Technology Capability Needs of Future Earth Science Missions

Ronald P. Salazar
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Paul S. Caruso, Jr.
NASA **Goddard Space Flight Center**
Greenbelt, Maryland

As a part of NASA's New Millennium program, capability needs for future earth science space missions have been collected, appropriate technologies to meet these capability needs identified and a set of candidate mission architectures developed. This paper describes the process that was used and lists the capability needs for future earth science missions that resulted from that process.

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 developing and validating revolutionary technologies, reducing development times and life cycle mission costs, enabling highly capable and agile spacecraft and promoting nationwide teaming and coordination. 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 flights are carried with the help of Integrated Product Development Teams (IPDT) which are responsible for identifying and supplying high value technologies to the flight system development teams.

The program began with a deep space emphasis but it has recently begun to focus additionally on the needs of NASA's Mission to Planet Earth (MTPE). Because of future budgetary constraints the program has established the goals of ensuring continuity of existing critical Earth Observation 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 high technologies of specific value to future earth science missions in a series of low cost, rapid turnaround earth orbiting missions carried out within the programmatic structure of the New Millennium Program.

The first step in focussing on earth science needs was to collect the views of two major constituencies. The first of these was a group of earth scientists who met at a workshop held in Landover Maryland in March 1995. This group identified technology capability needs of fourteen future earth science mission themes. A matrix showing the mission science themes vs. technology needs is shown in Figure 1. The assembled group identified six of these missions as the most likely candidates for near term science missions and thus deserving of the first priority in identifying promising technologies to meet the capability needs. In April 1995, the New Millennium Science Working Group met in Pasadena and five new members were added to represent the MTPE program. At this meeting a seventh mission was added to the list of highest prior ty for technology identification.

The other major constituency was EOS as represented by two groups, the Mission to Planet Earth Program Office and the science instrument developers. A program office working group was established to identify the future technology needs of instruments, spacecraft and operations and the results were documented in a Technology Infusion Plan which is summarized here. Direct input from major instrument developers was the source of other capability needs.

The second step in the process was to integrate and quantify the performance of the two sets of capability needs. The results of this effort are shown in Figure 2. This shows that in most cases the required capabilities were clustered in one part of the performance spectrum with one or two outliers that desired significantly greater performance.

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 focus the discussion. The candidate validation missions are described in Figure 3. The technology identified by the IPDT had to fit in the low cost mission architectures that were identified. The mission architectures were designed to fit the cost and schedule constraints imposed by the expected program funding profile. Some of the important features of these mission architectures were 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 LLV/Taurus class, the smallest of the half-Pegasus class; c) short mission lifetimes determined by the time required to validate the technology; d) each mission demonstrates an advanced end-to-end science measurement although there are no science measurement requirements as such, only those necessary to validate the measurement

Concurrent with the process described above, a National Research Council panel was studying the current EOS architecture and making recommendations for the future. As a result of this study, NASA decided that the major payoff for future EOS missions would come from an investment in the science instruments themselves rather than the spacecraft or other infrastructure that support them. New technology instruments will be smaller and can be supported by smaller, lower cost launch vehicles and spacecraft. It was therefore decided that the major portion of the new technology investment in the demonstration missions should go toward advanced technology instruments rather than spacecraft technology.

The subsequent mission definition process has concentrated on identifying new technology instruments that can lead to dramatically smaller EOS instruments than those presently in use. A set of high value spacecraft technologies has also been identified as flight candidates.

Figure 1 Earth Science Mission Capability Requirement Summary

_ _W M ___ _M CODE Y MISSION CAPABILITY REQUIREMENT SUMMARY

MILLENNIUM MISSION [illegible]

REQUIRED CAPABILITIES	ATMOS. A1	A2	A3	OCEAN O1	O2	O3	O4	G1	TERRESTRIAL L1	L2	L3	L4	L5	L6
SPACECRAFT CAPABILITIES														
High efficiency power system			●							●	●			●
Mass data storage	●	●	●			●				●	●	●		
[illegible]	●	●	●	●	●	●	●	●	●	●	●	●	●	●
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			●									●	●	
Light Thermally Stable Optical Materials	●	●	●			●						●		
Cryocoolers - miniature, long-lived,						●						●	●	
UV, VIS, IR, FIR Detectors & Focal Plane Arrays	●	●	●									●		
Compact												●		
Fiber based wide angle optics														
High performance narrow band optical filters	●	●	●							●				
Antennas, Lightweight & Deployable		●								●	●			
Active Microwave				●	●				●					
Large Passive Microwave	●			●	●					●	●			
												●		●
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	●	●	●	●	●	●	●	●	●	●	●			
					●	●			●	●		●		

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
- Geomagnetism
- L6 Laser Altimetry Topo Mapping

*** Workshop candidates for Millennium flight demonstrations**

Figure 2a.

