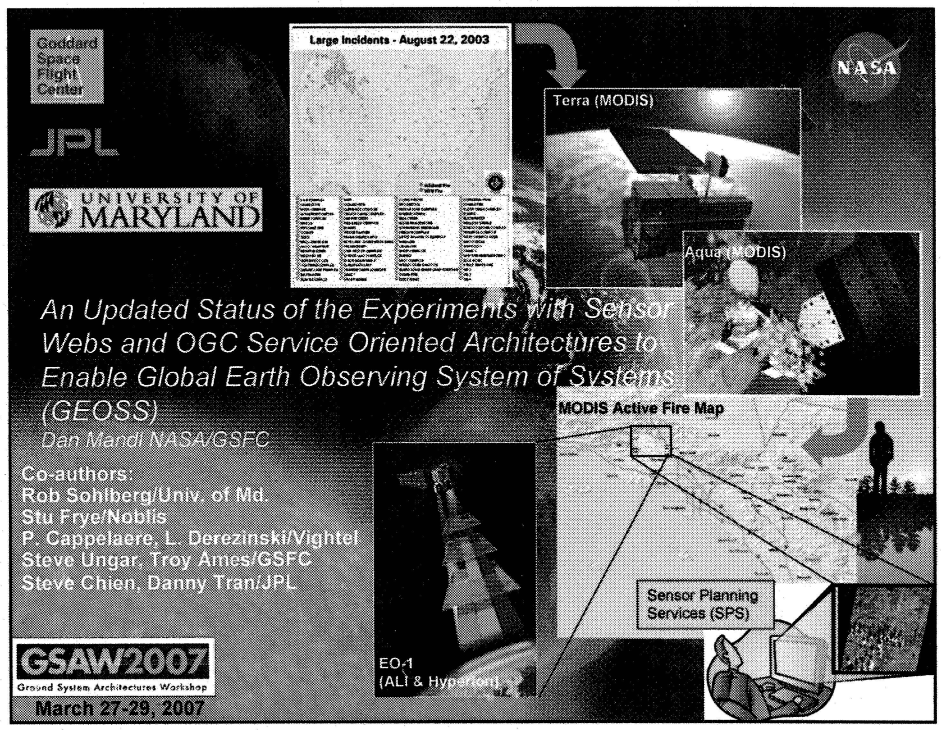


Agenda

- Introduction
- Problem
- Basic service oriented architecture approach
- Series of experiments
- Next experiments
- Conclusion

2

Introduction

- Sensor Web – a collection of sensors (space/terrestial) nodes and computational nodes (e.g. models) connected by a communication fabric which act as a cohesive whole.
- Global Earth Observing System of Systems
  - International agreement signed by 67 nations to create interoperable earth observing assets
- Experiments with sensor webs and service oriented architectures
  - 10 satellites, UAV, in-situ sensors, models, emulators, web processing nodes
  - Instant "ad-hoc" sensor webs
  - Open Geospatial Consortium standards
  - On-demand science

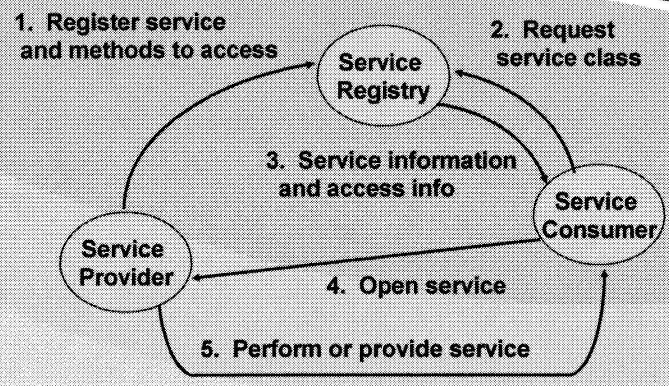
3

Problem

- How to make existing sensors, models, emulators compatible with future assets integrated into sensor web
  - Standards evolve
  - Retrofit of old systems expensive
  - New systems continue to evolve
- Would like the following capabilities while seamlessly integrating old and new components into sensor web
  - Discovery of data availability and algorithm availability
  - Automatic tasking of sensors
  - Easy specification of algorithm service chain
  - Automatic execution of service chain
  - Automatic delivery of finished science product to desktop

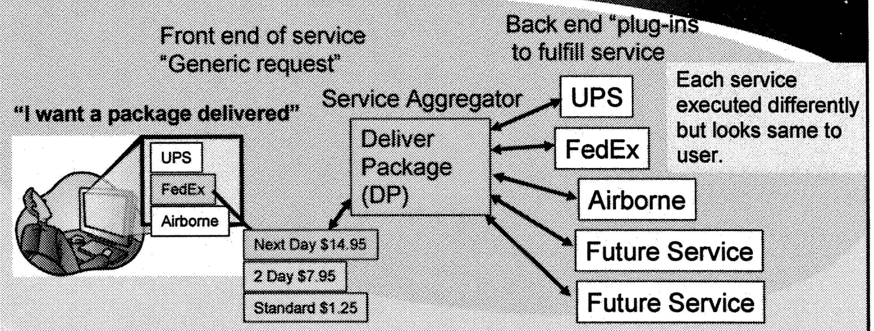
4

Service Oriented Architecture as an Approach



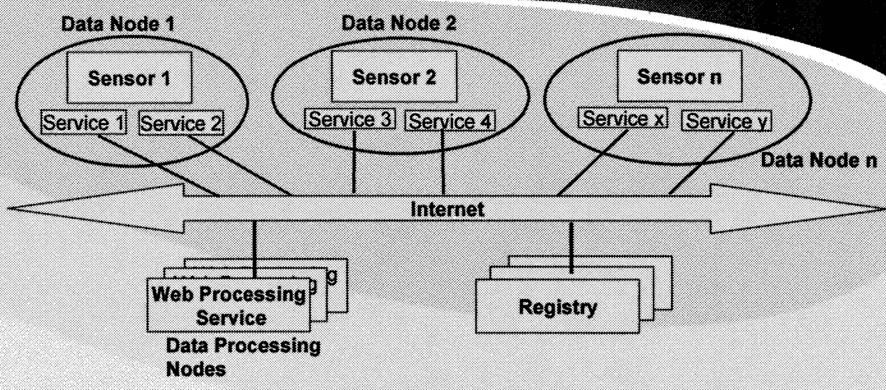
- Single interface standard not required
- Supports multiple hardware and software architectures simultaneously
- Service consumer only has to know how to interface to registry
- Registry contains all pertinent information of how services are provided

Example with Web Services



- **Discovery of services** enabled via Internet search tools
- **Details of service implementation hidden** to simplify user access
- **Scalability enabled** because new services can be easily plugged in
- **Obsolescence prevention** because new services can be easily plugged in and removed in real-time
- **Fault tolerant** because user can locate and connect to alternative service

