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Report to the Chairman, Committee on Science, House of Representatives

June 1995

NASA's EARTH OBSERVING SYSTEM

Estimated Funding Requirements

GAO/NSIAD-95-175

GAO

United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

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June 9, 1995

The Honorable Robert S. Walker
Chairman, Committee on Science
House of Representatives

Dear Mr. Chairman:

This report responds to your request that we estimate the total funding requirements for the National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS). We are responding to other parts of your EOS request in separate reviews.

Background

EOS is the centerpiece of NASA's Mission to Planet Earth, whose overall goal is to understand the total Earth system (air, water, land, life, and their interactions) and the effects of natural and human-induced changes on the global environment. EOS has three major components: a system of satellites to collect 15 years of key climate-related data; the EOS Data and Information System (EOSDIS) to operate the satellites and process, archive, and distribute the data; and teams of scientists to develop algorithms for converting sensor data into useful information and to conduct research using the information.

According to NASA's 1995 Mission to Planet Earth/Earth Observing System Reference Handbook, the baseline program will involve three series of primary satellite missions and several smaller missions. There are also some joint missions planned with other nations. To obtain 15-year data sets, each of the primary missions will include a series of three satellites. Most of the smaller missions and cooperative missions will also be repeated three or more times, although some may fly only once. Additional information about the EOS satellite missions is included in appendix I.

The EOS program, initiated in fiscal year 1991, will span 32 years. As currently planned, the first satellite carrying EOS instruments will begin operations in 1997 and the last satellite will cease operations in 2020. Processing data and conducting research will continue for another 2 years, through 2022. NASA has budgeted $2.6 billion through fiscal year 1995 for EOS and requested about $1 billion for fiscal year 1996.

Results in Brief

We estimated that funding requirements for the EOS baseline program would total about $33 billion for fiscal years 1991-2022. NASA is studying ways to reduce future EOS funding requirements and expects to substantially change the baseline program when these studies are completed in July 1995. According to NASA officials, preliminary results of these studies indicate that technology development and operational improvements could reduce annual funding for the second and third satellites in each series by as much as 30 percent. If NASA were able to reduce annual funding by 30 percent in future years, our estimate of total funding requirements drops to $27 billion. NASA officials believe that further reductions may be possible from increased collaboration with other agencies, international partners, and the commercial sector. It remains to be seen whether NASA will be able to achieve the level of reductions being discussed.

Life-Cycle Funding Estimate for EOS Baseline Program

Our life-cycle estimate of $33 billion represents the total funding requirements for fiscal years 1991-2022 in current dollars; the figure includes estimated inflation.[1] The total estimated funding requirements in constant 1995 dollars, which does not include estimated future years' inflation, is $21 billion. The estimate includes funding for satellites, launch services, EOSDIS, science, construction of facilities, and civil service personnel.

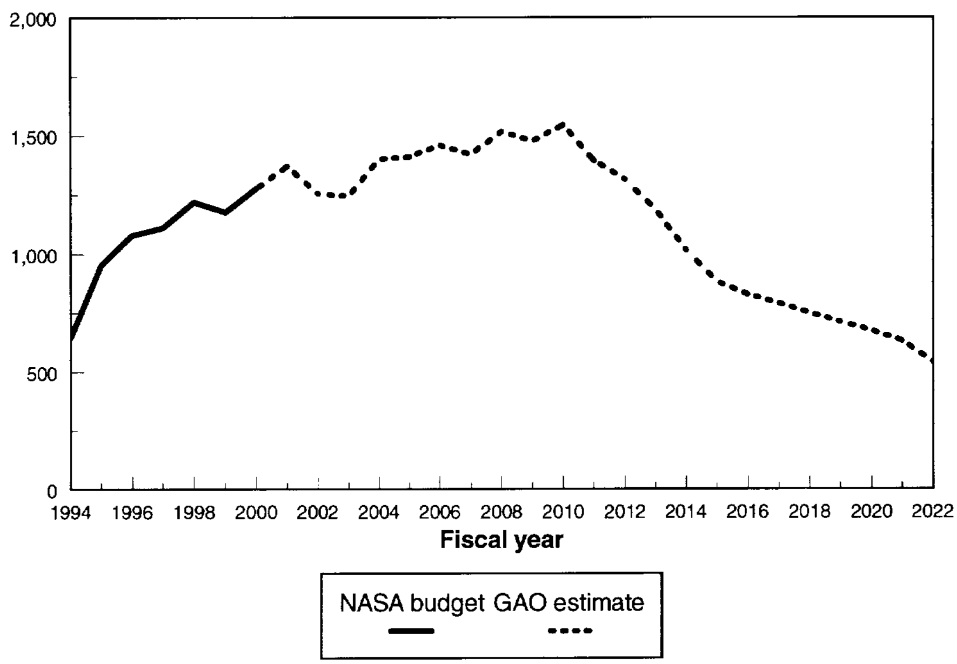
The EOS baseline assumes that the initial set of satellites will be repeated with no substantial changes to the spacecraft or instruments. The satellite segment accounts for about 35 percent of the total baseline funding; launch services about 4 percent; EOSDIS about 27 percent; science and algorithms about 31 percent; civil service personnel about 4 percent; and other elements, such as construction of facilities, less than 1 percent.

