.6	449.3	456.0
Construction of Facilities	455.9	--	374.8	344.3	349.3	354.6	359.9
Environmental Compliance and Restoration	66.1	--	90.5	91.8	93.3	94.7	96.1
Inspector General	37.5	37.0	37.4	38.0	38.5	39.1	39.7
NASA Total	17,646.5	18,010.2	18,529.1	18,807.0	19,089.2	19,375.5	19,666.1

FY 2014 reflects funding amounts specified in the June 2014 Operating Plan per P.L. 113-76.

FY 2015 reflects only funding amounts specified in P.L. 113-235, the Consolidated and Further Continuing Appropriations Act, 2015. For projects in development, NASA's tentatively planned FY 2015 funding level is shown. FY 2015 funding levels are subject to change pending finalization of the FY 2015 operating plan.

The totals for the Exploration and Space Operations accounts in this document supersede the figures in the draft appropriations language.

Senator CRUZ. Thank you very much, Administrator Bolden. Thank you for joining us here this morning, and thank you for your many, many years of honorable service to our nation.

I'd like to start by asking a general question. In your judgment, what is the core mission of NASA?

Mr. BOLDEN. Mr. Chairman, I've given that a lot of thought over the last few days, and so I went back and looked at the original Space Act of 1958. I won't quote it, but essentially our core mission from the very beginning has been to investigate, explore space and the Earth environment, and to help us make this place a better place. So that's the nut of it right there.

And, I have to admit, another core part of it, because we have multiple—if you want to say multiple cores, which is hard—aero-

nautics is an essential part of what NASA does. It is the Big A in NASA. If someone from another planet came down and looked at our budget, they probably would not believe that, because it is the least funded or the skimpiest funded portion of the budget, but we're working on it.

Senator CRUZ. Well, there's no doubt that there are multiple important priorities within NASA. But I would suggest that almost any American would agree that the core function of NASA is to explore space. That's what inspires little boys and little girls across this country. It's what sets NASA apart from any other agency. It's the mission that landed man on the moon. It has the potential to explore new worlds beyond our imagination.

You and I have had this conversation many times.

Mr. BOLDEN. Yes, sir.

Senator CRUZ. And you know that I am concerned that NASA, in the current environment, has lost its full focus on that core mission, and I want to talk for a minute about the current budget.

If you look at the current budget of NASA, and if you compare 2009 to 2016, we can see from 2009 to 2016 that Earth Sciences has had a 41 percent increase in the budget. In contrast, exploration and space operations, what I would consider the core function of NASA, has seen its budget drop 7.6 percent. And looking at the remainder of the elements, Planetary Sciences is a 3 percent increase, Heliophysics is a 10 percent increase, and Astrophysics is a 10 percent increase.

In my judgment, this does not represent a fair or appropriate allocation of resources, that it is shifting resources away from the core functions of NASA to other functions. Do you share that assessment?

Mr. BOLDEN. Mr. Chairman, I am very interested in your chart. However, I will say one thing. It is interesting to note that there is a decrease in exploration or human spaceflight when, in fact, that was somewhat intentional because we were trying to get the cost of exploration down as we reached farther out into the solar system. It used to cost us $2B a year to maintain the Space Shuttle, whether we flew it or not. Today, NASA pays—I want to say we now have two contracts that are in the neighborhood of about $6.8B that will give us 16 fights on a combination of Boeing and SpaceX missions, carrying American astronauts to space. That will probably take place over about maybe three or 4 years.

So I think that decrease is actually a little bit of what we were trying to do, get the cost of flying humans into space down. That's what's driving the market, is reducing launch costs.

So the fact that Earth Science has increased, I'm proud to say it has enabled us to understand our planet far better than we ever did before because it's absolutely critical.

If I go back to what used to be my home state, and your state, the state of Texas, we have the Texas Soil Observation Network, which is strongly supported by NASA. Senator, I don't need to tell you, when I lived in Houston, the elevation sank a matter of inches over the period of time that I lived there, and that was because we were pumping water out of the ground and we just didn't realize what was going on.

But now, because of some of NASA's efforts, we have satellites that are able to look and actually measure the difference in gravitational field of Earth, and we can tell that we're emptying out the aquifers, and that's just looking at our environment, trying to make sure that we have a better place for all of us in which to live. I think that's critical.

Senator CRUZ. I am confident, though, that it's not your testimony to this subcommittee that NASA has all the resources it needs——

Mr. BOLDEN. Oh, no.

Senator CRUZ.—for space exploration——

Mr. BOLDEN. No, no, no.

Senator CRUZ.—and that it has suddenly gotten less expensive and more affordable. Indeed, as you know, the first hearing this subcommittee had, we heard from expert testimony as to the real challenges if we are going to go back to the Moon or to Mars or beyond, that it's going to require a significant investment. And I would suggest that this chart does not suggest that the investment of budgetary resources is going where it should, and let me note one specific matter.

This past December, *Orion* completed a nearly flawless maiden unmanned test flight on the Exploration Flight Test 1 mission. But despite the success of SLS and *Orion,* the President's budget request cuts funding by over $441 million. Does the Administration lack confidence in SLS and *Orion* and their ability to get American astronauts to space beyond low-Earch orbit in the 2021 timeframe?

Mr. BOLDEN. Senator, quite the contrary. I think the Administration has the utmost confidence in us, and that's the reason that they presented the bill for $18.5B that they did to the Congress.

The President trusts me to take whatever amount of funds the Congress appropriates to us and appropriately balance that across our portfolio because we do have multiple things for which we are responsible.

The fact that we now have a set date where the launch complex at the Kennedy Space Center and SLS will be ready for flight in November 2018; the fact that we're going to have a set date when *Orion* will be ready to be integrated with SLS and we'll have that this summer; the fact that we had a successful test on the solid rocket booster out at Promontory Point, Utah 2 days ago; the fact that we now have two contractors who are upgrading their facilities at the Kennedy Space Center and at Cape Canaveral Air Force Station so that we can launch American astronauts to space from American soil in 2017; the fact that we now have a robust competition for American companies to get cargo to space where that used to be the job of the government; I think that speaks highly to the confidence that the Administration and hopefully this Congress has in our ability to do exactly what you want us to do.

I would say—you asked me about your chart—there's a lot of chartsmanship. I'm not sure what you include in exploration, for example. So by my statements, I was not acknowledging that I agree with the numbers on the chart. I don't want everyone to say I accept the numbers on the chart, because when you talk about exploration, a lot of times people don't count the launch complex. You can't go anywhere if you don't have a place from which to

launch. A lot of times people don't count commercial crew and cargo. We can't go anywhere if we don't have a robust, sustainable low-Earth orbit infrastructure.

So there are a lot of things that people don't count. We can't go anywhere if the Kennedy Space Center goes under water and we don't know it. That's understanding our environment.

So, as Senator Nelson said, it is absolutely critical that we understand Earth's environment because this is the only place that we have to live. Having had an opportunity to view it from a place where—I look around and I'm not sure anybody else here has had that opportunity. We've got to take care of it, and the only way we can take care of it is that we know what's happening. And the only way we know what's happening is to use instruments that we developed in NASA, and we do it better than anybody else. I'm proud to say that.

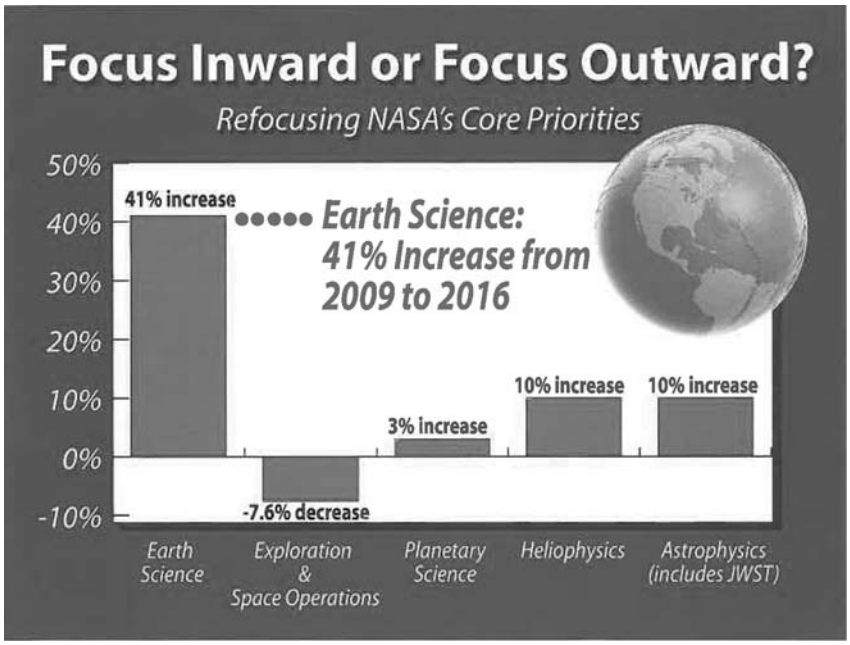
I always come and brag on my workforce. We do it better than anybody else in the world, and that allows us to get data to you and Members of the Congress and the Administration, who make decisions. We don't make decisions. We don't give you opinions. We give you data.

So I'm very proud of what we've done, and I'll go back and take it for the record to see whether we agree with the numbers on the chart, Mr. Chairman.

[The information referred to follows:]

The chart shows an increase in the Earth Science budget from 2009 to 2016 of 41 percent. In the FY 2009 Appropriation, the Earth Science Division's fraction of the full-Agency budget was 9.1 percent, while in the President's Budget Request for FY 2016, this fraction is 10.5 percent. Therefore, in absolute terms, the Earth Science fraction of the Agency's budget has increased by only 1.4 percent. This modest increase supports missions such as Orbiting Carbon Observatory (OCO–3), Climate Absolute Radiance and Refractivity Observatory (CLARREO) technology demonstration, and research & analysis. It also supports the transfer of activity from the National Oceanic and Atmospheric Administration (NOAA) to NASA for developing certain Earth-observing satellites (which takes advantage of NASA expertise in developing Earth-observing satellites).

It is important to note that Earth Science is one of NASA's core missions. The Agency's authorizing statute establishes a list of nine objectives for the Agency, and the first of these is "(1) The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space." The National Academies' 2007 Decadal Survey for Earth Science, "Earth Science and Applications from Space," recommended that: "The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth Science and applications." The proposed budget for FY 2016 is still about 20 percent below the actual levels of the late 1990s, which was the funding level recommended by the Decadal Survey. The increase demonstrates the important role that NASA Earth Science plays in the Nation's science priorities—including those recognized in the NRC Decadal Survey—and confidence in NASA's ability to effectively implement missions.



Senator CRUZ. Thank you, Mr. Administrator.

I now recognize Senator Nelson for his questions.

Senator NELSON. Well, I'm going to defer to the Ranking Member of the Subcommittee, but let me just point out, budgets are not always as clear as what we think they are. Whereas it does show, as you stated, the President's request from what is existing appropriations, which, by the way, is guided by Senator Shelby and Senator Mikulski, a significant plus-up in commercial crew, in which we clearly have an interest, we the United States, in being able to put Americans on American rockets and not pay the Russians to get to and from the International Space Station.

But where it looks like that there is, as you said, about a $400 million reduction in the President's request for *Orion* and the Space Launch System, look at the other things that go along with that, exploration ground systems up $59 million in the President's request, exploration R&D up $93 million in the President's request. And then when you get to something that nobody understands, including this Senator, it also includes part of the exploration, cross-agency support, that's up $84 million. Space technology, which is all a part of the exploration program, but it's a different line item, that's up in the President's request $129 million.

So I think just those numbers, just looking at the specific, isolated SLS and *Orion,* doesn't tell us the whole story. I would defer to the Ranking Member.

Senator PETERS. Thank you, Mr. Chairman. And thank you, Ranking Member Nelson.

I want to just follow along with some of the thoughts that both of the individuals have brought up.

Chairman Cruz, looking at this chart, I think it's also important to note that if you look at a longer timeframe, looking back through the Bush Administration, and prior to that the Clinton Administration, it's my understanding that the money that was spent on Earth Sciences was considerably higher during the Clinton Administration than is currently being spent during the Obama Administration. So it is not as if there has been a big increase from a baseline. It's actually coming back from a major reduction that occurred during the Bush Administration.

I would like to, therefore, enter into the record actually a report that we have from the National Academy of Sciences, their "Earth Science and Applications From Space," a midterm assessment that was done back in 2007. If I may quote something from the report—if I may enter this, without objection?

Senator CRUZ. Without objection.

[The information referred to follows:]

EARTH SCIENCE AND APPLICATIONS FROM SPACE: NATIONAL IMPERATIVES FOR THE NEXT DECADE AND BEYOND

Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future, National Research Council

Pdf available at *http://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*

Executive Summary

A VISION FOR THE FUTURE

Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important challenges for society as it seeks to achieve prosperity, health, and sustainability.

These declarations, first made in the interim report of the Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future,[1] are the foundation of the committee's vision for a decadal program of Earth science research and applications in support of society—a vision that includes advances in fundamental understanding of the Earth system and increased application of this understanding to serve the nation and the people of the world. The declarations call for a renewal of the national commitment to a program of Earth observations in which attention to securing practical benefits for humankind plays an equal role with the quest to acquire new knowledge about the Earth system.

