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NASA REPORT ON THE STATUS OF CURRENT AND FUTURE SATELLITE SYSTEMS

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Executive summary

NASA currently operates 17 Earth Science missions. Although all missions were conceived as research missions, it has turned out that the efficiency of the communications and ground data handling systems has supported operational and near-real-time applications. All missions are currently producing data, but several also show signs of aging. Except for Suomi-NPP (October 2011), SAC-D/Aquarius (June 2011) and LDCM/Landsat-8 (February 2013), all missions have passed their nominal design life, and are currently in extended operations.

NASA's Earth Science Program ($1.8 Billion budget) is implementing a balanced and robust plan to accomplish a broad set of critical Earth observation measurements from space. The program advances knowledge of the integrated Earth system, the global atmosphere, oceans (including sea ice), land surfaces, ecosystems, and interactions between all elements, including the impacts of humans. A balance of satellite measurements, science research, technology development and applications are needed to address a complex global Earth system. NASA's plans for the launch of 14 missions and 2 instruments (on a host mission) in the future.

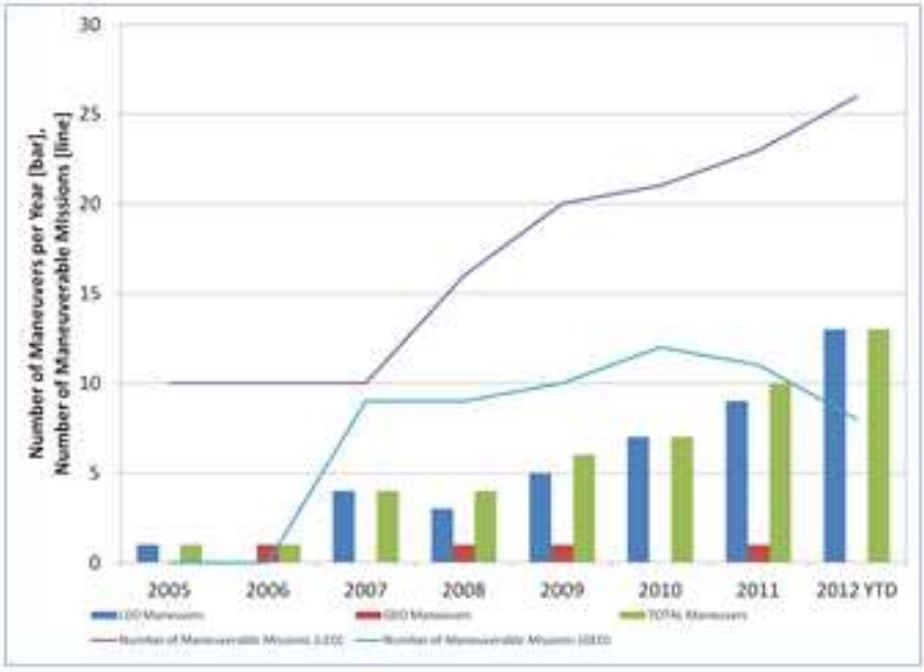
NASA Report on the status of current and future satellite systems

1 CURRENT SATELLITE SYSTEMS

NASA currently operates 17 Earth Science missions (see Tables 1 and 2). All missions are currently producing data, but several also show signs of aging. Except for Suomi-NPP (October 2011), SAC-D/Aquarius (June 2011) and LDCM/Landsat-8 (February 2013), all missions have passed their nominal design life, and are currently in extended operations. Signs of battery aging have been observed in GRACE, CloudSat, and SORCE, all of which require intensive battery management and duty-cycling of instruments, which can reduce both quality and spatial/temporal coverage of the datasets. The Jason-1 mission exhibited signs of additional memory degradation and was moved to a lower 'geodetic' orbit in May 2012, where it will pose less risk to the altimetry constellation, but still provide a marine geoid dataset in addition to continuing oceanographic products. Instruments with reduced capability (noted in RED, Table 2) are the Landsat-7 ETM+ (failed Scan Line Corrector), QuikSCAT's SeaWinds (antenna no longer rotates so that the data are used primarily to cross-calibrate with other on-orbit scatterometers), Terra's ASTER (SWIR module is no longer functional), Aqua AMSU (Channel 4 has failed) and Aqua AMSR-E. JAXA re-started AMSR-E rotation in December 2012 at a much lower rate (2rpm vs 40rpm), and is using it for cross-calibration with AMSR-2, which allows the AMSR-E and AMSR-2 datasets to be merged into one climate data record. Instruments that no longer provide data (noted in RED, Table 2) are Aqua's HSB, TRMM's CERES, Jason's TRSR, and Aura's HIRDLS. All other sensors are fully functional and are producing standard products that meet or exceed specifications.

