TECHNOLOGY CAPABILITY NEEDS OF FUTURE EARTH SCIENCE MISSIONS

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Abstract

Technology capability needs for future earth science space missions have been collected as an input to NASA's New Millennium Program. Candidate technologies to meet these capability needs have been identified and a set of candidate mission architectures developed. This paper describes the process that was used to develop the capability needs and lists the needs that resulted from that process. These capability needs are presented and discussed to encourage the development of new technologies to meet the needs.

New Millennium Program

NASA's New Millennium Program has the goal of revolutionizing space and earth science programs to achieve exciting and frequent missions in the 21st century. The approach taken involves demonstrating and validating revolutionary technologies in order to reduce development times and life cycle mission costs. The program aims to demonstrate high value technologies through a series of near term validation flights where technology demonstration is the overriding mission goal. The technology validation projects are carried out with the support of Integrated Product Development Teams (IPDTs) which are responsible for identifying and supplying high value technologies to the flight system development teams.

Capability Needs Development Process

The New Millennium program began with a deep space emphasis but it has recently begun to focus on the needs of NASA's Mission to Planet Earth (MTPE) Enterprise. Because of future budgetary constraints, the MTPE program has established the goals of ensuring continuity of existing critical Earth observing System (EOS) measurements at reduced cost as well as performing additional important measurements enabled by new technology.

The response of New Millennium to meet the MTPE goals is to demonstrate technologies of specific value to future earth science missions in a series of low cost, rapid turnaround earth orbiting missions.

The first step in focusing on earth science needs was to collect the views of the major constituencies. One of these was represented by a group of earth scientists who met at a workshop in Landover Maryland in March 1995 at the invitation of the New Millennium program. This group identified the technology capability needs of fourteen future earth science mission or measurement themes. A matrix showing the mission science themes vs. capability needs is given in Table 1. The assembled group and a subsequent Science Working Group meeting in Pasadena in April, 1995, identified seven of these missions as most likely to be a candidate for a near term New Millennium demonstration mission. These seven are identified on the right hand part of Table 1. The subsequent work with this constituency to quantify capability needs and identify appropriate technologies concentrated on this shorter list of seven mission science themes.

The other major constituency was the Mission to Planet Earth program office. The centerpiece of the MTPE is the Earth Observing System, whose prime goal for technology development is to continue the highly calibrated EOS measurements indefinitely at greatly reduced cost. Another initiative, the Earth System Science Pathfinder (IASP), will utilize advanced technology to enable totally new measurements. The process of identifying needs and technologies followed by the MTPE program office is described below.

The Mission to Planet Earth Program - A Technology Needs Assessment

The MTPE program seeks to further understanding of our planet as an integrated system consisting of

Table 1. Earth Science Mission Capability Requirements Summary

MTPE MISSION CLASS

REQUIRED CAPABILITIES	A1	A2	O1	O2	O3	M	G1	L1	L2	L3	L4
SPACECRAFT CAPABILITIES											
High efficiency power system										●	
Mass data storage	●									●	
GPS (on-a-chip)	●						●		●	●	
GPS Attitude Determination	●						●		●	●	●
Precision Spacecraft pointing							●				
Low cost 3-axis stabilization											
Tight Formation Flight Subsystems							●		●		●
Efficient Micro-propulsion							●				
Drag-free Compensation							●		●		
Extremely High Bandwidth Communications									●		●
In Situ Sensor Interrogation/Uplink											
Tether											
Inflatable Structures										●	
Atomic Oxygen Resistant Materials							●		●	●	
SENSOR CAPABILITIES											
Reliable long-lived solid-state lasers											
Light Thermally Stable Optical Materials	●	●			●						●
Cryocoolers - miniature, long-lived, vib.-isolated	●	●			●						●
UV, VIS, IR, FIR Detectors & Focal Plane Arrays	●	●									●
Compact hi-resolution spectrometer	●	●									●
Fiber based wide angle optics											●
High performance narrow band optical filters	●	●									
Antennas, Lightweight & Deployable		●							●		
Active Microwave			●	●					●	●	
Large Passive Microwave	●		●	●				●			
Miniaturized SAR				●					●	●	
Low mass, athermal, telescopes	●	●									●
Superconducting gravity gradiometer							●				
Terahertz oscillators	●	●									
High-efficiency diode and optical mixers	●	●									
Miniaturized Fields and Particles Instruments											
Accelerometer								●			
OPERATIONS CAPABILITIES											
On-board processing	●	●	●	●	●			●	●	●	●
Autonomous Spacecraft/Mission operations	●	●	●				●				●
Spacecraft Constellation Operations							●				
Efficient End-to-end Data Management	●	●	●	●	●	●	●	●	●	●	●
Distributed Real-time Downlink				●	●			●	●		●