The committee strongly reaffirms these declarations in the present report, which completes the National Research Council's (NRC's) response to a request from the National Aeronautics and Space Administration (NASA) Office of Earth Science, the National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite Data and Information Service, and the U.S. Geological Survey (USGS) Geography Division to generate consensus recommendations from the Earth and environmental science and applications communities regarding (1) high-priority flight missions and activities to support national needs for research and monitoring of the dynamic Earth system during the next decade, and (2) important directions that should influence planning for the decade beyond.[2] The national strategy outlined here has as its overarching objective a program of scientific discovery and development of applications that will

[1]National Research Council (NRC), *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, The National Academies Press, Washington, D.C., 2005, p. 1; referred to hereafter as the "interim report."

[2]The other elements of the committee's charge are shown in Appendix A. As explained in the Preface, the committee focused its attention on items 2, 3, and 4 of the charge.

enhance economic competitiveness, protect life and property, and assist in the stewardship of the planet for this and future generations.

Earth observations from satellites and in situ collection sites are critical for an ever-increasing number of applications related to the health and well-being of society. The committee found that fundamental improvements are needed in existing observation and information systems because they only loosely connect three key elements: (1) the raw observations that produce information; (2) the analyses, forecasts, and models that provide timely and coherent syntheses of otherwise disparate information; and (3) the decision processes that use those analyses and forecasts to produce actions with direct societal benefits.

Taking responsibility for developing and connecting these three elements in support of society's needs represents a new social contract for the scientific community. The scientific community must focus on meeting the demands of society explicitly, in addition to satisfying its curiosity about how the Earth system works. In addition, the federal institutions responsible for the Earth sciences' contributions to protection of life and property, strategic economic development, and stewardship of the planet will also need to change. In particular, the clarity with which Congress links financial resources with societal objectives, and provides oversight to ensure that these objectives are met, must keep pace with emerging national needs. Individual agencies must develop an integrated framework that transcends their particular interests, with clear responsibilities and budget authority for achieving the most urgent societal objectives. Therefore, the committee offers the following overarching recommendation:

Recommendation: **The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications.**

The objectives of these partnerships would be to facilitate improvements that are needed in the structure, connectivity, and effectiveness of Earth-observing capabilities, research, and associated information and application systems—not only to answer profound scientific questions, but also to effectively apply new knowledge in pursuit of societal benefits.

The world faces significant environmental challenges: shortages of clean and accessible freshwater, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in the chemistry of the atmosphere, declines in fisheries, and the likelihood of substantial changes in climate. These changes are not isolated; they interact with each other and with natural variability in complex ways that cascade through the environment across local, regional, and global scales. Addressing these societal challenges requires that we confront key scientific questions related to ice sheets and sea-level change, large-scale and persistent shifts in precipitation and water availability, transcontinental air pollution, shifts in ecosystem structure and function in response to climate change, impacts of climate change on human health, and the occurrence of extreme events, such as severe storms, heat waves, earthquakes, and volcanic eruptions. The key questions include:

- Will there be catastrophic collapse of the major ice sheets, including those of Greenland and West Antarctic and, if so, how rapidly will this occur? What will be the time patterns of sea-level rise as a result?
- Will droughts become more widespread in the western United States, Australia, and sub-Saharan Africa? How will this affect the patterns of wildfires? How will reduced amounts of snowfall change the needs for water storage?
- How will continuing economic development affect the production of air pollutants, and how will these pollutants be transported across oceans and continents? How are these pollutants transformed during the transport process?

- How will coastal and ocean ecosystems respond to changes in physical forcing, particularly those subject to intense human harvesting? How will the boreal forest shift as temperature and precipitation change at high latitudes? What will be the impacts on animal migration patterns and on the prevalence of invasive species?
- Will previously rare diseases become common? How will mosquito-borne viruses spread with changes in rainfall and drought? Can we better predict the outbreak of avian flu? What are the health impacts of an expanded ozone hole that could result from a cooling of the stratosphere, which would be associated with climate change?
- Will tropical cyclones and heat waves become more frequent and more intense? Are major fault systems nearing the release of stress via strong earthquakes?

The required observing system is one that builds on the current fleet of space-based instruments and brings to a new level of integration our understanding of the Earth system.

SETTING THE FOUNDATION: OBSERVATIONS IN THE CURRENT DECADE

As documented in this report, the extraordinary U.S. foundation of global observations is at great risk. Between 2006 and the end of the decade, the number of operating missions will decrease dramatically, and the number of operating sensors and instruments on NASA spacecraft, most of which are well past their nominal lifetimes, will decrease by some 40 percent (see Figures ES.1 and ES.2). Furthermore, the replacement sensors to be flown on the National Polar-orbiting Operational Environmental Satellite System (NPOESS)[3] are generally less capable than their Earth Observing System (EOS) counterparts.[4] Among the many measurements expected to cease over the next few years, the committee has identified several that are providing critical information now and that need to be sustained into the next decade—both to continue important time series and to provide the foundation necessary for the recommended future observations. These include measurements of total solar irradiance and Earth radiation and vector sea-surface winds; limb sounding of ozone profiles; and temperature and water vapor soundings from geostationary and polar orbits.[5]

As highlighted in the committee's interim report, there is substantial concern that substitution of passive microwave sensor data for active scatterometry data will worsen El Niño and hurricane forecasts as well as weather forecasts in coastal areas.[6] Given the status of existing surface wind measurements and the substantial uncertainty introduced by the cancellation of the CMIS instrument on NPOESS, the committee believes it imperative that a measurement capability be available to prevent a data gap when the NASA QuikSCAT mission, already well past its nominal mission lifetime, terminates.

Questions about the future of wind measurement capabilities are part of a larger set of issues related to the development of a mitigation strategy to recover capabilities lost in the recently announced descoping and cancellations of instruments and spacecraft planned for the NPOESS constellation. A request for

[3]See a description at http://www.ipo.noaa.gov/.

[4]NASA's Earth Observing System (EOS) includes a series of satellites, a science component, and a data system supporting a coordinated series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. See http://eospso.gsfc.nasa.gov/eos_homepage/description.php.

[5]As discussed in the Preface and in more detail in Chapter 2, the continuity of a number of other critical measurements, such as sea-surface temperature, is dependent on the acquisition of a suitable instrument on NPOESS to replace the now-canceled CMIS sensor.

[6]Also, see pp. 4-5 of the Oceans Community Letter to the Decadal Survey, available at http://cioss.coas.oregonstate.edu/CIOSS/Documents/Oceans_Community_Letter.pdf, and the report of the NOAA Operational Ocean Surface Vector Winds Requirements Workshop, June 5-7, 2006, National Hurricane Center, Miami, Fla., P. Chang and Z. Jelenak, eds.

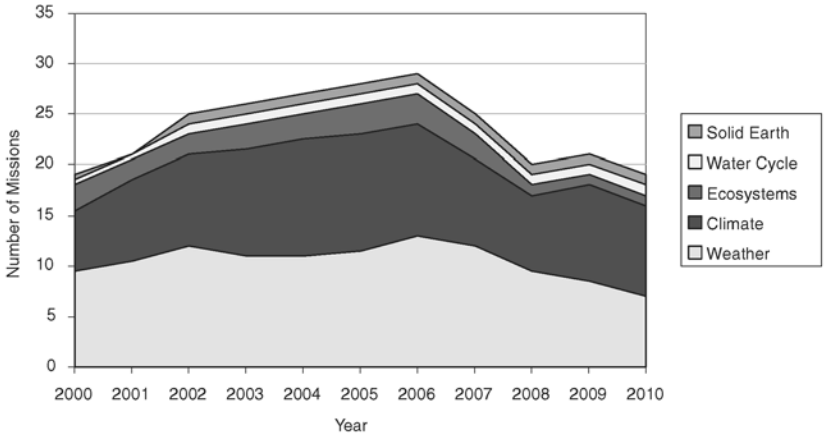


FIGURE ES.1 Number of U.S. space-based Earth observation missions in the current decade. An emphasis on climate and weather is evident, as is a decline in the number of missions near the end of the decade. For the period from 2007 to 2010, missions were generally assumed to operate for 4 years past their nominal lifetimes. Most of the missions were deemed to contribute at least slightly to human health issues, and so health is not presented as a separate category. SOURCE: Information from NASA and NOAA Web sites for mission durations.

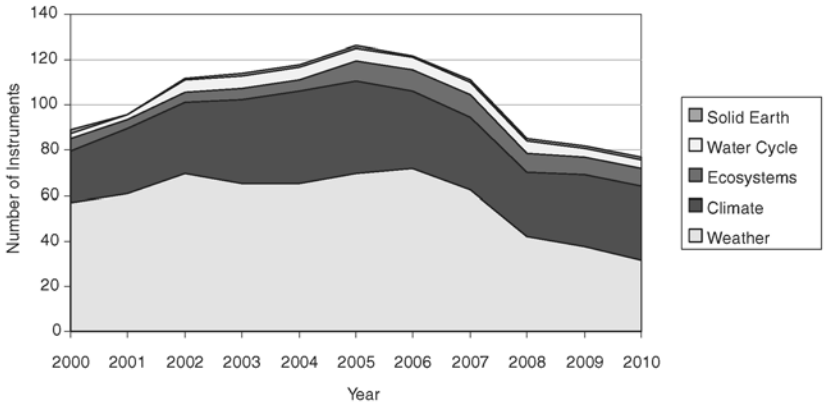


FIGURE ES.2 Number of U.S. space-based Earth observation instruments in the current decade. An emphasis on climate and weather is evident, as is a decline in the number of instruments near the end of the decade. For the period from 2007 to 2010, missions were generally assumed to operate for 4 years past their nominal lifetimes. Most of the missions were deemed to contribute at least slightly to human health issues, and so health is not presented as a separate category. SOURCE: Information from NASA and NOAA Web sites for mission durations.

the committee to perform a fast-track analysis of these issues was approved by the NRC shortly before this report was released. Nevertheless, based on its analysis to date, the committee makes the following recommendations:

Recommendation:[7] **NOAA should restore several key climate, environmental, and weather observation capabilities to its planned NPOESS and GOES-R**[8] **missions; namely:**

- **Measurements of ocean vector winds and all-weather sea-surface temperatures descoped from the NPOESS C1 launch should be restored to provide continuity until the CMIS replacement is operational on NPOESS C2 and higher-quality active scatterometer measurements (from XOVWM, described in Table ES.1) can be undertaken later in the next decade.**
- **The limb sounding capability of the Ozone Monitoring and Profiling Suite (OMPS) on NPOESS should be restored.**[9]

The committee also recommends that NOAA:

- **Ensure the continuity of measurements of Earth's radiation budget (ERB) and total solar irradiance (TSI) through the period when the NPOESS spacecraft will be in orbit by:**
  - **—Incorporating on the NPOESS Preparatory Project (NPP)**[10] **spacecraft the existing "spare" CERES instrument, and, if possible, a TSI sensor, and**
  - **—Incorporating these or similar instruments on the NPOESS spacecraft that will follow NPP, or ensuring that measurements of TSI and ERB are obtained by other means.**
- **Develop a strategy to restore the previously planned capability to make high-temporal- and high-vertical-resolution measurements of temperature and water vapor from geosynchronous orbit.**

The high-temporal- and high-vertical-resolution measurements of temperature and water vapor from geosynchronous orbit were originally to be delivered by the Hyperspectral Environmental Sensor (HES) on the GOES-R spacecraft. Recognizing the technological challenges and accompanying potential for growth in acquisition costs for HES, the committee recommends consideration of the following approaches:

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[7]Inaccurate wording of this four-part recommendation in the initially released prepublication copy of this report was subsequently corrected by the committee to reflect its intent to recommend a capability for ensuring continuity of the ongoing record of measurements of total solar irradiance and of Earth's radiation budget. As explained in the description of the CLARREO mission in Chapter 4, the committee recommends that the CERES Earth radiation budget instrument and a total solar irradiance sensor be flown on the NPOESS Preparatory Project (NPP) satellite and that these instruments or their equivalent be carried on the NPOESS spacecraft or another suitable platform.

[8]GOES-R is the designation for the next generation of geostationary operational environmental satellites (GOES). See https://osd.goes.noaa.gov/ and http://goespoes.gsfc.nasa.gov/goes/spacecraft/r_spacecraft.html. The first launch of the GOES-R series satellite was recently delayed from the 2012 time frame to December 2014.

[9]Without this capability, no national or international ozone-profiling capability will exist after the EOS Aura mission ends in 2010. This capability is key to monitoring ozone-layer recovery in the next two decades and is part of NOAA's mandate through the Clean Air Act.

[10]The NASA-managed NPP, a joint mission involving NASA and the NPOESS Integrated Program Office (IPO), has a twofold purpose: (1) to provide continuity for a selected set of calibrated observations with the existing Earth Observing System measurements for Earth science research and (2) to provide risk reduction for four of the key sensors that will fly on NPOESS, as well as the command and data-handling system. The earliest launch set for NPP is now September 2009, a delay of nearly 3 years from the plans that existed prior to the 2006 Nunn-McCurdy recertification. See http://jointmission.gsfc.nasa.gov/ and http://www.nasa.gov/pdf/150011main_NASA_Testimony_for_NPOESS-FINAL.pdf.