NEW MILLENNIUM PROGRAM

INTEGRATED EARTH MISSION CAPABILITY NEEDS
"TALL POLES"
SPACECRAFT NEEDS

SPACECRAFT CAPABILITY	MOST NEED:	SOME NEED:
HIGH EFFICIENCY POWER	< 300W	1KW+
HIGH CYCLE LIFE BATTERIES	15,000-30,000 CYCLES	
MASS DATA STORAGE	< 200GB	>2TB
ADVANCED FLIGHT COMPUTER	32BIT	
HIGH BANDWIDTH DATA BUS	< 50MB/S	600MB/S
MINIATURIZED, LOW COST ATTITUDE DETERMNATION	0.1DEG	0.01 DEG
ORBIT DETERMINATION	10M	<10CM
PRECISE ATTITUDE DETERMINATION	0.01DEG	0.001DEG FOR PIXEL CO-REGIS.
ULTRA LOW COST S/C		$100K/EA., >100 S/C
FORMATION FLYING	10 - 100KM	1KM
MICRO PROPULSION		0.1N
DRAG COMPENSATION		1e-4M/SEC2
HIGH BANDWIDTH COMM.	50 - 150MB/S, PHASED ARRAY	600MB/S
ATOMIC OXYGEN RESISTANT MATL	400 - 700KM	250KM

Figure 2b.

NEW MILLENNIUM PROGRAM

IINTEGRATED EARTH MISSION CAPABILITY NEEDS

"TALL POLES"

SENSOR NEEDS

(THE FOLLOWING ARE ALL STRONGLY DEPENDENT ON THE MEASUREMENT TECHNIQUE)

SENSOR CAPABILITY	MOST NEED:	SOME NEED:
LIGHT, THERMALLY STABLE OPTICAL MATL.	SiC	
UV, VIS, IR, MM DETECTOR & ARRAYS	UV-12MICRON	8-16MICRON, QWIP; 2.5-5MM, MMIC
MIN., LONG-LIVED, LOW VIB. CRYOCOOLERS	65-100K	30-45K
HIGH PERF., NARROW BAND OPTICAL FILTERS		80%
HIGH QUANTUM EFF. PHOTOMULTIPLIER TUBE		0.2-1MICRON
WEDGE FILTERS		TBS
HIGH EFFICIENCY DIODE & OPTICAL MIXERS		500-640GHZ
WIDE ANGLE OPTICS	15-40DEG	
EFF., LONG-LIVED SOLID STATE LASERS	0.5-2MICRON, 5-10%EFF.	
AUTONOMOUS OPTICAL ALIGNMENT		10ARC-SEC
LIGHTWEIGHT DEPLOYABLE ANTENNAS		
ACTIVE MICROWAVE	1-2M	
LARGE PASSIVE MICROWAVE		10Mx10M
SYNTHETIC APERTURE RADAR		3.5Mx12M
SCANNING PASSIVE MICROWAVE	0.5-1.6M	
HIGH EFFICIENCY ACTIVE RF COMPONENTS	1.2-94GHZ, HMIC, MMIC	
ACCELEROMETER		10e-10G/(HZ)e1/2
STABLE PHASE CENTER MICROWAVE ANTENNA		3MICRON
INTEGRATED DETECTOR	ELECTRONICS "'	
HIGH SPEED A/D CONVERTERS " "'		>14BIT, >1 MHZ 20BIT, 0.2MHZ
LIGHTWEIGHT, LOW POWER ELECTRONICS		
MINIATURIZED DETECTOR MECHANISMS		
DATA COMPRESSION ASICS		

Figure 2c.