ATMOSPHERIC SCIENCES	
A1	Atmospheric Sounder
A2	Tropospheric Pollutants
A3	Tropospheric Winds LIDAR
OCEAN SCIENCES	
O1	Surface Wind
O2	Sea Ice Hazard Mapping
O3	Ocean Color
O4	In-Situ Data Relay
GRAVITY MAPPING	
G1	Ocean and Land Surface Gravity Mapping
TERRESTRIAL SCIENCES	
L1	Soil Moisture
L2	SAR Topographic Mapping
L3	SAR Biomass
L4	Landsat Pathfinder
L5	Geomagnetism
L6	Laser Altimetry Topo Mapping

Workshop candidates for early New Millennium flight demonstrations

land, oceans, and atmosphere and to monitor global change. Recently, a comprehensive reshaping effort was completed that aligned program requirements with projected budgetary constraints. This activity identified new technology development as a key ingredient to offset anticipated financial limitations. Internal and external review teams postulated that, if nurtured, new and innovative subsystem and system architectures would merge and allow many of the stated program objectives to be achieved with less complex flight segments requiring shorter development time. Concurrent reductions in system size, mass, power, and consumables would also enable the use of smaller spacecraft and launch vehicles. More autonomous ground operations were also envisioned to reduce traditional staffing levels. In response to this vision of the future, a systematic, top-level, program-wide Technology Infusion Plan[1] was prepared to initiate the process of identifying key technology advancements for Earth science missions. A hierarchical approach, shown pictorially in Figure 1, was taken where mission objectives guide the selection of instrument technology needs which, in turn, influence complementary advancements in spacecraft and ground system capabilities. A focused, requirements driven approach with direct project or user connectivity was sought to effectively harness supplier capabilities and to leverage available funds so that useful end products would result. The process started with a technology needs survey performed by the Goddard Space Flight Center (GSFC) MTPE program office. Contributions were actively solicited from the Earth science community and other user groups, flight projects, and the ground operations team so that all elements received proper representation.

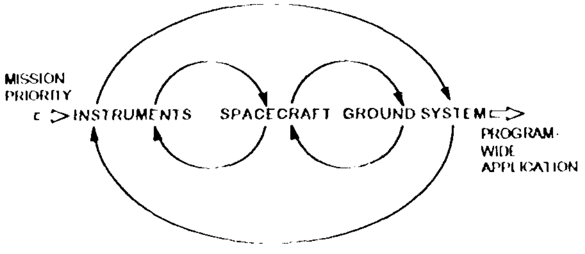

Figure 1. Technology Development Dynamics

After a series of meetings and workshops, some candidate mission sets were proposed that assisted in the prioritization process. Advancements in instrument and sensor technologies were judged to have the highest potential payback to the MTPE program because, historically, state-of-the-art scientific instruments have long development times and drive the requirements for supporting spacecraft and ground systems. In order to further define specific technology needs, a survey form was prepared and distributed widely. The collected results of that survey showed trhat the desired technologies fell mainly into the four general categories listed below:

(a) microelectronic devices and innovative packaging that provide significant reductions in overall volume, mass, and power for the whole spectrum of Earth observing instruments,

(b) detector systems that cover the wavelength bands of interest to Earth science that require minimal or no active cooling,

(c) detector arrays that eliminate the need for scanning mechanisms, and

(d) higher image resolution devices.

Associated spacecraft and ground system technologies that would complement advanced instrument and sensor development and, at the same time, enhance the scientific mission were also identified. Priority items included improvements in orbit determination, attitude knowledge, data handling and storage, and level of on-board autonomy.

To illustrate how this hierarchical technology assessment process works, application to a recently approved New Millennium advanced land imaging flight validation mission (Earth Orbiter-1) is described below.