Basic Concept

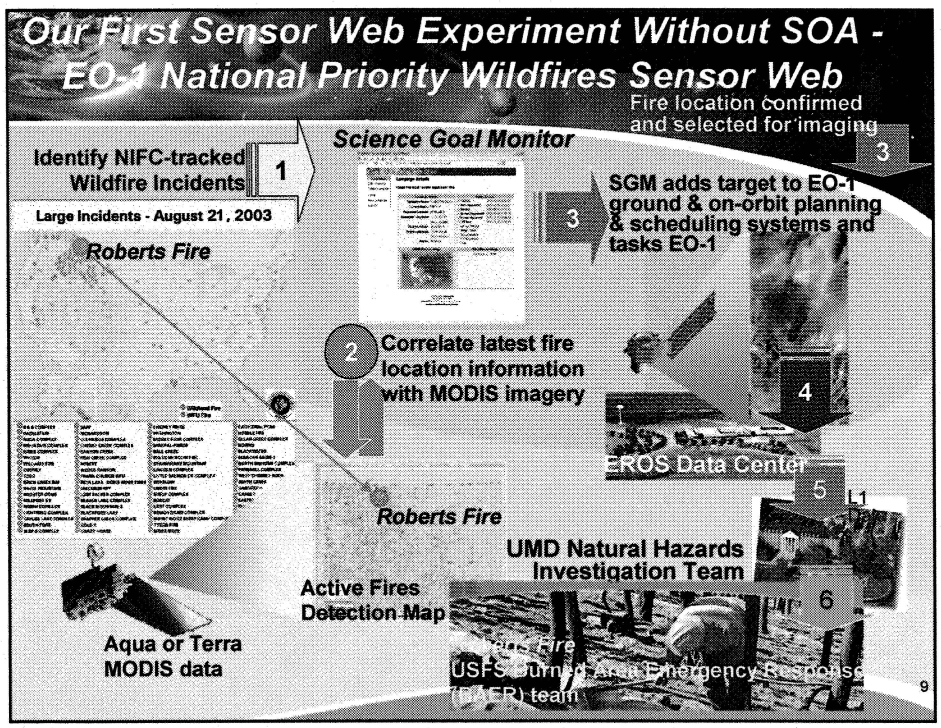


- Encapsulate sensors, models and emulators with software agents
  - Hide details
- Provide seamless space/ground messaging capability such as via Internet and sensor-based message bus
- Add registries to enable users to discover components and how to use them automatically