NEW MILLENNIUM PROGRAM

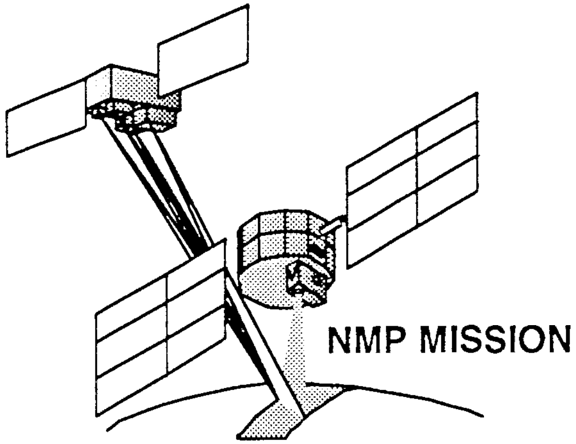
INTEGRATED EARTH MISSION CAPABILITY NEEDS
"TALL POLES"
OPERATIONS NEEDS

OPERATIONS CAPABILITY	MOST NEED:	SOME NEED:
ON-BOARD PROCESSING	<1 GFLOPS	3-10GFLOPS
AUTONOMOUS S/C/ MISSION OPERATIONS	AUTO DNLNK, NAV, STATIONKEEPING	VIRTUAL PLATFORM SYNTHESIS:
	CLOUD DETECT& RESCEDULE	S/C TO S/C COMM., SYNCH.
		& MISSION DATA SYNTHESIS
EFFICIENT END-TO-END DATA MANAGEMENT	<0.5TB/DAY	2TB/DAY
DISTRIBUTED LOW COST REAL TIME DOWNLINK		
HIGH RATE	50-150MB/S	
LOW RATE	1KB/S	

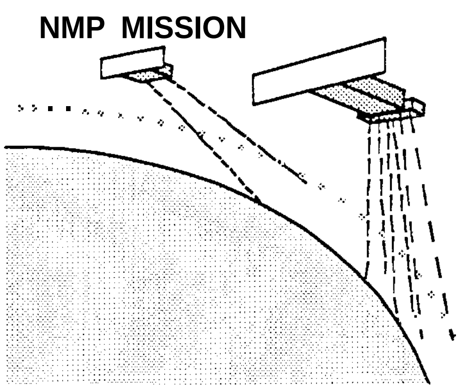
Figure 3a. NEW MILLENNIUM PROGRAM

CANDIDATE TECHNOLOGY DEMONSTRATION MISSIONS

VIS1ON- ENSURE CONTINUITY OF EXISTING EOS MEASUREMENT GOALS AT MUCH REDUCED COST



- LAND IMAGER REPLACEMENT
  - KEY OBJECTIVES
    - DEMONSTRATE ADVANCED LAND IMAGER
    - CO-FLY WITH LANDSAT, EOS OR SSTI/LEWIS
  - SCIENCE APPLICATIONS
    - HIGH RESOLUTION MAPPING FOR COASTAL ZONE PRODUCTIVITY, VEGETATION B1OCHEMISTRY, ARID REGION GEOLOGY
  - KEY TECHNOLOGIES
    - LOW MASS, THERMALLY STABLE WIDE FOV OPTICS
    - AUTONOMOUS STATIONKEEPING



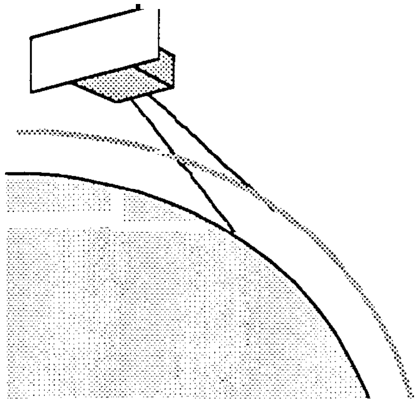
- ATMOSPHERIC TEMPERATURE & MOISTURE SOUNDER
  - KEY OBJECTIVES
    - DEMONSTRATE ADVANCED TEMP. & MOISTURE MEASUREMENT
    - CO-FLY WITH EOS/ AIRS
  - SCIENCE APPLICATIONS
    - WEATHER PREDICTION & CLIMATOLOGY
  - KEY TECHNOLOGIES
    - LOW MASS, THERMALLY STABLE OPTICS
    - AUTONOMOUS STATIONKEEPING

Figure 3b.

