Agenda

- **Dan Mandl**
  - EO-1 Overview
  - Sensor Web overview
  - EO-1 Testbed activities

- **Steve Chien**
  - Sensor webs experiments with floods and volcanoes
  - Continuous Activity Scheduling Planning Execution and Replanning (CASPER) system

- **Sandra Grosvenor**
  - Science Goal Monitor

- **Stuart Frye**
  - Warts, bumps and blemishes
Introduction to EO1 Mission

Key information:

- Managed by GSFC
- First Earth-Observing Mission sponsored by the New Millennium Program
- A mission devoted entirely to the flight validation of 13 advanced technologies applicable to future land-imaging missions
- Approved in March 1996 and launched in November 21, 2000
- All technologies were flight-validated by December 2001 and EO-1 is now in an Extended Mission
- Sufficient fuel to operate through at least September 2004
Introduction to EO1 Mission

◆ **Payload:**
  - **Advanced Land Imager (ALI)**
    (visible, 30 m & 10m resolution)
  - **Hyperion**
    (hyperspectral, 220 bands, 30m res.)
  - **Atmospheric Corrector**
    (hyperspectral, 242 bands, 250m res.)

◆ **Two Mongoose V CPU’s (8 MIPS and 256 Mb RAM)**
  - Flight control software on CDH CPU
  - Autonomy software (including cloud cover detection software) on Wideband Advanced Recorder and Processor (WARP) Mongoose CPU
After base mission, three more mission phases evolved as depicted in chart below:

- Sensor Web/Testbed phase is active now.
- Virtual observatory phase is the phase in which as much mission autonomy as possible will be implemented to reduce the cost as much as possible of running the EO-1 mission.
  - Includes semi-autonomous tasking of EO-1.
Evolution Towards Integrated Observations

Today: “Stovepiped” Observing Systems

Near Term: Evolution Towards Distributed Space Systems for Integrated Observations

GOES-W

GOES-E

Command high resolution closer viewing
A sensor web is a coherent set of distributed “nodes”, interconnected by a communications fabric, that collectively behave as a single, dynamically adaptive, observing system.
Sensor Web Nodes & Interactions

Vantage Points

- Far-Space
- Near-Space
- Airborne
- Terrestrial

Capabilities

- Permanent
  - LEO/HEO: Sentinel satellites for continuous monitoring
- Deployable
  - Suborbital: In situ measurement in research campaigns & validation of new remote sensors
- Surface-Based Networks: Ocean buoys, air samplers, strain detectors, ground validation sites

Volcano Ash Plume
Hurricane
Forest Fire
Oil Spill
Algal Bloom

Models & Data Assimilation

Data Warehouses & Data Mining

Slide by Steve Talabac/586
Benefits of Sensor Web Dynamic Measurement Techniques and Adaptive Observing Strategies

- **Event driven observations**
  - Improved system response (to catch transient events)
- **Model-driven observations**
  - Improved predictive capability
- **Intelligent data collection**
  - Improve efficiency of resource utilization
- **Sensor data fusion**
  - Improved science integration
Experimenting with Following Capabilities
(Under categories of event driven sensor webs and intelligent data collection)

- **Automatic science product generation**
  - Archives
  - Tasking “ad hoc” set of satellites automatically

- **Ad Hoc constellations**
  - Capability to rapidly combine data from heterogeneous sets of satellites on-orbit and other instrumentation such as in-situ instruments to create new science products not originally planned
  - “Ad hoc” constellation planning and scheduling for the sensor webs
    - Capability to rapidly reconfigure and schedule different groupings of “ad hoc” satellites
    - “Ad hoc” constellation planning and scheduling hidden from user

- **User specifies high level goals and system takes care of details**
  - Virtual observatory

- **Make use of existing assets**

- **Enable radiometric crosswalk**
  - Ability to rapidly mosaic and fill in images with different satellites and instrumentation
Sensor Web Vision

How we’d like it to be!