Figure 1 shows our estimate of annual funding requirements for the EOS baseline through fiscal year 2022. The annual funding estimate through fiscal year 2000 is based on NASA's projections in the President's fiscal year 1996 budget. NASA's budget projections are included in appendix II. Our estimate includes adjustments to NASA's budget estimates to reflect a $100-million reduction resulting from NASA's recently completed agencywide review of operations and the addition of funding for civil service personnel working on the program. After fiscal year 2000, the figure reflects our estimate of annual funding requirements.

[1]Unless otherwise noted, dollar amounts are in current dollars that include estimated future years' inflation based on an index provided by NASA. NASA's index reflects estimated price increases in the aerospace industry rather than the general economy.

Funding requirements rise sharply during the early years leading up to the launch of the first satellite in 1998. The continued rise in funding through 2010 reflects the period where NASA will fund most of the production, launch, and operation of the EOS satellites. After 2010, funding requirements for science, EOSDIS, and civil service personnel will gradually decline as individual satellite missions are completed.

Figure 1: Estimated Annual Funding Requirements for the EOS Baseline (Current dollars in millions)



NASA officials believe that funding estimates for the EOS program should extend to 2019 rather than 2022. This is based on the fact that the last 15-year data set will be obtained by 2017, followed by another 2 years of processing and research. We have presented estimated funding requirements through 2022 because EOS satellites will continue to operate and collect data through 2020, EOSDIS will continue to process the data beyond that, and the scientific research begun under EOS will continue for another 2 years.

NASA Actions to Reduce Future Funding

NASA officials know that, in today's environment of declining budgets for the civil space program, the baseline program described in the 1995 EOS handbook is unaffordable. Recognizing that EOS' objective is to collect consistent long-term data sets—not to fly a particular satellite or instrument for 15 years—NASA is studying ways to change the baseline program and reduce future funding requirements. According to NASA officials, preliminary results of these studies indicate that technology development and operational improvements could reduce annual funding for the second and third satellite missions by as much as 30 percent. If NASA were able to reduce annual funding by 30 percent in future years, our estimate of total funding drops to $27 billion. NASA officials believe that further reductions may be possible from collaboration with other agencies, international partners, and the commercial sector. Several factors could affect NASA's ability to achieve future reductions.

Technology Advancements and Operational Improvements

Technology advancements are almost certain to occur over the 32-year life of the EOS program, but it is too early to determine the effect these advancements will have on reducing funding requirements. A NASA Advisory Council task force reported in February 1995 that EOS should be an ideal candidate for advanced technology development.[2] However, the task force found little evidence that advanced technology was being developed for and incorporated into the program. The report also noted that NASA lacked a plan or road map for incorporating new technology into EOS.

NASA officials expect to complete a technology plan by the end of August 1995. To develop this plan, NASA is studying several technology development opportunities, including reductions in the size of spacecraft and instruments, major advancements in high performance computing, new launch systems, and more efficient operations. For example, some instruments benefit from making measurements under exactly the same conditions. Currently, these kinds of simultaneous measurements require the instruments to be collocated on one satellite. Advanced technology and operating techniques may allow these types of instruments to fly in close formation on individual small satellites, potentially reducing funding requirements and greatly increasing the flexibility to replace individual instruments. NASA officials stressed that they need stable funding between now and fiscal year 2000 to develop and demonstrate the technology that will reduce future funding requirements. NASA is also soliciting advice from

[2]NASA Federal Laboratory Review, prepared by the NASA Federal Laboratory Review Task Force, NASA Advisory Council (Feb. 1995).

outside groups and industry on technology that could be used in the EOS program.