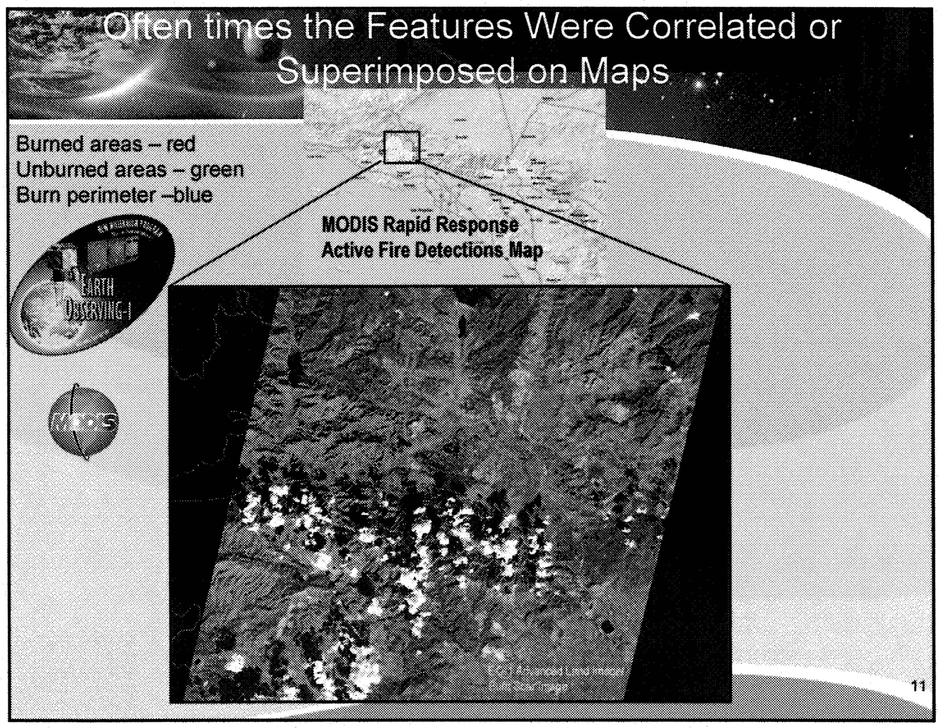
7

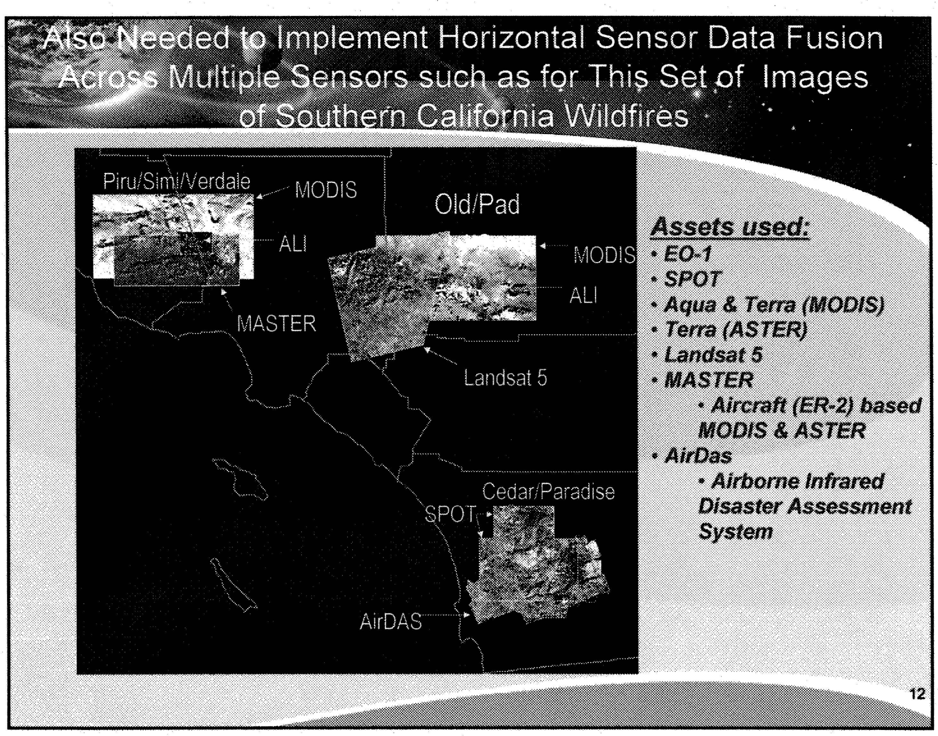
Series of Experiments

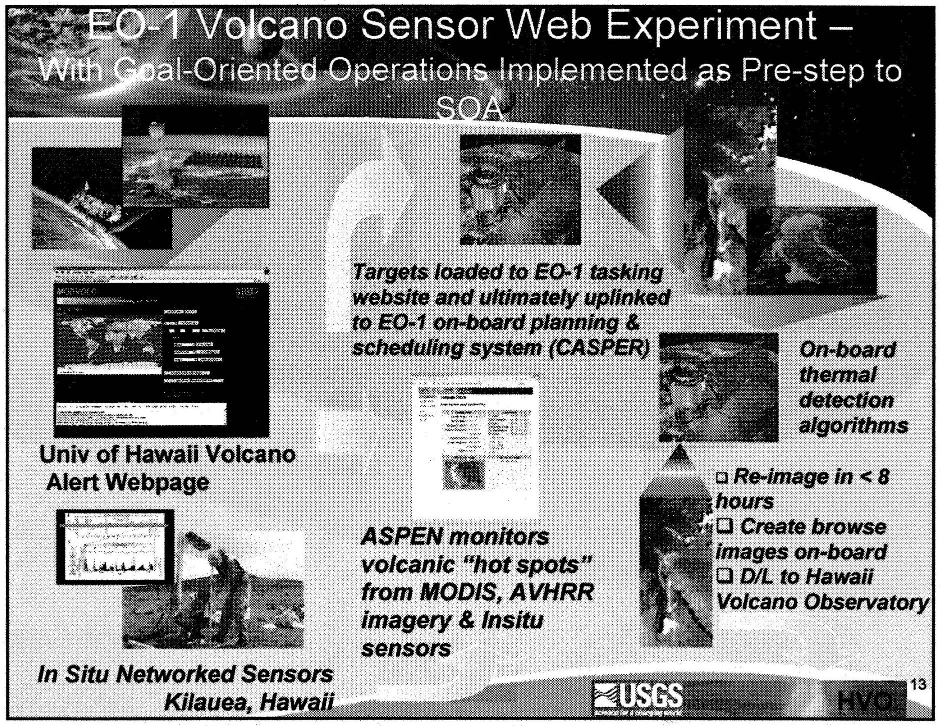
8

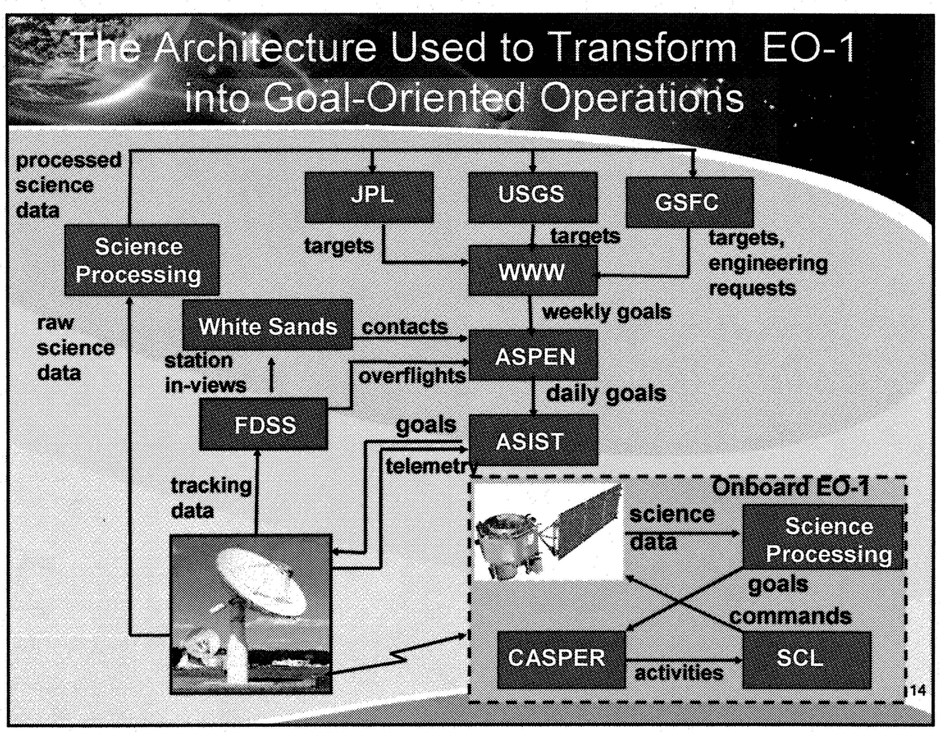

Our First Sensor Web Experiment Without SOA -
EO-1 National Priority Wildfires Sensor Web
Fire location confirmed and selected for imaging
3
Identify NIFC-tracked Wildfire Incidents
1
Science Goal Monitor
Large Incidents - August 21, 2003
Roberts Fire
SGM adds target to EO-1 ground & on-orbit planning & scheduling systems and tasks EO-1
3
2
Correlate latest fire location information with MODIS imagery
4
EROS Data Center
5
L1
Roberts Fire
UMD Natural Hazards Investigation Team
6
Active Fires Detection Map
Aqua or Terra MODIS data
USFS Burned Area Emergency Response (BAER) team
9

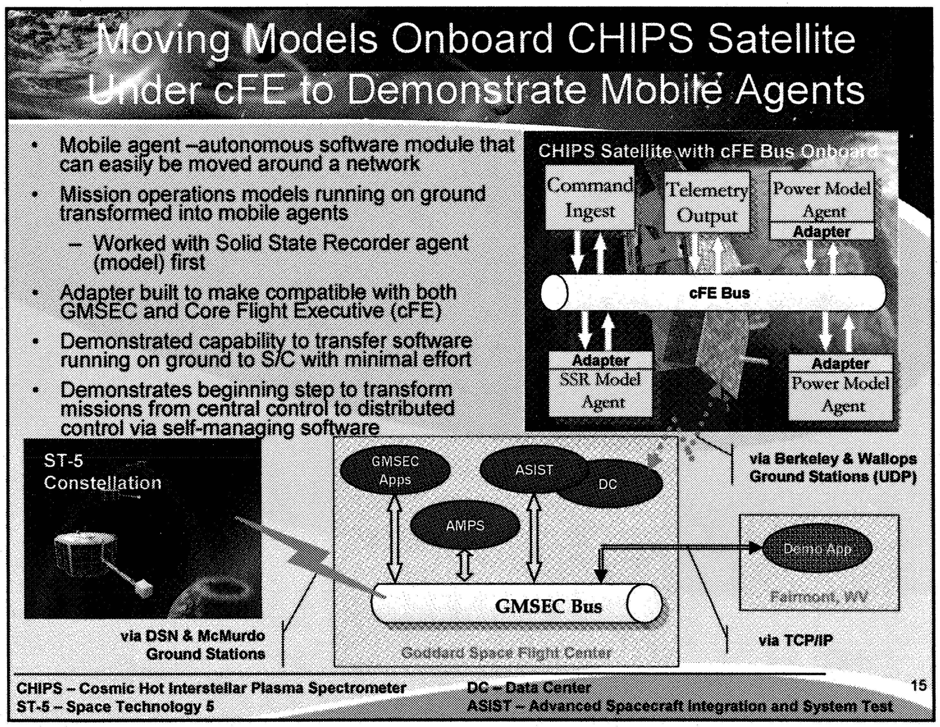

End product of Event Driven Service Chain
Detection and Tasking
Automatically task to acquire image data
USGS
Data Processing
Downlink data
Perform Level 0 processing
Perform Level 1 processing
Geo-rectification
Precisely match image to earth coordinates
Enhance vegetation image to highlight burned areas (red)
Assessment, Planning and Implementation
Ground Verification
Glacier National Park
August 21, 2003
Burned Area Reflectance Classification (BARC) map -
used by Forestry Service to efficiently rehabilitate burned areas
Burn Severity
Unburned
Low/Unburned
Low
Medium
High


Often times the Features Were Correlated or Superimposed on Maps
Burned areas – red
Unburned areas – green
Burn perimeter –blue
MODIS Rapid Response
Active Fire Detections Map
EARTH OBSERVING-1
11

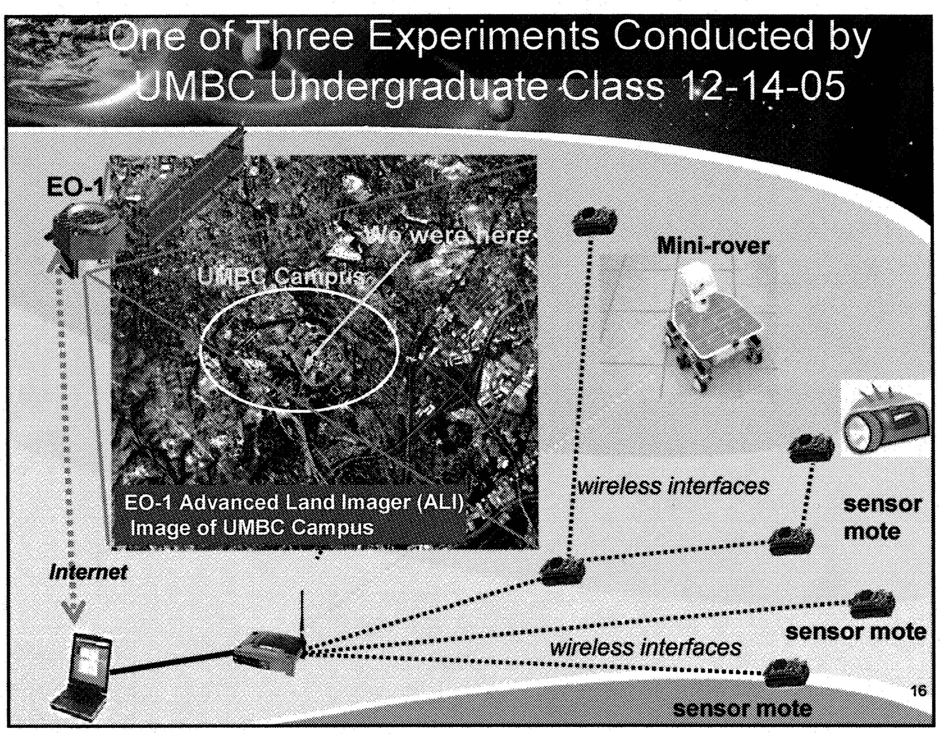

Also Needed to Implement Horizontal Sensor Data Fusion Across Multiple Sensors such as for This Set of Images of Southern California Wildfires
Piru/Simi/Verdale
MODIS
ALI
MASTER
Old/Pad
MODIS
ALI
Landsat 5
Cedar/Paradise
SPOT
AirDAS
Assets used:
• EO-1
• SPOT
• Aqua & Terra (MODIS)
• Terra (ASTER)
• Landsat 5
• MASTER
• Aircraft (ER-2) based MODIS & ASTER
• AirDas
• Airborne Infrared Disaster Assessment System
12