Virtual Observatory

Choose observation band and/or satellite and image will automatically be taken:

- Landsat
- AVHRR
- MODIS
- MISR
- ASTER
- Hyperion
- ALI

http://aaaprod.gsfc.nasa.gov/Website/terminology.cfm
After ascertaining that the Robert fire is at lat 48.564 long – 114.163, EO-1 is tasked to take closer high resolution look.

SGM causes MOPSS, CMS, CASPER (ground version) to task EO-1 via command load and causes EO-1 to downlink the image to EROS Data Center (EDC) at Sioux Falls.

EDC performs L0 and L1 processing and FTP's image to Natural Hazards investigators at UMD.

UMD team transforms image into ERDAS format and FTP's file to USFS/Salt Lake City where burn extent product is derived. Result is sent to BAER team at Robert Fire.
MODIS Rapid Response Overview

Terra

Direct Broadcast Receiving Station

Backup Feed L1B Data

MODIS Rapid Response System NASA/GSFC

EDOS MODIS L0 Data

EDOS

GES DAAC NASA/GSFC

NOAA

NASA Earth Observatory
http://earthobservatory.nasa.gov

MODIS home page
http://modis.gsfc.nasa.gov

MODIS L0 Data

T+2-5hrs

L1B Data

T+30min

USDA Forest Service Remote Sensing Application Center

Active Fire Locations

T+5hrs

University of Maryland Geography Dept

NASA/GSFC

GOFC Fire Partners

Active Fire Locations Handcrafted Imagery

T+5hrs

Burn Severity Maps

T+30min

Twice Daily 3am/pm MT

T+2-5hrs

Web Fire Maps and Fire Feature Server
http://firemaps.geog.umd.edu

Active Fire Maps
http://activefiremaps.fs.fed.us

http://rapidfire.sci.gsfc.nasa.gov

Active Fire and Corrected Reflectance

http://rapidfire.sci.gsfc.nasa.gov

http://earthobservatory.nasa.gov

http://modis.gsfc.nasa.gov
EO-1 Wildfire Sensor Web Experiment

Detection and Tasking
- Use National Inter-agency Fire Center ICS/209 database to identify national priority fires.
- Locate fire precisely with MODIS Active Fire detections from Terra and Aqua.
- Automatically task EO-1 to acquire image data.

Geo-rectification
- Precisely match image to earth coordinates.
- Enhance vegetation image to highlight burned areas (red).

Data Processing
- Downlink data
- Perform Level 0 processing
- Perform Level 1 processing

Assessment, Planning and Implementation
- Classify burned areas into color coded burn severity, augmented with ground verification.
- Plan deployment of rehabilitation resources to highest risk areas (red in overlay).
- Apply treatments to control things such as erosion, invasive species etc.

Burn Severity
- Unburned
- Low/Unburned
- Low
- Medium
- High

Glacier National Park  August 21, 2003

Two Burned Area Reflectance Classification (BARC) map overlays are shown on top of Advanced Land Imager (ALI) data taken semi-autonomously by the EO-1 Sensor Web. The EO-1 image request was generated automatically based on fire location triggers detected by MODerate-resolution Imaging Spectro-radiometer (MODIS) Instruments onboard Terra and Aqua satellites. The upper left Overlay is the BARC map for the Robert fire and the lower right. Overlay is the BARC map for the Middle Fork Complex fire. The overlays were created by the Forest Service Burn Area Emergency Response teams to identify areas at high risk and to contract rehabilitation treatments. Satellite data such as this assists in efficient use of resources.
On 11-2-03, the NASA Wildfire SensorWeb was employed to collect data on the burn scars resulting from the Simi Valley, Val Verde and Piru fires in Southern California. MODIS active fire detections for the duration of the event were used to target an acquisition by the ALI and Hyperion instruments onboard EO-1. Such data are employed by the USDA Forest Service for Burned Area Emergency Response mapping. BAER maps are used to target high risk areas for erosion control treatments. In this image, burned areas appear red while the unburned areas appear green. The blue burn perimeter vector is based on ground data.
NOAA/NESDIS GOES Real-Time Cloud Product Automatically Commands EO-1 to Choose One of Two Scenes