Increased Cooperative Arrangements

Collaborating with other agencies that operate Earth observing satellites may be possible, but it is too early to tell how much this might reduce EOS funding requirements. For example, NASA currently plans to fly an EOS instrument on a 3-year Japanese satellite mission to collect ocean surface wind data. It has not been determined how follow-on missions will be accomplished and who will be responsible for funding them. To continue this data set, NASA is exploring options with two other agencies interested in this type of data, the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense. NASA and NOAA are also reviewing the potential benefits of collocating research and operations activities, incorporating EOS technology into NOAA weather satellites, and combining NASA and NOAA data systems.

EOS already involves extensive international participation, and it is unclear whether significant savings can be achieved through additional participation. NASA is negotiating 10 cooperative agreements with 6 different international partners, including the European Space Agency, Japan, France, Canada, the United Kingdom, and Russia. Only two of the agreements have been completed. None cover the 15-year period required by EOS for long-term consistent data sets. For example, NASA plans to fly its Stratospheric Aerosols and Gases Experiment instrument on a Russian Meteor satellite to accomplish what was formerly known as the AEROSOLS mission. However, the agreement signed by the United States and Russia only covers the flight of one EOS instrument on one Meteor, which has a mission life of 3 years. NASA officials believe that the Russians will agree to continue flying copies of the instrument long enough to provide the required 15-year data set.

Finalizing and maintaining the current international partnerships involving EOS spacecraft and instruments represents a challenge. The Multifrequency Imaging Microwave Radiometer instrument demonstrates both the promise and pitfalls of international cooperation. The European Space Agency is developing this instrument for one of its spacecraft scheduled to fly as part of an international EOS mission. Since the inception of EOS, NASA has counted on the European Space Agency to provide a copy of this instrument for one of NASA's primary satellite missions. However, the Europeans recently indicated that they may not provide the instrument for flight on NASA's satellite. Since this instrument is essential for the NASA mission, the agency is exploring other options. NASA has begun discussions with Japan about providing a copy of a similar type of instrument it developed for one of its satellites. In the event that there is not an international contribution for this type of instrument, NASA may have to provide the funding.

Several factors could affect NASA's ability to achieve significant reductions. First, some instruments have not yet been assigned to a spacecraft and are considered "flights of opportunity." NASA's baseline program assumes that NASA will only fund the instruments for these missions and that other requirements will be provided through cooperative arrangements. However, if NASA is unable to find a partner to contribute the spacecraft and launch for the missions, NASA may have to fund these items or cancel the missions. Second, if the introduction of new technology or increased cooperative arrangements is delayed from the second set of satellites to the third set, the cumulative reductions would be much smaller. Third, most NASA spaceflight missions have historically experienced significant increases in funding requirements from initial estimates.[3] Even if reductions are achieved through technology advancements, funding increases in other areas could offset these savings.

Scope and Methodology

To develop an estimate of total life-cycle funding requirements for the baseline EOS program, we used NASA's estimates for the program's initial phase and met with Mission to Planet Earth officials to develop the assumptions used to prepare detailed estimates of each program element through completion. For example, based on discussions with these officials, we assumed that copies of spacecraft and instruments required less funding than the originals that included research and development costs. We included funding for science, EOSDIS, and civil service personnel through 2022, 2 years beyond the end of the last satellite mission, which is a typical practice for science missions, according to NASA.

In our current dollar estimates, we used inflation factors supplied by NASA that represent estimated inflation in the aerospace industry, which tends to run higher than estimated inflation for the general economy. NASA uses this index for programs that are in the early stages and include significant new development efforts and uncertainties. NASA officials agreed that this is the appropriate index to use for the EOS program. For most years covered by our estimate, NASA's inflation index was 4.6 percent. By

[3] NASA Program Costs: Space Missions Require Substantially More Funding Than Initially Estimated (GAO/NSIAD-93-97, Dec. 31, 1992).

comparison, the gross domestic product price index averaged 3.1 percent for 1996 through 2013. Funding for civil service personnel was inflated by a factor of 2.1 percent, based on civilian federal pay raises projected in the President's fiscal year 1996 budget request.