EO-1 Volcano Sensor Web Experiment –
With Goal-Oriented Operations Implemented as Pre-step to SOA
Targets loaded to EO-1 tasking website and ultimately uplinked to EO-1 on-board planning & scheduling system (CASPER)
On-board thermal detection algorithms
Univ of Hawaii Volcano Alert Webpage
❑ Re-image in < 8 hours
❑ Create browse images on-board
❑ D/L to Hawaii Volcano Observatory
ASPEN monitors volcanic "hot spots" from MODIS, AVHRR imagery & Insitu sensors
In Situ Networked Sensors Kilauea, Hawaii
USGS
HVO
13

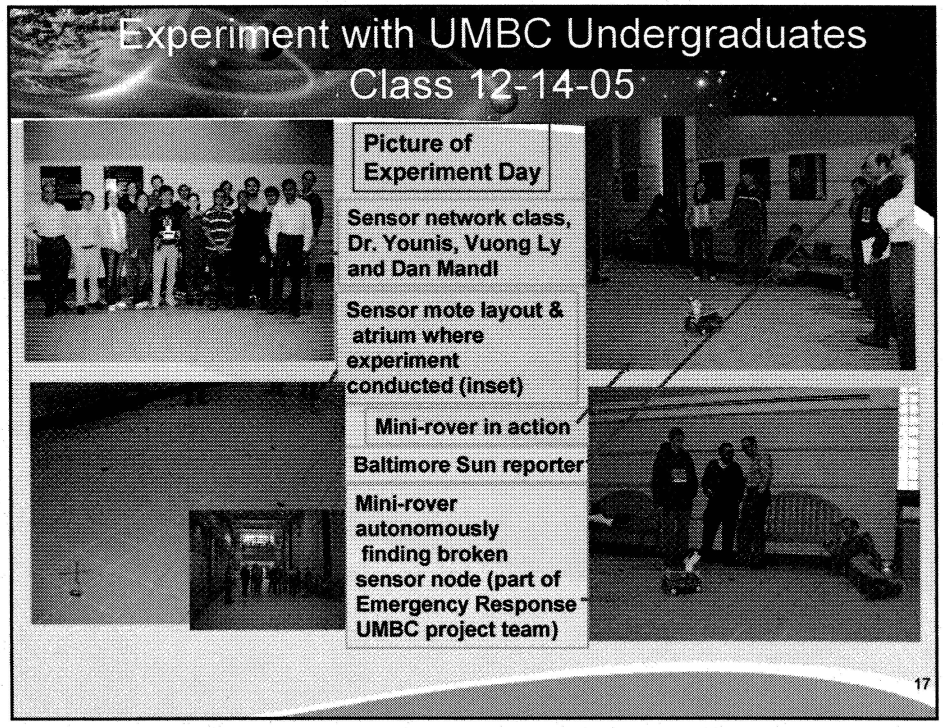

The Architecture Used to Transform EO-1 into Goal-Oriented Operations
processed science data
JPL
USGS
GSFC
Science Processing
targets
targets
targets, engineering requests
WWW
raw science data
White Sands
contacts
weekly goals
ASPEN
station in-views
overflights
daily goals
FDSS
goals
ASIST
tracking data
telemetry
Onboard EO-1
science data
Science Processing
goals
commands
CASPER
activities
SCL
14