• Working with NASA, complete the GIFTS instrument, deliver it to orbit via a cost-effective launch and spacecraft opportunity, and evaluate its potential to be a prototype for the HES instrument, and/or

• Extend the HES study contracts focusing on cost-effective approaches to achieving essential sounding capabilities to be flown in the GOES-R time frame.

The committee believes that such approaches will both strengthen the technological foundation of geostationary Earth orbit (GEO)-based soundings and provide the requisite experience for efficient operational implementation of GEO-based soundings.

The recommendations above focus on issues whose resolution requires action by NOAA. The committee also notes two issues of near-term concern mostly for NASA:

1. Understanding the changing global precipitation patterns that result from changing climate, and
2. Understanding the changing patterns of land use due to the needs of a growing population, the expansion and contraction of economies, and the intensification of agriculture.

Both of these concerns have been highlighted in the scientific and policy literature;[11] they were also highlighted in the committee's interim report. The committee believes that it is vital to maintain global precipitation measurements as offered by the Global Precipitation Measurement (GPM) mission, and to continue to document biosphere changes indicated by measurements made with instruments on the Landsat series of spacecraft.

Recommendation: **NASA should ensure continuity of measurements of precipitation and land cover by:**

- **Launching the GPM mission in or before 2012, and**
- **Securing before 2012 a replacement for collection of Landsat 7 data.**

The committee also recommends that NASA continue to seek cost-effective, innovative means for obtaining information on land cover change.

Sustained measurements of these key climate and weather variables are part of the committee's strategy to achieve its vision for an Earth observation and information system in the next decade. The recommended new system of observations that will help deliver that vision is described below.

NEW OBSERVATIONS FOR THE NEXT DECADE

The primary work in developing a decadal strategy for Earth observation took place within the survey's seven thematically organized panels (see Preface). Six of the panels were organized to address multidiscipline issues in climate change, water resources, ecosystem health, human health, solid-Earth natural hazards, and weather. This categorization is similar to the organizing structure used in the Global Earth Observation System of Systems (GEOSS) process. Each panel first set priorities among an array of candidate space-based measurement approaches and mission concepts by applying the criteria shown in Box ES.1. The assessment and subsequent prioritization were based on an overall analysis by panel members of how well each mission satisfied the criteria and high-level community objectives. Recommendations in

[11] For example, see the IPCC Third Assessment Report, *Climate Change 2001*, available at http://www.ipcc.ch/pub/reports.htm or at http://www.grida.no/climate/ipcc_tar/, and the 2005 Millennium Ecosystem Assessment Synthesis reports, which are available at http://www.maweb.org/en/Products.aspx#.

BOX ES.1 CRITERIA USED BY THE PANELS TO CREATE RELATIVE RANKINGS OF MISSIONS

- Contribution to the most important scientific questions facing Earth sciences today (scientific merit, discovery, exploration)
- Contribution to applications and policy making (societal benefits)
- Contribution to long-term observational record of Earth
- Ability to complement other observational systems, including planned national and international systems
- Affordability (cost considerations, either total costs for mission or costs per year)
- Degree of readiness (technical, resources, people)
- Risk mitigation and strategic redundancy (backup of other critical systems)
- Significant contribution to more than one thematic application or scientific discipline

Note that these guidelines are not in priority order, and they may not reflect all of the criteria considered by the panels.

previous community-based reports, such as those of the World Meteorological Organization, were also considered.

The complete set of high-priority missions and observations identified by the panels numbered approximately 35, a substantial reduction from the more than 100 missions suggested in the responses to the committee's request for information (see Appendixes D and E) and numerous other mission ideas suggested by panel members (see Table 2.3). The panel reports in Part III of this report document the panels' analyses. As described in Chapter 2, the committee derived a total of 17 missions for implementation by NASA and NOAA.

In developing the recommended set of missions, the committee recognized that a successful Earth observation program is more than the sum of its parts. The committee's prioritization methodology was designed to achieve a robust, integrated program—one that does not crumble if one or several missions in the prioritized list are removed or delayed or if the mission list must evolve to accommodate changing needs. The methodology was also intended to enable augmentation or enhancement of the program should additional resources become available beyond those anticipated by the committee. Robustness is thus measured by the strength of the overall program, not by the particular missions on the list. It is the range of observations that must be protected rather than the individual missions themselves.

The committee's recommended Earth observation strategy consists of:

- 14 missions for implementation by NASA,
- 2 missions for implementation by NOAA, and
- 1 mission (CLARREO) that has separate components for implementation by NASA and NOAA.

These 17 missions are summarized in Tables ES.1 (NOAA portion) and ES.2 (NASA portion). The recommended observing strategy is consistent with the recommendations from the U.S. Global Change Research Program (USGCRP), the U.S. Climate Change Science Program (CCSP), and the U.S. component of GEOSS. Most importantly, the observing strategy enables significant progress across the range of important societal issues. The number of recommended missions and associated observations is only a fraction of the number

TABLE ES.1 Launch, Orbit, and Instrument Specifications for Missions Recommended to NOAA

Decadal Survey Mission	Mission Description	Orbit[a]	Instruments	Rough Cost Estimate (FY 06 $million)
2010-2013				
CLARREO (instrument reflight components)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometer	65
GPSRO	High-accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate, and space weather	LEO	GPS receiver	150
2013-2016				
XOVWM	Sea-surface wind vectors for weather and ocean ecosystems	LEO, SSO	Backscatter radar	350

NOTE: Missions are listed by cost. Colors denote mission cost categories as estimated by the committee. Green and blue shading indicates medium-cost ($300 million to $600 million) and small-cost (<$300 million) missions, respectively. The missions are described in detail in Part II, and Part III provides the foundation for selection.

[a]LEO, low Earth orbit; SSO, Sun-synchronous orbit.

of currently operating Earth missions and observations (see Figures ES.1 and ES.2). *The committee believes strongly that the missions listed in Tables ES.1 and ES.2 form a minimal, yet robust, observational component of an Earth information system that is capable of addressing a broad range of societal needs.*

Recommendation: **In addition to implementing the re-baselined NPOESS and GOES program and completing research missions currently in development, NASA and NOAA should undertake the set of 17 missions[12] recommended in Tables ES.1 and ES.2 comprising low-cost (<$300 million), medium-cost ($300 million to $600 million), and large-cost ($600 million to $900 million) missions and phased appropriately over the next decade.[13] Larger, facility-class (>$1 billion) missions are not recommended. As part of this strategy:**

- **NOAA should transition to operations three research observations. These are vector sea-surface winds; GPS radio occultation temperature, water vapor, and electron density soundings; and total solar irradiance (restored to NPOESS). Approaches to these transitions are provided through the recommended XOVWM, GPSRO, and CLARREO missions listed in Table ES.1.**
- **NASA should implement a set of 15 missions phased over the next decade. All of the appropriate low Earth orbit (LEO) missions should include a Global Positioning System (GPS) receiver to augment operational measurements of temperature and water vapor. The missions and their specifications are listed in Table ES.2.**

[12]One mission, CLARREO, has two components—a NASA component and a separate NOAA component.

[13]Tables ES.1 and ES.2 include cost estimates for the 17 missions. These estimates include costs for development, launch, and 3 years of operation for NASA research missions and 5 years of operation for NOAA operational missions. Estimates also include funding of a science team to work on algorithms and data preparation, but not funding for research and analysis to extract science from the data. All estimates are in fiscal year 2006 dollars.

TABLE ES.2 Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

Decadal Survey Mission	Mission Description	Orbit[a]	Instruments	Rough Cost Estimate (FY 06 $million)
2010-2013				
CLARREO (NASA portion)	Solar and Earth radiation; spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally resolved interferometer	200
SMAP	Soil moisture and freeze-thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	300
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	300
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	700
2013-2016				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	300
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	400
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka- or Ku-band radar Ku-band altimeter Microwave radiometer	450
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High-spatial-resolution hyperspectral spectrometer Low-spatial-resolution imaging spectrometer IR correlation radiometer	550
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	800
2016-2020				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	300
PATH	High-frequency, all-weather temperature and humidity soundings for weather forecasting and sea-surface temperature[b]	GEO	Microwave array spectrometer	450
GRACE-II	High-temporal-resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	450
SCLP	Snow accumulation for freshwater availability	LEO, SSO	Ku- and X-band radars K- and Ka-band radiometers	500
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	600
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	650

NOTE: Missions are listed by cost. Colors denote mission cost categories as estimated by the committee. Pink, green, and blue shading indicates large-cost ($600 million to $900 million), medium-cost ($300 million to $600 million), and small-cost (<$300 million) missions, respectively. Detailed descriptions of the missions are given in Part II, and Part III provides the foundation for their selection.

[a]LEO, low Earth orbit; SSO, Sun-synchronous orbit; GEO, geostationary Earth orbit.

[b]Cloud-independent, high-temporal-resolution, lower-accuracy sea-surface temperature measurement to complement, not replace, global operational high-accuracy sea-surface temperature measurement.

In developing its plan, the committee exploited both science and measurement synergies among the various priority missions of the individual panels to create a capable and affordable observing system. For example, the committee recognized that ice sheet change, solid-Earth hazards, and ecosystem health objectives are together well addressed by a combination of radar and lidar instrumentation. As a result, a pair of missions flying in the same time frame was devised to address the three societal issues.

The phasing of missions over the next decade was driven primarily by consideration of the maturity of key prediction and forecasting tools and the timing of particular observations needed for maintaining or improving those tools. For established applications with a clear operational use, such as numerical weather prediction (NWP), the need for routine vector sea-surface wind observations and atmospheric temperature and water vapor soundings by relatively mature instrument techniques set the early phasing, and these capabilities are recommended to NOAA for implementation. For less mature applications, such as earthquake forecasting and mitigation models, the committee recommends obtaining new surface-deformation observations early in the decade to accelerate tool improvements. Observations of this type, which are more research-oriented, are recommended to NASA for implementation.

In setting the mission timing, the committee also considered mission costs relative to what it considered reasonable future budgets, technology readiness, and the potential of international missions to provide alternative sources of select observations. Rough cost estimates and technology readiness information for proposed missions were provided to the committee by NASA or culled from available information on current missions. The committee decided not to include possible cost sharing by international partners because such relationships are sometimes difficult to quantify. Cost sharing could reduce significantly the U.S. costs of the missions.

Given the relatively large uncertainties attached to cost and technology-readiness estimates, the committee chose to sequence missions among three broad periods in the next decade, namely, 2010-2013, 2013-2016, and 2016-2020. Missions seen to require significant technology development—such as high-power, multifrequency lasers for three-dimensional winds and aerosol and ozone profiling, and thin-array microwave antennas and receivers for temperature and water vapor soundings—were targeted for either the middle or late periods of the next decade; the exact placement depended on the perceived scientific and forecasting impact of the proposed observations (see Chapter 2).

Large uncertainties are also associated with attempts to factor international partner missions into the timing of U.S. missions during the next decade. For example, at the beginning of the next decade, there are international plans for GCOM-C (2011) and EarthCARE (2012), missions that are aimed at observing aerosol and clouds. As a result, the committee targeted for a later time a U.S. mission to explore cloud and aerosol interactions. The European Space Agency's Earth Explorer program has recently selected six mission concepts for Phase A studies, from which it will select one or two for launch in about 2013. All of the Phase A study concepts carry potential value for the broader Earth science community and provide overlap with missions recommended by this committee. Accordingly, the committee recognizes the importance of maintaining flexibility in the NASA observing program to leverage possible international activities, either by appropriate sequencing of complementary NASA and international partner missions or by exploring possible combinations of appropriate U.S. and internationally developed instruments on various launch opportunities.

The set of recommended missions listed in Tables ES.1 and ES. 2 reflects an integrated, cohesive, and carefully sequenced mission plan that addresses the range of urgent societal benefit areas. Although the launch order of the missions represents, in a practical sense, a priority order, it is important to recognize that the many factors involved in developing the mission plan preclude such a simple prioritization (see discussion in Chapter 3 and decision strategies summarized in Box ES.2).

BOX ES.2 PROGRAMMATIC DECISION STRATEGIES AND RULES

Leverage International Efforts

- Restructure or defer missions if international partners select missions that meet most of the measurement objectives of the recommended missions; then (1) through dialogue establish data-access agreements, and (2) establish science teams to use the data in support of the science and societal objectives.
- Where appropriate, offer cost-effective additions to international missions that help extend the values of those missions. These actions should yield significant information in the identified areas at substantially less cost to the partners.

Manage Technology Risk

- Sequence missions according to technological readiness and budget risk factors. The budget risk consideration may favor initiating lower-cost missions first. However, technology investments should be made across all recommended missions.
- Reduce cost risk on recommended missions by investing early in the technological challenges of the missions. If there are insufficient funds to execute the missions in the recommended time frames, it is still important to make advances on the key technological hurdles.
- Establish technology readiness through documented technology demonstrations before a mission's development phase, and certainly before mission confirmation.