We conducted our work from January 1995 to June 1995 in accordance with generally accepted government auditing standards. We did not obtain official agency comments on this report. However, we discussed a draft of this report with program officials and incorporated their comments where appropriate.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 10 days from its issue date. At that time, we will send copies to the Ranking Minority Member, Committee on Science; the NASA Administrator; and other appropriate congressional committees. We will also make copies available to other interested parties upon request.

Please contact me on (202) 512-8412 if you or your staff have any questions concerning this report. Major contributors to this report were Frank Degnan, Richard Eiserman, and Sandra Gove.

Sincerely yours,

David R. Warren
Director, Defense Management
and NASA Issues

EOS Satellite Missions

According to the National Aeronautics and Space Administration's (NASA) 1995 Mission to Planet Earth/Earth Observing System Reference Handbook, the baseline program will involve three series of primary satellite missions and several smaller missions. There are also some joint missions planned with other nations. Under the baseline plan, as many as 36 spacecraft would carry 80 instruments, and NASA would provide 21 of the spacecraft and 65 of the instruments.

To obtain 15-year data sets, each of the primary missions will include a series of three satellites. Most of the smaller missions and cooperative missions will also be repeated three or more times, although some may only fly once. Figure I.1 shows the satellite missions planned under the Earth Observing System (EOS) baseline. Table I.1 describes each mission. Descriptions of the instruments carried by each satellite mission are in table I.2.

The primary missions have been designated AM, PM, and CHEM. Eight of the primary satellites are planned to be medium-sized spacecraft, with the ninth being somewhat larger. The primary satellites will each carry three to six instruments. Smaller satellites will carry from one to three instruments. The instruments are, for the most part, the same for all the satellites in a series.

Several missions involve cooperative arrangements with other countries. In these missions, other nations provide instruments for NASA satellites or satellites for NASA instruments. NASA's cooperative missions currently involve the European Space Agency, Canada, Japan, France, the United Kingdom, and Russia. International partners are involved in the AM, PM, CHEM, RadarALT, TRMM, METEOR, and ADEOS missions shown in figure I.1.