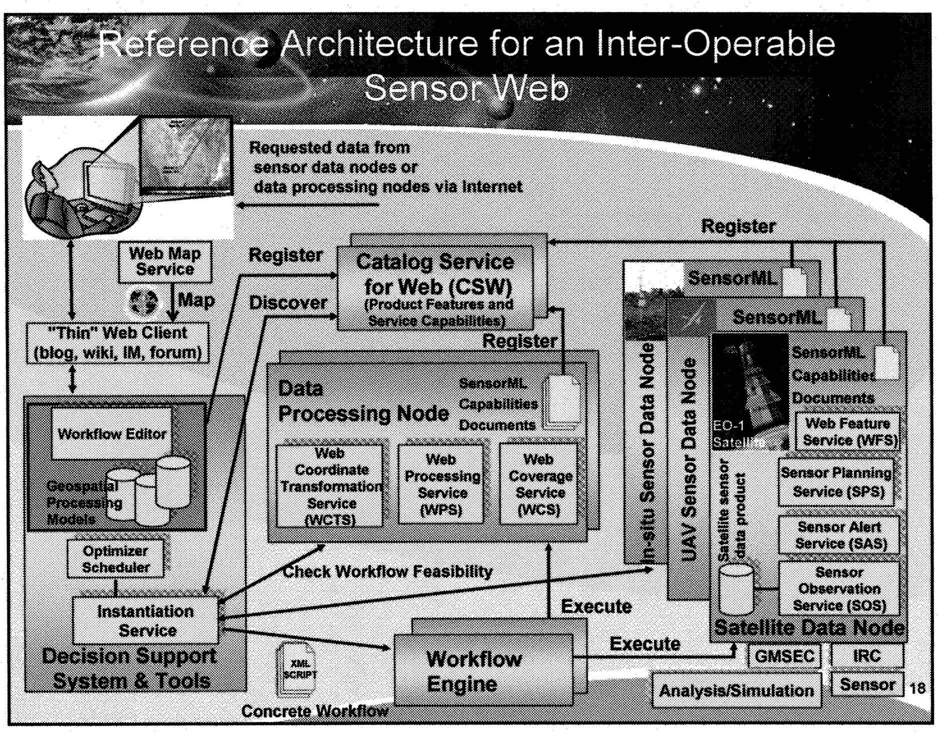


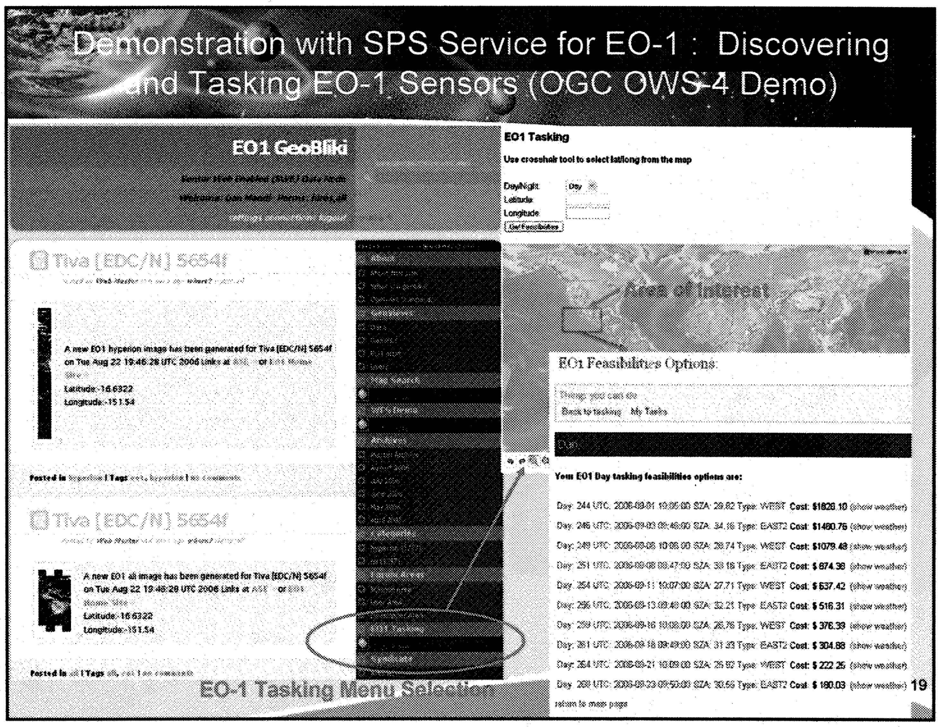
Moving Models Onboard CHIPS Satellite Under cFE to Demonstrate Mobile Agents
Mobile agent –autonomous software module that can easily be moved around a network
Mission operations models running on ground transformed into mobile agents
– Worked with Solid State Recorder agent (model) first
Adapter built to make compatible with both GMSEC and Core Flight Executive (cFE)
Demonstrated capability to transfer software running on ground to S/C with minimal effort
Demonstrates beginning step to transform missions from central control to distributed control via self-managing software
CHIPS Satellite with cFE Bus Onboard
Command Ingest
Telemetry Output
Power Model Agent
Adapter
cFE Bus
Adapter
SSR Model Agent
Adapter
Power Model Agent
ST-5 Constellation
GMSEC Apps
ASIST
DC
AMPS
GMSEC Bus
Goddard Space Flight Center
via Berkeley & Wallops Ground Stations (UDP)
Demo App
Fairmont, WV
via TCP/IP
via DSN & McMurdo Ground Stations
CHIPS – Cosmic Hot Interstellar Plasma Spectrometer
ST-5 – Space Technology 5
DC – Data Center
ASIST – Advanced Spacecraft Integration and System Test
15

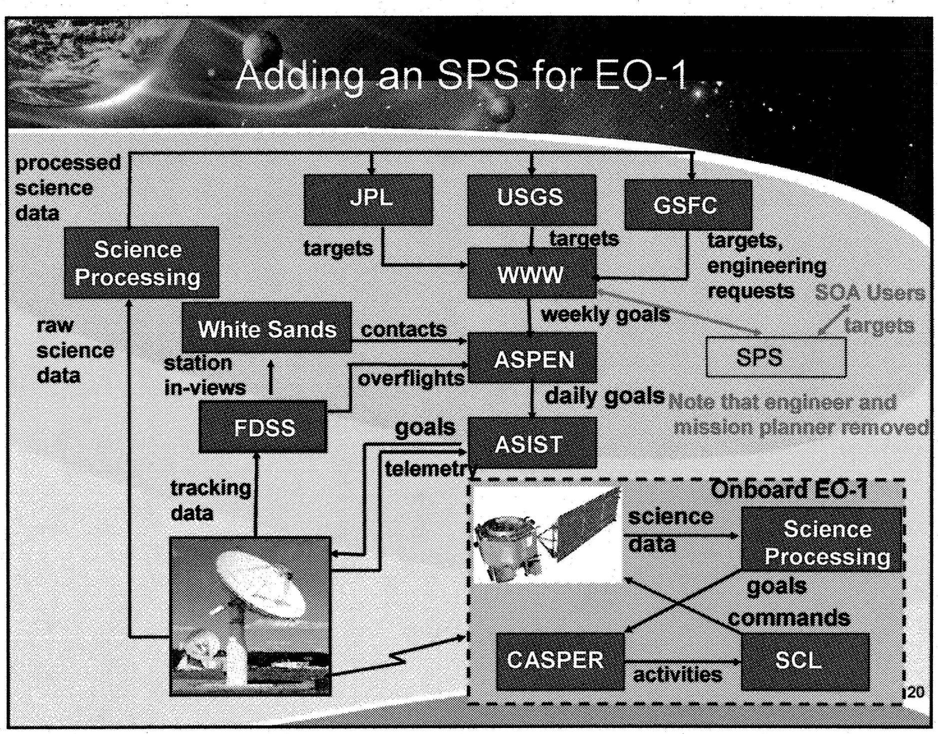


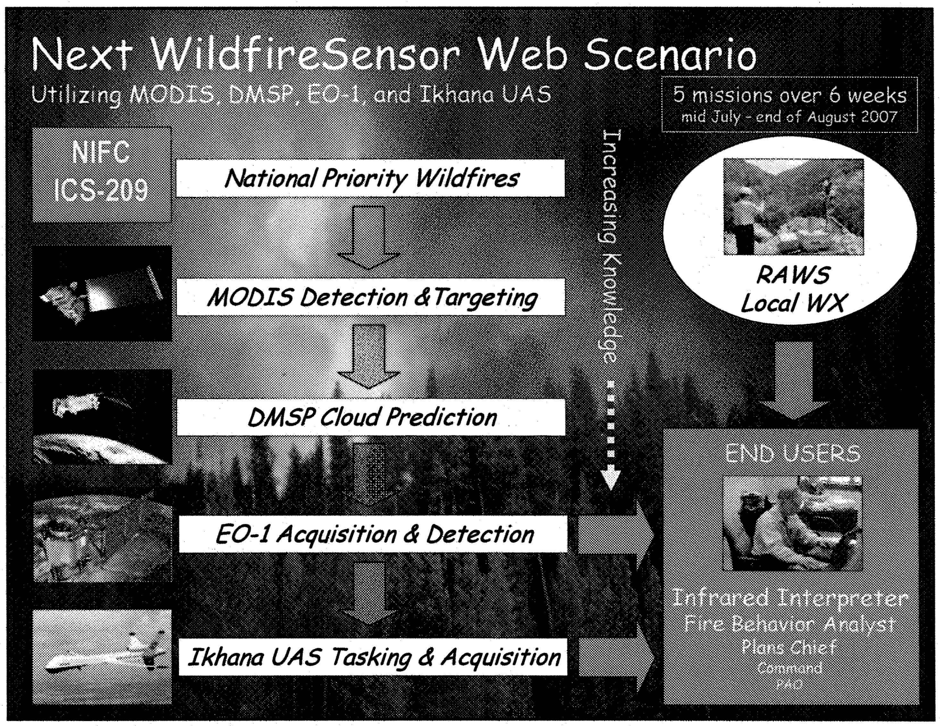
One of Three Experiments Conducted by UMBC Undergraduate Class 12-14-05
EO-1
We were here
UMBC Campus
EO-1 Advanced Land Imager (ALI) Image of UMBC Campus
Internet
Mini-rover
wireless interfaces
sensor mote
wireless interfaces
sensor mote
sensor mote
16

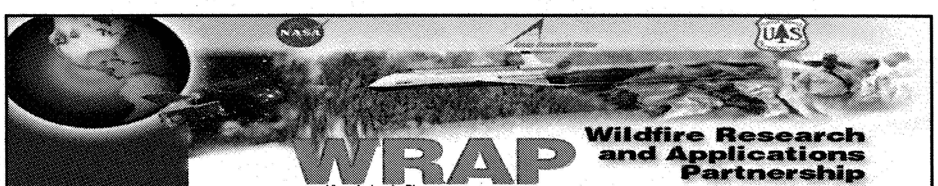

Experiment with UMBC Undergraduates
Class 12-14-05
Picture of Experiment Day
Sensor network class, Dr. Younis, Vuong Ly and Dan Mandl
Sensor mote layout & atrium where experiment conducted (inset)
Mini-rover in action
Baltimore Sun reporter
Mini-rover autonomously finding broken sensor node (part of Emergency Response UMBC project team)
17