It was determined, via a peer review process, that advanced technology could be employed to develop an instrument that could be flown in place of the Landsat Enhanced Thematic Mapper (ETM+) for future land imaging missions. The proposed baseline instrument employs a pushbroom combination of multispectral and hyperspectral detectors arranged on a partially populated uncooled focal plane and covering the wavelength range from 0.4 to 2.5 micrometers. A three mirror anastigmatic optical system of hot pressed silicon carbide provides a light, rigid, and thermally stable configuration. Radiometric calibration of 5% or better is achieved by incorporation of devices that allow sun, moon, and deep space as well as ground viewing. When compared to the present generation ETM+, the new instrument concept eliminates the need for a scan mirror and radiative cooler and reduces volume, mass, and power requirements by about a factor of 8. Complementary spacecraft and ground system technologies under consideration that support this instrument include an advanced fiber optic data bus to handle the high data rates generated by the land imager, data compression, an X-band phased array, cloud editing, auto navigation and control, and increased levels of on-board spacecraft autonomy to name a few. Validation of these technologies will have a synergistic effect on future MTPE programs.

The process outlined above is being applied to other high priority Earth science missions and will spawn additional advancements in instrument, spacecraft, and ground system capabilities that can then be infused into the missions of the future.

Capability Needs vs. Technology Needs

The stated needs of the future missions are a combination of capability needs and technology needs. The difference between these two is both real and artificial. Capability needs, such as "downlink with a data rate of 600 Mb/s" are theoretically independent of technology. That is, the capability could be provided by more than one distinct technology, e.g. optical or RF. If RF, then different frequencies could be used. Technology needs are more near term and assume a particular technology, e.g. "a Ka-band phased array antenna." On the other hand, the statement of the quantitative capability need, i.e. "600 Mb/s," is generally made by someone who knows the capabilities and limitations of particular technologies.

The two approaches are obviously intertwined. In the collection of needs the capabilities were stressed, so that revolutionary new technologies to meet the need could be identified. One of the purposes of this paper is to expose the needs to a broader audience so that exciting new technologies can be proposed for future demonstration missions.

Integrated Capability Needs

The next step in the process was to integrate and quantify the two sets of capability needs, one from the science working group and one from the MTPE program office, so that specific technology validation experiments could be identified.

The information for this step was obtained by further, detailed discussions with scientists and instrument developers involved with the science measurement themes listed above. The results of this effort are shown in Tables 2, 3 and 4.

The capability needs are grouped into sensor capabilities, spacecraft capabilities and operations capabilities. There is clearly some overlap between all of these, especially as higher degrees of flight system integration are desired. The grouping should be seen as one of convenience only without any implication as to the best location for capabilities.

‘1’wet columns of information are given for each need. The middle column contains the level of capability that would satisfy most of the future missions that were studied. The last column shows a capability that is desired by only one or two future missions. In other words, a technology demonstration that provided the capability shown in the middle column would provide a valuable step forward while one that met the capability shown in the right band column would satisfy even the most demanding of the futur c science missions that were surveyed. In the following sections the furthe discussion and rationale for the. capability needs is given.

Sensor Capability Needs

The integrated needs of science instruments arc. presented in ‘1’able. 2. The.sc. capabilities and technologies were identified as those that would result in smaller, lighter, simpler, less costly, more reliable future science instruments. It will be clear in the table that most of the needs arc strongly attached to a particular technique, for example lightweight, the.rlnally stable optical materials are needed for optical sensors whereas techniques such as inflatable antennas arc needed for microwave sensors. Thus some selection between measurement techniques is inherent in prioritizing the technologies.

Rationale for Sensor Capability Need s

Materials

Materials with light weight and low thermal expansion ar c dc.sired fot optical instrument structures, optics and integrated optical structural assemblies. Silicon Carbide is seen as a major candidate to meet these needs.

Optics

optical designs with wide fields of view can be used to eliminate scanning minor assemblies, thus greatly reducing complexity, mass and cost.

Optical Elements

Wedge fillers are desired 10 provide spectrometer functionality in a greatly reduced size. High performance, narrow hand optical filters arc desired for future instruments that rely on detecting either laser backscatter or thermal emission from the atmosphere.

‘1’able ‘2, Integrated Sensor Capabilit y Needs

Capability	General Need	Limited Need
Large Area Pushbroom Imaging Spectrometers	Multispectral Arrays	Hyperspectral Arrays Wedge Filters
Wide Angle optics	151040 dc.glees	
Stable, Light Weight Optics and Support Structures	Silicon Carbide or Composite Elements	
Improved UV, Visible, IR, and Microwave Detectors	Uncooled	QWIP (3 to 16 microns) MMIC (54 to 183 Ghz)
Superconducting Bolometers	Low Power Local Oscillators	
1 Enhanced Cryocoolers	5s to 80 K 5 Year Lifetime Low Vibratory Disturbance	30 1045 K
Solid State Lasers	(). S to 2 microns 10E4 1() pulses 3 to 5% Efficiency	2.5 Thz 1 meal oscillators
Optical Mixers and Multipliers		2.5 Thz
Narrow Band Optical Filters	().?.9 m 0.32 microns 0.82 to 0.94 microns	
Improved, Less Costly Calibration Techniques	0.4 to 10 microns	5% Radiometric Accuracy 1% Radiometric Stability
High Speed Analog to Digital Converters	>1? bits	>14 bits (>1 Mhz) 20 bits (O.? Mhz)
Data Compression ASICS	1 ossless	Lossy

