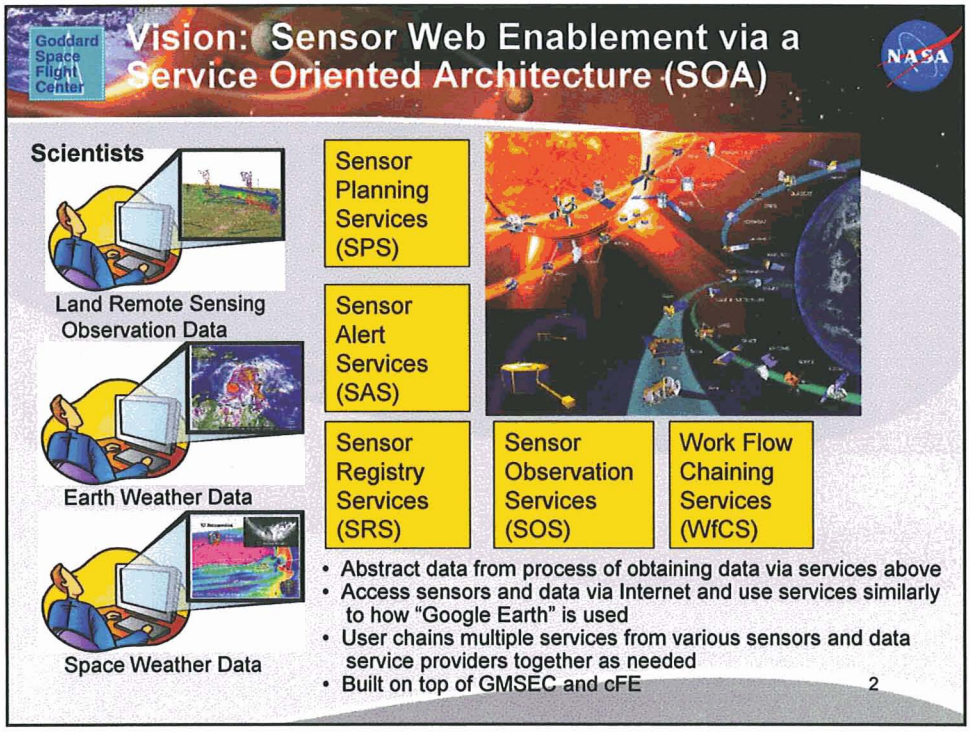
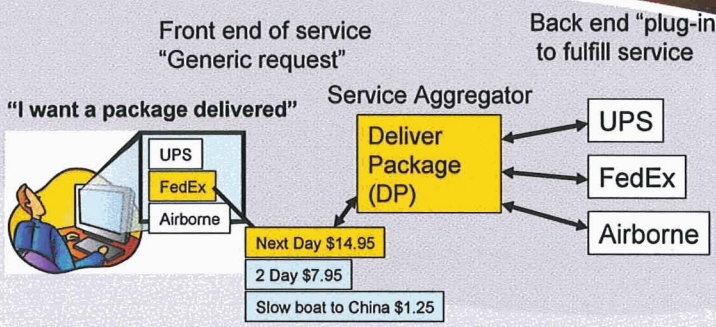
Source of Acquisition
NASA Goddard Space Flight Center



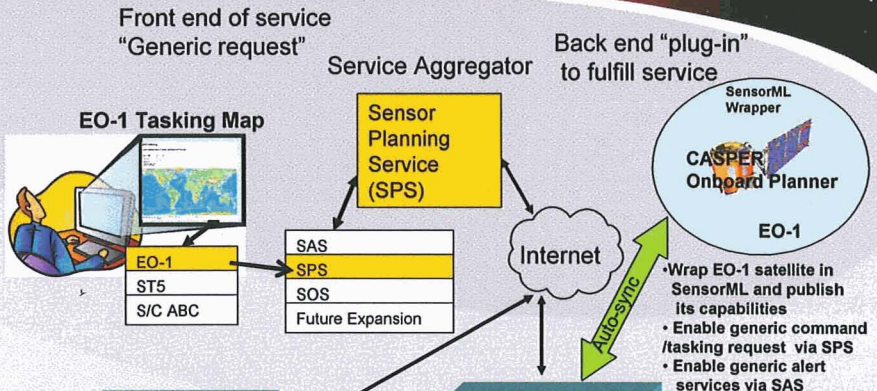
Service Example



- User discovers service on Internet with search tools
- User picks desired service, pays and doesn't get involved in details of how service is provided
- New services can be easily plugged in and removed thus circumventing risk of obsolescence
- Fault tolerant because user can locate and connect to alternative service

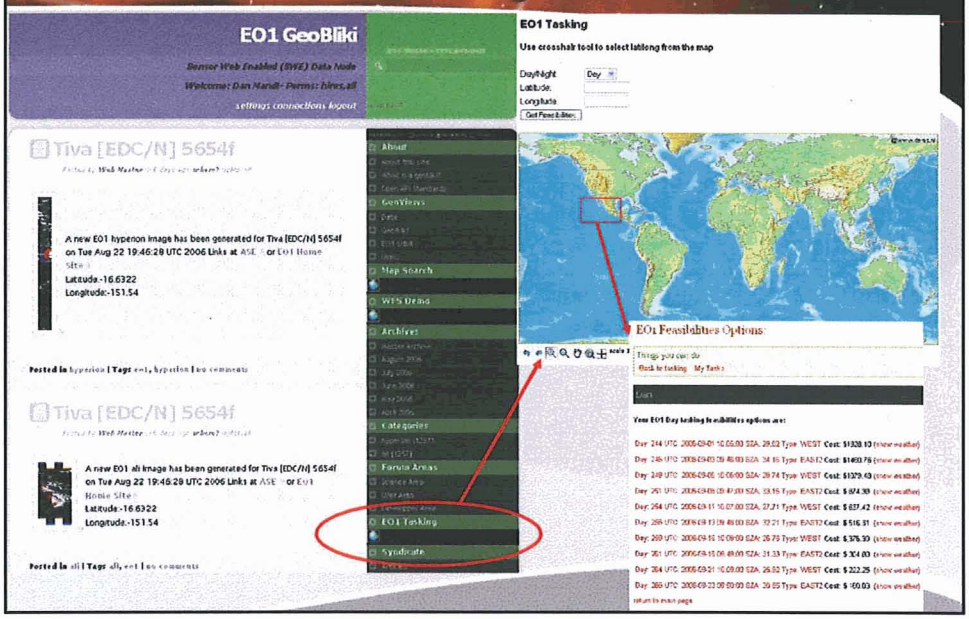
3

SPS Example: Discovering and Tasking EO-1 Sensors (OGC OWS-4 Demo)

