NASA Earth Science Mission Control Center Enterprise Emerging Technology Study (MCC Technology Study)

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Agenda

- 2013 Study MCC Goals and Attributes
- 2014 – 2015 Study Formulation
- 2014 – 2015 Key Findings and Recommendations

2013 Study MCC Goals and Attributes

MCC Technology Study

Next Generation MCC Goals and Attributes

Goals

Lower Costs

- Efficient resource utilization
- Common reuse of services and tools
- Reduced operating staff requirements

Adaptive Architecture

- Easily incorporate changing mission portfolios and operational needs
- Common services and standards and Service Oriented Architecture (SOA) processing
- Support collaboration, data sharing, common tools and algorithms
- Flexible to accommodate changing partners & capabilities as missions come and go

Maintain Cyber Security

- Incorporate Agency standards and req'ts
- Use appropriate level of protection needed for missions
- Understand the evolving threat

Key Attributes

Processing Virtualization

- Reuse and flexible movement of processing software among IT resources. (Server/Client architecture
- Common Services (cloud storage, processes, collaboration

Interoperability

- Infrastructure Standards
- Integrated Network Services (provided by NASA Common Service Office/NASA Integrated Communications Services (CSO/NICS)

Automation

- 24/7 to lights out ops
- Flexibility of Operations Tempo
- Automated alerting (provided by CSO/NICS)

Technology Refresh

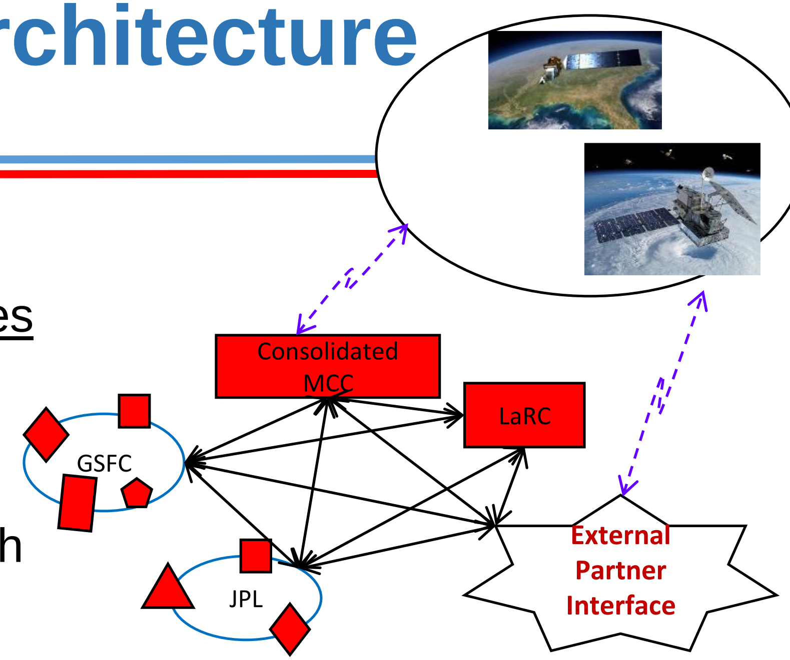
- Cyber refresh to maintain cyber security
- Increase system cyber protection

2014 – 2015 Study Formulation

MCC Technology Study

MCC Enterprise Architecture

VISION: A NASA Earth Science Mission Control Center (MCC) Enterprise Architecture that enables the efficient and secure operations of all current and future NASA Earth Science missions, and enables the delivery of high value science products and mission operations services to Earth Science mission stakeholders.



ENTERPRISE ARCHITECTURE MISSION: The mission of the NASA Earth Science MCC Enterprise Architecture is to provide a common, robust baseline capability to support the functionality and services common across Earth Science mission operations. Key architecture attributes include operational automation and processing virtualization to lower operating costs, an interoperable infrastructure (e.g., standards, network connectivity) to accommodate requirements / system diversity and change, and cyber security. The Enterprise Architecture is envisioned to provide common services and tools based on open interfaces, and provide data, processes, and computing resources to enable reuse, upgrades, resource sharing, mission customization, and collaboration.