Figure I.1: Operational Periods for Planned EOS Satellites

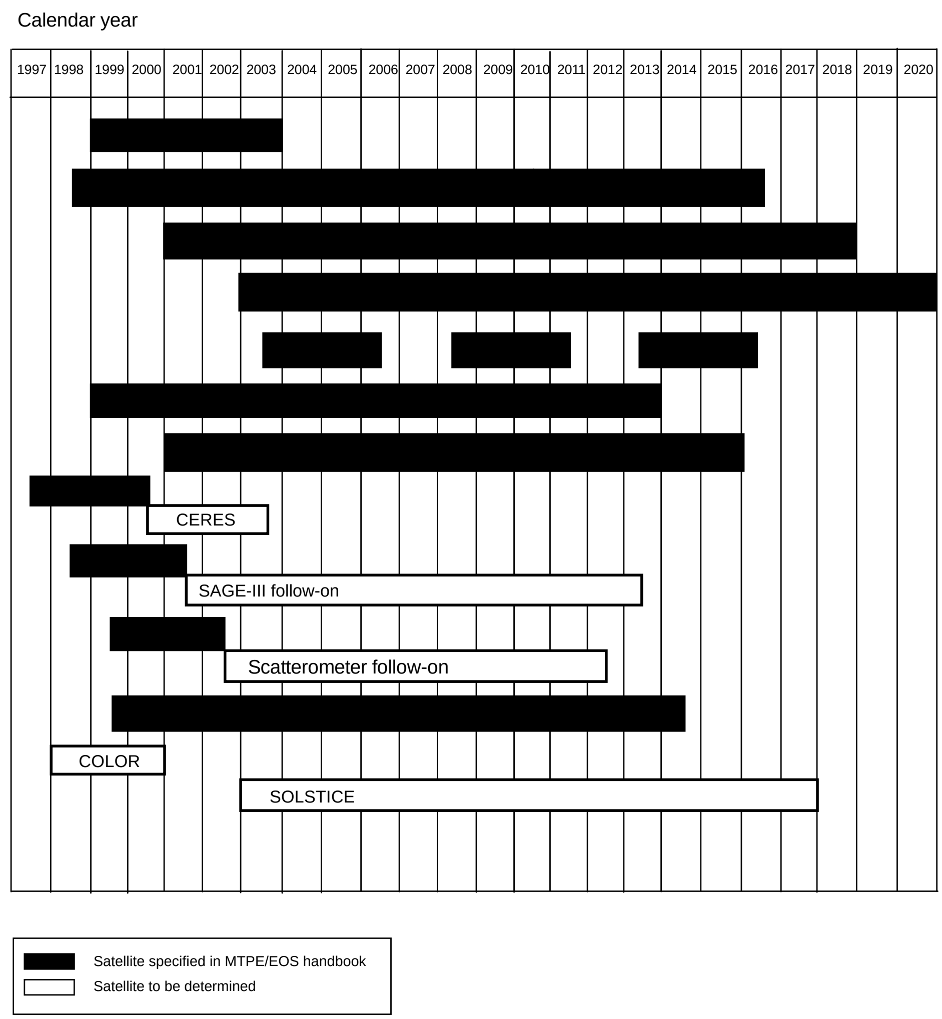


Table I.1: Description of EOS Satellite Missions

Satellite	Description
LANDSAT-7 ETM+	Continues land-imaging satellite series. Future LANDSAT-type instrument is planned to be carried on AM-2 and AM-3.
AM ASTER CERES EOSP LATI MISR MODIS MOPITT	Morning equator-crossing mission will study clouds, aerosols, and radiation balance; the terrestrial ecosystem; land use; soils; terrestrial energy/moisture; tropospheric chemical composition; volcanoes; and ocean productivity. ASTER and MOPITT are manifested on AM-1 only. EOSP and LATI are manifested for AM-2 and AM-3 only.
PM AIRS AMSU CERES MHS MIMR/AMSR MODIS	Afternoon equator-crossing mission will study cloud formation, precipitation, and radiative properties; air-sea fluxes of energy and moisture; sea-ice extent; and ocean primary productivity. The PM series will carry instruments that are prototypes for future operational weather satellites.
CHEM HIRDLS MLS ODUS TES	Chemistry mission will study atmospheric chemical composition; chemistry-climate interactions; and air-sea exchange of chemicals and energy.
LaserALT GLAS	Laser altimeter mission will study ice sheet mass balance.
RadarALT DORIS SSALT TMR	Radar altimeter mission will study ocean circulation. NASA is considering a joint mission with France.
ISS and METEOR SAGE-III	SAGE-III instrument carried on the International Space Station and Russian METEOR satellite will study distribution of aerosols, ozone profiles, and greenhouse gases in the lower stratosphere.
TRMM CERES LIS	Tropical Rainfall Measuring Mission will study precipitation and Earth radiation budget in the tropics and high latitudes. TRMM is a joint mission with Japan.
ADEOS-II SEAWINDS	Japanese satellite carrying NASA scatterometer instrument will study ocean surface wind vectors.
ACRIMSAT ACRIM	Mission will monitor the variability of total solar irradiance and is currently planned to fly on a series of small satellites.
Flight of opportunity COLOR	Ocean color instrument will study ocean primary productivity and will work in concert with AM series until PM series is launched.
Flight of opportunity SOLSTICE	Mission will study full-disk solar ultraviolet irradiance.