Respond to Budget Pressures and Shortfalls

- Delay downstream missions in the event of small (~10 percent) cost growth in mission development. Protect the overarching observational program by canceling missions that substantially overrun.
- Implement a system-wide independent review process that permits decisions regarding technical capabilities, cost, and schedule to be made in the context of the overarching science objectives. Programmatic decisions on potential delays or reductions in the capabilities of a particular mission could then be evaluated in light of the overall mission set and integrated requirements.
- Maintain a broad research program under significantly reduced agency funds by accepting greater mission risk rather than descoping missions and science requirements. Aggressively seek international and commercial partners to share mission costs. If necessary, eliminate specific missions related to a theme rather than whole themes.
- *In the event of large budget shortfalls,* re-evaluate the entire set of missions in light of an assessment of the current state of international global Earth observations, plans, needs, and opportunities. Seek advice from the broad community of Earth scientists and users and modify the long-term strategy (rather than dealing with one mission at a time). Maintain narrow, focused operational and sustained research programs rather than attempting to expand capabilities by accepting greater risk. Limit thematic scope and confine instrument capabilities to those well demonstrated by previous research instruments.

The missions recommended for NASA do not fit neatly within the existing structure of the systematic mission line (i.e., strategic and/or continuous measurements typically assigned to a NASA center for implementation) and the Earth System Science Pathfinder (ESSP) mission line (i.e., exploratory measurements that are competed community-wide). The committee considers all of the recommended missions to be strategic in nature, but recognizes that some of the less complex and less technically challenging missions could be competed rather than assigned. The committee notes that historically the broader Earth science

research community's involvement in space-borne missions has been almost exclusively in concert with various implementing NASA centers. Accordingly, the committee advises NASA to seek to implement the recommended set of missions as part of one strategic program, or mission line, using both competitive and noncompetitive methods to create a timely and effective program.

The observing system envisioned here will help to establish a firm and sustainable foundation for Earth science and associated societal benefits in the year 2020 and beyond. It can be achieved through effective management of technology advances and international partnerships, and through broad use of space-based science data by the research and decision-making communities. In looking beyond the next decade, the committee recognizes the need to learn from implementation of the 17 recommended missions *and* to efficiently move select research observations to operational status. These steps will create new space-based observing opportunities, foster new science leaders, and facilitate the implementation of revolutionary ideas. With those objectives in mind, the committee makes the following recommendation:

Recommendation: **U.S. civil space agencies should aggressively pursue technology development that supports the missions recommended in Tables ES.1 and ES.2; plan for transitions to continue demonstrably useful research observations on a sustained, or operational, basis; and foster innovative space-based concepts. In particular:**

- **NASA should increase investment in both mission-focused and cross-cutting technology development to decrease technical risk in the recommended missions and promote cost reduction across multiple missions. Early technology-focused investments through extended mission Phase A studies are essential.**
- **To restore more frequent launch opportunities and to facilitate the demonstration of innovative ideas and higher-risk technologies, NASA should create a new Venture class of low-cost research and application missions (~$100 million to $200 million). These missions should focus on fostering revolutionary innovation and on training future leaders of space-based Earth science and applications.**
- **NOAA should increase investment in identifying and facilitating the transition of demonstrably useful research observations to operational use.**

The Venture class of missions, in particular, would replace and be very different from the current ESSP mission line, which is increasingly a competitive means for implementing NASA's strategic missions. Priority would be given to cost-effective, innovative missions rather than those with excessive scientific and technological requirements. The Venture class could include stand-alone missions that use simple, small instruments, spacecraft, and launch vehicles; more complex instruments of opportunity flown on partner spacecraft and launch vehicles; or complex sets of instruments flown on suitable suborbital platforms to address focused sets of scientific questions. These missions could focus on establishing new research avenues or on demonstrating key application-oriented measurements. Key to the success of such a program will be maintaining a steady stream of opportunities for community participation in the development of innovative ideas, which requires that strict schedule and cost guidelines be enforced for the program participants.

TURNING SATELLITE OBSERVATIONS INTO KNOWLEDGE AND INFORMATION

Translating raw observations of Earth into useful information requires sophisticated scientific and applications techniques. The recommended mission plan is but one part of this larger program, all elements of which must be executed if the overall Earth research and applications enterprise is to succeed.

The objective is to establish a program that is effective in its use of resources, is resilient in the face of the evolving constraints within which any program must operate, and is able to embrace new opportunities as they arise. Among the key additional elements of the overall program that must be supported to achieve the decadal vision are (1) sustained observations from space for research and monitoring, (2) surface-based and airborne observations that are necessary for a complete observing system, (3) models and data assimilation systems that allow effective use of the observations to make useful analyses and forecasts, and (4) planning and other activities that strengthen and sustain the Earth observation and information system.

Obtaining observations that serve the full array of science and societal challenges requires a hierarchy of measurement types, ranging from first-ever exploratory measurements to long-term, continuous measurements. Long-term observations can be focused on scientific challenges (sustained observations) or on specific societal applications (operational measurements). There is connectivity between sustained research observations and operational systems. Operational systems perform forecasting or monitoring functions, but the observations and products that result, such as weather forecasts, are also useful for many research purposes. Similarly, sustained observations, although focused on research questions, clearly include an aspect of monitoring and may be used operationally. While exploratory, sustained, and operational measurements often share the need for new technology, careful calibration, and long-term stability, there are also important differences among them; exploratory, sustained, and operational Earth observations are distinct yet overlapping categories.

An efficient and effective Earth observation system requires a continuing interagency evaluation of the capabilities and potential applications of numerous current and planned missions for transition of fundamental science missions into operational observation programs. *The committee is particularly concerned about the lack of clear agency responsibility for sustained research programs and the transitioning of proof-of-concept measurements into sustained measurement systems.* To address societal and research needs, both the quality and the continuity of the measurement record must be ensured through the transition of short-term, exploratory capabilities into sustained observing systems. Transition failures have been exhaustively described in previous reports,[14] whose recommendations the present committee endorses.

The elimination from NPOESS of requirements for climate research-related measurements is only the most recent example of the nation's failure to sustain critical measurements. The committee notes that despite NASA's involvement in climate research and its extensive development of measurement technology to make climate-quality measurements, the agency has no requirement for extended measurement missions, except for ozone measurements, which are explicitly mandated by Congress. **The committee endorses the recommendation of a 2006 National Research Council report that stated, "NASA/SMD [Science Mission Directorate] should develop a science strategy for obtaining long-term, continuous, stable observations of the Earth system that are distinct from observations to meet requirements by NOAA in support of numerical weather prediction."**[15]

The committee is concerned that the nation's civil space institutions (including NASA, NOAA, and USGS) are not adequately prepared to meet society's rapidly evolving Earth information needs. These institutions have responsibilities that are in many cases mismatched with their authorities and resources: institutional mandates are inconsistent with agency charters, budgets are not well matched to emerging needs, and shared responsibilities are supported inconsistently by mechanisms for cooperation. These are issues whose solutions will require action at high levels of the federal government. Thus, the committee makes the following recommendation:

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[14]NRC, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*, National Academy Press, Washington, D.C., 2000, and NRC, *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations*, The National Academies Press, Washington, D.C., 2003.

[15]NRC, "A Review of NASA's 2006 Draft Science Plan: Letter Report," The National Academies Press, Washington, D.C., 2006, p. iv.

Recommendation: **The Office of Science and Technology Policy, in collaboration with the relevant agencies and in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations. This plan should recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs.**

The space-based observations recommended by the committee will provide a global view of many Earth system processes. However, satellite observations have limited spatial and temporal resolution and hence do not alone provide a picture of the Earth system that is sufficient for understanding all of the key physical, chemical, and biological processes. In addition, satellites do not directly observe many of the changes in human societies that are affected by, or will affect, the environment. To build the requisite knowledge for addressing urgent societal issues, data are also needed from suborbital and land-based platforms, as well as from socio-demographic studies. The committee finds that greater attention is needed to the entire chain of observations from research to applications and benefits. Regarding complementary observations, the committee makes the following recommendations:

Recommendation: **Earth system observations should be accompanied by a complementary system of observations of human activities and their effects on Earth.**

Recommendation: **Socioeconomic factors should be considered in the planning and implementation of Earth observation missions and in developing an Earth knowledge and information system.**

Recommendation: **Critical surface-based (land and ocean) and upper-air atmospheric sounding networks should be sustained and enhanced as necessary to satisfy climate and other Earth science needs in addition to weather forecasting and prediction.**

Recommendation: **To facilitate the synthesis of scientific data and discovery into coherent and timely information for end users, NASA should support Earth science research via suborbital platforms: airborne programs, which have suffered substantial diminution, should be restored, and unmanned aerial vehicle technology should be increasingly factored into the nation's strategic plan for Earth science.**

Myriad steps are necessary for providing quantitative information, analyses, and predictions for important geophysical and socioeconomic variables over the range of needed time scales. The value of the recommended missions can be realized only through a high-priority and complementary focus on modeling, data assimilation, data archiving and distribution, and research and analysis.[16] To this end, the committee makes the following recommendations:

[16]NASA's research and analysis (R&A) program has customarily supplied funds for enhancing fundamental understanding in a discipline and stimulating the questions from which new scientific investigations flow. R&A studies also enable conversion of raw instrument data into fields of geophysical variables and are an essential component in support of the research required to convert data analyses to trends, processes, and improvements in simulation models. They are likewise necessary for improving calibrations and evaluating the limits of both remote and in situ data. Without adequate R&A, the large and complex task of acquiring, processing, and archiving geophysical data would go for naught. Finally, the next generation of Earth scientists—the graduate students in universities—are often educated by performing research that has originated in R&A efforts. See NRC, *Earth Observations from Space: History, Promise, and Reality (Executive Summary)*, National Academy Press, Washington, D.C., 1995.

Recommendations:

- **Teams of experts should be formed to consider assimilation of data from multiple sensors and all sources, including commercial providers and international partners.**
- **NOAA, working with the Climate Change Science Program and the international Group on Earth Observations, should create a climate data and information system to meet the challenge of ensuring the production, distribution, and stewardship of high-accuracy climate records from NPOESS and other relevant observational platforms.**
- **As new Earth observation missions are developed, early attention should be given to developing the requisite data processing and distribution system, and data archive. Distribution of data should be free or at low cost to users, and provided in an easily accessible manner.**
- **NASA should increase support for its research and analysis (R&A) program to a level commensurate with its ongoing and planned missions. Further, in light of the need for a healthy R&A program that is not mission-specific, as well as the need for mission-specific R&A, NASA's space-based missions should have adequate R&A lines within each mission budget as well as mission-specific operations and data analysis. These R&A lines should be protected within the missions and not used simply as mission reserves to cover cost growth on the hardware side.**
- **NASA, NOAA, and USGS should increase their support for Earth system modeling, including provision of high-performance computing facilities and support for scientists working in the areas of modeling and data assimilation.**

SUSTAINING AN EARTH KNOWLEDGE AND INFORMATION SYSTEM

A successful Earth information system should be planned and implemented around long-term strategies that encompass the life cycle from research to operations to applications. The strategy must include nurturing an effective workforce, informing the public, sharing in the development of a robust professional community, ensuring effective and long-term access to data, and much more. An active planning process must be pursued that focuses on effectively implementing the recommendations for the next decade as well as sustaining and building the knowledge and information system beyond the next decade.

***Recommendation:* A formal interagency planning and review process should be put into place that focuses on effectively implementing the recommendations made in the present decadal survey report and sustaining and building an Earth knowledge and information system for the next decade and beyond.**

The training of future scientists who are needed to interpret observations and who will turn measurements into knowledge and information is exceedingly important. To ensure that effective and productive use of data is maximized, resources must be dedicated to an education and training program that spans a broad range of communities. A robust program that provides training in the use of these observations will result in highly varied societal benefits, including improved weather forecasts, more effective emergency management, better land-use planning, and so on.

***Recommendation:* NASA, NOAA, and USGS should pursue innovative approaches to educate and train scientists and users of Earth observations and applications. A particularly important role is to assist educators in inspiring and training students in the use of Earth observations and the information derived from them.**

Senator PETERS. Thank you, Mr. Chairman.

A quote from it is that it noted that the Bush-era reductions in Earth Science funding were having a "disastrous consequence on Earth observation record." So it seems as if we are trying to correct what the National Academy of Sciences, and I know the Chairman has mentioned that he wants science to drive our process here, which makes sense to have it. But here we have the foremost experts in science in our country saying that the cuts that we saw in Earth Sciences were disastrous in the Bush era.

So I would assume that you are taking a look at those types of reports from our experts and are addressing that. So how does this year's requested increase in Earth Science funding address the priorities that you see coming from the scientific community?

Mr. BOLDEN. Senator Peters, I think you know very well we are guided, particularly in the science arena, by the input of the experts, dominantly by what we call decadal surveys. They are studies by learned people in specific areas that come from the National Research Council, and they give us guidance. It's not mandatory, but they give us guidance on how we should put our emphasis.

So if you look at all of our programs, whether it's in heliophysics, planetary science, Earth science, or the others, we're generally trying to do what the experts say NASA should be putting its focus on. And you're absolutely right, across the board we're really trying to get the science community back up to the levels of spending of prior years, and that can't all be done at one time.

So we take what seems to be the most important things told to us by the scientific community, put our focus on that, and also we try to look at things that are going to contribute ultimately, going back to Senator Cruz' comment to everything that we do. If there is a choice to be made, we try to put our focus on what is going to enable us to get humans to Mars. As I said before, when you look at science, areas like heliophysics, areas like planetary science, areas like Earth Science are all critical in providing data that helps us to speed our way to Mars.