MCC Technology Study Charter

- To identify emerging trends in technology, requirements, and other areas which will impact how we build ground systems and operate missions over the next 5-15 years.
- To identify those trends for which early study or development funding could increase the likelihood of their use and benefit to our future mission efforts.

- To raise awareness of the many factors affecting our future mission operations vision and the need to understand how “the rate of change” must affect our long-term thinking.
- To recommend steps to prepare for MCC capabilities envisioned for 2020 addressing new kinds of missions such as small satellites, hosted payloads, and advances in UAVs and in situ sensors.

It is not . . .

- A definition of a future MCC ground system architecture
- A recommendation of ESD-wide or Agency-wide new practices and approaches

Observed Trends and Guiding Principles

Observed Trend: Mission Operations is gaining visibility as a key mission cost element:

- NASA Technology Roadmap, TA11 to provide more science functionality
- NASA 2014 Technology Capabilities Assessment Team (TCAT) finding that mission operations take 20-30% of mission costs (not 10%)
- European Space Agency commitment to "Common Core" ground system software
- DoD 2014 Defense Authorization Act (default is shared vs dedicated MCC)

Guiding Principles:

Create flexibility to:

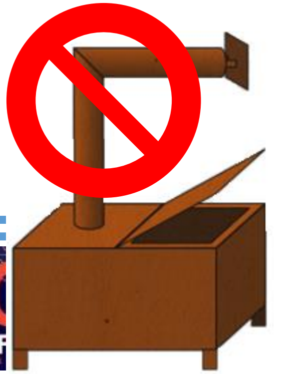
- Accommodate diversity rather than one-size fits all and provide options within a common baseline
- Enable continual evolution of capabilities

Enable extensibility so as to:

- Increase the value of mission operations capabilities more than just reducing the initial implementation cost (e.g., to be able to extend mission life).

Provide incentives to:

- Leverage a common baseline rather than dictating standard solutions
- Encourage, enable and reward collabo-ration, sharing, leveraging best practices
- Avoid vendor/product lock-in



Bottom Line: Develop smarter reusable/reconfigurable MCC components to lower overall mission development and operations costs and enable a greater emphasis on science.

"… I was not happy because they came in with another satellite program that was going to come out of Schriever Air Force Base with another standalone ground system. I'll tell you today everybody in this room, especially blue-suitors here today, we're not gonna put a new ground system on Schriever Air Force Base. That's not gonna happen. We have too many. The only ground system we're gonna put on Schriever Air Force Base next is gonna be a common ground system . . . We have spent hundreds and hundreds of millions of dollars in standalone ground systems; we're gonna have one squadron out there with--if we keep going down the path, we'll have five separate ground systems to operate five separate satellites. It's the dumbest thing in the world and it doesn't enable us to get into the future. We have to get to a common ground system and we're gonna get to a ground system and we're gonna get to it one way or the other. We cannot fail in this endeavor. So if you're an industry partner and you come to me and you decide that you're [not] gonna recommend a common ground system to me, it is not gonna go well--if you don't have a common ground system, it's not gonna go well. . . . We need a common ground system."