Reference Architecture for an Inter-Operable Sensor Web
Requested data from sensor data nodes or data processing nodes via Internet
Web Map Service
Map
"Thin" Web Client (blog, wiki, IM, forum)
Register
Discover
Catalog Service for Web (CSW)
(Product Features and Service Capabilities)
Register
Register
Data Processing Node
SensorML Capabilities Documents
Web Coordinate Transformation Service (WCTS)
Web Processing Service (WPS)
Web Coverage Service (WCS)
Workflow Editor
Geospatial Processing Models
Optimizer Scheduler
Instantiation Service
Decision Support System & Tools
Check Workflow Feasibility
Execute
Execute
XML SCRIPT
Concrete Workflow
Workflow Engine
SensorML
SensorML
SensorML Capabilities Documents
In-situ Sensor Data Node
UAV Sensor Data Node
EO-1 Satellite
Satellite sensor data product
Web Feature Service (WFS)
Sensor Planning Service (SPS)
Sensor Alert Service (SAS)
Sensor Observation Service (SOS)
Satellite Data Node
GMSEC
IRC
Analysis/Simulation
Sensor
18


Demonstration with SPS Service for EO-1 : Discovering and Tasking EO-1 Sensors (OGC OWS-4 Demo)
EO1 GeoBliki
Tiva [EDC/N] 5654f
Tiva [EDC/N] 5654f
EO1 Tasking
Use crosshair tool to select lat/long from the map
Area of Interest
EO1 Feasibilities Options
Your EO1 Day tasking feasibilities options are:
EO-1 Tasking Menu Selection
19


Adding an SPS for EO-1
processed science data
JPL
USGS
GSFC
Science Processing
targets
targets
WWW
targets, engineering requests
SOA Users
raw science data
White Sands
contacts
weekly goals
targets
SPS
station in-views
overflights
ASPEN
daily goals
Note that engineer and mission planner removed
FDSS
goals
ASIST
telemetry
tracking data
Onboard EO-1
science data
Science Processing
goals
commands
CASPER
activities
SCL
20

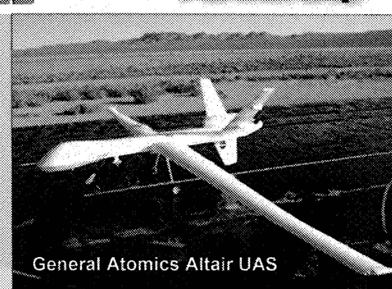




12-Channel Wildfire Scanner Specifications

Channel 1:	0.42 - 0.45 um
Channel 2:	0.45 - 0.52 um
Channel 3:	0.52 - 0.60 um
Channel 4:	0.60 - 0.62 um
Channel 5:	0.63 - 0.69 um
Channel 6:	0.69 - 0.75 um
Channel 7:	0.76 - 0.90 um
Channel 8:	0.91 - 1.05 um
Channel 9:	1.55 - 1.75 um
Channel 10:	2.08 - 2.35 um
Channel 11:	3.60 - 3.79 um (VIIRS M12)
Channel 12:	10.26 -11.26 um (VIIRS M15)

FOV: 42.5 or 85.9 degrees (selectable)
IFOV: 1.25 mrad or 2.5 mrad (selectable)
Spatial Res.: 3 – 50 meters (altitude dependant)



Also compatible with the GA Mariner, Predator-B & Cessna Caravan C208.

- Targeting input from NIFC, MODIS Rapid Response, and GOES.
- Onboard, real-time geolocation and product generation for both imagery and fire detects.
- Browse and fire detects available via Google Earth interface within ca. 4 minutes.
- Cal/Val coordination with MODIS Land Team and CEOS-LPV.
- Activities in plan with AIST PIs for SensorWeb implementation in concert with MODIS and EO-1.

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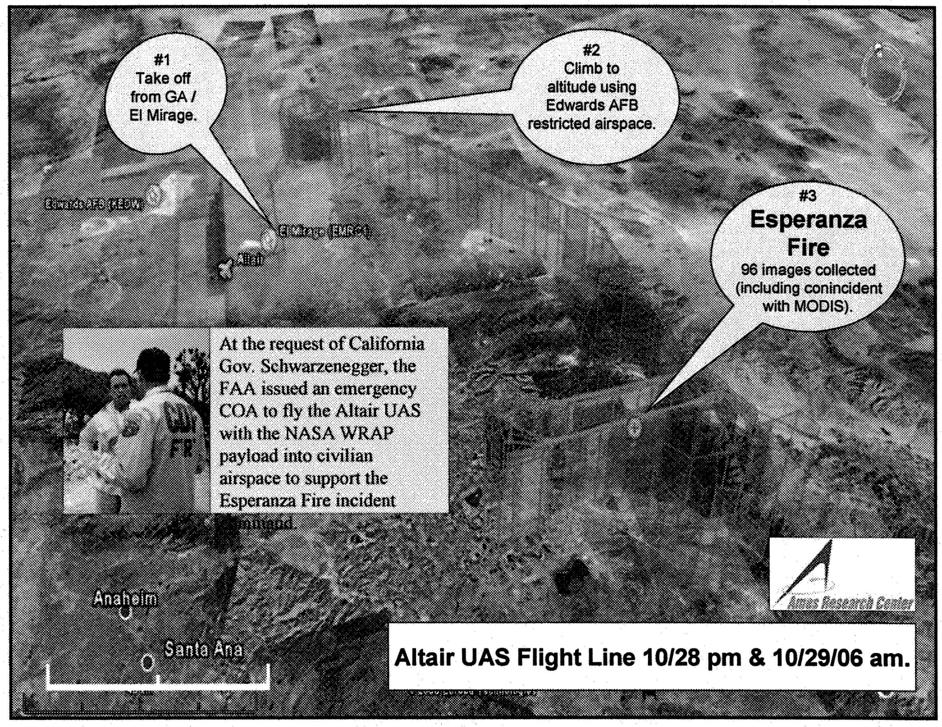

Conclusion

- Integrating sensors with open source, interoperable reusable science services facilitates the vision of Global Earth Observing System of Systems
- Creating these open services, lowers the cost of performing science analysis and creating new methods
- With the OGC or similar standards, any set of sensors can become a virtual sensor web
- With the OGC or similar standards, old and new assets can interoperable cost-effectively

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Glossary

DSS – Decision Support System

SOS – Sensor Observation Service

CSW – Catalog Services For the Web

SPS – Sensor Planning Service

GMSEC – Goddard Mission Services Evolution Center

WCS – Web Coverage Service

IML – Instrument Markup Language

WCTS – Web Coordinate Transformation Service

SAS – Sensor Alert Service (Pub/Sub)