The most recent NASA mission is the **Landsat Data Continuity Mission (LDCM)** which was successfully launched (photo on left) on February 11, 2013. After a 3-month on-orbit check-out phase, operations will be transferred to USGS and the satellite will be renamed Landsat 8. LDCM is the eighth mission in the Landsat series which has been continuously observing Earth's land surfaces since 1972. This freely available data is critical for monitoring climate change, agriculture, disasters, energy, water and urban development. As of May 5, all spacecraft and instrument systems continue to perform normally. LDCM under-flew the Landsat 7 satellite from Friday, Mar. 29, to Sunday, Mar. 31, collecting more than 1,200 coincident scenes.

Once new missions are launched, NASA must continually monitor their positions to avoid collisions with other satellites. Increased solar activity has led to more uncertainty in collision analysis calculations and consequently intensified analysis and planning activities to determine collision avoidance maneuvers. A history of collision avoidance maneuvers is shown in the figure below. Active monitoring of close approach events has steadily increased since 2008. In addition to increasing the resources dedicated to collision assessment, NASA has updated the agency's orbital debris procedures, and invested in analysis tool improvements, including an international partnership to share maneuver ephemeris data.



1.1 Research Missions for Operational Use

Although all missions were conceived as research missions, it has turned out that the efficiency of the communications and ground data handling systems has supported operational and near-real-time applications. Our interagency partners have rated most NASA missions as High Utility for operational applications, with Terra, Aqua, TRMM and Suomi-NPP rated Very High. All missions have met their original success criteria and are meeting the objective for sustained measurements on decadal time scales. This objective is met not only due to the satellites' longevity, but also to the sustained calibration/validation program and the data systems tools which enhance data quality and access. Continued operation of the missions is determined through a biennial science review process, called the "Senior Review", which evaluates the continuing science value. Operational uses of the missions are considered in the review, but science remains the defining factor for continuation. The most recent Senior Review, conducted March-May 2013, found that all of NASA's missions currently in extended operations are still producing valuable science datasets for research, and should be extended for another 2 years. The next Senior Review is scheduled for mid-2015.

1.2 Real-time Direct Broadcast Data

Several of NASA's missions provide for the real-time transmission of satellite data to the ground in support of operational activities and disaster monitoring. As the Earth is being observed by satellite instruments on these platforms the data is transmitted using omni-directional antennas. Users who have compatible ground receiving equipment and are in direct line of sight to the satellite may receive these transmissions. This Direct Broadcast capability is currently available for selected instruments on the Aqua, Terra, and Suomi-NPP missions. More information on the required hardware and ground station processing software can be found at NASA's Direct Readout Laboratory (DRL) website: http://directreadout.sci.gsfc.nasa.gov. NASA also provides access to Near Real-Time (NRT) global data and products from the MODIS (on Terra and Aqua), OMI and MLS (on Aura), and AIRS (on Aqua) instruments in less than 2.5 hours from observation from the Land and Atmosphere Near real-time Capability for EOS (LANCE) data system at http://earthdata.nasa.gov/lance.