We're looking at radiation. We're looking at the sun because it determines the time of year or the time when you want to launch a human on a mission that's going to take eight months. So it's important for us to look at all that, and it's unfortunate that people tend to want to talk about one versus the other.

We are at a time in the agency when we work more synergistically across our mission directorates. Science helps exploration. Exploration helps science. Technology development is absolutely critical because the most important risks that I have to draw down are risks that deal with technology that we don't have today, and that's why we asked for the increased funding for technology development that we've not been able to get.

So it is absolutely critical that the Committees and the Congress trust NASA and some pretty smart people. You ask us to be your experts, and I consider myself to be the Congress' subject-matter expert when it comes to exploration science and aeronautics. If I'm not doing that well, you ought to fire me, to be quite honest.

Senator PETERS. Well, it's clear from your answer how science is driving us, including observations of the Earth and the practical applications. I think we're going to talk about it later. Hopefully

we'll have time to talk about certainly the spillovers of the work of NASA into economic development and small business, but other areas of making sure we're studying our planet have very strong economic consequences, particularly, for example, in agriculture.

I know NASA funds the Global Observatory for Ecosystem Services that's used extensively by a university in my state, Michigan State University, the first land grant university in the country, a leader in agricultural sciences. They collect data from LANDSAT satellites and distribute those to scientists, educators, and users around the world, and have significant applications when it comes to the agricultural community in this country that relies on that kind of information to plan and to do things related to increasing agricultural production.

Are there other areas like that that you see as incredibly important in terms of just our day-to-day commercial activities here on our planet?

Mr. BOLDEN. Yes, sir, there are. We just recently completed a conference, a meeting with policymakers and others in the states of California and Nevada about water, water resources, and letting them know how our Earth Science assets were available to help them understand how to utilize the limited water that's available, to give them hints about drought and flood cycles. I mentioned to Senator Cruz the Texas Soil Observation Network.

Texas is a big state, and Texas has probably the fewest organic ways to measure things like soil moisture. Due to the fact that we launched the Soil Moisture Active-Passive mission just recently, something we call SMAP, we now are able to measure very accurately soil moisture in every state of the union and around the globe, and that is becoming essential data to the people in Texas in their water resources management.

Whether you're talking about farmers or ranchers, you want to maximize crop yield. So we need to be able to tell them how to get more efficiently and effectively water into their particular areas. So those are the kinds of things that I would hope people would not overlook when you talk about what we do in Earth Science. It's really about making life better for people on this planet.

Senator PETERS. Thank you, Mr. Bolden. Another question for you, if I may.

Since the end of the Shuttle program in 2011, the United States has relied on the Russian Soyuz for crew transportation to the International Space Station. The Soyuz cost, it's my understanding, has risen from $25 million per seat in 2010 to now more than $76M for us to take a ride on the Soyuz up to the Space Station. NASA will have paid Russia over $2.1B by the time domestic providers Boeing and SpaceX are able to launch their astronauts in 2017.

If you could elaborate for us, please, on how failing to fully fund the $1.2 billion request for commercial crew program affects the Space Station program, and more specifically our continued dependence on the Russians.

Mr. BOLDEN. Senator, because we are now operating on two firm fixed-price contracts with Boeing and SpaceX, any amount short of the $1.2B that we requested will mean we will have to reduce the milestones that the two manufacturers accomplish. We can't pick

one over the other. We're contractually obligated to both. So it will mean both will be slowed down and we won't make 2017.

That will mean that we'll have to go back and rely on the Russians continually to provide transportation for our crews, so that puts us at risk, as came out in my hearing with the House Appropriations Committee, when we have to depend on someone else to get our crews to the International Space Station. We have a great relationship. I'm not worried, but I would feel much better if I knew I was dependent on two American companies.

Senator PETERS. Well, I think we would all agree with you. Thank you so much.

Mr. BOLDEN. Thank you very much.

Senator CRUZ. Thank you very much.

Senator Gardner?

STATEMENT OF HON. CORY GARDNER,
U.S. SENATOR FROM COLORADO

Senator GARDNER. Thank you, Mr. Chairman.

And thank you, Administrator Bolden, for your time and testimony today.

It has been an interesting conversation, but I do think it merits kind of focusing back in on what we believe NASA's core mission to really be.

Now, you mentioned that NASA's core mission going back to the 1950s, looking at the organic legislation to create the legislation, I kind of want to go there. We talked about water management in California. We talked about the Texas soil management system.

I'm sorry, Chairman, I'm not as familiar with the Texas soil management perhaps as I should be. But I want to just ask a couple of questions.

Is there any other agency or department in the Federal Government who is sending Rovers to Mars? There's not.

Mr. BOLDEN. No, sir. There is no other nation that has a Rover.

Senator GARDNER. Are there any other agencies that are looking at soil in Texas?

Mr. BOLDEN. I would hope so, but I——

Senator GARDNER. Are there any other agencies——

Mr. BOLDEN. We collaborate with——

Senator GARDNER. Are there any other agencies that are tasked with sending *Orion,* which you said performed flawlessly——

Mr. BOLDEN. Senator, I get your drift, but——

Senator GARDNER. Drift is a good point, because that's exactly what I want to talk about.

Mr. BOLDEN. Senator——

Senator GARDNER. Because it seems to me that NASA perhaps has drifted away from its core mission, and I'm concerned about that. We have so many other agencies and departments that are looking at our soil sciences and our water management. And I understand the importance of going to space and putting a satellite and looking down and measuring and monitoring what we can do, but I am concerned that when we talk about how we're going to have a future of robots on Mars, that we're not funding the Opportunity Rover on Mars in the 2016 budget. So I just want to ask a few questions.

In 2010, President Obama went to the John F. Kennedy Space Center, and he committed to a manned mission to Mars, correct?

Mr. BOLDEN. Yes, sir.

Senator GARDNER. On December 5, 2014, *Orion* launched atop a ULA Delta–4 heavy rocket, the Orion–4 Flight Test, and you said it, I think—I wrote it down, because I think we tweeted it already—*Orion* performed flawlessly.

Mr. BOLDEN. And some people say near flawlessly.

Senator GARDNER. Near flawlessly, OK. I'll take the flawless.

Mr. BOLDEN. I'll take the flawless.

Senator GARDNER. A two-orbit, 4-hour flight that tested many of the systems most critical to safety, launch, high-speed reentry systems, avionics, altitude control, you name it. It was a success. You called it flawless.

Would you consider *Orion* and SLS instrumental in achieving a manned mission to Mars?

Mr. BOLDEN. They're absolutely essential, Senator. And I would also say, again, sort of as I talked to Senator Cruz about being careful when you draw something out and talk about that one thing singularly, there is, to my knowledge—and I will have to take this for the record, but to my knowledge, there is only one agency of the Federal Government that develops the instruments, launches the satellites and the like that explore our planet, to the extent that we do, and that's NASA.

[The information requested follows:]

NASA is the Nation's civil space agency. As such, NASA (among other activities) designs, procures, develops, and launches Earth monitoring spacecraft that provide critical space-based observations of our planet. Data from NASA Earth-observing research satellites is made available rapidly (often in near-real time), and thus is often used by other Federal agencies with "operational missions" to improve their operational products, such as weather predictions and disaster response planning and execution. In addition to other Federal agencies, state and local governments and other organizations routinely use NASA research data for applied and operational purposes.

NASA solicits and funds a broad suite of research studies to improve our understanding of the Earth and its processes as an integrated system, using measurements from NASA research satellites and also operational and research satellites from partner agencies and international partners. NASA researchers also develop and demonstrate application products—based on the measurements of the spaceborne constellation and the understanding gained from the research program—that deliver direct societal benefit and strengthen our Nation. Because of its unsurpassed technical and systems engineering expertise and its role as the Nation's civil space agency, "operational" agencies such as NOAA have utilized NASA services to develop and implement spaceborne Earth observation satellites in support of their missions.

So, if we did not do it, many of the satellites that NOAA operates, once we get them in orbit and hand them off to them, they become NOAA satellites, not NASA satellites. But because we have the expertise, like the Jet Propulsion Lab, Goddard Space Flight Center, and our contractors, when you talk about sensors, there are not a lot of people in the world who do the stuff that our people do when you talk about sensors.

So if we stop doing it, it doesn't mean that's why I think it's core, because if you take Earth Science out of NASA, the Nation loses its dominant capability to do the types of Earth Science investigations that this Nation does.

So I just caution that if we're going to talk about core things and things that only NASA does, you really do need to look at LANDSAT. NASA does not own LANDSAT. LANDSAT belongs to the Department of the Interior. But if it were not for NASA producing the LANDSAT satellite because of the expertise that we have in developing the instruments, there would be no LANDSAT. That's a 40-year continuous program.

If you took that away from NASA, we would not have it, the Nation would not have it. Right now, the Department of Defense is really hurting for weather satellites. NOAA was really hurting for weather satellites a few years ago when we were putting together a program that was ultimately canceled called NPOESS that was going to be a joint NASA-NOAA-DOD weather satellite. It was finally canceled because the cost had gotten out of hand, we just weren't getting anywhere close.

NASA, because we are always looking at newer, more state-of-the-art sensors, had developed sensors that we put on a satellite that was called NPOESS Preparatory Project, NPP. NPP is now a major weather satellite for NOAA and the National Weather Service that was not supposed to be a weather satellite. If NASA had not done that, this nation and other people around the world would not be able to do the things that they do about understanding the climate, predicting hurricanes and tornadoes, which we can't predict.

But, I just caution people about saying, OK, NASA shouldn't be doing this. We are the core producers of instruments and satellites that look at this planet. We're better than anybody else in the world, and if you took that out of NASA, you've got to put it somewhere, and there are other agencies that do not have that.

We are known for our program management capability. That's why everybody comes to us to get satellites. I think if you talk to Dr. Sullivan over in NOAA, if you talk to any of the secretaries about where they would go to get a good satellite, hopefully they would tell you they'd come to us.

Senator GARDNER. Well, given the comments that you made about President Obama's commitment to the manned mission to Mars, given your comments about the *Orion* SLS being instrumental in the manned Mars mission, I still don't understand why we have seen a reduction, then, in the *Orion* program from 2015 to 2016, the SLS program from 2015 to 2016. There's no doubt about it that I support science and research funding, but I also support identifying priorities and funding priorities.

So I'm very concerned that this budget document, the document that Senator Cruz put forward in a chart, Chairman Cruz put forward in a chart about what NASA's priorities are, where they're at, and really if we're seeing the kind of drift that is going to make our mission the core mission that I believe it should be, difficult to reach.

The budget request for Earth Science put a little number to this 41 percent increase. For Fiscal Year 2016, it is $1.95B, a lot of systems monitoring Earth, multiple agencies supporting Earth Sciences. But we are without the basic required system to send pioneers to Mars.

So, a 41 percent increase, but yet NASA, the only agency, the only part of our government that is working on sending people out there, doesn't have the basic capacity to do that, while we're decreasing and increasing our sciences.

So, I know I'm running out of time, but I'm concerned with the small amount of money that we've allocated to our mission that's been endorsed by the President.

Mr. Chairman, I'll yield back to you.

Mr. BOLDEN. Senator, may I make a comment? Again, I want to make a slight correction. You are absolutely correct that we don't have everything that we need to get humans to Mars. That is not in human exploration. That is in space technology. This agency and this President have been requesting—we requested a billion dollars when I became the NASA Administrator to establish a Space Technology Mission Directorate because the things that we're missing in being able to effectively and safely send humans to Mars, the majority of that is not done in the Human Exploration Mission Directorate. I need it to be done in the Space Technology Mission Directorate, and that's not funded efficiently.

Senator GARDNER. So why not fund the Mars Opportunity Rover in the 2016 budget?

Mr. BOLDEN. Mars Opportunity Rover, Senator, we are getting incredible data from Mars through Curiosity, through Opportunity. We're getting ready to send InSight. We cannot continue to operate instruments and missions whose time has passed because I won't be able to put something like Insight on Mars in 2016 that, for the first time ever, is going to core deeper into the surface of the planet. I don't have a Rover that can do that today.

I have to make choices. Hopefully, you trust me. Senator, my choice since becoming the NASA Administrator was to put $49B on human spaceflight and $11B on Earth Science—$498M. I'm sorry. Thank you—$498M on human spaceflight and $11B on Earth Science.

Now, if you put that on a chart, the science community is going to kill me because that was the fear when I became the NASA Administrator, that I was going to put $498B on human spaceflight and I was going to put some measly amount into science. I have tried not to do that. I have tried to focus this agency on all the things it's important for us to do.

So I think the balance overall is good—$498B for human spaceflight, $11B for Earth Science. I think that's a fair allocation for funds on the part of this Administration and this agency, and it's unfortunate that everyone doesn't recognize the fact that we've done that. That's significant.

Senator GARDNER. Mr. Chairman, you've been more than generous with the time.

Mr. BOLDEN. Human space flight dwarfs what we've been doing in other areas.

Senator CRUZ. Senator Nelson?

Senator NELSON. Senator Gardner, every now and then we have to put on the green eyeshades and get into the budget. The President's proposed budget, which you can disagree with, is a 10 percent increase in Earth Science. It is, from $1.773 billion, a $175 million increase. That's about 10 percent.