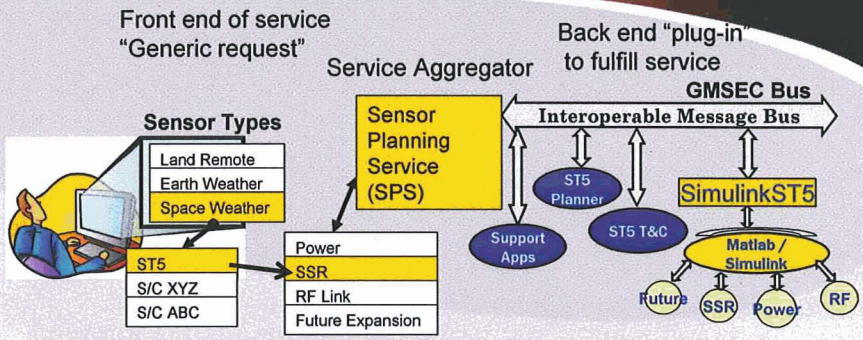


4

SPS Example: Discovering and Tasking EO-1 Sensors (OGC OWS-4 Demo)

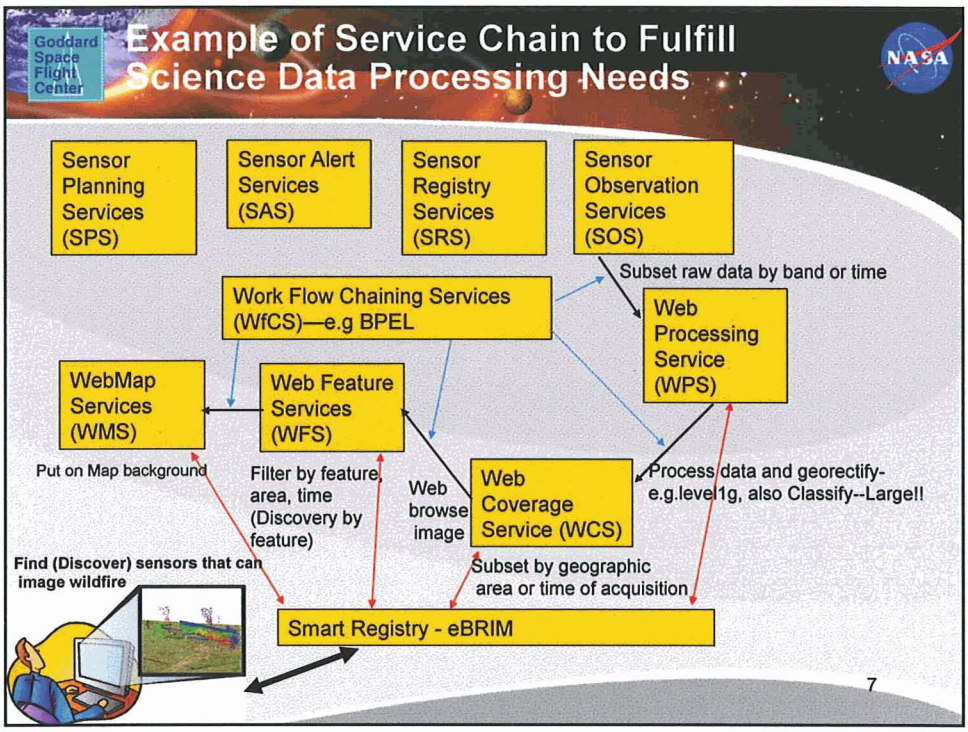


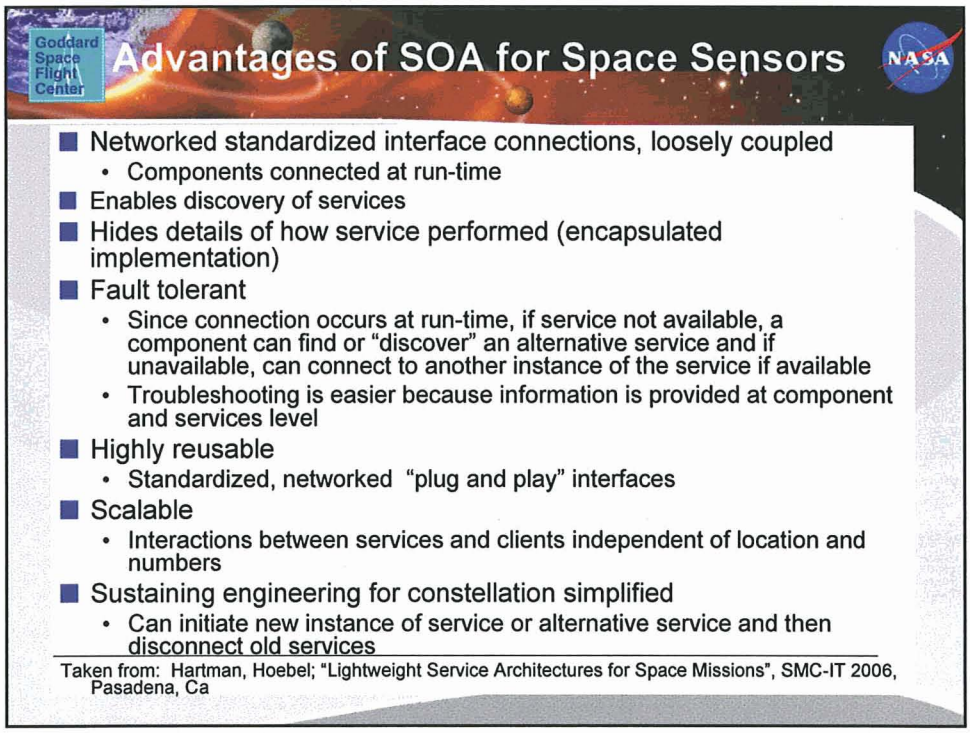
SPS Example Using ST5 Built on Top of GMSEC