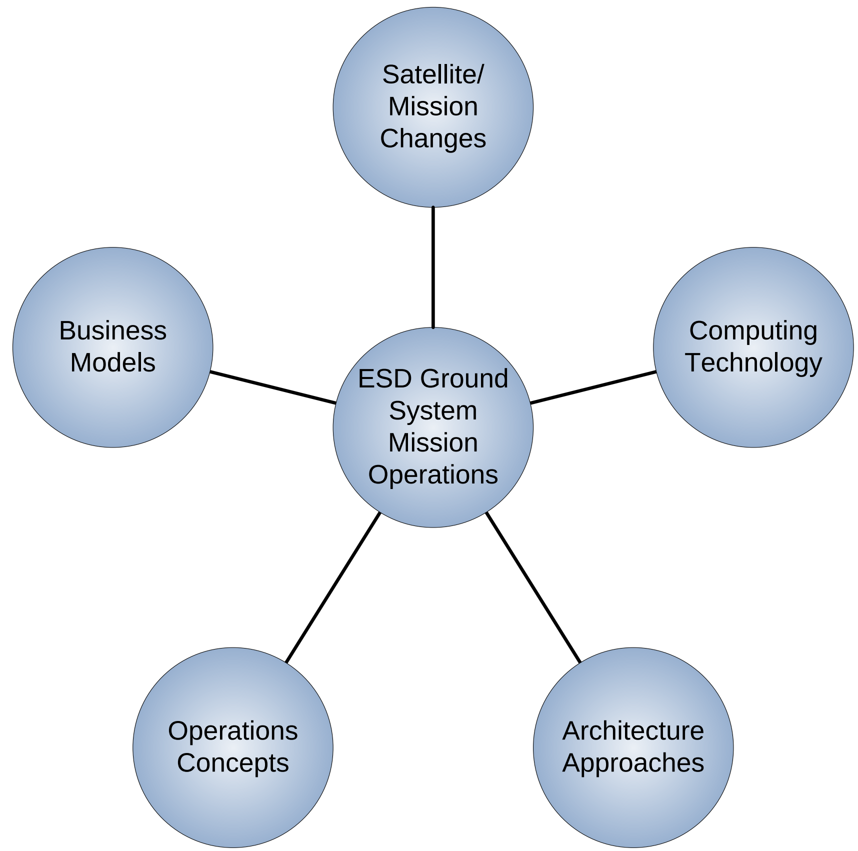
http://www.afspc.af.mil/library/speeches/speech.asp?id=757

MCC Evaluation Parameter Space:

Factors Influencing Future Mission Operations Planning

Highlights and examples of trends:

- Satellite/Mission Changes
  - Smallsats/constellations scale ops 10-100s of s/c
  - More joint missions w/shared ops responsibility
  - Smart sensors, more autonomous ops
- Computing Technology
  - Reconfigurable components and adaptable networks enable virtual MCC (zero-footprint)
  - Cloud services/virtualization enables 'anytime/anywhere' access to data for control
  - Security challenges need validation
- Architecture Approaches
  - Common software services based on standard interfaces enable cost effective reuse, upgrades
- Operations Concepts
  - Increased autonomy in both satellite and payload control functions
  - Expert systems assist human operators with real time anomaly assessments
- Business Models
  - MCC development options based on a suite of solutions enabled by common software and virtual processing from traditional dedicated solutions to multi-mission or multi-center facilities, to hosted payloads, to out-sourced MCC, MCC as a service, etc.



Backup slides include the set of parameters considered for each factor and how they change the current MCC models

Use Case Scenario Gap Analysis

Dimension	Use Case Scenario		
	Hosted Payload	Small Satellites	Airborne Science
Assumed Environment	Science payload attached to a GEO telecommunications satellite	NASA center operating a cluster of 10s of small satellites for a science mission	Real-time science data delivery to customers and stakeholders
Example Mission Operations Leveraging Trends	Cloud-based command and telemetry operations, operators have “anytime, anywhere” access, data delivery using commercial links	Utilization of Zero Footprint Control Centers, secure Cloud-based data operations, use of commercial links for telemetry and commanding	Citizen scientist chaining information for air, space, and ground assets
Management Gaps	Procurement issues and processes affect overall mission cost and schedule	Cost points for mission control applications	Distributed identity management systems, international data/asset sharing, trusted information ingest
Technology Gaps	Data packaging compatibility with commercial transponders	Gaps in data standards, command encryption protocols, Cloud-based virtualization & data operations	Cross-platform planning & tasking services, real-time comms between air, space, and ground, in-flight reconfigurability