Now, if you want to solve the problem of what you're talking about, of going to Mars and ramping it up, then what we need is more than the President's request of a half-billion-dollar increase for NASA. We could pour the juice, like we did in the Apollo program, where the Nation's space budget was more like 5 percent of the entire Federal budget instead of the existing NASA budget being less than a percent of the total Federal budget, and you will certainly find this senator supporting you in that.

What I have tried so hard to do in the past several years, in what little bit of influence I have in this committee, is to keep it bipartisan. The history of this committee was that it should never have even been bipartisan. It was non-partisan, and that's what NASA was. And yet, in the past couple of years, we got into these flaps over the sequester, and all of the senators on your side before you arrived were voting to cut the NASA budget by $1.5 billion from the President's request in 2015, which would have absolutely eviscerated this little agency.

Thank goodness we are to the point now that we are talking about this core mission and trying to explore the heavens and realizing that space flight is not cheap.

I would also point out to my colleague from Texas that he and I are from Gulf states, and on June 1st hurricane season starts, and we are so dependent upon the protection from those natural disasters that plague the shores of our respective states by being able to have the advanced warning by virtue of the accurate predictions of the weather satellites.

And as the Administrator says, NASA builds them and then turns them over to NOAA. And then coming up, here we've got the Global Participation Measurement, GPM. These are current Earth Science missions. What does it do? It predicts extreme weather events. The ISS RapidScat, it gives weather forecasting and storm tracking. And then I'll just give you one more. We talked about Soil Moisture Active Passing. That's SMAP that the Administrator already talked about, weather forecasting.

All of these things, if you would look behind what appears to be on the surface and get in, and where you have a disagreement, I want to hear about it. But I don't think, and I certainly don't think the Chairman of the Subcommittee has a disagreement with trying to get accurate weather forecasting——

Senator GARDNER. And if you listen to my comments, I'm not talking about that either. I'm just talking about are we focusing on the heavens in NASA or are we focusing on dirt in Texas? So that's what I want to talk about, and I think that's the point of this discussion, and I think it's talking about how we can make sure that we're allowing NOAA to do the work that it's doing in weather, and allowing NASA to look at Mars, and allowing our agencies to work together to predict weather. Certainly Colorado has had its fair share of terrible, terrible and tragic weather events, and that's something that we have to fund, and we will continue to do that. I'm just trying to figure out where the proper role and the proper mission lies in government.

But I'll remind, too, that the sequester was a bipartisan accomplishment. Whether or not we like it and want to change it, it was bipartisan.

Senator NELSON. Well, fortunately, the sequester, thanks to Senator Shelby, did not happen on NASA, or else we would be way behind and we wouldn't be talking about launching Americans on American rockets in 2017. And, by the way, I'm still hopeful that's going to be 2016. The two companies that are competing, Boeing and SpaceX, still think they can make 2016 for the first American riding the rocket. I am not applying.

Mr. Chairman, I want to get down in the weeds and ask the Administrator a technical question.

Mr. Administrator, we're thinking on the SLS that we're going to have the upper stage as a Delta–4. And yet, because of this senator and others, such as Senator McCain and I were the authors in the defense authorization bill saying America has got to start changing its rocket engines from the Russian rocket engines, the RD–180, and notably the SLS will use the Delta–4 upper stage as a stopgap until an upper stage suitable for deep space missions can be developed.

So are we spending wise money human-rating the Delta–4 as an interim upper stage when later on we might be shifting to another upper stage that we're going to develop? I know that's a question down in the weeds, but we need to look at that.

Mr. BOLDEN. Yes, sir. Senator, we are looking at what we call the Exploration Upper Stage, and it is our intent that as we go along, as I talked about, we're looking at the total program. We would prefer to have the Exploration Upper Stage be the vehicle of choice, if you will, and just have to certify that vehicle. But again, because we're looking at the funding available for the EM–1 for the very first flight of the integrated system, we're going to fly with what we call the Interim Cryogenic Propulsion Stage, which is the Delta–4 upper stage. But eventually we will work our way to a single Exploration Upper Stage.

Senator NELSON. And as you all develop your out-year budgets, do you anticipate that ULA's plans to phaseout the Delta–4 in 2018 is going to effect the cost and the risk of the SLS program?

Mr. BOLDEN. Senator, I'm not aware of ULA's decision in that regard, to be quite honest. What I am aware of is the fact that we, along with the Department of Defense, are looking for a way to get the U.S. off reliance on engines and launch vehicles that depend on engines from other nations. But I don't have any information that talks about when or if ULA is going to phaseout the Delta–4. I'm sorry.

Senator NELSON. And that's why I bring it up, because of what we put in the defense budget about the RD–180 and developing a follow-on engine to the RD–180, which is the main engine in the Atlas–5. I would hope that there is opportunity for NASA to work with DOD on a propulsion system that benefits both defense and civil space, particularly with regard to the SLS's Advanced Booster upgrade.

Mr. BOLDEN. Yes, sir. Senator, we work with DOD continually. There is an organization that's headquartered in the Marshall Space Flight Center called the National—I knew I shouldn't have said this. It's NIRPS, and I will take it for the record to get someone to tell us what NIRPS stands for. [National Institute for Rocket Propulsion Systems] But it's an interagency propulsion study

group, and much of our work emanates right there where we're talking with the DOD and NASA and others about what the nation needs.

What the Nation needs is a new launch system, and my caution would be don't focus on the engine because engines on rockets don't work like people think. You don't go get a new engine and stick it on a rocket. You have to have an integrated system.

So I think what the Air Force secretary has said, Secretary James has probably said, if I remember correctly, is what they're looking at is a new launch system for this nation, which would include a new American-made rocket to go with the American-made body. But launch systems are systems, are integrated systems.

As a matter of fact, when you talked about human-rating the upper stage, it's not the upper stage that we human rate. It's the launch system that includes the upper stage. So we human-rate SLS, *Orion,* and the upper stage as an acceptable human-rated launch system, and if we change any component, we've got to go back in and re-rate it.

So my only caution there is don't get hung up on the engine but focus on the integrated system because that's what the Nation needs.

Senator CRUZ. Administrator Bolden, in your exchange with Senator Gardner, you told this committee that NASA in your tenure had spent $498B on human spaceflight. Now, politicians are famously bad at math, but I just did some quick back-of-the-envelope analysis, and NASA's budget is about $18B. You've been administrator seven years. That's $126B. So I assume you must have misspoken because that's over 300 percent the total budget of NASA for your tenure.

Mr. BOLDEN. That's what I said. I am now told by my staff that I was right when I gave you the first number, which was $49B, so I misspoke. You're right.

Senator CRUZ. I assumed it must have been.

Mr. BOLDEN. You're absolutely right.

Senator CRUZ. I just wanted to clarify the record.

Mr. BOLDEN. You're absolutely right.

Senator CRUZ. That $498B, the math was not adding up if that number——

Mr. BOLDEN. I'm a pilot, a Marine pilot. I should have known that.

Senator CRUZ. Sadly, Congress for some time has demonstrated an inability to distinguish between millions and billions, so you're in good company here.

Mr. BOLDEN. Yes, sir.

Senator CRUZ. I want to note, you have spent a great deal of time at this hearing defending the importance of Earth Sciences, defending the importance of weather observation. I think everyone would agree with that. There's no one at this hearing that disagrees that we need to observe what's happening with our weather—that we need to know more and have weather satellites.

I would note, though, that Senator Gardner's questions I think were quite accurate. NASA's core competence is not Texas soil conservation. Now, I'm a Texan. I love our Texas soil. But there are a lot of people studying Texas soil. We've got a whole U.S. Depart-

ment of Agriculture that spends a lot of time and energy studying the soil in Texas and everywhere else.

That ain't what makes NASA special. And I have to say, if NASA ever becomes the place to study Texas soil, you're going to lose a whole lot of bright new engineers who want to go explore the galaxy.

To my mind, that exchange underscored the central point I made at the outset of this hearing. It's not that Earth sciences are not valuable, but in the last 6 years there has been a disproportionate increase. We've seen Earth Sciences increase 41 percent, and we've seen exploration and space operations, what should be the core mission, what NASA exists to do, decrease 7.6 percent. That, in my view, is disproportionate, and it is not consistent with the reasons so many talented young scientists have joined NASA.

So it's my hope that this committee will work in a bipartisan manner to help refocus those priorities where they should be, to get back to the hard sciences, to get back to space, to focus on what makes NASA special. I am hopeful that this subcommittee will move forward with the NASA reauthorization and that in that process, we will continue this discussion of getting back to the core priorities of NASA.

With that, I'll recognize Senator Peters for an additional round.

Senator PETERS. Thank you, Mr. Chairman. I would certainly follow on with that.

It certainly is your core mission to go into space, but also aeronautics, and as I mentioned in my opening comments, we have to look at your portfolio as very broad. You provide the tools to study deep space. You provide the tools to study Earth Science. So if you're looking at others studying the soil of Texas or the soil in Michigan with Michigan State University, it's NASA that provides those scientists with the tools that they need in order to do that because of your expertise of going into space.

But I want to take this last question to talk about another one of your core missions, which is aeronautics, which is also closer to the Earth, but it has been part of your history. As I mentioned in my opening comments, NASA came out of an organization that was involved in aeronautics and advancing commercial fight here on Earth. If you look at commercial applications for your technologies, there's probably no bigger bang to the taxpayers when it comes to your work in aeronautics.

I appreciated in your opening comments talking about aeronautics and the substantial contributions NASA makes to that industry, which is a multi-billion-dollar industry here for the United States, and we want to continue to be the preeminent aeronautics country in the world, at least that's certainly my desire and I hope others' on the Committee as well.

So I want to refer back to the National Academy's report that I referenced earlier from 2012 which expressed concern at NASA's lack of a dedicated flagship research aircraft. The committee noted that existing flight assets can't achieve a sustained supersonic flight or low-boom design goals or demonstrate the system-level capabilities of a highly fuel-efficient, low-noise aircraft.

So, Administrator Bolden, given the incredible importance of the aviation industry to the United States economy and the increasing

investments being made by our international competitors who are, indeed, investing very heavily in this type of innovation, what does NASA need to keep America competitive in aeronautics, particularly with regard to low-boom supersonic transport, which is likely to be the future for flight across the globe?

Mr. BOLDEN. Senator, if I can take the opportunity to kind of speak to both the comments that you and the Chairman have made, particularly about what is our core mission and how we inspire people, I'm really proud to have Dr. Dava Newman, as Senator Nelson mentioned earlier, here to hear most of this as the nominee to be the deputy. One of these days you all hopefully, if this committee sees to support her, you will have someone who can come before the Committee and speak with very much authority about what the next generation is interested in and what they need.

I would advise that there is also—and I should not do this, probably, but there is a supporting member sitting in the back row up there who is one of Dr. Newman's former students who can speak to her qualifications.

When we go out and talk to students, as we both do quite a bit, in areas of aeronautics, in areas of space science and Earth science, young men and women want to know that they will have a place to go, and they choose majors in colleges and universities based on what this Nation has said its priorities are.

We are worried about young men and women not wanting to go into the field of aeronautics because they don't see us doing what other nations in the world are doing. So your point about focusing on aeronautics is critical.

We hope that we will see some young men and women decide that they want to get into the field of optics because that is a dying field in the United States, but that is one of the fields that supplies NASA's ability to be the core provider for Earth imaging satellites, for Earth sensors and the like.

Going back to Senator Cruz's comment, we do not do Texas soil conservation. We provide instruments that provide data to the plethora of people who do Texas soil conservation. So I did not mean to mislead you, Senator, in thinking that NASA—we don't do any of that. We teach people how to use the instruments that we create. We teach them how to use the data. I have scientists who travel around the world and help people learn how to create drought and flood models, for example, from the data that comes from NASA-provided satellites.

We are not the decisionmakers. We are not the people who decide what's good for one area or another. So I probably mislead the Committee if I gave you all the impression that that was what NASA Earth Science does. NASA Earth Science, like NASA Heliophysics, NASA Aeronautics and everything, going back to Senator Peters' question, through our low-boom testing out at the Armstrong Flight Research Center over the last few years, we have given the FAA and industry optimism that we can, in fact, solve the problem of sonic booms that today create havoc for people on the ground, break windows, do all kinds of stuff, and we believe that we are on the verge of developing technology, vehicle design if you will, that will limit the impact of a sonic boom on Earth. It

will help to deflect it elsewhere, and that's the whole concept behind low boom, our low-boom studies.

Due to the work that we did with the U.S. Air Force, the U.S. Department of Defense, the Air Force Research Laboratory on inadvertent impact to the ground, which is one of the things that kills a large number of military pilots, we worked on an automated system that is now credited with the save of an Air Force F–16 in Syria. It uses an automated system to recognize that where the pilot is going, the trajectory is not good. It's going to take him into a mountain or somewhere into the ground and they're going to suffer another loss due to inadvertent impact with terrain. That's the kind of work that we do, and that's vital.

So we need to have sufficient funding for aeronautics if we're going to continue to do that kind of work, and that's the point. I'm not asking for NASA's budget to get back up to 4 percent of the Federal budget. That would be irresponsible on my part. But I am asking that we support the President's budget as my team has laid out and recommended to the President and to this Congress, because we think it's the most balanced way to bring this nation what we need so that we maintain our leadership in space, science, exploration, technology, and everything.