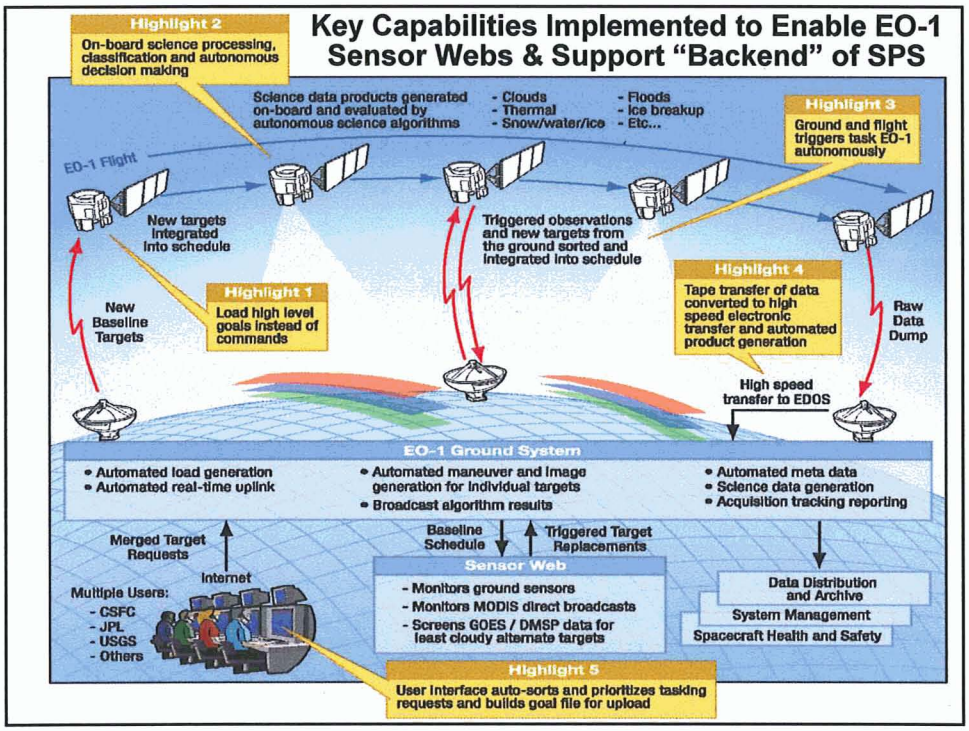


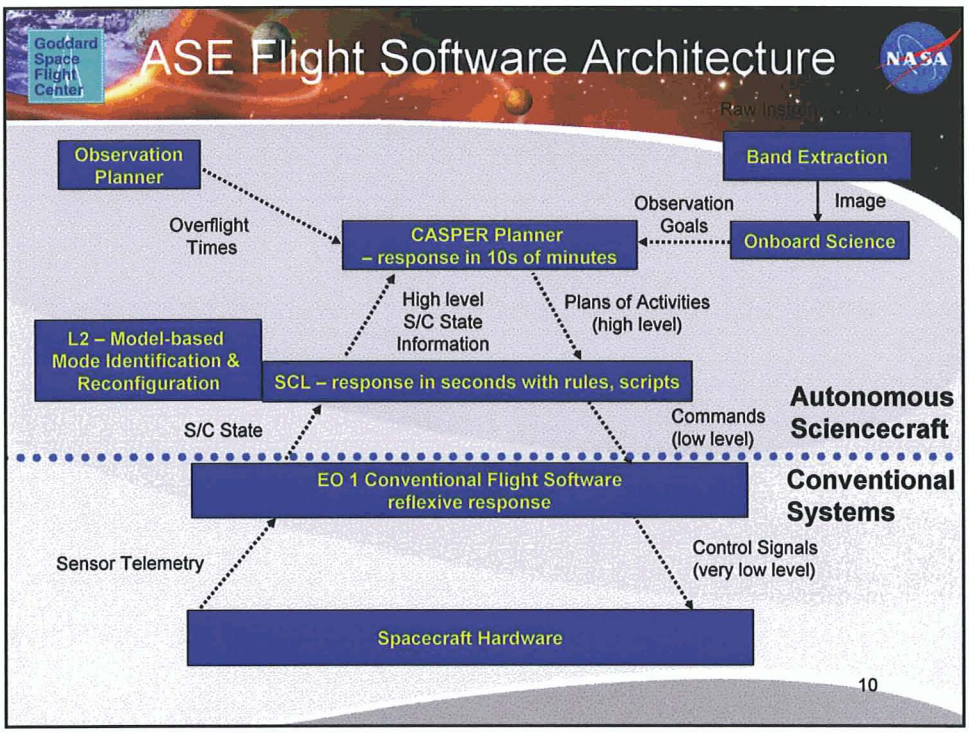
- Validated new "back-end" predictive models which predicted problems for selected subsystems (SSR, RF Link, Power) and then autonomously initiated corrective actions through planning system before problem occurred
  - Unique innovation--Models self-update over time using real-time telemetry (e.g. as solar array degrades, charge current for battery changes over time, therefore model of state of battery has to change)
- Used GSFC Mission Services Evolution Center (GMSEC) message bus to enable communications between support components