(No manual intervention)
NOAA/NESDIS GOES Real-Time Cloud Product Automatically Commands EO-1 to Choose One of N Scenes
(Choice of targets is made onboard EO-1 by CASPER)

Cloud Top Pressure (CTP’s) derived from the GOES-East and GOES-West Sounders hourly (10 km pixels)

Step 1: Submit n competing acquisition targeted

Step 2: Automatically query GOES RT cloud data 1-4 hours before overflight

Step 3: Uplink n CTP’s to EO-1

CASPER selects least cloudy alternate

SGM queries for cloud top pressures for alternate 1 to alternate n

EO-1 Missions Ops Center (MOC)

ASIST/FEDS
MOPSS

CASPER - (Continuous Activity Scheduling Planning Execution and Replanning) system
## Targeted EO-1 Sensor Web Experiments

<table>
<thead>
<tr>
<th>Target</th>
<th>Space sensors</th>
<th>Ground Sensors</th>
<th>Coordination</th>
<th>Partners</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildfires</td>
<td>EO-1 (ALI, Hyperion), Terra/Aqua (MODIS)</td>
<td>N/A</td>
<td>SGM and/or ASE</td>
<td>GSFC, JPL, UMD, USFS, NOAA</td>
<td>ongoing</td>
</tr>
<tr>
<td>Floods</td>
<td>Quickscat, Terra/Aqua (MODIS), EO-1</td>
<td>Delin’s Gnd Sensorweb</td>
<td>SGM and/or ASE</td>
<td>JPL, GSFC Dartmouth Flood Observatory</td>
<td>ongoing</td>
</tr>
<tr>
<td>Volcanoes</td>
<td>MODIS, GOES, ASTER, EO-1</td>
<td>TBD</td>
<td>SGM and/or ASE</td>
<td>GSFC, JPL, Univ. of Hawaii</td>
<td>ongoing</td>
</tr>
<tr>
<td>Algal Blooms</td>
<td>EO-1</td>
<td>Seahorse</td>
<td>SGM and/or ASE</td>
<td>GSFC, ARL (Univ. of Penn.)</td>
<td>future</td>
</tr>
<tr>
<td>Dust storms</td>
<td>EO-1, TBS</td>
<td>SGM and/or ASE</td>
<td>JPL, GSFC, NRL</td>
<td></td>
<td>future</td>
</tr>
</tbody>
</table>

SGM = Science Goal Monitor  
ASE = Autonomous Sciencecraft Experiment (includes CASPER)  
CASPER = Continuous Activity Scheduling, Planning Execution and Replanning (software)
Related Sensor Web Tasks Using EO-1 as a Testbed

On-board Processing
- On-board Cloud Cover Detection Validation complete
- Hyperpectral Compression WG
  - On-board data mining
  - On-board intelligent image compression
  - Working group
- Preliminary EO-1 Autonomy Experiment
  - On-board planning
  - On-board feature detection
  - Dynamic SW Bus

End-to-End Communications
- Smart Antenna
  - Ground phased array
  - “Cell tower” com to sat
- Science Goal Monitor (SGM)
  - Semi-autonomous coordination of imaging
- Livingstone On-board Model Based Diag Tool
  - Autonomous anomaly diagnosis and recommendations

Autonomous Coordination
- Autonomous Science Experiment (ASE)
  - Migration of ST6 onto EO-1
- EO-1, Terra, Aqua Sensor Web Demo 1 & 2
  - Uses MODIS inst center to detect fires and volcanoes
  - Uses SGM/ASE to coord image collect with various levels of autonomously

Operational Testbed
- EO-1, Gnd Sensor Sensor Web
  - Sensors similar to ones at Huntington Botanical Garden trigger EO-1 image
- Intelligent Distributed Spacecraft Technology Testbed

Funded by ESTO
Funded by NMP
Funded by IS
Proposed activity

Partially funded – rest of task proposal submitted to CICT IS NRA
Onboard Cloud Cover Assessment