WFS – Web Feature Service

WMS – Web Map Service

WPS – Web Processing Service

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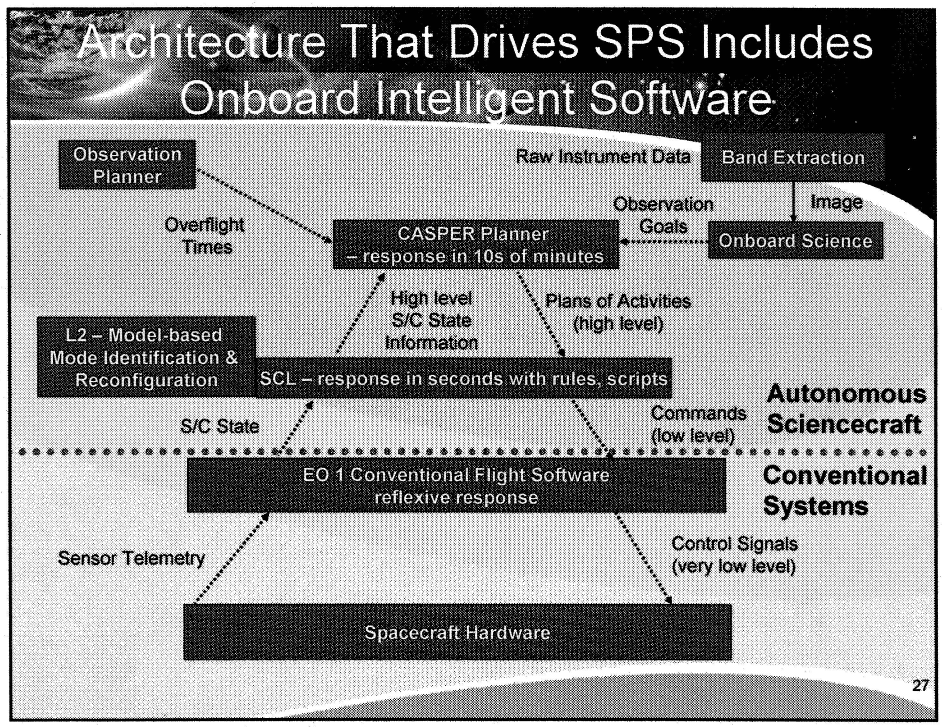
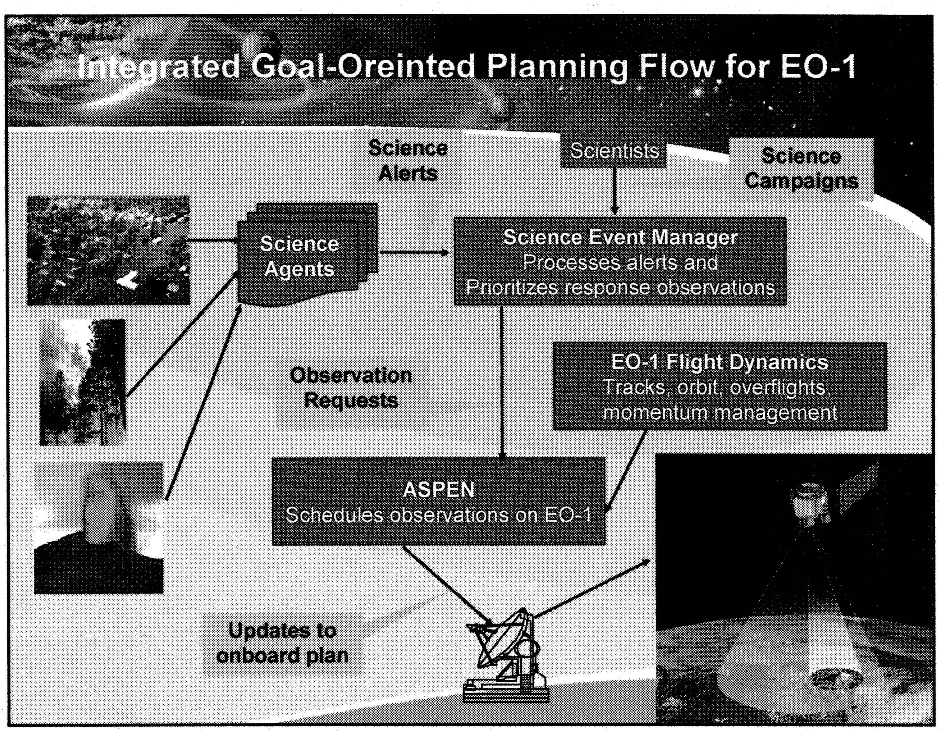
Backup Slides

26


Architecture That Drives SPS Includes Onboard Intelligent Software
Observation Planner
Raw Instrument Data
Band Extraction
Observation Goals
Image
Overflight Times
CASPER Planner – response in 10s of minutes
Onboard Science
High level S/C State Information
Plans of Activities (high level)
L2 – Model-based Mode Identification & Reconfiguration
SCL – response in seconds with rules, scripts
Autonomous Sciencecraft
S/C State
Commands (low level)
EO 1 Conventional Flight Software reflexive response
Conventional Systems
Sensor Telemetry
Control Signals (very low level)
Spacecraft Hardware
27

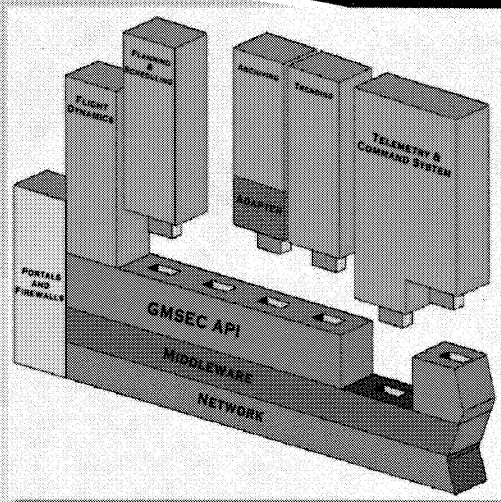

Integrated Goal-Oreinted Planning Flow for EO-1
Science Alerts
Scientists
Science Campaigns
Science Agents
Science Event Manager
Processes alerts and
Prioritizes response observations
EO-1 Flight Dynamics
Tracks, orbit, overflights,
momentum management
Observation Requests
ASPEN
Schedules observations on EO-1
Updates to onboard plan

Underlying "Plug and Play" Message Bus Architecture-- Goddard Mission Services Evolution Center (GMSEC)

GMSEC architecture provides a scalable and extensible ground and flight system approach

- Standardized messages formats
- Plug-and-play components
- Publish/Subscribe protocol
- Platform transparency
- ST5 first mission to be totally GMSEC compliant

More info at: http://gmsec.gsfc.nasa.gov



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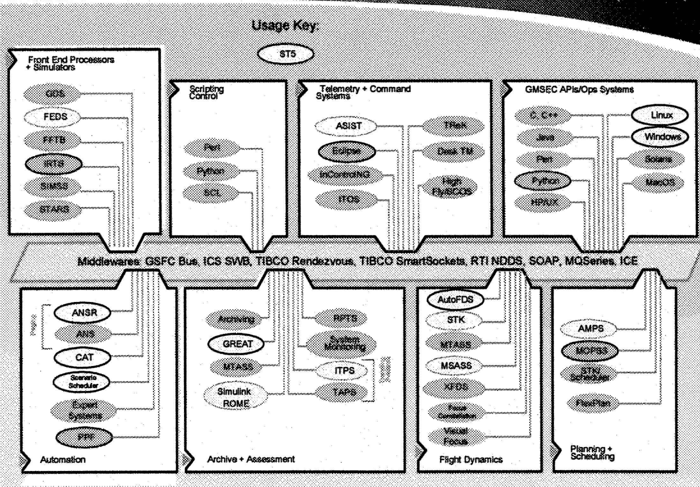
Example of Rapid Mission Configuration Using GMSEC Interoperable Catalog Components



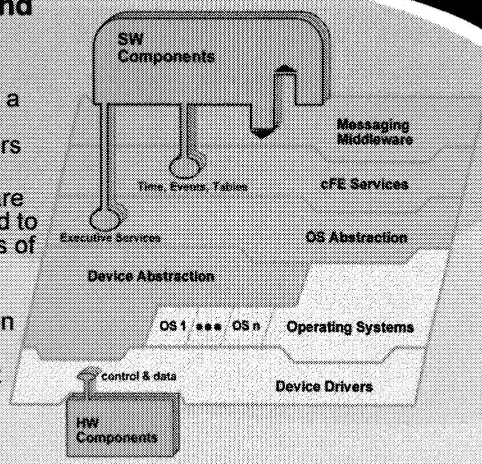
GMSEC approach gives users choices for the components in their system. The ST-5 mission rapidly selected key components from the GMSEC catalog.