Table I.2: EOS Instruments and Measurements

ACRIM	Active Cavity Radiometer Irradiance Monitor monitors the variability of total solar irradiance.
AIRS	Atmospheric Infrared Sounder measures atmospheric temperature and humidity.
AMSU	Advanced Microwave Sounding Unit provides atmospheric temperature measurements.
ASTER (Japan)	Advanced Spaceborne Thermal Emission and Reflection Radiometer provides high spacial resolution images of the land surface, water, ice, and clouds.
CERES	Clouds and Earth's Radiant Energy System measures Earth's radiation budget and atmospheric radiation.
DORIS (France)	Doppler Orbitography and Radiopositioning Integrated by Satellite provides orbital positioning information and ionospheric correction for SSALT.
COLOR	Ocean color instrument provides measurements of the role of oceans in the global carbon cycle and ocean primary productivity.
EOSP	Earth Observing Scanning Polarimeter globally maps radiance and linear polarization of reflected and scattered sunlight to obtain atmospheric aerosol content.
ETM+	Enhanced Thematic Mapper Plus provides high spatial resolution images of the land surface, water, ice, and clouds.
GLAS	Geoscience Laser Altimeter System measures ice sheet topography, cloud heights, and aerosol vertical structure.
HIRDLS (UK-US)	High-Resolution Dynamic Limb Sounder observes gases and aerosols in troposphere, stratosphere, and mesosphere to assess their role in global climate system.
LATI	Landsat Advanced Technology Instrument provides high spacial resolution images of the land surface, water, ice, and clouds beyond Landsat ETM+.
LIS	Lightning Imaging Sensor measures the distribution and variability of lightning.
MHS	Microwave Humidity Sounder provides atmospheric water vapor profile.
MIMR (ESA)	Multifrequency Imaging Microwave Radiometer measures precipitation rate, cloud water, water vapor, sea surface roughness, sea surface temperature, ice, snow, and soil moisture.
MISR	Multi-Angle Imaging Spectrometer measures the top-of-the-atmosphere, cloud, and surface angular reflectance.
MLS	Microwave Limb Sounder measures thermal emissions from the atmospheric limb.
MODIS	Moderate-Resolution Imaging Spectrometer studies biological and physical properties of terrestrial, oceanic, atmosphere, and ecosystems.
MOPITT (Canada)	Measurements of Pollution in the Troposphere measures upswelling radiance to produce tropospheric CO profiles and total column CH4.
ODUS (Japan)	Ozone Dynamic Ultraviolet Sounder measures total atmospheric column of ozone concentraion.
SAGE III	Stratospheric Aerosol and Gas Experiment provides profiles of aerosols, ozone, and trace gases in the mesosphere, stratosphere, and troposphere.
SEAWINDS	Provides all weather measurements of ocean surface wind speed and direction.
SOLSTICE	Solar Stellar Irradiance Comparison Instrument measures full disk solar ultraviolet irradiance.

(continued)

SSALT (France)	Solid-State Altimeter maps the topography of the sea surface and its impact on ocean circulation.
TES	Tropospheric Emission Spectrometer provides profiles of all infrared active species from Earth's surface to lower stratosphere.
TMR	Topex Microwave Radiometer provides atmospheric water vapor corrections for SSALT.

Additional Funding Information

NASA's current EOS estimate for fiscal years 1991 through 2000 is $8.2 billion. This estimate, which is about $100 million less than NASA's estimate in the President's fiscal year 1996 budget, reflects reductions recently identified during NASA's agencywide review. About $2.6 billion was budgeted through fiscal year 1995. EOS represents about two-thirds of Mission to Planet Earth's $12.1-billion budget for fiscal years 1991-2000. NASA's EOS estimate includes funding for satellites, science, the EOS Data and Information System (EOSDIS), launch services, and construction of facilities, as shown in table II.1. NASA does not include funding for civil service personnel in its estimate.

Table II.1: President's Fiscal Year 1996 Budget Request for EOS

Current dollars in millions

	Prior	1994	1995	1996	1997	1998	1999	2000	Total
AM series	$385.1	$198.8	$260.8	$202.2	$97.0	$107.6	$56.7	$82.6	**$1,390.8**
PM series	64.3	50.1	88.8	127.3	188.2	239.8	235.7	226.1	**1,220.3**
Chemistry series	9.6	2.2	10.3	27.7	82.1	107.4	147.5	182.0	**568.8**
Special spacecraft	40.0	20.9	85.5	69.7	92.9	95.8	89.1	93.0	**586.9**
Landsat 7	32.5	74.1	87.4	78.8	56.1	48.8	8.0	1.6	**387.3**
Algorithm development	91.8	46.8	58.3	85.4	122.7	154.5	200.8	221.7	**982.0**
EOSDIS	244.4	188.2	230.6	289.8	309.8	291.9	317.4	358.7	**2,230.8**
Space station platform	104.0								**104.0**
EOS science			37.3	58.4	47.5	56.4	63.4	73.2	**336.2**
Launch services	3.1	16.2	41.7	86.7	95.3	100.9	46.8	33.2	**423.9**
Construction of facilities	45.2	18.0	17.0	17.0					**97.2**
Tracking and data support				1.6	2.1	2.3	1.1	1.3	**8.4**
Total	**$1,020.0**	**$615.3**	**$917.7**	**$1,044.6**	**$1,093.7**	**$1,205.4**	**$1,166.5**	**$1,273.4**	**$8,336.6**

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