2014-2015 Key Findings and Recommendations

MCC Technology Study

Key Findings

Principles

- **Approach the architecture as a system:** There are many, many factors that together should affect our final mission operations and system design decisions.
- **Use the best of the old and the new while reducing costs:** We cannot simply discard our current infrastructure and capabilities – we must plan to leverage our heritage and move deliberately towards our new goals taking advantage of new capabilities.
- **The only constant is change:** Work with changing technical capabilities to respond to the high rate of change in both space data systems requirements and operations concepts.
- **The architecture must be flexible across many domains:** New systems will combine aspects of multiple existing approaches used in a more versatile open-system approach that leverage appropriate new technologies.
- **Incentivize for new solutions:** Encourage the creation of new flexible systems to meet the growing breadth of common needs across our new missions.

Themes

- **Lower cost and ubiquitous access:** Innovative MCC concepts and low ops costs can become mission-enabling criteria, especially combined with small satellite and hosted payloads.
- **Internet of Things:** Data from new internet-connected sources (space and ground-based sensors / equipment / facilities) will help inform mission ops planning and execution.
- **Use of Standards:** In-depth analysis and prototyping is necessary to influence and take full advantage of new standards in order to achieve low cost consistency across system development and operations.
- **Accounting for the Rate of Change:** Requirements, cost-points, technology, business models, and operations concepts are all changing rapidly…plan for continuing change.
- **Development of Use Cases:** Mission ops concepts captured in use case scenarios are effective in understanding needs and evaluating new MCC architecture requirements and technology investments.

Summary of Recommendations

- The team identified three Key Recommendations to help evolve NASA Earth science mission control systems towards the MCC Enterprise Architecture:
  - Actively participate in mission operations “Community of Interest” activities to represent Earth science interests
  - Invest in new technologies to benefit Earth science missions through improved mission operations concepts
  - Devise a capability for experimenting and validating advanced mission operations technologies and concepts

where the Enterprise Architecture includes:

  - a common, robust baseline capability across mission operations, comprised of common services and tools to enable reuse and customization, and
  - an interoperable infrastructure enabling process virtualization, automation, and cyber security

Mission Operations Community of Interest Participation

- The key benefit of a Community of Interest is to support collaboration, and share knowledge and strategies to address common mission operations challenges.
  - NASA's Mission Operations Strategy Team (TCAT follow-on) or the NASA Mission Operations System Strategy Group that advises NASA on CCSDS mission operations strategy.
  - CCSDS: New Planning & Scheduling standards working group
- Suggested study areas that will impact Earth science missions and operations concepts:
  - Emerging mission operations standards for handling future changes
  - Small satellite data handling standards
  - Techniques for fleet management of satellite clusters
  - System of Frameworks concepts to support mission operations

Technology Investments to Improve Earth Science Mission Operations

- Develop, evaluate and evolve new technologies that would uniquely benefit ESD's ability to respond to mission and technology trends.
- Suggested technology topics include:
  - Advancing near real-time mission planning and sensor tasking
  - Developing expert tools for virtual operations
  - Leveraging the Internet of Things into space and ground systems, demonstrating strategies to manage security challenges and investigating technology to find specific data to detect events and enable on orbit sensor tasking

Experiment and Validate Advanced Mission Operations Concepts

- Collaborate across SMD and NASA to consider feasibility of test environment(s) to exercise new operations concepts and supporting technology.
  - Testbeds may include ground-based prototypes and on orbit resources (e.g., an ISS test payload, an end-of-life mission, or a dedicated cubesat).
  - Testbed would enable designers to upload and test new flight software or exercise new protocols.
  - Mission planning teams could propose new capabilities, allowing a user to interact with a live spacecraft without impacting basic spacecraft health.
- Suggested challenges to test and mature mission operations concepts include:
  - Demonstrate integrated Cloud services
  - Explore and validate cyber security strategies
  - Rapidly configure modular MCC components
  - Prototyping a Zero Footprint Control Center
  - Infuse mission operations improvements into spacecraft and instrument design

Conclusion

- The study team believes that the Earth Science science and mission plans of the future can benefit from involvement and investment in mission operations advances today