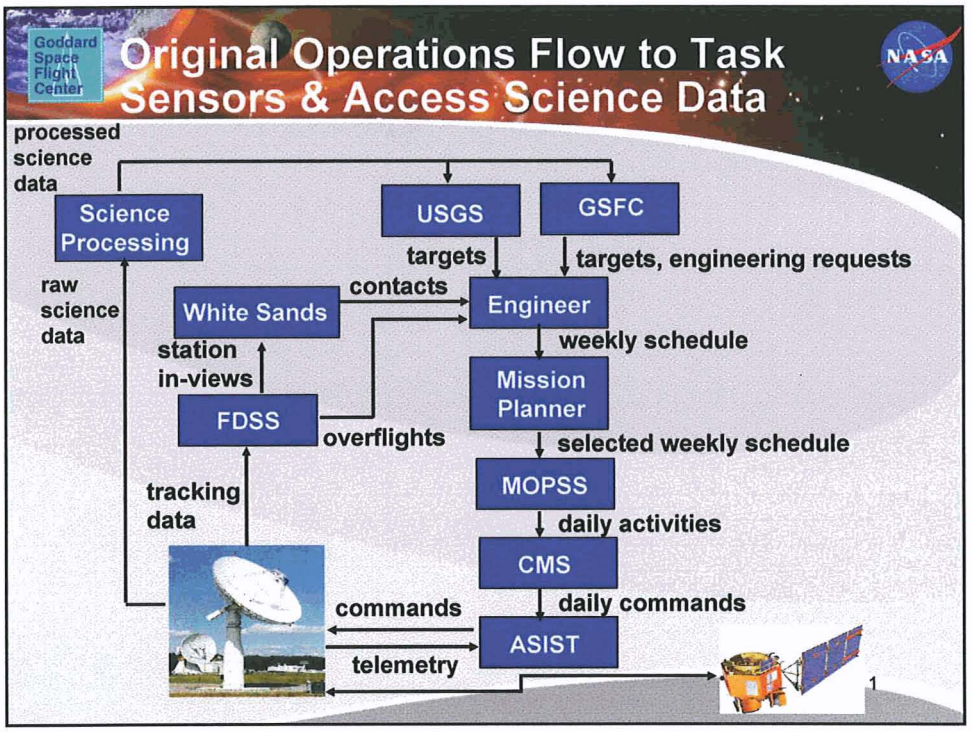
6

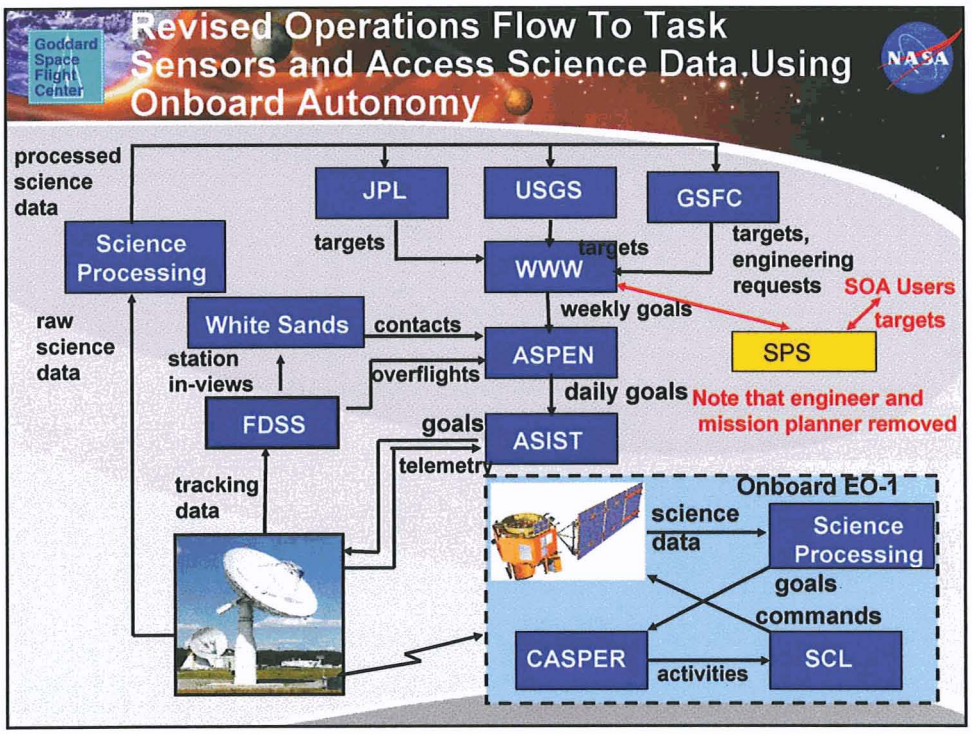

Goddard Space Flight Center
Example of Service Chain to Fulfill Science Data Processing Needs
NASA
Sensor Planning Services (SPS)
Sensor Alert Services (SAS)
Sensor Registry Services (SRS)
Sensor Observation Services (SOS)
Subset raw data by band or time
Work Flow Chaining Services (WfCS)—e.g BPEL
Web Processing Service (WPS)
WebMap Services (WMS)
Web Feature Services (WFS)
Put on Map background
Filter by feature, area, time (Discovery by feature)
Web browse image
Web Coverage Service (WCS)
Process data and georectify- e.g.level1g, also Classify--Large!!
Find (Discover) sensors that can image wildfire
Subset by geographic area or time of acquisition
Smart Registry - eBRIM
7


Goddard Space Flight Center
Advantages of SOA for Space Sensors
NASA
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


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
Internet
Baseline Schedule
Triggered Target Replacements
Sensor Web
- Monitors ground sensors
- Monitors MODIS direct broadcasts
- Screens GOES / DMSP data for least cloudy alternate targets
Multiple Users:
- CSFC
- JPL
- USGS
- Others
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


Goddard Space Flight Center
ASE Flight Software Architecture
NASA
Observation Planner
Band Extraction
Overflight Times
Observation Goals
Image
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
10


Goddard Space Flight Center
Original Operations Flow to Task Sensors & Access Science Data
NASA
processed science data
Science Processing
USGS
GSFC
targets
targets, engineering requests
raw science data
White Sands
contacts
Engineer
weekly schedule
station in-views
Mission Planner
FDSS
overflights
selected weekly schedule
tracking data
MOPSS
daily activities
CMS
daily commands
commands
ASIST
telemetry
1