- Flight validated an onboard cloud cover detection algorithm and determine the performance that is achieved on the Mongoose V
  - Used Hyperion sensor measurements
  - Algorithm developed by MIT / Lincoln Lab
- Final onboard cloud cover assessment of an EO-1 8 second (.75 Gbyte) Hyperion scene (taken March 4, 2003, El Mhamid) was expected to take hours but instead took less than 30 minutes
- Streamlined algorithm by:
  - Performing level 0 on all data and then selecting the needed 6 bands
  - Converted level 0 data to radiance (level 1R) one scan line (256 pixels) at a time
  - Performed pixel by pixel cloud assessment
- Determined that we could perform onboard cloud assessment faster with the following capabilities:
  - Subsampling of raw data (can get close to same results without processing all data)
  - User defined area of interest within image and only process that portion
  - Direct access to science recorder
  - Cloud assessment algorithm can be expanded since we had more margin than expected
- For 20 test cases on ground, performed cloud assessment within 5% for major test cases, final validation underestimated 5-10%
Onboard Cloud Cover Assessment

First onboard test case March 4, 2003

Cheyenne, Wy

Performed simulated cloud assessment on ground with real image

El Mahmid: Path 201 Row 39

Algorithm produced a cloud amount value of 47.1% for this scene
Key Technology to Enable Sensor Web Framework:
Middleware to enable “plug and play”! (GMSEC)

Mission Planning Component

Evolve planning toolbox:
- Port AMPS to Linux/Personal Oracle – EO-1/ST-5(funded)
- Integrate scenario scheduler for near real-time replanning – EO-1/ST-5(funded)
Integrate SGM as component of AMPS to enable web based abstract planning (goal oriented mission planning) - EO-1(proposed)
Demonstrate operational loadable onboard planning tool-EO-1/CASPER(funded)
Integrate Simulink Model into planning toolbox (proposed on ST-5)

Develop cost-effective seamless, continuous space to ground link for low earth orbiting satellites(funded):
- Like “cell tower” network

Adapters enable new components to be easily plugged-in, Gnd & S/C

Evolve “plug and play” flight SW capability:
- Easily loadable new flight SW functionality – EO-1/CASPER –(funded, ongoing)
- Demonstrate “hot” plug and play flight SW through command link – proposed for EO-1, then LISA
- Build spec for flight SW “plug” – target LISA and Con-X to make operational (like USB for Flight SW)
- Establish flight SW reuse library – in process by Flight SW Branch (in process Flight SW Branch)

Target is to enable Sensor Web framework:
- Distributed collaborative planning components achieve goals with increasing autonomy
Target Mission Messaging Architecture

- Create seamless messaging system across constellation/mission components using Dynamic Software Bus (DSB) & IP
  - Multi-protocol
  - Easy integration of heritage components to create “ad hoc” constellations
  - Components send each other messages similar to internet (URL) by knowing registered name, details taken care of by system
  - Once in place, “progressive” mission autonomy easy to create and integrate

![Diagram of Target Mission Messaging Architecture](image)
Example of how we are attempting to tie together Onboard and ground planning and scheduling tools.

Science Goal Monitor (on ground) - response seconds to days

CASPER Planner (in S/C) - response in 10s of minutes

SCL – response in seconds with rules, scripts

EO-1 Conventional Flight Software reflexive response

Band Stripping SW

Onboard Science

Sensor Telemetry

Spacecraft Hardware

Control Signals (very low level)

Commands (low level)

Observation Goals

Plans of Activities (high level)

High level S/C State Information

S/C State

New

Status

Sub-goals

Science High Level Goals

Status (web-based)

Image

Instrument Data

SCL is key adapter to plug in our new components
## An Onboard Plug-in Model-Based Diagnostic Tool to be used on EO-1

<table>
<thead>
<tr>
<th>SCL Components</th>
<th>Simple declarative model</th>
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<td>Sensors</td>
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<tr>
<td>EO-1 1773 Data Bus</td>
<td></td>
</tr>
<tr>
<td>Livingstone</td>
<td></td>
</tr>
<tr>
<td>WARP SSR M-5 Processor</td>
<td></td>
</tr>
<tr>
<td>RAM</td>
<td></td>
</tr>
<tr>
<td>CASPER</td>
<td></td>
</tr>
<tr>
<td>Mission Operations Control (MOC) / Ground Processing Unit (GPU)</td>
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</tr>
</tbody>
</table>
WiFi for Satellites (Smart Antennas)