Backup

MCC Technology Study

Evaluation Parameter Space

- Satellite/Mission Changes
  - Small Satellites
  - Satellite Constellations
  - Satellite Networking
  - Commercial Hosted Payloads
  - Rapid Mission Development & Deployment
  - New Mission Types
  - Onboard Autonomous Tasking
  - Mission Data Requirements
- Computing Technology
  - Virtualization
  - Cloud Technology
  - Software Defined Networking
  - System Monitoring & Automation
  - Model-based Capabilities
  - Security
  - Standards
  - Internet of Things
  - Remote/Mobile Access
  - Disruption Tolerant Networking
  - Data Analytics
  - Device Consolidation
- Architecture Approaches
  - Common Software Solutions
  - Use of COTS and FOSS
  - Service-based Capabilities
  - Open System Architecture
  - Enterprise Architecture
  - Zero Footprint Control Center
  - Advances in System Development Tools and Processes
- Operations Concepts
  - Changing Support Needs
  - Changing Personnel Roles
  - Changing Environment
- Business Models
  - One-Off Solutions
  - Common Facility
  - Common Software
  - Multi-mission, Incremental Addition
  - Multi-mission Enterprise
  - Multi-center Commonality
  - European Budget Reduction Business Model
  - Outsource
  - Hosted Payload

Evaluation Parameter Space
Satellite/Mission Changes

Study Case	Reason for Choice	Disruptive Nature
Small Satellites	Moving from academic demonstration to science and technology operational missions	Mission operations stressor due to mission cadence, comms and ops support stressor due to number of active satellites
Satellite Constellations	Government and private sector both designing satellite constellations for missions	Need to scale operations support from 10s of satellites to 100s of satellites
Satellite Networking	Satellite fleets being designed with cross communications capabilities	Flexible support drives the need for mission operational and data systems standards
Hosted Payloads	Commercial entities actively seeking to host science payloads to supplement normal business	Change to mission operations and data streaming models; government not in control of all data links and spacecraft bus
Rapid Mission Development & Deployment	Modular spacecraft as an architecture paradigm	Drives the need for MCC innovation and standards
New Mission Types	Satellites may be able to be revived and repurposed	Implies indefinite MCC support needs/repurposing
Onboard Autonomous Tasking	Migration of MCC functions to the spacecraft	MCC expert knowledge and decisions migrated to space
Data Requirements	New satellite/mission needs imply data systems support changes	Increased data volume, velocity, & variety; low-latency data product generation; data provenance & security

Evaluation Parameter Space Computing Technology

Study Case	Reason for Choice	Disruptive Nature
Virtualization	Use of virtual machines are commonplace technologies	MCC can switch support modes by changing the current virtual machine; new method for packaging and distributing software
Cloud Technology	Enabling technology for "anytime, anywhere" access to data and virtualized applications	MCC data, applications, and services are dynamic; modular mission architectures; security is a fundamental concern
Software Defined Networking	Decoupling the network control functions from the data flow functions to bring greater efficiency	Real-time adaptable networking control, especially between government and private networks; standards driven interfaces for network control
System Monitoring & Automation	A natural result of the desire to reduce the budget impacts of mission operations	Brings in the ability for support through machine learning and smart instruments to bring value added to minimal operations crews
Model-Based Capabilities	Models of mission and subsystem entities permit developing new operational efficiencies	Validation of command and operational sequences prior to attempting execution
Security	Major issue in considering new ways of designing the MCC, especially with Cloud-based technologies and commercial networks	Converting from closed government systems to commercial and open standards based systems will present many security challenges to MCC design