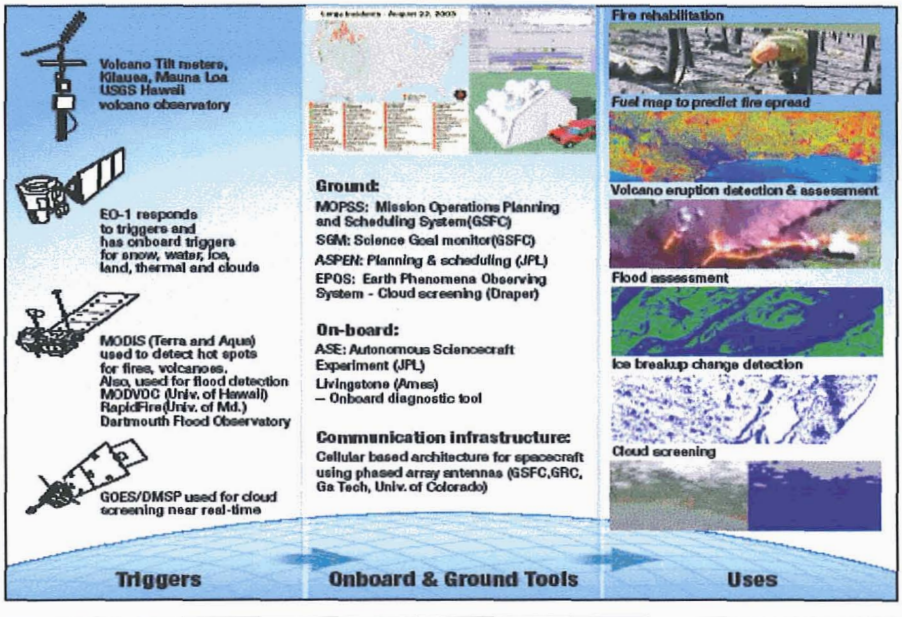

Goddard Space Flight Center
Revised Operations Flow To Task Sensors and Access Science Data Using Onboard Autonomy
NASA
processed science data
JPL
USGS
GSFC
Science Processing
targets
targets
targets, engineering requests
WWW
SOA Users
targets
raw science data
White Sands
contacts
weekly goals
ASPEN
SPS
station in-views
overflights
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

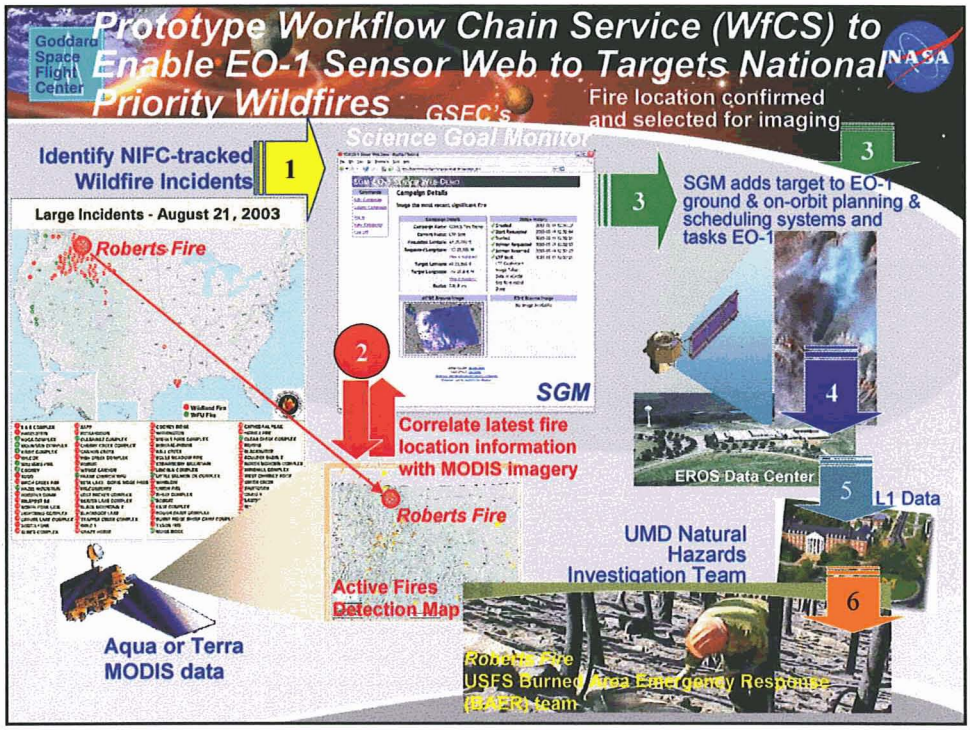
Key Differences

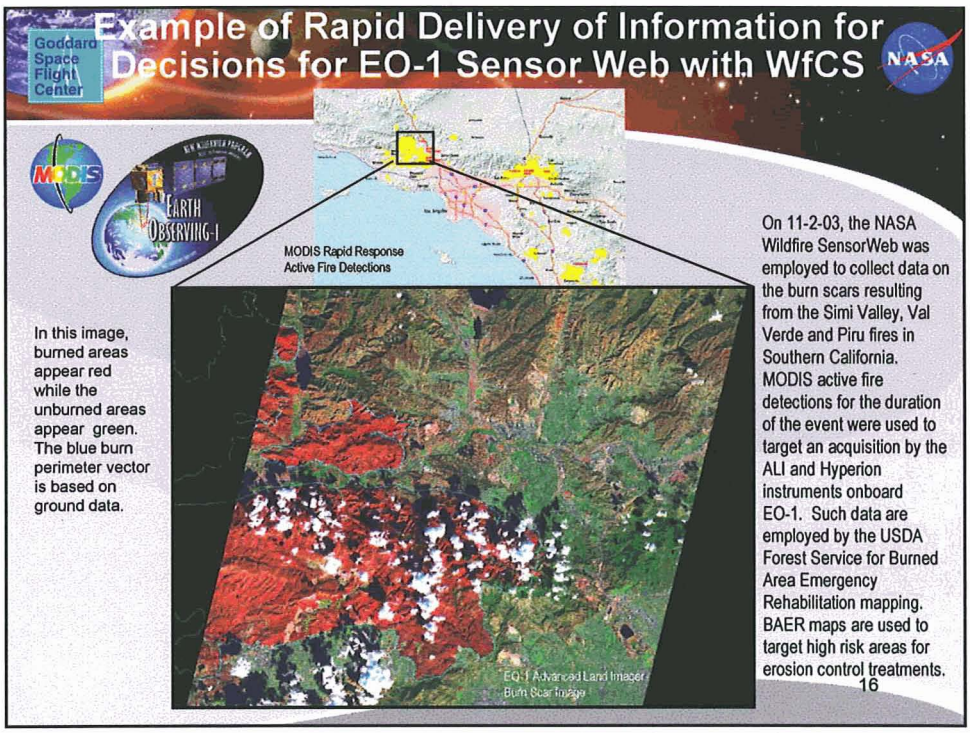
- Scenes and ground contacts are selected automatically based on scene priorities
- World Wide Web interface for requesting and acquiring observations
- High-level scene and contact "goals" are uploaded to the spacecraft instead of detailed command sequences
- Execution sequence can be automatically changed on-board
- Priority observations can be requested and acquired within hours
- Science data is immediately available for analysis on-board compared to days or weeks