Detectors

Improved low cost, detectors are required especially for certain parts of the frequency spectrum, namely Quantum Well Infrared Photodetectors (QWIP) for long wavelength infrared and Monolithic Microwave Integrated Circuits (MMIC) for millimeter wavelength.

Coolers

Long lived, lightweight, low cost vibrationless cryocoolers are desired mostly for cooling infrared detectors.

Antennas

Lightweight, low cost, deployable microwave antennas are required for future SAR, radar and passive microwave instruments. Stable phase center antennas are required for missions requiring very precise distance measurements using RF links.

RF Components

More efficient, low cost RF components are needed for future SAR, radar and passive microwave instruments.

Lasers

Reliable, power efficient, lighter weight lasers are the key components in lidars for wind, aerosol and precise topography measurement.

Controls

Autonomous optical alignment is required to maintain alignment for laser backscatter collectors.

Mechanisms

Miniaturized mechanical devices, such as piezoelectrics are desired for a number of applications, including compact Fourier Transform Spectrometers for atmospheric temperature and chemistry studies.

Accelerometers

Sensitive lightweight accelerometers are required for missions requiring detection and perhaps compensation of very small forces acting on the satellite.

Electronics

High speed, low cost, reliable highly integrated electronics are required for the signal chains and command and data sections of all sensors.

Spacecraft Capability Needs

Table 3 contains what were considered the major areas where advances in spacecraft capability would enable either new missions now considered unaffordable or the continuation of present measurements at greatly reduced cost. In some cases the improvements are called out in traditional subsystems, such as power sources, while in others a new cross subsystem architecture is implied, such as multi-functional structures or very small spacecraft.

Rationale for Spacecraft Capability Needs

Power

More efficient power systems are needed for all missions but are seen as enabling for those missions that use large amounts of power. These are represented by active sensors such as synthetic aperture radars (SAR) and lidars. The missions that would use them are of the long term monitoring variety, thus the need for batteries with high cycle life.

Attitude and Orbit Determination

The future missions desire on-board attitude and orbit determination approaches that are low cost and easily adaptable to new missions. Combination of functions, such as can be done with GPS receivers that can provide both position and attitude, is seen as a promising approach to that objective. The need for very precise attitude knowledge stems from the desire to co-register pixels from different instruments on different platforms flying in formation.

Propulsion

Two needs were identified for propulsion capabilities, one for very low thrust, lightweight propulsion components and the other for drag compensation methods. The former is required for low cost microspacecraft. The latter is required for lower cost orbit maintenance and also to enable missions such as gravity measurement which operate at low altitude, around 300 km, in a high drag environment. Drag needs to be compensated both to provide reasonable mission lifetimes and also to remove a major source of experimental error.

Command and Data Handling

The need for high capacity, high rate data storage devices and high rate data busses comes primarily from SARs and hyperspectral imagers. Both of these have the potential for collecting data over large swaths, from 50 to 200 km with resolution as low as 10 to 30m. Instrument concepts have been developed with data rates up to hundreds of Mbits per second. Efficient mission architectures, with downlinks only about once a day, require lightweight reliable low cost on-board memories of hundreds of Gbits capacity.

'1'able 3. Spacecraft Capability Needs

Capability	General Need	Limited Need
Resource Efficient Power Generation	4010 50 W/kg	60 to 80 W/kg >1 kw payload power
Improved Energy Storage Capacity	40 m 60 Whr/kg up to 30, 000 cycles	701090 Whr/kg
Precise Orbit 1)etermination	3 to 5 m	1to 0.1 m
Miniaturized Attitude Control	GPS on a chip or equivalent 0.1 degree	0.01 to 0.003 degree for pixel coregistration
Advanced Propulsion Systems	High Specific Impulse (500" to 1000 s) 1 to 22 N Thrust Levels	0.1 N
Increased Mass Data Storage	Up to 200 GB	Up to 2 TB
1 enhanced On-Board Flight Computer	32 bit	
High Bandwidth Data Systems	50 Mb/s MIL-STD-1773 with Backward Compatibility Interface Simplification ATM Protocol	300 10600" M h/S
High Bandwidth Communications	50 to 150 Mb/s X-Band Phased Array Ka-Band Phased Amy (25.5 to 27 Ghz) Associated Ka-Band Flight Components	300 to 600 M b/s
Atomic Oxygen Resistant Materials and Stable Coatings	400 to 1000 km Altitude (Polar orbits)	2S() to 350 km Altitude
Integrated Multi-Functional Structures	Mechanical, Electrical, Thermal	
Formation Flying Separation Maintenance	2500 km	500 m
Very Small, 1 ow Cost Spacecraft		Less than 10 kg; ~$100K each