Table 1 - Current NASA LEO Satellites

Satellite	Operator	Equatorial Crossing Time	Mean Altitude	Launch Date	Data Access	Instrument Status
Jason-2 (Op) (Ocean Surface Topography Mission)	NASA/NOAA, EUMETSAT/CNES	66-deg Non Sun-Sync	1336	20-Jun-2008	Handbook	**Science:** Sea surface topography (Follow on to Jason-1) **Instruments:** LRA, JMR, DORIS-NG, POSEIDON-3, AMR, GPSP
Suomi-NPP (Op)	USA NASA/NOAA	13:30	833	28-Oct-2011	Suomi Data Direct Broadcast	**Science:** Atmospheric dynamics, water and energy cycle, clouds and aerosols, radiation, GHG, air/sea fluxes; also supporting operational weather forecasting & ozone monitoring **Instruments:** CrIS, CERES, VIIRS, ATMS, OMPS

Table 2 - Current NASA Research and Development (R&D) Satellites

Satellite	Space Agency	Equatorial Crossing Time and Mean Altitude	Launch Date	Data Access	Instruments	Status, Applications and Other Information
TRMM	NASA/JAXA	35 Deg Inclination Non Sun-Sync 402 km	28-Nov-1997	PMM Data TRMM Data	LIS, PR, CERES, VIRS, TMI	Atmospheric dynamics, water and energy cycle, lightning, precipitation, radiation
Landsat-7	NASA/USGS	10:05 (D) 705 km	15-Apr-1999	Earth Explorer	ETM+	Earth resources, land surface, environmental and disaster monitoring, agriculture and forestry, ice and snow cover
QuikSCAT	NASA	6:00 (A) 803 km	19-Jun-1999	PO.DAAC	SeaWinds	Sea surface wind vectors
Terra	NASA	10:30 (D) 705 km	18-Dec-1999	Terra Data Direct Broadcast	ASTER, MODIS, MOPITT, MISR, CERES	Atmospheric dynamics and chemistry, water and energy cycle, clouds, aerosols, radiation, GHG, carbon and water, air-land exchange
ACRIMSAT	NASA	10:50 (D) 720 km	20-Dec-1999	ASDC	ACRIM-III	Total solar irradiance, solar constant

NMP EO-1	NASA	9:45 (D) 680 km	21-Nov-2000	Archive Earth Explorer New Data	ALI, Hyperion, LEISA AC	Land surface and earth resources
Jason-1	NASA/CNES	66-deg Non Sun-Sync 1324 km	7-Dec-2001	PO.DAAC	LRA, JMR, DORIS-NG, POSEIDON-2, TRSR	Oceanography, geodesy/gravity, climate monitoring, marine meteorology
GRACE	NASA/DLR	89 Deg Inclination Non Sun-Sync 485 km	17-Mar-2002	PO.DAAC	MWA, Accelerometers, GPS	Earth mass distribution, with application to ground water, ocean currents and ice sheets, GPS (P,T,humidity)
Aqua (EOS PM-1)	NASA	13:30 (A) 705 km	4-May-2002	EOSDIS Direct Broadcast	MODIS, AIRS, CERES, AMSU-A, AMSR-E, HSB	Atmospheric dynamics, water and energy cycle, clouds and aerosols, radiation, GHG, air/sea fluxes, precipitation
SORCE	NASA	40 Deg Inclination Non Sun-Sync 640 km	25-Jan-2003	DISC	SIM, SOLSTICE, TIM, XPS	Total and spectral solar irradiance
Aura	NASA	13:45 (A) 705 km	15-Jul-2004	DISC	MLS, TES, HIRDLS, OMI	Chemistry and dynamics of atmosphere, O3, GHG, aerosols
CALIPSO	NASA/CNES	13:30 (A) 705 km	28-Apr-2006	ASDC	CALIOP, IIR, WFC	Aerosols and clouds
CloudSat	NASA/CSA	13:30 (A) 705 km	28-Apr-2006	Cloudsat DPC	CPR	Cloud vertical profiling

SAC-D / Aquarius	NASA/CONAE	18:00 (A) 651 km	10-Jun-2011	PO.DAAC	L-Band Radiometer, L-Band Scatterometer, CARMEN-1, DCS, HSC, Lagrange, MWR, NIRST, ROSA, SODAD, TDP	Sea Surface Salinity
LDCM (Landsat-8)	NASA/USGS	10:05 (D) 705 km	11-Feb-2013	Landsat-8 Data Products	OLI, TIRS	Earth resources, land surface, environmental and disaster monitoring, agriculture and forestry, ice and snow cover