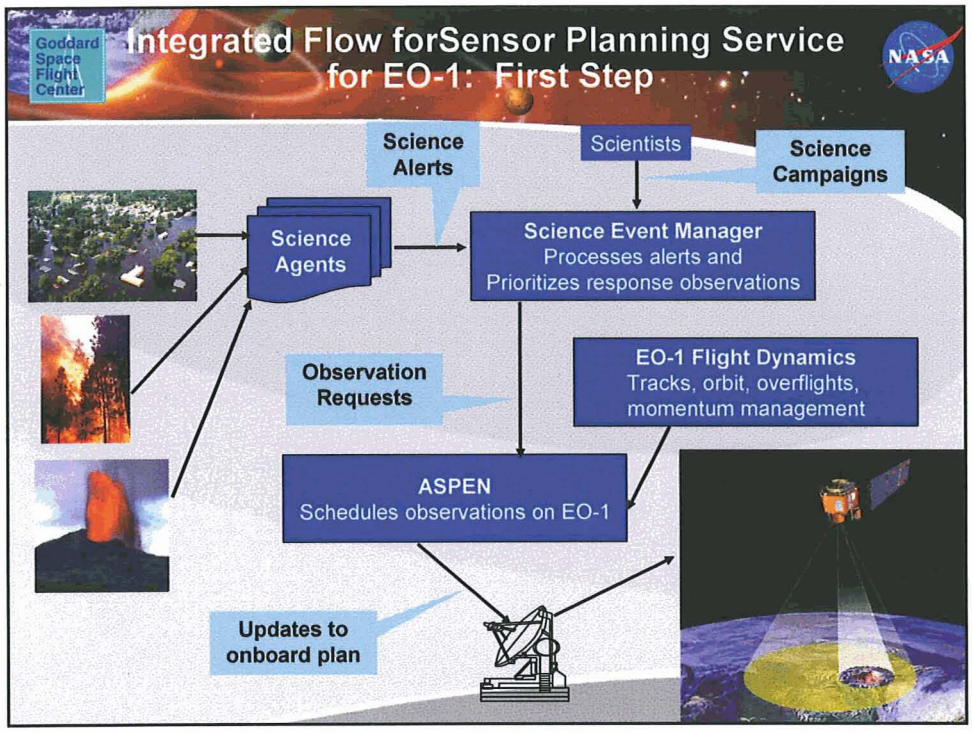
13

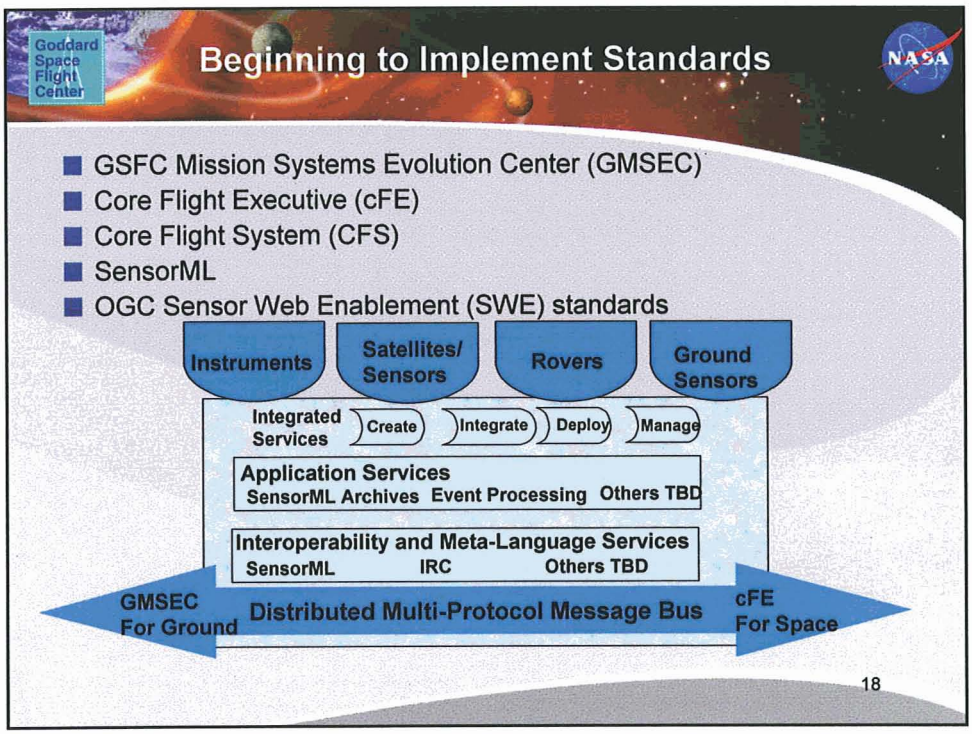
Various EO-1 Sensor Web Experiments Conducted