NEW MILLENNIUM' PROGRAM

CANDIDATE TECHNOLOGY DEMONSTRATION MISSIONS

VISION- ENSURE CONTINUITY OF EXISTING EOS MEASUREMENT GOALS AT MUCH REDUCED COST



- ATMOSPHERIC CHEMISTRY

KEY OBJECTIVE

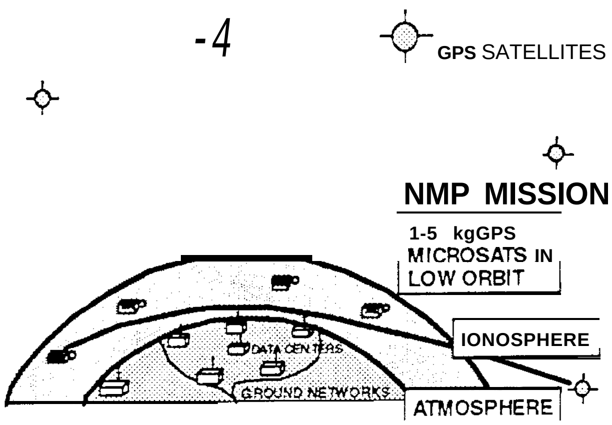
- DEMONSTRATE TROPOSPHERIC POLLUTANT MEASUREMENT

SCIENCE APPLICATIONS

- MONITORING OF KEY TROPOSPHERIC & STRATOSPHERIC CHEMICAL POLLUTANTS

KEY TECHNOLOGIES

- ADVANCED DETECTORS
- LIGHTWEIGHT OPTICS



- GPS CONSTELLATION

KEY OBJECTIVE

- DEMONSTRATE MULTI-PLATFORM, LOW COST ATMOSPHERIC SOUNDING
- DEPLOY 6-12 LOW COST, LOW MASS SATELLITE CONSTELLATION

SCIENCE APPLICATIONS

- WEATHER PREDICTION & CLIMATOLOGY
- 3D IONOSPHERE IMAGING
- GEOID MEASUREMENT

KEY TECHNOLOGIES

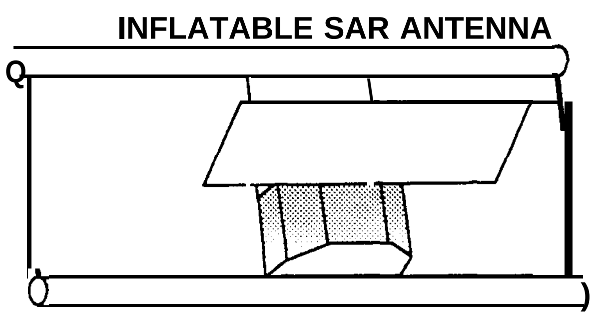
- GPS ON A CHIP
- 1-5 KG AUTONOMOUS S/C

Figure 3 c.

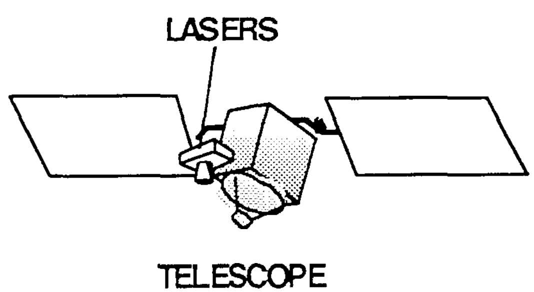
NEW MILLENNIUM PROGRAM

CANDIDATE TECHNOLOGY DEMONSTRATION MISSIONS

VIS1ON- NEW EOS MEASUREMENTS ENABLED BY NEW TECHNOLOGY



- LIGHT SAR
  - KEY OBJECTIVES
    - DEMONSTRATE LIGHTWEIGHT SAR
  - SCIENCE APPLICATIONS
    - LAND TOPOGRAPHY, BIOMASS & HAZARD MONITORING
  - KEY TECHNOLOGIES
    - LIGHTWEIGHT SAR ELECTRONICS
    - INFLATABLE SAR ANTENNA



- LIDAR
  - KEY OBJECTIVES
    - DEMONSTRATE ADVANCED LIDAR COMPONENTS
  - SCIENCE APPLICATIONS
    - TROPICAL, TROPOSPHERIC WIND, CLOUDS& AEROSOLS
  - KEY TECHNOLOGIES
    - LIGHTWEIGHT, HIGH EFFICIENCY LASER
    - ADVANCED POWER COMPONENTS