Failed Instruments

***** *CERES on TRMM*
***** *TRSR on Jason-1*
***** *HSB on Aqua*
** HIRDLS on Aura*

Reduced Function Instruments

** SeaWinds on QuikSCAT (no antenna rotation, only used for cross-calibration)*
** ETM+ on Landsat-7 (failed scan line corrector)*
** ASTER (SWIR module not functioning)*
** AMSU on Aqua (channel-4 failed)*
** AMSR-E on Aqua (reduced rotation rate for cross-calibration with AMSR-2)*
** SORCE - Battery degradation, Instruments turned off during orbit night*
** Cloudsat - Battery degradation, Instruments turned off during orbit night*

2 FUTURE SATELLITE SYSTEMS

With the U.S. President's FY2014 budget request ($1.85 Billion), NASA's Earth Science Program is implementing a balanced and robust plan to accomplish a broad set of critical Earth observation measurements from space. The program advances knowledge of the integrated Earth system, the global atmosphere, oceans (including sea ice), land surfaces, ecosystems, and interactions between all elements, including the impacts of humans. A balance of satellite measurements, science research, technology development and applications are needed to address a complex global Earth system. Table 3 and Table 4 summarize NASA's future plans for the launch of 14 missions and 2 instruments (on a host mission).

2.1 Earth Systematic Missions (ESM)

NASA's ESM includes a broad range of multi-disciplinary science investigations aimed at developing a scientific understanding of the Earth system and its response to natural and human-induced forces and changes. The ESM program develops Earth observing research satellite missions, manages the operation of NASA facility research missions once on orbit, and produces standard mission products in support of NASA and National research, applications, and policy communities.

The five current flight missions in formulation or development contained in the ESM program are the Global Precipitation Measurement (GPM Core), Ice, Cloud, and Land Elevation Satellite (ICESat)-2, Soil Moisture Active-Passive (SMAP), Stratospheric Aerosols and Gas Experiment (SAGE)-III, and Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) missions.

The program has adjusted the mission timelines and budgets to accommodate increasing launch vehicle costs (for SMAP) and the reallocation of funding based on Agency priorities. The SMAP launch date and funding profile is driven by launch vehicle availability and the current plan supports a late 2014 launch. The Agency continues with the pre-formulation studies, formulation, and development of other Decadal and climate missions such as Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI), Surface Water and Ocean Topography (SWOT), Pre-Aerosols, Carbon and Ecosystems (PACE), and on pre-formulation studies for the Orbiting Carbon Observatory (OCO-3) instrument, Climate Absolute Radiance and Refractivity Observatory (CLARREO), Active Sensing of Carbon dioxide Emissions over Nights, Days and Seasons (ASCENDS), Aerosols, Clouds and Ecosystems (ACE), Geostationary Coastal and Air Pollution Events (GEO-CAPE), and Hyperspectral Infrared Imager (HyspIRI).

2.2 Earth System Science Pathfinder (ESSP)

ESSP provides an innovative approach to Earth science research by providing frequent, regular, competitively selected opportunities that accommodate new and emerging scientific priorities and measurement capabilities. These opportunities

represent a series of relatively low-to-moderate cost, small-to-medium sized missions. They are competitively selected, principal investigator lead missions that focus on scientific objectives to support a selected subset of studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth. NASA currently funds the development of the Orbiting Carbon Observatory (OCO-2) mission, the Earth Venture-class missions, and several other missions in pre-formulation under ESSP.

The planned launch vehicle for the OCO-2 satellite was the Taurus XL. Following the Taurus XL failure in March 2011 and the loss of NASA's Glory mission, NASA put the contract for the Taurus XL on hold pending the outcome of a failure investigation. NASA completed an independent replan review in November 2012 and a new mission plan was approved in January 2013. The current projected OCO-2 launch readiness date is February 2015.