Telecommunications

The future investigations desire fixed nml-deployable high gain antennas that can be steered electronically to reduce the mass, power, cost, risk and complexity of present high gain and low gain antennas. Applications include both TDRSS and direct to the ground. Most moderate data rate missions arc well served by rates in the range of 50 to 150 Mb/s while the aforementioned SAR and hyperspectral imagers need rates as high as 600 Mb/s.

Materials

The need for materials also stems from the desire to operate at low altitudes. Some of these missions require large deployable antennas and structures made of plastic materials, such as inflatables. Present materials are susceptible to degradation by atomic oxygen.

Multifunctional Structures

Present spacecraft are designed, built and tested along lines that stress functional and subsystem separation. As spacecraft become smaller the structures and the teams that build them must become more highly integrated.

Formation Flying

Formation flying covers a spectrum of mission architectures, all using more than one spacecraft that together form a larger measurement system. This capability is desired for several reasons. The first is to enable the potential to replace individual EOS instruments without having to replace entire multi-instrument platforms. The second reason is to allow the eventual replacement of the large multi-instrument platforms with a number of much smaller cooperating single instrument platforms. The third reason is to enable science measurements that by their nature rely on multiple spacecraft, such as interferometric SAR and gravity measurement.

Very Small Spacecraft

Some future mission architectures require the dispersion of many small satellites so that simultaneous, geographically separated measurements can be taken. In order to build, launch and operate such satellite constellations, each one must a) cost hundreds of thousands, not millions; b) weigh kilograms, not hundreds of kilograms and c) operate autonomously.

Operations Capability Needs

Table 4 contains operations capability needs that are expected to result in more autonomous, self maintaining flight systems, easier, lower cost access to ground antennas and more efficient ground transport of data.

On-Board Processing

Several of the missions can make use of very powerful on-board processors, either general purpose or dedicated designs. Processors with "GigaFLOPS equivalent" processing speed can be used to perform the type of processing that is now done on the ground before any scientific or operational use of the data is made. Examples are processing of SAR data to the image stage or operations on specially weighted combinations of spectral data from hyperspectral imagers. It is difficult to quantify the processing speed needed for these types of processors because two different technology paths might be used to provide the capability, either very powerful general purpose computers or specially designed digital signal processors. The choice between these should consider technology development or non recurring cost, recurring cost of each new device as well as the mass and power of the flight devices.

Autonomy

Each of the future missions desires to operate with a high degree of autonomy so that routine operations, maintenance and health monitoring can be done efficiently. There is also the desire to command the spacecraft at a high level, so that operations team sizes are reduced and the scientists can be in more direct control of their experiments.

Ground Stations

Lower cost, autonomous ground stations will reduce cost by allowing more ground stations to be widely dispersed at the most efficient locations and operated by smaller staff. Higher downlink rates allow the data to be transferred with fewer passes and less use of ground station time.

Ground Data Handling

Improvements in ground data handling, including both storage and distribution are needed to efficiently handle large data volumes and to distribute data quickly to dispersed data users.

Interactive Access

The users of data from space borne instruments desire to command the investigations at a high level and have widely dispersed access to data over global networks.

Strawman Mission Architecture Development

Once the capability needs were identified, they were transmitted to the IPDTs so that they could identify technologies to supply the appropriate functionality and performance. Concurrent with the IPDT activity a series of technology validation mission architectures was defined to help focus the discussion. These mission architectures provided the IPDT technology developers with enough of a mission context to develop concepts and costs for actual technology demonstrations.

The validation mission architectures are briefly described in Table 5. Each one is built around a science measurement theme, including as its centerpiece an advanced instrument and then key supporting technologies. Some of the important features of these mission architectures are the following: a) short mission development cycles with a goal for the first launch date in late 1998; b) small, low cost launch vehicles, the biggest being of the LMLV/Taurus class, the smallest of the half-Pegasus class; c) short mission lifetimes determined by the time required to validate the technology and d) each mission demonstrating an advanced end-to-end science measurement with no science data requirements as such, only those necessary to demonstrate an approach relative to a known standard.

