Earth Science Technology Program (ESTP)

Systems Engineering Seminar

June 5, 2001

George J. Komar
Program Manager
301-286-0007
Background

• The Earth Science Biennial Review (June 1997) recommended that future missions be implemented with shorter development time and using the best suitable technology.

• The resulting plan included the establishment of a flexible, science-driven technology strategy that would develop very specific technologies and provide a broad portfolio of emerging technologies for infusion into a range of missions.

• To meet these challenges the Earth Science Technology Program was established and the Earth Science Technology Office (ESTO) created in March 1998.
Shift from “Technology Derived from Missions” to “Missions Enabled by Technology”

Enterprise Objectives

Missions

Technology Program

Enterprise Objectives

Technology Program

Missions

Enterprise objectives established
Missions sets derived from Enterprise Objectives
Technology programs derived from mission requirements

Enterprise objectives drive technology
Technology expands mission horizons
Missions evolve from convergence of objectives and technology
Variability
- Precipitation, evaporation & cycling of water changing?
- Global ocean circulation varying?
- Global ecosystems changing?
- Stratospheric ozone changing?
- Ice cover mass changing?
- Motions of Earth & interior processes?

Forcing
- Atmospheric constituents & solar radiation on climate?
- Changes in land cover & land use?
- Surface transformation?
- Changes in global ocean circulation?
- Stratospheric trace constituent responses?
- Sea level affected by climate change?
- Pollution effects?

Response
- Clouds & surface hydrological processes on climate?
- Ecosystem responses & affects on global carbon cycle?
- Changes in global ocean circulation?
- Stratospheric trace constituent responses?
- Sea level affected by climate change?

Consequence
- Weather variation related to climate variation?
- Consequences in land cover & land use?
- Coastal region change?
- Consequences in land cover & land use?
- Weather variation related to climate variation?

Prediction
- Weather forecasting improvement?
- Transient climate variations?
- Trends in long term climate?
- Future atmospheric chemical impacts?
- Future concentrations of carbon dioxide and methane?

Deriving Measurement Requirements from the Research Strategy

Legend:
- Red: Requires both systematic & exploratory satellites
- Blue: Requires systematic satellite observations
- Purple: Requires exploratory satellite observations
- Green: Requires pre-operational and/or systematic/expl
- Pink: Use available/new observations in better models
Earth Science Technology Office

http://esto.nasa.gov

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Technology Development Program Elements

- Components
- Systems
- Validation

Advanced Concepts
- New Component & System Concepts

NIAC

Earth Sciences
- Capability Needs & Technology Strategy
- Instruments, Platforms & Data Systems

Science Implementation Plan
- Applications Strategy
- Science/Applications Priorities

Advanced Technology Initiatives
- Earth Science-Unique Component Technologies

SBIR/STTR
- Components & Systems

SBT
- Space Base Technologies

NMP
- In-Space Validation

IIP
- Instrument Systems & Demo

Info Systems (IS)
- Next Generation Information Systems

IS
- Intelligent Systems

SOMO
- Comm & Network Systems

Commercial, other Government Programs
(Interconnections with NASA Programs not shown)

Earth Science Missions:
- EOS, ESSP, R&A, & International Spaceborne, Airborne and In Situ Campaigns

ESTO
Earth Science Technology Office
ESTO provides requirements

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<th>Advanced Concepts</th>
<th>Platforms</th>
<th>Information Systems</th>
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<td>Partnering Internal</td>
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<tr>
<td>Partnering External</td>
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</tbody>
</table>

- **Funding by ESTO**
- **Cost sharing**
- **Funding by others**

- Instrument Incubator Program
- Advanced Platform-enabling Technologies
- Advanced Information Systems

- NMP
- Supercomputing & Modeling

**ESTP Implementation**

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http://esto.nasa.gov
ESTO Technology Investments

GSFC (25)
IIP 5
ATI 6
AIST 2
Proto 7
TM 5

JPL (31)
IIP 9
ATI 7
AIST 8
Proto 1
TM 6

LaRC (10)
IIP 1
ATI 2
AIST 1
Proto 1
TM 6

Other NASA Centers (4)
ARC (AIST -1; Proto -1)
GRC (AIST - 1; Battery - 1)

National Labs (7)
Aerospace Corporation (ATI - 1)
DOE PNNL (Proto - 1)
JHU/Applied Physics Laboratories (IIP - 2)
Draper Laboratories (AIST - 1)
Naval Research Laboratories (AIST -1)
Sandia National Laboratories (IIP - 1)