30

Core Flight Executive (cFE), an Extension for GMSEC for Flight SW

cFE provides a framework that simplifies the development and integration of applications

- Layered Architecture – software of a layer can be changed without affecting the software of other layers
- Components communicate over a standard message-oriented software bus, therefore, eliminating the need to know the details of the lower layers of inter-networking.
- Software components can be developed and reused from mission to mission.
- Developed by Flight SW Branch at GSFC
- To be used on LRO
- More info at: http://gmsec.gsfc.nasa.gov



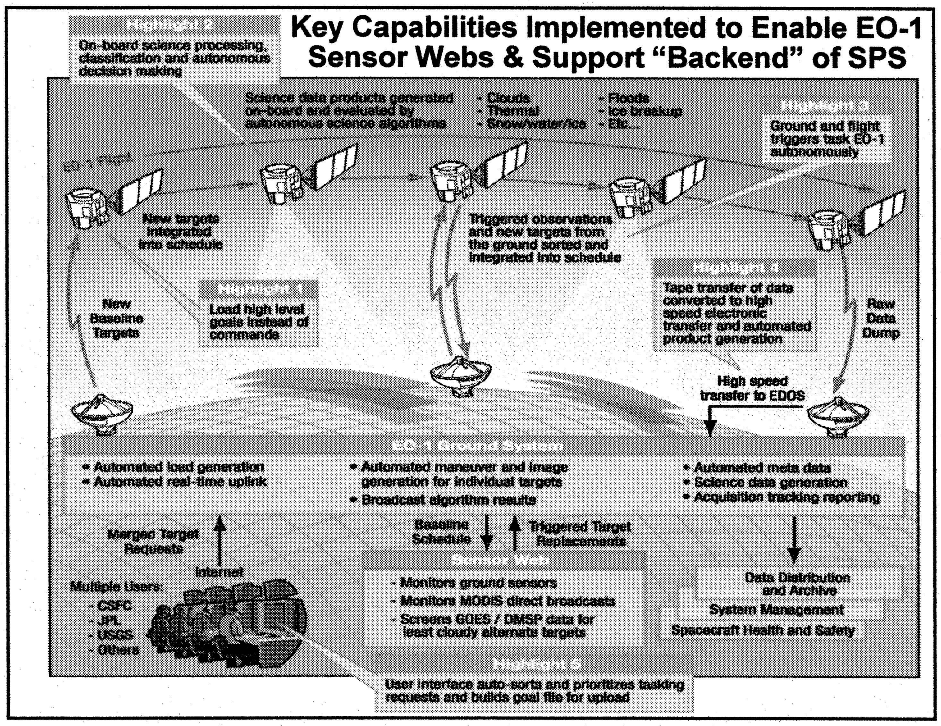
31

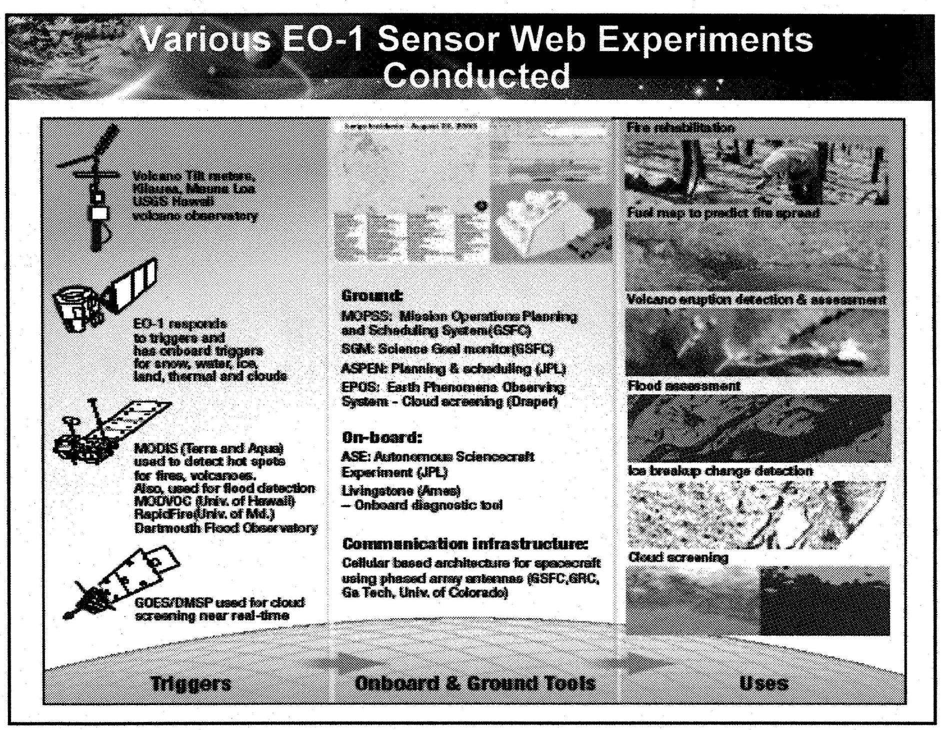
Advantages of SOA for Space Sensors

- Networked standardized interface connections, loosely coupled
  - Components connected at run-time
- Enables discovery of services
- Hides details of how service performed (encapsulated implementation)
- Fault tolerant
  - Since connection occurs at run-time, if service not available, a component can find or "discover" an alternative service and if unavailable, can connect to another instance of the service if available
  - Troubleshooting is easier because information is provided at component and services level
- Highly reusable
  - Standardized, networked "plug and play" interfaces
- Scalable
  - Interactions between services and clients independent of location and numbers
- Sustaining engineering for constellation simplified
  - Can initiate new instance of service or alternative service and then disconnect old services

Taken from: Hartman, Hoebel; "Lightweight Service Architectures for Space Missions", SMC-IT 2006, Pasadena, Ca

32


Key Capabilities Implemented to Enable EO-1 Sensor Webs & Support "Backend" of SPS
Highlight 2
On-board science processing, classification and autonomous decision making
Science data products generated on-board and evaluated by autonomous science algorithms
- Clouds
- Thermal
- Snow/water/ice
- Floods
- Ice breakup
- Etc...
Highlight 3
Ground and flight triggers task EO-1 autonomously
EO-1 Flight
New targets integrated into schedule
Triggered observations and new targets from the ground sorted and integrated into schedule
Highlight 1
Load high level goals instead of commands
New Baseline Targets
Highlight 4
Tape transfer of data converted to high speed electronic transfer and automated product generation
Raw Data Dump
High speed transfer to EDOS
EO-1 Ground System
• Automated load generation
• Automated real-time uplink
• Automated maneuver and image generation for individual targets
• Broadcast algorithm results
• Automated meta data
• Science data generation
• Acquisition tracking reporting
Merged Target Requests
Baseline Schedule
Triggered Target Replacements
Internet
Multiple Users:
- GSFC
- JPL
- USGS
- Others
Sensor Web
- Monitors ground sensors
- Monitors MODIS direct broadcasts
- Screens GOES / DMSP data for least cloudy alternate targets
Data Distribution and Archive
System Management
Spacecraft Health and Safety
Highlight 5
User interface auto-sorts and prioritizes tasking requests and builds goal file for upload


Various EO-1 Sensor Web Experiments Conducted
Volcano Tilt meters, Kilauea, Mauna Loa USGS Hawaii volcano observatory
EO-1 responds to triggers and has onboard triggers for snow, water, ice, land, thermal and clouds
MODIS (Terra and Aqua) used to detect hot spots for fires, volcanoes. Also, used for flood detection MODVOC (Univ. of Hawaii) RapidFire(Univ. of Md.) Dartmouth Flood Observatory
GOES/DMSP used for cloud screening near real-time
Ground:
MOPSS: Mission Operations Planning and Scheduling System(GSFC)
SGM: Science Goal monitor(GSFC)
ASPEN: Planning & scheduling (JPL)
EPOS: Earth Phenomena Observing System - Cloud screening (Draper)
On-board:
ASE: Autonomous Sciencecraft Experiment (JPL)
Livingstone (Ames) – Onboard diagnostic tool
Communication infrastructure:
Cellular based architecture for spacecraft using phased array antennas (GSFC,GRC, Ga Tech, Univ. of Colorado)
Fire rehabilitation
Fuel map to predict fire spread
Volcano eruption detection & assessment
Flood assessment
Ice breakup change detection
Cloud screening
Triggers
Onboard & Ground Tools
Uses