Evaluation Parameter Space Computing Technology

Study Case	Reason for Choice	Disruptive Nature
Standards	Standards are part of NASA's operating mode through CCSDS and other organizations	There is a need for new standards to support the evolving data communications and architecture concepts; small satellite data standards
Internet of Things	Next step in the evolution of the Internet's capabilities and operating modes	Smart devices adding value to data and providing services distributed anywhere there is connectivity
Remote/Mobile Access	Ned to support "anytime, anywhere" access on a variety of platforms	Movement away from fixed consoles and infrastructure; operators utilize personal computing platforms.
Delay/Disruption Tolerant Networking and Other Trends	Need to support intermittent connectivity, high channel error rates, and long delay-bandwidth products; support commercial data distribution channels	Need be able to provide ad hoc connectivity over commercial and government networks; intermix science data with commercial telecom data
Data Analytics	Open Data initiative, open standards, and data sharing require these capabilities	Need for long-term planning and management data, tools, and products
Device Consolidation	MCC hardware and software eventually need upgrades and replacements	Compatibility issues with new hardware and software due to rapid pace of change in the commercial world

Evaluation Parameter Space Architecture Approaches

Study Case	Reason for Choice	Disruptive Nature
Common Software Solutions	Meet the budget realities that will only be more constrained in the future	Need for enterprise approaches to MCC implementation and adoption of standards
Use of Commercial Off The Shelf (COTS) and Free and Open Source Software (FOSS)	New paradigms for mission control applications software development and distribution	Ability to import applications from other domains, need for application security review, plan for software obsolescence
Service-Based Capabilities	Entity design based on functions provided and services rendered	Ability to upgrade or add new capabilities to entities without reconfiguring the entire system
Open System Architecture	Standards-based architecture from the ground to the space-based instrument	Architecture becomes vendor agnostic, use of well-defined application interfaces
Enterprise Architecture	Mission control centers and applications software are becoming commoditized	Turnkey applications software, mission operations become a System of Frameworks
Zero Footprint Control Center Architecture	Availability of virtual, Cloud-based applications and data access	Mission operations software and data access becomes an “appliance” application
Advances in System Development Tools and Processes	New ways of interacting with personal computing devices and the applications they enable	Significant computing ability in a personal device, Cloud-based data access, “citizen scientist” participation, integration with the Internet of Things

Evaluation Parameter Space Operations Concepts

Study Case	Reason for Choice	Disruptive Nature
Changing Support Needs	Satellite design changes, adoption of expert systems and automation, new financial constraints	Increased autonomy in all phases of operations, single operators managing a fleet of satellites, distributed data gathering satellite clusters, smarter spacecraft require different operations
Changing Personnel Roles	New models for organizing personnel for mission control staffing	Changing roles, responsibilities, and skill mixes, managing satellite fleets and hosted payloads
Changing Environment	Changes in the communications, computing, architecture, and staffing drive a changing environment	Movement towards untethered mission support, virtual control centers, standard support and operations services

Evaluation Parameter Space Business Models

Study Case	Reason for Choice	Disruptive Nature
One-Off Solutions	Represents the traditional mission-specific paradigm for the MCC architecture	May be appropriate for specific mission classes with one-of-a-kind needs
Common Facility	Develop a landlord-tenant model for facility operations and maintenance	Need to be modular and reconfigurable to support multiple missions
Common Software	Develop a catalog of common software applications for MCC support	Tension between common software, new developments, and mission-specific
Multi-Mission, Incremental Addition	Use a common core infrastructure for multi-mission support and augment as necessary	Will force common approaches to be taken for MCC operations; may also need budget resilience for “down” times
Multi-mission Enterprise	Adoption of an enterprise approach over a mission-specific approach	Will force new operational, acquisition, and funding approaches
Multi-center Commonality	Use commonality in mission operations across multiple ESD mission control centers	Can force more widespread adoption of standards, open systems approaches, and common MCC elements
European Budget Reduction Business Model	Different funding paradigm for traditional US government approach	Fix ground system budgets at a lower amount than traditional to force improved operations approaches
Outsource	NASA no longer in total control of the mission control center	Mission operations are treated as a procured, commodity service
Hosted Payload	Major differences from the traditional mission operations approach	NASA no longer prime on launch, rapid I&T cadence, need to interact with commercial control and data centers