Goddard Space Flight Center
Prototype Workflow Chain Service (WfCS) to Enable EO-1 Sensor Web to Targets National Priority Wildfires
NASA
Identify NIFC-tracked Wildfire Incidents
1
Large Incidents - August 21, 2003
Roberts Fire
GSFC's Science Goal Monitor
SGM
2
Correlate latest fire location information with MODIS imagery
Roberts Fire
Active Fires Detection Map
Aqua or Terra MODIS data
Fire location confirmed and selected for imaging
3
3
SGM adds target to EO-1 ground & on-orbit planning & scheduling systems and tasks EO-1
4
EROS Data Center
5
L1 Data
UMD Natural Hazards Investigation Team
6
Roberts Fire
USFS Burned Area Emergency Response (BAER) team

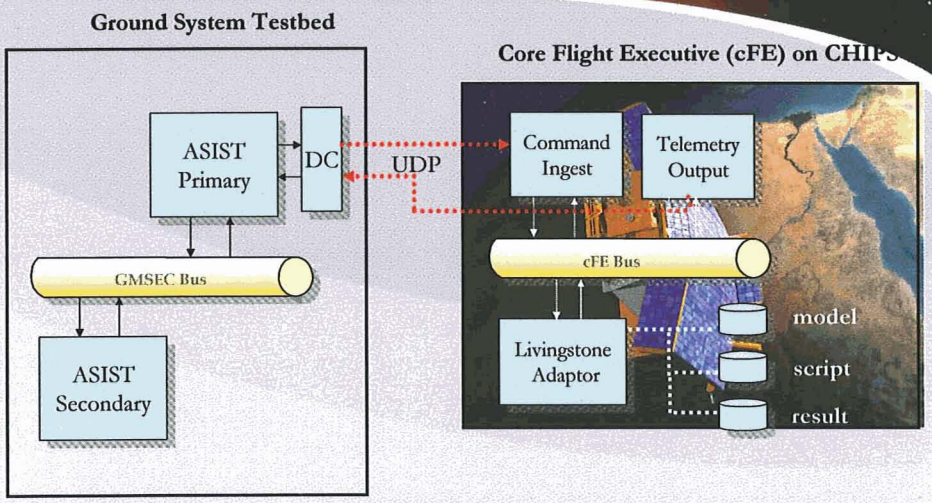

Goddard Space Flight Center
Example of Rapid Delivery of Information for Decisions for EO-1 Sensor Web with WfCS
NASA
MODIS
EARTH OBSERVING-1
MODIS Rapid Response Active Fire Detections
In this image, burned areas appear red while the unburned areas appear green. The blue burn perimeter vector is based on ground data.
EO-1 Advanced Land Imager Burn Scar Image
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 Rehabilitation mapping. BAER maps are used to target high risk areas for erosion control treatments.
16


Goddard Space Flight Center
Integrated Flow forSensor Planning Service for EO-1: First Step
NASA
Science Alerts
Scientists
Science Campaigns
Science Agents
Science Event Manager
Processes alerts and Prioritizes response observations
Observation Requests
EO-1 Flight Dynamics
Tracks, orbit, overflights, momentum management
ASPEN
Schedules observations on EO-1
Updates to onboard plan


Goddard Space Flight Center
Beginning to Implement Standards
NASA
GSFC Mission Systems Evolution Center (GMSEC)
Core Flight Executive (cFE)
Core Flight System (CFS)
SensorML
OGC Sensor Web Enablement (SWE) standards
Instruments
Satellites/ Sensors
Rovers
Ground Sensors
Integrated Services
Create
Integrate
Deploy
Manage
Application Services
SensorML Archives
Event Processing
Others TBD
Interoperability and Meta-Language Services
SensorML
IRC
Others TBD
GMSEC For Ground
Distributed Multi-Protocol Message Bus
cFE For Space
18

GMSEC Extended to S/C Bus--Onboard Integrated Message Bus Demonstration (December 2005)

Goddard Space Flight Center



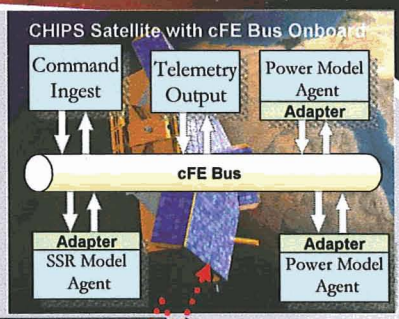
DC – Data Center
ASIST – Advanced Spacecraft Integration and System Test

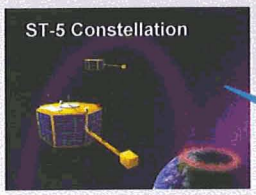
19

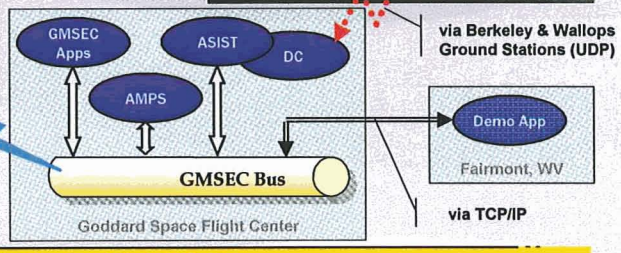
Moving ST5 Models Onboard CHIPS Satellite Under cFS to Demonstrate Mobile Agents

Goddard Space Flight Center

- Mobile agent –autonomous software module that can easily be moved around a network
- Models 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 move software running on GMSEC onboard to run under cFE
- Demonstrates beginning step to transform missions from central control to distributed control via self-managing software







via Berkeley & Wallops Ground Stations (UDP)

via DSN & McMurdo Ground Stations

via TCP/IP

CHIPS – Cosmic Hot Interstellar Plasma Spectrometer
ST-5 – Space Technology 5
DC – Data Center
ASIST – Advanced Spacecraft Integration and System Test

Extended Efforts

- GMSEC to used on SDO, GLAST, LRO
- GMSEC providing framework for C3I work in the Constellation Program
  - Will be used for ground and constellation of laboratories
- Two recent follow-on 3 year awards from AIST ESTO call for proposal to extend ST5 efforts
  - *An Inter-operable Sensor Architecture to Facilitate Sensor Webs in Pursuit of GEOSS*
    - *Key topic – Interoperability and demonstration of service oriented architecture for space missions and sensor webs*
    - PI: Dan Mandl - 3 year effort
  - *Using Intelligent Agents to Form a Sensor Web for Autonomous Mission Operations*
    - Key topic distributed mission control
    - Extend effort depicted on slide 16 in which ST-5 components turned into mobile agents for use onboard spacecrafts with GMSEC/CFS
    - PI: Ken Witt/ISR Co-I Dan Mandl/GSFC – 3 year effort