We are the world's leader. But, boy, there are people nipping at our heels. So if I'm not allowed to balance our spending the way that we have done right now, we could very easily fall behind in some critical areas.

I really get concerned when we focus on an individual piece, we focus like a laser on an individual part of a budget in an agency that is multi-missioned. You would change the agency if we stopped doing what we have done for more than 50 years today.

Senator CRUZ. Thank you very much, Administrator Bolden. Thank you for being here this morning. I think this hearing has been helpful.

The hearing record will remain open for 2 weeks. During that time, senators are asked to submit any questions for the record.

Upon receipt, Mr. Bolden, I would ask you to submit your written answers to the Committee as soon as possible if there are any additional questions.

I want to thank you for being here this morning.

And, with that, the hearing is now adjourned.

[Whereupon, at 10:51 a.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. MARCO RUBIO, U.S. SENATOR FROM FLORIDA

Thank you for your testimony Administrator Bolden. I am proud that Florida has such a rich history and relationship with NASA. From the earliest launches of rockets that established manned missions, to the Apollo program and the continued support for the International Space Station, Florida is proud to take ownership in NASA's past and will certainly be a part of its future.

It is important that the Committee examine NASA's plans for human exploration, including collaboration with international partners and commercial space interests-assets that can and should be used in the most effective manner to serve all taxpayers and advance America's space competitiveness.

NASA states that its vision is "to reach for new heights and reveal the unknown so that what we do and learn will benefit all humankind." I certainly agree with this vision. But in order to achieve it, the agency must have a clear mission with a roadmap and timeline outlining how that mission will be accomplished. This clear mission should be firmly rooted in space exploration.

Over the past several years, NASA has consistently increased the funding of earth sciences. While there may be admirable research being conducted in this area, I am greatly concerned that this large emphasis may detract from the mission and focus on NASA. I am interested in hearing more from the Administration on this topic.

Also, I believe one of the best ways to promote the core mission of NASA is through continued support for our commercial partners. In Florida, for instance, commercial partners are seeking to use NASA facilities and purchase equipment that is underutilized and in need of maintenance.

According to NASA's Office of the Inspector General (OIG), NASA is the ninth largest Federal Government real property holder, with more than 124,000 acres and over 4,900 buildings and other structures with a replacement value of more than $30 billion. NASA's annual operations and maintenance costs have steadily increased, and as of 2012, the Agency had over $2.3 billion in annual deferred maintenance costs. We should examine a way to alleviate these operations and maintenance costs in a way that complements the efforts of both NASA and the commercial space industry.

Again, I believe that NASA and our space program are at their best when we have a clearly defined mission and goals that allows the agency and commercial industry to advance American ingenuity and the boundaries of human discovery. It is imperative that we continue to have a funded robust space exploration program that promotes America's economic, scientific, and security interests, and that effectively utilizes its resources. Thank you.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. ROGER F. WICKER TO HON. CHARLES F. BOLDEN, JR.

Question 1. Do you support the mission to Mars?

Answer. Yes.

Question 2. Why hasn't NASA requested funding for the 130 ton launch capability that will take us to Mars?

Answer. NASA's strategy for incrementally increasing the SLS lift capability is driven by the need for lift capacity in each exploration regime. Per the 2010 Authorization Act, NASA is starting with the 70mt initial capability and will advance from there to meet exploration objectives, arriving at the Mars-class 130 mt capability when it is needed. Our analyses show the 105 metric ton (mt) configuration, made possible by the addition of an Exploration Upper Stage, enables a variety of human and cargo missions in the proving ground of cis-lunar space, which are necessary to prepare for future missions to Mars. Once we are ready for missions to the vicinity of Mars, we will progress to the 130-mt configuration. NASA could not accom-

plish these human exploration missions effectively and efficiently without the evolving capabilities of SLS.

Question 3. How does the rising cost and overall shortage of helium impact NASA's propulsion testing and what cost reduction measures is NASA taking to mitigate these rising costs?

Answer. NASA's helium contracts were recently re-competed for FY15–19. The contract provides a fixed price for helium thru FY 2019. There was a 16 percent price increase as compared to the previous (FY10–14) contract period. This was partly due to a ~10 percent increase in FY15 Federal Crude helium pricing.

Helium is provided by refiners thru the Federal "In-Kind" Program, where the crude helium feedstock is supplied and priced by the Bureau of Land Management (BLM) on a yearly basis. Through this program, NASA attains price stability for refined helium and maintains priority status for helium supply per the Helium Privatization Act of 1996 (now expired) and reaffirmed in the Helium Stewardship Act of 2013 (HSA).

The rising cost and overall shortage of helium has heightened NASA sensitivity to helium pricing and availability and are a catalyst for increased emphasis on *reducing helium use* and pursuing *recovery/reclamation* opportunities. Current helium reduction initiatives are described below.

Propulsion Systems

NASA is working to develop sensors to reduce over purging of hydrogen systems with helium. One example is a hydrogen vent line sensor developed by Glenn Research Center (GRC) and demonstrated at Stennis Space Center (SSC). The sensor will be tested at Kennedy Space Center (KSC) to move toward FY16 qualification for use at Pad 39 B for the Space Launch System (SLS) program.

Stennis Space Center (SSC) is NASA's primary rocket test site for large hydrogen fueled rockets such as the RS–25, which powered the Space Shuttle in the past and will power the Space Launch System (SLS) in the future; and the RS–68, which powers the Delta 4 launch vehicle. Hydrogen propulsion requires the use of helium as a purge gas and for inerting tanks and lines since it is the only gas with a boiling point lower than hydrogen. SSC routinely buys large quantities of gaseous helium for these uses to support its testing operations. In support of engine testing, NASA includes conservation measures such as changes to operational procedures and a focus on reducing leakage in systems which has resulted in reduced helium requirements over the last decade.

Kennedy Space Center (KSC) is the primary rocket launch site for the RS–25 and SLS. KSC also supports launches using the RS–68, which powers the Delta 4 launch vehicle at Cape Canaveral Air Force Station (CCAFS). Under a Small Business Innovation Research (SBIR) project KSC has investigated the potential use of Tridyne as a pressuring agent to reduce the mass of the helium required for tank pressurization in flight. KSC is looking at SLS Pad 39 B system mods to reduce helium usage for SLS. Currently one proposal is expected to result in reduction of SLS tank pulse purges between launch attempts, potentially reducing helium usage by up to 200,000 standard cubic feet (scf) or more per launch attempt.

Both KSC and SSC have an ongoing efforts to evaluate and eliminate leakage in the miles of gaseous helium (GHe) pipeline systems used to distribute GHe to users.

Balloon Program

The NASA Balloon Program is managed out of NASA's Wallops Flight Facility (WFF) and operated at the Columbia Scientific Balloon Facility (CSBF) in Palestine, TX. Normal annual operations include 3–4 campaigns with 1–9 missions per campaign. The average annual launch rate is 10 to 16 scientific missions per year

The Balloon Program Office (BPO) utilizes scientific balloons ranging in size from 4 million cubic feet (MCF) to 40 MCF. Float altitudes range from 90kft to 150kft. Helium is used as the lifting gas in the balloons. If a launch abort is necessary during the inflation process, the balloon is destroyed by releasing the helium into the atmosphere in order to protect the scientific payload or the launch crew. At the end of a successful mission, the balloon is separated from the flight train by rupturing the balloon. This action releases the helium into the atmosphere. BPO standard operations are designed to minimize helium waste. One technique employed is to transfer helium between multiple helium ISOPAKs to maximize helium usage.

One technology interest of the BPO, which potentially would reduce the helium requirements, is the safe utilization of a lifting gas substitute, such as hydrogen. The BPO is in contact with the Technology Development Office that is monitoring development activities in this area.

NASA continues to explore advanced technologies intended to improve helium sustainability. These projects will focus on the efficient use of helium and/or alternatives to helium.

Question 4. Is there a process in which NASA can recover helium once it is used for testing purposes?

Answer. Yes. NASA continues to pursue recovery/reclamation opportunities either through new technologies or procedural preservation efforts as described below.

KSC converts bulk liquid helium to high pressure gas for application in our space launch programs. Investigations are underway to implement a gas collection/reclamation system as part of a project to test the use of liquid helium (LHe) pumps to replace less efficient conventional gas compressors. The intent is to capture and reclaim the pump startup purges that previously would have been vented and lost to the atmosphere. If successful, the intent is to implement a similar recovery/reclamation system in the planned replacement helium Conversion Compression Facility (CCF) that will support future SLS launches as well as support all other KSC customers.

SLS conducted a review of helium use at our component vendors. VACCO produces much of NASA's cryogenic valves and disconnects. Early in the Space Launch System (SLS) program NASA had a helium reclamation system installed at VACCO to reduce the amount of helium used to test and checkout components during development. The system has greatly reduced the helium necessary for VACCO and paid for itself several times over. We have also loaned out the system to other government agencies.

- VACCO is currently forecasting a 70 percent to 85 percent He Reclamation Savings (dependent on a number of specific variables associated with individual tests)
- The initial program projections for Helium Supply cost were ~$5.3M. However, today the current forecast for helium supply costs is just over $1M due to the reclamation success.

NASA has been pursuing helium recovery and reclamation for several years. Through the Small Business Technology Transfer (STTR) Program, two particular projects have been delivered which demonstrated the ability to separate helium

from a hydrogen/helium gas mixture. The recovered helium meets the stringent purity requirements for reuse. Both systems use fuel cell technology to extract pure hydrogen from a mixed hydrogen/helium gas mixture, leaving nearly pure helium.

The first project was designed by Sierra Lobo, Inc (SLI). SLI delivered a system that was installed and tested at NASA Stennis' E–3 facility. The system demonstrated the ability to output high quality helium from a hydrogen/helium gas mixture. The helium/hydrogen gas mixture was collected, helium extracted and recovered. Below is a picture of a system delivered by Sierra Lobo, Inc.

The second successful test was conducted by Sustainable Innovations, Inc. (SII) in support of SSC. SII delivered a prototype unit in 2014 that successfully demonstrated the ability to capture, separate and compress helium from a mixture derived from test operations. This system featured a subsystem that captured the vented hydrogen and helium gas mixture, an electrochemical separation subsystem that effectively purified both hydrogen and helium streams, and a compression subsystem that permitted high pressure gas delivery. Each subsystem performed well in project tests and the subsystems were shown to integrate seamlessly.

The ability to effectively recover and reclaim helium is heavily dependent on how the original helium is used and the quantities involved. Commercial reclamation systems do exist but are typically utilized in closed systems and are often limited by their throughput, typically requiring the use of collection systems to allow batch processing of any contaminated helium.

With the largest NASA helium uses occurring during launch operations and engine testing, the challenge for NASA is multi-faceted. SSC in partnership with KSC has an FY15 Small Business Innovative Research (SBIR) initiative that seeks to improve upon the demonstrated technology or develop new alternative cryogenic gas separation technology. Additional development is needed to increase the efficiency of the recovery process, capture large amounts of mixed gases, and provide real-time solid state sensor technologies for characterizing constituent gases. Specific areas of interest includes the following technologies:

- enhanced membrane technologies including Proton Exchange Membrane (PEM) fuel cells that increase the efficiency, recovery production rate or life span of fuel cell based separation technologies;
- development of alternative cryogenic gas separation technologies;
- technologies for the rapid capture and storage of high volumes of mixed cryogenic gases;
- development of zero trapped gas system technologies to improve purge effectiveness; and
- development of real-time, solid state sensor technologies for monitoring the current state of the system concentration levels and helium/nitrogen purge process effectively (*e.g.,* hydrogen, oxygen, water vapor content, etc.).

For NASA's Balloon Program Office (BPO), helium is the lifting gas (*i.e.,* the propellant) for BPO missions. Just as other propellants are consumed in the mission, helium is consumed in BPO missions. It is not considered feasible to recapture the helium at the end of a stratospheric balloon mission, since the termination technique requires the rupture of the balloon envelope to bring the scientific instrument back to earth safely.

In summary, NASA continues to investigate opportunities to recover and collect contaminated launch and engine test helium especially for smaller GHe usage quantities or program tests that lend themselves to closed loop systems.

Question 5. From a cost benefit standpoint, assuming helium cost will only continue to rise, would it not make sense for NASA to research and develop propulsion test technology to reclaim and store helium for future use?

Answer. NASA continues to pursue ways to reduce and/or reuse helium. Some of the challenges that must be overcome include scale-up of the technology to allow large volumes of mixed gases to be processed and capture of mixed purge gases during test operations without affecting performance of the rocket engine system. The programmatic challenge is the upfront cost to deploy the technology, the scale on which these systems can operate, and the limited number of areas in which NASA could actually use it (primarily for hydrogen transfer line and tank inerting operations). Helium would have to become considerably more expensive (or supply more uncertain) to justify a return-on-investment case, or additional funding would be required just based on the principle that conservation of helium is strategically important.

Today helium is the highest value gas used in propulsion testing. NASA's current supply from our "In-Kind" Program managed by the BLM offers price stability and priority of supply under the Federal Program. The increased costs of helium and potential impacts particularly when the Federal Helium Reserve closes, makes the helium conversation more important from a product cost and future supply aspect. The challenge is how to do it efficiently and in a cost effective manner.

Question 6. Why has NASA steered ocean science funding away from Stennis Space Center?