Small Corps. (16)
AstroPower, Inc. (TM - 1)
ElectroEnergy, Inc. (TM - 1)
EcoLogic (Proto - 1)
Fibertek, Inc. (ATI - 1)
GS&T, Inc. (Proto - 1; TM - 2)
Maxwell Technologies, Inc. (AIST - 1)
Pico Dyne, Inc. (AIST -1)
QSS, Inc. (AIST - 1; Proto -1)
SGT (Proto - 2)
Spaceborne, Inc. (ATI - 1)
Syagen Technology, Inc. (ATI -1)
Various Vendors (TM - 1)

Large Corps. (15)
BAE Systems (IIP-1)
Ball Aerospace (ATI - 2)
CSC (Proto - 1)
ITT Industries (AIST - 1; TM - 1)
Lockheed Martin (AIST - 1; Proto -1)
Orbital Sciences Corp. (IIP - 1)
RITSS (Proto - 4)
SAIC (AIST - 1)
TRW (AIST -1)

Academia (28)
Clemson University (Proto - 1)
Colorado State U. (IIP - 1)
George Mason U. (Proto -2; TM - 1)
George Washington U. (TM - 1)
Howard University (AIST - 1)
Johns Hopkins University (ATI-1; TM - 1)
Morgan State U. (TM - 1)
Ohio State University (Proto - 1)
Ohio University (AIST - 1)
Rutgers University (IIP - 1)
Stanford University (ATI - 1)
UAH (AIST -2; Proto - 1; TM - 1)
U. of Arizona (IIP -2; AIST - 1)
U. of California, Berkeley (IIP - 1)
U. Of Kansas (IIP - 1; AIST -1)
U. Of Missouri (TM - 1)
U. Of Virginia (Proto - 1)
U. of Washington (AIST - 2)

NOAA (1)
IIP - 1

Esto Technology Investments

IIP: 27
ATI: 23
AIST: 30
Prototyping: 27
Tech. Maturation: 30
Battery Earmark: 1
Total Awards: 137

GSFC (25)
IIP 5
ATI 6
AIST 2
Proto 7
TM 5

JPL (31)
IIP 9
ATI 7
AIST 8
Proto 1
TM 6

LaRC (10)
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Instrument Technology

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<tr>
<th>CURRENT INVESTMENTS (IIP)</th>
<th>FUTURE INVESTMENTS (IIP)</th>
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<td>• 27 Contracts</td>
<td>• Active Remote Sensing</td>
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<tr>
<td>4 Active Optical</td>
<td>• Lasers</td>
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<tr>
<td>Laser, Lidar</td>
<td>• Radars</td>
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<tr>
<td>9 Passive Optical</td>
<td>• Radiometers</td>
</tr>
<tr>
<td>Radiometer, Spectrometer</td>
<td></td>
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<tr>
<td>4 Active Microwave</td>
<td></td>
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<tr>
<td>Radar, Altimeter</td>
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<tr>
<td>7 Passive Microwave</td>
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<tr>
<td>Radiometer, GPS</td>
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<tr>
<td>3 In situ</td>
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<tr>
<td>ADVANCED TECH INITIATIVES</td>
<td>ADVANCED CONCEPTS</td>
</tr>
<tr>
<td>• 23 Contracts</td>
<td>• NIAC-funded Studies</td>
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<tr>
<td>3 Far IR/Sub-millimeter wave</td>
<td>• ESE Vision</td>
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<tr>
<td>4 Focal Plane Subsystem</td>
<td>- Large ultra-lightweight deployable structures</td>
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<td>10 Laser</td>
<td>- Large aperture systems</td>
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<tr>
<td>4 Microwave Radar/Radiometer</td>
<td>- Ultra-high resolution imaging</td>
</tr>
<tr>
<td>1 UV Radar/Radiometer</td>
<td>- Rapid, low-cost sensor production</td>
</tr>
<tr>
<td>1 Misc. Data Processing</td>
<td>- Biological sensors</td>
</tr>
</tbody>
</table>

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Laser Sounder Technology for Atmospheric CO₂ Measurements from Space

- Measurement of CO₂ and O₂ column extinction from laser surface-echo pulse

Measure CO2 column extinction and O2 extinction from laser surface echo pulse energy

λ = 1572 nm (CO₂)
λ = 761 nm (O₂)

~500 km alt sun sync orbit

laser beam
ground track
(typically 50-100m dia 7m separation)

Terminator
(i.e. dawn/dust line)

Earth

Day

Night

TRL=2
Ocean Altimetry Evolution

TOPEX/Poseidon

Description
TOPEX/Poseidon satellite orbits the earth about 830 miles above the surface. It carries a radar altimeter which measures the height of the sea surface to an accuracy of about 4 cm.