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Extended Efforts

- Goddard Institute for Systems, Software and Technology Research (GISSTR) contract effort being applied to extend ST5 effort by Institute of Scientific Research (ISR)
  - Building GMSEC compliance tester for new components
  - Help to synergize other ESTO awards with above mentioned awards
  - Integrate ROME in collaboration with Capitol College into TRMM, GLAST and MMS
- West Virginia Challenge Grant (set-aside) to be applied to develop Sensor Modeling Language (SensorML) schemas for follow-on SOA efforts
  - SensorML schemas will describe sensor capabilities and once put in online registries, will enable discovering of those capabilities on the Internet
- Open Geospatial Consortium (OGC) ongoing testbed effort OGC Web Services 4 (OWS-4) June 2006- December 2006
  - 200 member organization of OGC
  - 40 organization participating in OWS-4
  - Sensor Planning Service (SPS) one of key services being demonstrated with EO-1

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Acknowledgements

- Additional info at: eo1.gsfc.nasa.gov
  and ase.jpl.nasa.gov
- Other Team Members:
  - GSFC: Jerry Hengemihle, Scott Walling & Bruce Trout (Microtel), Jeff D'Agostino (Hammers), Seth Shulman (Operations Lead, Honeywell), Lawrence Ong (SSAI), Stephen Ungar (EO-1 Scientist), Thomas Brakke
  - JPL: Steve Chien (ASE Principal Investigator), Rob Sherwood (ASE Experiment Mgr), Daniel Tran (Software Lead), Rebecca Castano (Onboard Science Lead), Ashley Davies (Science Lead), Gregg Rabideau, Ben Cichy, Nghia Tang
  - Interface & Control Systems (ICS): Darrell Boyer, Jim Van Gaasbeck
  - Univ. of Maryland: Rob Sohlberg (Wildfire Sensor Web)
  - Univ. of AZ: Victor Baker, Felipe Ip, James Dohm
  - ASU: Ronald Greeley, Thomas Doggett
  - MIT LL: Michael Griffin, Hsiao-hua Burke, Carolyn Upham

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Acronyms

- ASE – Autonomous Sciencecraft Experiment
- ASIST – Advanced Spacecraft Integration and System Testing
- ASPEN – Automated Scheduling Planning Environment
- CASPER – Continuous Activity Scheduling Planning Execution and Replanning
- CMS – Command Management Systems
- MOPSS – Mission Operations Planning and Scheduling Systems
- SCL - Spacecraft Command Language

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Goddard Space Flight Center

NASA

Backup

25

Goddard Space Flight Center

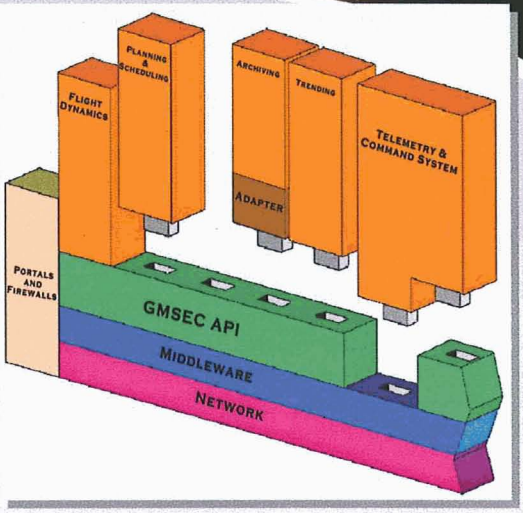
NASA

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

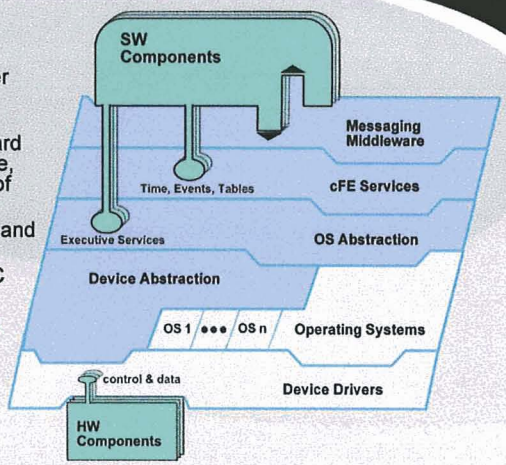


26

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

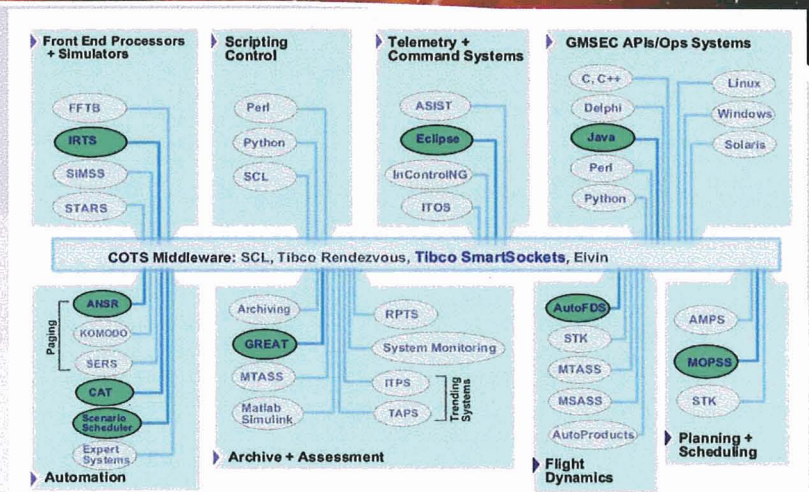
cFE provides a framework that simplifies the development and integration of applications

- 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



27

Example of Rapid Mission Configuration Using GMSEC Interoperable Catalog Components



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

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