Answer. NASA uses the annual omnibus solicitation, Research Opportunities in Space and Earth Sciences (ROSES) to compete program elements in the Science Mission Directorate, including oceans. These Federal opportunities in ROSES are open to all eligible domestic institutions, including Stennis Space Center. Awards to successful institutions are made following the NASA peer review process.

Question 7. No ROSES grants were awarded to the Gulf of Mexico Initiative in 2014. Is NASA abandoning the Gulf of Mexico Initiative?

Answer. The Gulf of Mexico is an important region to NASA and the Nation. In the aftermath of Hurricanes Katrina and Rita, NASA's Applied Sciences Program undertook the Gulf of Mexico Initiative (GOMI) focused on the Gulf region to help build capabilities in applying Earth Science data. Through two special competitive grant solicitations, NASA's Applied Sciences Program sponsored 48 projects to improve the use of Earth observations to support water resources, health, disasters, agriculture, and ecosystem management in the Gulf region.

With the completion of the last GOMI Project in January 2013, the need for a dedicated, capacity-building effort focused on the Gulf has been addressed. Other competitive research programs in NASA's Applied Sciences Program and the broader Earth Science Division have and will continue to encompass coastal management issues and the Gulf region through peer-reviewed solicitations.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. ROY BLUNT TO HON. CHARLES F. BOLDEN, JR.

Question 1. Your budget request for NASA's Science Mission Directorate (SMD) is $5.28 billion—roughly 28 percent of the entire NASA budget request of $18.53 billion.

Moreover, this request for the Science Mission allocates the largest proportion of funding—$1.95 billion—to the Earth Science account. The Earth Science program includes several accounts associated with climate change research.

In our current financial environment, where we have enacted budget caps on discretionary spending, why is NASA spending over 10 percent of its total budget on the Science Mission and climate change research?

Answer. The National Aeronautics and Space Act, as amended [P.L. 85–568, 72 Stat., 426], states the first objective for NASA is to contribute to "The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space." Thus, Earth Science has been part of NASA's core mission since NASA's early years. The President's FY 2016 request for Earth Science is slightly over 10 percent of the total agency request. This is not much different from actual appropriations for the last four fiscal years (FY 2012–2015), which average 10.0 percent, ranging from 9.8 percent (FY 2013) to 10.3 percent (FY 2014).

Within the overall NASA Earth Science activity, climate change research remains an important—although not the sole—element of Earth Science study. Indeed, measurements from many NASA Earth observing research satellites are used routinely by other Federal agencies to improve their operational products and forecasts. For example, measurements from NASA's Global Precipitation Measurement (GPM) Core Observatory/GPM constellation, Moderate Resolution Imaging Spectroradiometer (MODIS), and the Jason-2 ocean altimeter mission are used routinely by NOAA and the DOD weather services to improve global and regional weather forecasts and extreme event predictions. Soil moisture data from GPM, Gravity Recovery and Climate Experiment (GRACE), and the Soil Moisture Active-Passive (SMAP) mission are used routinely by NOAA and FEMA to produce daily flood hazard forecasts and drought monitoring products. Data from the NASA MODIS instruments are used by civil and DOD agencies for a variety of environmental forecasts including dust storm and visibility predictions.

NASA collaborates closely with the other Federal agencies involved in climate research, through mechanisms such as the legislatively-mandated U.S. Global Change Research Program. However, NASA is the only civil Federal organization that can procure, develop, and launch Earth monitoring spacecraft that provide critical space-based observations to support research, and then conduct the scientific re-

search they bring forward. NASA provides sustained and experimental observations, and focuses on space-based platforms to advance research, technology development, and national capabilities. These responsibilities are described in the National Plan for Civil Earth Observations. The results from these activities are documented in peer-reviewed literature, and the resulting information and knowledge are made routinely and widely available to scientists, managers, and citizens throughout the Nation and the world. NASA's Earth research covers diverse topics, both long- and short-term phenomena and processes, including those associated with droughts, floods, fires, air pollution, land cover/land use change, oceans, and polar ice.

Question 2. The administration's budget request proposes to cut funding for the heavy-lift Space Launch System (SLS) rocket by $343 million. It also proposes to cut the *Orion* crew capsule by nearly $98 million. There is concern that these cuts may prevent NASA from meeting its schedule to test *Orion* and SLS, and its goal of a manned SLS/*Orion* mission by 2021.

Given all this, how does it make sense to allocate $1.95 billion to Earth Sciences and climate change research while underfunding SLS and *Orion*?

Answer. The FY 2016 President's Budget Request is consistent with the outyear profile proposed in the FY 2015 Budget and provides the funding level needed to keep SLS, *Orion,* and Exploration Ground System (EGS) on track for the first integrated launch of Exploration Mission-1 (EM–1). We have identified our Agency Baseline Commitment for the SLS and EGS which supports a launch capability readiness date of November 2018 at 70 percent and 80 percent Joint Confidence Level (JCL), respectively, to the EM–1 launch readiness date. The integrated launch date for EM–1 is to be determined after all three programs complete their Critical Design Reviews (CDRs). The integrated launch date for EM–2 will be set following the EM–1 mission.

While maintaining planned funding levels for SLS and *Orion,* the FY 2016 Request provides Earth Science with funding to address the priorities set forth in the 2007 Earth Science decadal survey.

Question 3. How does climate change research help ensure American leadership in deep space exploration?

Answer. NASA has since 1958 been charged with expanding human knowledge of the Earth and of phenomena in the atmosphere. As part of this responsibility, climate change research produces valuable and executable scientific knowledge that is actively being applied by the international community, policy makers, and industry to better understand the challenges posed by climate change, which in turn improves our Nation's posture in addressing these challenges now and into the future. We conduct climate change research for those reasons rather than to support deep space exploration, but studying climate change improves our ability to address and plan for its societal and economic impacts, which in turn will help us maintain our global leadership in space for science and exploration.

Question 4. How does climate change research assist in the development, construction, and testing of SLS and *Orion*?

Answer. NASA studies climate for many reasons. Any benefits to the development and testing of SLS and *Orion* are secondary. However, many NASA Centers and assets reside in vulnerable locations. The Johnson Space Center, Kennedy Space Center, Stennis Space Center, Michoud Assembly Facility, Wallops Flight Facility, and Jet Propulsion Laboratory have significant involvement in NASA's launch and rocket programs, and each are vulnerable to climate-induced changes. For example, Johnson, Kennedy, Stennis, Michoud, and Wallops are vulnerable to sea level changes and climate-induced upticks in extreme weather conditions, such as hurricanes and tropical storms. Meanwhile, JPL is vulnerable to geohazards such as landslides, earthquakes, wildfires, and even water shortages. NASA assets closely monitor changes in the climate that create these increasing vulnerabilities, to produce analyzable data to address these vulnerabilities. For example, NASA's Applied Science Program is dedicated to helping public and private organizations apply data from NASA's Earth-observing satellites and related scientific findings in their decision-making activities, to improve the quality of life and strengthen the economy. Both SLS and *Orion* will make prominent use of NASA Centers, some of which are vulnerable to changing environmental conditions. Our study of these changes will ultimately help us ensure NASA assets are as secure as possible.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARCO RUBIO TO HON. CHARLES F. BOLDEN, JR.

Question 1. The people, facilities and capabilities of NASA at Kennedy Space Center are one of Florida's most treasured and iconic assets, and I look forward to their participation in future Exploration missions.

However, as a new commercial space industry and marketplace begins to take root across the country and abroad, I am concerned the existing Federal regulations and requirements at KSC will unfairly disadvantage the State of Florida from competing in these new opportunities.

How are you now working with the state to help eliminate Federal impediments to a more favorable commercial operating environment? What steps are you taking to implement the expedited transfer of unneeded NASA assets the State's spaceport authority may be willing to take over and operate in partnership with commercial users?"

Answer. NASA has taken a number of actions to significantly reduce impediments to commercial operations. One example is the revision of safety requirements for commercial operators. Under the new rules, commercial entities operating within their own facilities or facilities that they have leased from NASA, need only follow OSHA and other relevant Federal safety and environmental requirements. Another initiative is related to the development of new commercial facilities on KSC. Such facilities may be constructed using Florida State building codes rather than the sometimes more restrictive NASA standards.

NASA has worked with both the State of Florida and commercial entities to provide a number of assets for use by the commercial space industry. Specifically, the State of Florida already has a Use Permit to operate the Orbiter Processing Facility 3 (OPF3) and associated Processing Control Center (PCC) which will be used by a commercial space industry company. We have also leased Launch Complex 39A to a commercial space launch provider for their use. We are in the final phases of providing the use of the Shuttle Landing Facility and associated land around the facility for a total of approximately 4,000 acres to the State of Florida to develop commercial operations.

Question 2. Competition is a key to controlling costs over the long-term as well as to improving the level of safety. Do you agree with this statement?

Answer. NASA agrees that competition is one key to controlling costs and helping to improve the level of safety. For this reason, supporting multiple competitors in our commercial cargo and crew programs is considered critical.

Question 3. In your opinion, what is the single greatest threat facing American access to space? And what is the best option for overcoming that threat?

Answer. Access to space for NASA should be considered in three categories:

- crewed missions to Earth orbit (*i.e.,* Commercial Crew Program to transport crews to and from the International Space Station [ISS]);
- uncrewed, expendable launch vehicles putting NASA's and the civil sector's satellites in Earth orbit and robotic planetary probes in space; and
- heavy lift launches beyond low-Earth orbit for both crew and cargo (*i.e.,* NASA's Space Launch System).

The greatest threat facing American access to space for crewed missions to Earth orbit is the current lack of capability to launch astronauts to orbit from U.S. soil. NASA's Commercial Crew Program is our answer to that threat, and we are well on our way with the progress our two commercial partners, Boeing and SpaceX, are making. The best way to secure this capability is to fully fund the FY 2016 President's Budget Request, which is required to keep NASA and both of its commercial partners on track to achieve first flights of these new crewed vehicles to ISS by the end of 2017.

For uncrewed expendable launch vehicles, NASA has a robust mechanism through its Launch Services Program to acquire and manage such services for the launch of NASA's satellites and planetary probes. NASA acquires these launch services on a competitive basis, with the vendors responsible to sustain and mature their systems and to deal with supply problems, including engines for their vehicles. The ISS cargo resupply endeavor managed under Commercial Resupply Services contracts has resulted in new medium class launch capabilities for science missions. NASA is evaluating the impact of the recent loss of SpaceX–7. The key for access to space in this category is encouraging and promoting an environment of innovation and competition for our U.S. commercial launch service providers.

For heavy-lift launch capability for crews and cargo beyond low-Earth orbit, NASA is progressing well in the development of the Space Launch System, and its

planning its evolution consistent with the 2010 NASA Authorization Act. Careful management of this program to both achieve a timely, successful first flight and an affordable production and operations cost for future flights is a major focus for NASA.

Question 4. I too often hear in Florida about challenges in launching from the Cape, and I fear companies may choose to launch elsewhere because of those challenges. What issues prevent a completely independent commercial launch capability in Florida, and what is NASA doing to overcome these issues?

Answer. Consistent with the 2010 National Space Policy and the 2013 National Space Transportation Policy, NASA leadership has been seeking to increase commercial utilization of the Kennedy Space Center (KSC) resources and to allow the commercial sector to demonstrate competitive and innovative approaches, to ultimately reduce space exploration costs for several years. In FY 2011, NASA began the 21st Century Space Launch Complex (21CSLC) initiative to support launch infrastructure, enable future exploration of the solar system, as well as new commercial opportunities in low-Earth orbit. Its primary purpose is to modernize and transform the Florida launch and range complex at Kennedy Space Center (KSC), Cape Canaveral Air Force Station (CCAFS), and Wallops Flight Facility (WFF) into a more robust launch capability that could support multiple users. Beneficiaries of this activity included current and future NASA programs, other U.S. Government agencies, and commercial industry.

The KSC has developed a multi-use, operational approach with the goal to accommodate commercial launch and reentry activity from KSC property while preserving public and property safety, and minimizing Governmental burden. KSC first developed a Future Development Concept with the broader national space community, which led to a KSC Master Plan that provides a flexible framework for evolving to a multi-user spaceport. This plan, available at: *http://masterplan.ksc.nasa.gov/,* describes how KSC will continue to transform over the next 20 years as a multi-user spaceport supporting government, commercial and other space launch users and providers. This 20-year plan describes KSC's future state, along with the supporting business focused implementation and operating framework necessary to enable this transformation.

Given the phase out of Space Shuttle operations, KSC recognized the need to safely manage a multi-use spaceport containing new NASA programs and commercial activity. KSC's current commercial safety policy is a set of requirements which ensures that NASA KSC is exercising reasonable diligence to protect the public and Center personnel, and safeguards the success of NASA missions and operations, while enabling commercial activities to the maximum possible extent. This supports KSC's commitment to safety while providing commercial partner autonomy in managing their operations.

One of the challenges in planning for Commercial Operations on KSC property has been flexibility in Range Flight Safety Services for launch operations. NASA is working with the Air Force (including the 45th Space Wing) and the Federal Aviation Administration (FAA) to define and implement the steps necessary to accommodate commercially-provided range flight safety services options for the commercial space industry when they launch within the Eastern Range (including from KSC property) under an FAA license.