Vital Statistics
Payload weight - 2,500 kg

Jason-1

Description
Jason is an oceanography mission to monitor global ocean circulation, improve global climate predictions, and monitor events such as El Niño conditions and ocean eddies. The Jason-1 satellite is a follow-on mission to the highly successful TOPEX/Poseidon mission.

Vital Statistics
Payload weight - 500 kg
Design Life is 5 years

Instruments
POSEIDON-2 – A solid state radar altimeter
DORIS – Doppler tracking system receiver
JMR – Microwave radiometer
TRSR – GPS tracking receiver
LRA – Laser retroreflector array

Future Ocean Altimetry Mission

Description
Integrate Altimeter/Radiometer/GPS into one instrument
- Reduce Mass/Power/Volume
- Simplify spacecraft Interfaces
Significant Increase in Science
- Global measurement of 2-D surface currents
- Full global sampling of ocean mesoscale eddies, which have the largest contribution to ocean kinetic energy spectrum

Vital Statistics
Payload weight - 100 kg
Design Life is 5 years

TRL=3
Information Systems Technology

CURRENT INVESTMENTS (Prototyping)

- Interactive Access
- Open Distributed Architecture
- Storage Management Technology
- Prototype Management & Assessment
- Automated Systems Operations
- Network Prototypes

FUTURE INVESTMENTS (AIST)

- Data Collection Process
- Systems Management
- Transmission
- Infrastructure
- Analysis, Search & Display
- Data & Information Production

AIST NRA:

- On-board Satellite Data Processing and Intelligent Sensor Control
- On-board Satellite Data Organization, Analysis and Storage
- Data Transmission and Network Config.
- Intelligent Platform Control
- Information Systems Architectures and Standards
- SBT: Image mining: high rate rad hard digital modem
- External: Internet Protocol (IP) ver. 6

ADVANCED CONCEPTS

ESE Vision

- Autonomous, reconfigurable, adaptable, interactive sensor webs
- Intelligent agents and sensors with pattern recognition
- Neural networking
- AI capabilities
# Cat's Eye Modulating Retro-reflectors for Free Space Optical Data Transmission

## Description and Objectives

Replace on-board hardwiring of electronic components with alignment tolerant free-space optical interconnects.

## Approach

Use quantum well based cat’s eye modulating retro-reflector nodes to optically transmit information.

## Schedule and Deliverables

- **Year one:** 4 Cat’s Eye modulating retro-reflectors
- **Year two:** Demonstration of free space link using CEMRRs

## TRL=2

[Diagram of Cat's Eye Modulating Retro-reflectors]
Advanced Holographic Memory

**Description and Objectives**

- Develop innovative holographic memory technology to enable real-time mass data storage/retrieval in space environment
- Demonstrate key capabilities:
  - High data storage capacity (up to 10GB/module)
  - High random access data transfer rate (up to 1GB/s)
  - Nonvolatile

**Approach**

Employ new beam steering technology developed at JPL and phase conjugation architecture for a compact implementation of memory system.

**Schedule and Deliverables**

- Initial system integration and proof-of-concept functionality demo: Aug '01
- Lab compact breadboard data storage/retrieval performance evaluation demo: July '02

**Application/Mission**

Data intensive missions, including:
- Earth Science Missions, e.g., PM-2A, CHEM-2, NPOESS, METOP.
- Other data intensive missions, e.g., HEDS, SIM

TRL=2
### Platform Technology

**CURRENT INVESTMENTS**

- None

**FUTURE INVESTMENTS**

- Advanced high bandwidth comm (optical)
- Low mass bus approaches: multifunctional
  - Structures; low mass pmad power
  - Generation; high efficiency propulsion
- Precision pointing systems (rotating antennas)
- Formation flying: autonomous control;
  - precision ranging; s/c-s/c comm links
- New platform capabilities: micro mass systems
  for balloons and UAVS; environmentally
  protected systems and deployment options
  for buoys and penetrators.