Table 4. operations Capability Needs

Capability	General Need	Limited Need
Enhanced On-Board Processing	1 GFLOPS-equivalent Efficient Load Processing	3 to 10 GFLOPS-equivalent Fusion of Multiple Data Streams
Progressive Flight Segment Autonomy	Scheduling and Sequencing Flight Segment Health Summarization Fault Detection, isolation, and Recovery Auto Navigation and Control	Cloud and Feature Editing Station Keeping and Formation Flying
Low Cost Ground Stations	Global Coverage 50-150 Mbps Downlink	300 to 600 Mbps Downlink
Advancements in Storage Management and Technology	0.5 TB/day Interoperability of Commercial Media and Software	2 TB/day
Improvements in interactive Access	Standardized Interfaces Networking	

Table 5. Summary of Strawman Mission Architectures

MISSION TITLE	KEY SCIENCE VISION ADDRESSED	KEY TECHNOLOGY VALIDATION	COMMENTS
LAND IMAGING	LAND SURFACE CHARACTERIZATION AND USE; BIO PRODUCTIVITY	ADVANCED IMAGER FORMATION FLYING	POTENTIAL REPLACEMENT FOR LANDSAT 8
ATMOSPHERIC NADIR SOUNDING	TEMPERATURE AND MOISTURE PROFILING	LIGHTWEIGHT COMPACT SPECTROMETER LONG WAVELENGTH DETECTORS FORMATION FLYING	POTENTIAL INFUSION INTO NPOESS MONITORING SATELLITES
TROPOSPHERIC CHEMISTRY	TROPOSPHERIC OZONE AND POLLUTANT MAPPING	LIGHTWEIGHT COMPACT SPECTROMETER LONG WAVELENGTH DETECTORS	
TROPOSPHERIC WINDS	TROPICAL TROPOSPHERIC WINDS	LIGHTWEIGHT SOLID STATE LASER AND TELESCOPE	TECH DEMONSTRATION FOR MISSING EOS MEASUREMENT GOAL
GPS CONSTELLATION/ATMOS SOUNDING	HIGH SPATIAL AND TEMPORAL RESOLUTION TEMPERATURE PROFILING	VERY SMALL S/C S/C CONSTELLATION GPS ON A CHIP	POTENTIAL TO INCREASE RESOLUTION AND DECREASE COST OF ATMOS. SOUNDING MEASUREMENTS
LIGHT SAR	GLOBAL TOPOGRAPHY AND TOPOGRAPHIC CHANGE	LIGHTWEIGHT SAR COMPONENTS	GREATLY REDUCE COST OF FUTURE TOPOGRAPHIC CHANGE MONITORING
LARGE APERTURE/SOIL MOISTURE	GLOBAL SOIL MOISTURE	VERY LARGE DEPLOYABLE ANTENNA SPARSE ARRAY ANTENNA TECHNIQUE	TECH DEMO FOR MISSING MEASUREMENT OF HYDROLOGICAL CYCLE
FLIGHT OF OPPORTUNITY	OCEAN WIND	ADVANCED SMALL, LOW POWER INSTRUMENT/COMPONENTS ADVANCED SMALL, LOW POWER S/C COMPONENTS	OCEAN WIND AN EXAMPLE OF SMALL INSTRUMENT DEMO
FORMATION FLYING/GRAVITY	GLOBAL GRAVITY MAPPING	CLOSE FORMATION FLYING S/C TO S/C RANGE AND RANGE RATE MEASUREMENT ACCELEROMETER	OCEAN CIRCULATION STUDIES
RADAR	WIND CLOUDS OCEAN TOPOGRAPHY	LIGHTWEIGHT RADAR COMPONENTS	

Conclusions

Capability and technology needs have been collected from the major constituencies of the Mission to Planet Earth Program to provide guidance from the future user point of view to technology developers and mission developers of the New Millennium program, Because of the reality of limited budgets, it is anticipated that some prioritization will be required and that the New Millennium missions can demonstrate only a subset of the desired future capabilities. Looking outside of that program, the technology needs collected here can serve as a guide for technology developers. Addressing the needs described here with less resource intensive solutions will enable exciting new missions as well as allow the continuation Of the EOS measurements at greatly reduced cost.

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References

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