The Earth Venture-class (EV) missions are part of a competitive program to select small instruments, small satellites, or airborne science campaigns to complement the larger NASA Earth science missions. In FY 2013, NASA will continue the five airborne science investigations selected through the initial Venture Class solicitation (EVS-1) in FY 2010 and started in FY 2011. NASA selected the Cyclone Global Navigation Satellite System (CYGNSS) mission as part of the Earth Venture Mission (EVM-1) solicitation in 2012. CYGNSS is currently in formulation and will launch in 2017. The Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument was selected in November 2012 as part of the Earth Venture Instrument (EVI-1) solicitation. TEMPO will be mounted on a commercial communications satellite in geostationary orbit to monitor air pollutants over North America beginning in 2017. Future solicitations for the Earth Venture Class project will be released every 4 years (EVS and EVM) and no more than 18-month intervals for EVI.

Table 3 - Future NASA LEO Satellites

Satellite	Operator	Equatorial Crossing Time	Mean Altitude	Launch Date	Data Access	Instrument Status
Jason-3 (Op) (Ocean Surface Topography Mission)	NASA/NOAA, EUMETSAT/CNES	66-deg Non Sun-Sync	1336 km	2014		**Science:** Sea surface topography (Follow on to Jason-2) **Instruments:** LRA, JMR, DORIS-NG, POSEIDON-3, AMR, GPSP

Table 4 - Future NASA Research and Development (R&D) Satellites

Satellite	Space Agency	Equatorial Crossing Time and Mean Altitude	Launch Date	Data Access	Instruments	Status, Applications and Other Information
GPM Core	NASA/JAXA	65 Deg Inclination Non Sun-Sync 407 km	Feb 2014		GMI, DPR	Global precipitation, evaporation, water cycle

SAGE-III-ISS Intl. Space Station Instrument only	NASA	51.6 Deg Inclination Non Sun-Sync 407 km	Aug 2014		Spectrometer	Stratospheric ozone, aerosols, water vapor
SMAP	NASA	18:00 (A) 685 km	Oct 2014		L-Band Radar, L-Band Radiometer	Soil Moisture, Freeze-thaw state
OCO-2	NASA	13:30 (A) 705 km	Feb 2015		Spectrometer	Carbon Dioxide sources and sinks
ICESat-II	NASA	94 Deg Inclination Non Sun-Sync 600 km	July 2016		ATLAS	Ice sheet thickness, sea ice thickness, vegetation height, carbon and biomass
GRACE FO (Follow-On)	NASA/DLR	89 Deg Inclination Non Sun-Sync 485 km	Aug 2017		Gravity, GPS	Ocean currents and mass, ice sheets, GPS (Pressure, Temperature, Humidity)
OCO-3 Instrument only	NASA	TBD	$\geq$2017		Spectrometer	Carbon Dioxide sources and sinks
SWOT	NASA/CNES	78 Deg Inclination Non Sun-Sync 970 km	2020		CO Sensor, Ka-Band Radar Interferometer	Lake levels, river discharge, ocean surface topography
PACE (Pre-ACE)	NASA	Sun-Synchronous 650 km	$\geq$2020		Spectrometer, Polarimeter	Aerosols, ocean color
ASCENDS	NASA	10:30 (A) 450 km	$\geq$2023		Laser	Carbon Dioxide (day and night)

CLARREO	NASA	90 Deg Inclined	TBD		IR, RS, GNSS	Spectrally resolved and calibrated Infrared (IR) and Reflected Solar (RS) Earth radiance, GNSS (T,P,humidity)
L-Band SAR	NASA	TBD	TBD		Multi-beam LIDAR, L-Band INSAR	Earth surface deformation, vegetation height, biomass profiles, ice motion
HyspIRI	NASA	TBD	TBD		Hyperspectral and TIR Imagers	Terrestrial and aquatic ecosystems, fires, mineral resources, volcanoes
GEO-CAPE	NASA	Geosynchronous	TBD		UV-Vis-NIR, IR imagers (CO detection)	Air pollution forecasting and transport, sources of aerosols and O3, coastal ecosystems, CO, NO2, SO2, HCHO
ACE	NASA	TBD	TBD		Spectrometer, Polarimeter, LIDAR, Cloud Radar	Aerosols, ocean color, cloud profiles