### ADVANCED TECH INITIATIVES

- Thermal coolers
- Mini Circuit Protection - SBIR
- Solar panel grid - SBIR
- Optical Comm
- Inflatable Membrane SAR
- Antenna Mesh
- Inflatable waveguide array
- IR Communication
- Remote Sensor Web
- ASIC
- Mobile Wireless - SBIR

### ADVANCED CONCEPTS

- Sensorcrafts
- Sensor webs
Large Aperture Mesh Antenna

Characteristics

- Offset-fed, parabolic, deployable mesh reflector
- 6-m aperture
- 40° offset angle
- 6 rpm rotation rate
- 1.41 & 2.69 GHz, V, H, U (passive) (6 channels)
- 1.26 GHz; VV, HH, VH, HV (active) (4 channels)
- 2 multichannel feedhorns (L/S-band, V/H-pol)
- Feedhorn dimensions 0.6 x 0.6 x 0.9 m
- Approx. equal beamwidths all channels
- >90% beam efficiency, <-18dB cross-pol
- 1.2° pointing control (0.1° knowledge) (3s)
Technology Program Readiness

<table>
<thead>
<tr>
<th>Basic Principles</th>
<th>Conceptual Design</th>
<th>Critical Component Tested</th>
<th>Pre-Prototype Tested</th>
<th>Prototype Developed to Qualify</th>
<th>Engineering Model Tested in Space App.</th>
<th>Operational</th>
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<tr>
<td>Observed &amp; Reported</td>
<td>Formulated</td>
<td>Tested Experimentally</td>
<td>Tested</td>
<td>Developed to Qualify</td>
<td>Tested in Space App.</td>
<td>Operational</td>
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- **Advanced Concepts**
  - ATI
  - IIP
  - AIST
  - SBIR
  - SBTP
  - NMP
  - S&M

- **Science & Appl. Measurement**
Development Roadmap for Large Antennas

- Large Deployable/Inflatable Antennas require testing in zero-G
  - deployment mechanism
  - surface shape/smoothness
  - structural control

Science Measurements:
- Soil Moisture
- Global Precipitation
- Topographic Hazards
- Sea Surface Salinity

Validation Flight:
- Validate deployment, rigidization, space survivability
- Structural accuracy/stability for 1 to >10 GHz
- Characterize vibration/thermal behavior
- Demonstrate material survivability
- Verify performance for radiometer
- Mass 50 kg (for antenna only)
Development Roadmap for Lasers/Lidars

- Large Deployable telescope require zero-G testing of
  - deployment mechanism
  - surface shape/smoothness
  - surface controls
- High power lasers require testing in space
  - thermal issues
  - lifetime

Ground Development:
- Deployable Telescope Components
- High Power Laser Transmitters

Validation Flights
- Validate Laser performance and lifetime
- Validate telescope deployment and optical performance

Science Measurements
- Tropospheric Chemistry
- Atmospheric CO₂, CH₄, CO
- Tropospheric Winds
Integrated Technology Plan To Enable Global Precipitation Measurement

Objective:
• Provide systematic estimation of global precipitation with three hours or less sampling interval
  • Improved weather forecasting
  • Global water cycle understanding

Instrument Incubator Program

Technology Challenges:
• Phased Array Antenna
• Large aperture radiometers
• Integrated Observatory with autonomous constellation control and operation
• High rate cross-link/down-link
• Autonomous space/ground internet protocol

Objective:
• Provide systematic estimation of global precipitation with three hours or less sampling interval

Instrument Incubator Program

Technology Challenges:
• Phased Array Antenna
• Large aperture radiometers
• Integrated Observatory with autonomous constellation control and operation
• High rate cross-link/down-link
• Autonomous space/ground internet protocol

Other Technology Development Programs

SBT - Lithium Ion Battery
Formation Flying
Constellation/Microsats
ESTO - Rad Hard Pentium Processor
Autonomous Internet Protocol

Global Precipitation Measurement Observation Strategy

• Cross Link
• Optical Communication

Launch

FY 00  01  02  03  04  05  06  07

ESTO

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http://esto.nasa.gov

Earth Science Technology Office
Program Output

“Bang for the Buck”
ESTO-supported technologies for infusion into NPP In-Situ Terminal:

1. Digital Demodulator ASIC (see next slide) is key technology component in digital receiver board. ESTO-funded ASIC final design and initial foundry run of chips which are now used in the operating board.

2. Reconfigurable Computing Application Development Environment (RCADE) tools evolved directly from ESTO Prototyping Program:\(^1\):
   - Allows rapid integration of ESE data processing algorithms into FPGAs.
   - Testing of FPGA processing using Terra MODIS data has already begun. Major bottleneck is re-programming the FPGAs when the algorithms are updated.

   - ESTO tool-set is designed to address this *exact* problem.