Description and Objectives

- Validate new antenna technologies that either used separately or in combination lower cost to purchase, maintain and operate ground antennas in the X and Ka-band for low earth orbiting satellites.
- Key objectives include increased reliability by eliminating moving parts, simultaneous users on one antenna system, wider and more flexible total coverage than present GN coverage, auto-detect of satellites entering the field of view of antennas and auto-adjust of Gain over Noise Temperature (G/T) depending on needed gain to receive data from satellite.

Approach

- Explore three technologies; adaptive beamforming using Digital Signal Processing (DSP) as backend and Space Fed Lens and Reflectarray as front end.
- Manipulate following parameters to minimize cost: aperture size, number of apertures, aperture efficiency and selection of beam forming algorithm.

Co-I's/Partners

- Dr. Mary Ann Ingram, Georgia Institute of Technology
- Dr. Felix Miranda, Dr. Richard Lee, Dr. Robert Romanofsky, Dr. Afroz Zaman, Glenn Research Center
- Dr. John Langley, Saquish Group

Schedule and Deliverables

3/15/04 - Complete S-Band antenna demo using DSP
3/15/05 - Complete X-Band antenna demo using DSP/SpaceFed Lens
3/15/06 - Complete X-band antenna demo using DSP/Reflectarray & if possible, Ka-Band antenna demo using DSP

Application/Mission

- EO-1 and similar missions that have S, X and Ka-Band communications

Ongoing research to use Smart Antennas to shape antenna patterns to enable efficient use of the space to ground communications spectrum for constellations.
Antenna patterns adjusted electronically thousands of times per second to follow users and avoid interference.

Data rates vary per link according to the configuration of the adaptive array.
Georgia Tech Task: Initial Setup of Test Element for Smart Antenna in July 2003

- Helical antenna element being setup for pass with EO-1 in July 2003

- Final test for year 1 will be four element system, adaptively combining the signal to enable capturing S-Band data from EO-1
  - Year 2 will work with X-Band data
  - Year 3 will work with Ka-Band data if possible
Georgia Tech: Successful Smart Antenna Tests at Georgia Tech 11-19-03 and 11-25-03

1. Prior to the pass: antenna with cement blocks to prevent it from blowing over. Atlanta skyline in the background. The antenna had a significant vertical wobble (ground plane) due to wind.

2. Students observing EO-1 signal spectrum.

3. Prior to pass, checking spectra of known interference.

4. Detected EO-1 spectrum during pass

In test 1, 11-19-03:
EO-1 spectrum detected on analyzer

In test 2, 11-25-03:
EO-1 signal digitized, fast fourier transform performed and EO-1 spectrum observed on computer screen.
Target Full Test System to be Built by Georgia Tech by End of First Year

- Card cage holds APCOM receivers, A-to-D converters, and digital down-converters

Field of view of the array (approx 45 degrees)
How it will probably look on roof at Georgia Tech
Space Fed Lens Element Being Developed at Glenn Research Center

Ka-band dual-beam space-fed lens array

Feed antenna
Lens
Test setup
Rotating stage
Lens array
Measured patterns
26.7 GHz
How Space Fed Lens Element Will Look

- Radome
- Multilayer lens antenna array
- Feed antenna subarrays
- Mechanical support
- Digital Beam Control (switch matrix)
- Feed antenna 1
- Feed antenna 2
- Vari gain amp
- Vari gain amp

Digital Beam Control
(switch matrix)
Another Element Being Developed at Glenn: Reflectarray

Ground Hybrid Phased Array

Ferroelectric Reflectarray Antenna

Ba$_2$Sr$_{1-x}$TiO$_3$ Crystal

Thin Film Phase Shifter

~500 Element Reflectarray

Principle Investigator: R. Romanofsky