1. “Scalable Remote Sensing Applications” which is a Parallel Problem Solving Environment (PSE) for Remote Sensing and Telemetry Processing.
Features:

- High rate front end
  - RF processing; CCSDS packet processing; Data capture
- Data processing and archive environment
- Level 1B, higher level products
  - Ancillary Data, Algorithms, Calibration tables
- Product query and distribution

NPP Digital Receiver Board

ESTO Digital De-Modulator ASIC
## Precise Global Real-time Onboard Navigation Capability For Earth Science Remote Sensing

**PI:** Yoaz Bar-Sever / JPL

### Description and Objectives

Develop GPS-based technology that will enable:
- Ultra-precise real-time orbit determination
- Global uniform coverage extending into space
- Autonomous navigation

Demonstrate an end-to-end NASA global differential system and its scientific benefits

### Approach

Extend JPL’s Wide Area GPS differential Technology to a global scale

Develop end-user hardware and software to enable autonomous navigation

Leverage NASA’s GPS infrastructure and commercial capabilities to demonstrate a global differential GPS service

### Application/Mission

Timely monitoring and response to natural hazards (e.g., SAR, AirSAR)

Intelligent, cooperating sensor webs in Earth orbit

Precise and secure navigation (e.g., RLV)

Prototype for Mars Network
Current Payoff

• (NavCom, Inc., a subsidiary of John Deere), has signed an agreement to provide correction data....

• System status
  - We have a signal. A “beta” signal is now available over North and South America for test and characterization, using a global beam of an Inmarsat Satellite.
  - Preliminary tests show the signal is received clearly in North America. The signal is based on the corrections to the GPS orbits and clocks generated at JPL.
A Second generation Spaceborne Precipitation Radar

Characteristics

Dual-frequency to improve dynamic range and sensitivity on rain measurements (TRMM radar has 1 frequency)
- Factor of two improvement in radar resolution to reduce errors caused by rain inhomogeneity
- Dual polarization to differentiate between liquid and frozen hydrometeors (TRMM radar has single polarization)
- Doppler capability to obtain vertical motion structure (TRMM radar none)
- Simultaneous doppler/polarization observations to constrain implicit rain ambiguity (TRMM radar makes reflectivity-only observations)
- Cross-track adaptive scan to increase swath coverage (a factor of 3 better than TRMM radar)
- Same frequency as TRMM radar to allow smooth extension and direct comparison of rain data record
- A factor of 2 to 3 mass reduction from TRMM radar

Airborne Demonstrator Precursor

- Mechanically scanned, horn fed reflector
- TWTA transmitters
- Ferrite T/R and polarization switches
- Dual-frequency (13.405 and 35.605 Ghz)
- Dual-linear Polarization at each frequency
- Scan Beam Capability 0-20 Degrees
- Match Beamwidths at Each Frequency/Polarization of Operation to Within 25%
- Antenna Patterns Sidelobe Level < -25 dB
- VSWR < 1.6
- Bandwidth at Each Frequency/Polarization > 10 MHz
PR-2 Airborne Payoff

- PR-2 (airborne) was selected to fly on the DC-8 during the CAMEX-4, a multi-agency field campaign to study hurricanes in August 2001.
- It will provide measurements of rain rate.
- PR-2 (airborne) will improve measurement capability over current systems
  - Dual-frequency (14/35 GHz) to improve dynamic range and sensitivity on rain measurements
  - Factor of two improvement in radar resolution to reduce errors caused by rain inhomogeneity
  - Dual polarization to differentiate between liquid and frozen hydrometeors
  - Doppler capability to obtain vertical motion structure
  - Cross-track adaptive scan over ±37° to increase swath coverage
- PR-2 (airborne) is a precursor demonstration of capability for GPM/ generation 2.
Objectives

- Build millimeter-wave atmospheric sounder using new miniature technology
  - Temperature and water vapor sounding capabilities (54, 118 & 183 GHz)
  - First MMIC based atmospheric sounder (54 & 118 GHz)
  - Reduced size/mass/power (fraction of AMSU)
-Operate prototype in the field on board ER-2
HAMSR Payoff

• HAMSR was selected to fly on the NASA ER-2 during the CAMEX-4, a multi-agency field campaign to study hurricanes in August 2001.
• It will provide core measurements of temperature, humidity, liquid water profiles as well as scattering from rain and ice.
• HAMSR is the first sounder to use new miniature MMIC technology, developed by NASA and integrated into a functional instrument under IIP.
• HAMSR is the only instrument to combine this measurement suite in a single, small package
Technology is Our Future