Integrated Large-Scale Modeling and Simulation at JPL: A Recent Appraisal

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Workshop on the

Frontiers of Computational Science and Engineering at Caltech: CSE@CIT

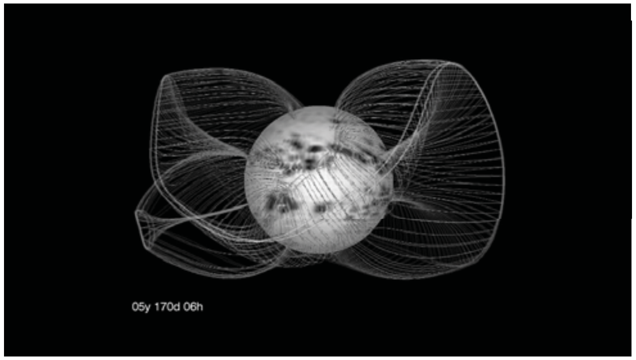
R&TD Initiative: Computing, Modeling, Simulation & Visualization

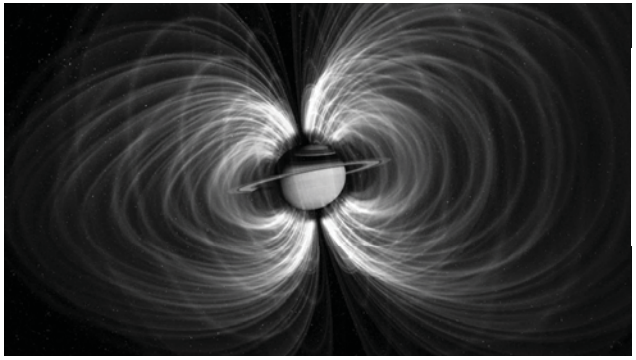
Initiative Long Term Objectives

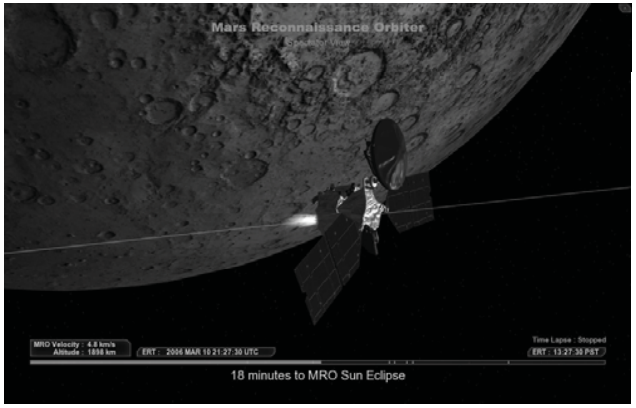
• Develop information system frameworks, tools, and libraries that dramatically enhance interoperability, reuse, and portability of models and simulations for science, engineering, and public engagement

Key achievements

• Integrated framework for multiple model-services developed; pulls all elements together to provide key services to applications; basis for coordination with MBED, Team-X, MSL, JUNO, MO&DA. High >1yr ROI demo'ed.
• Library of Reusable Models based on adaptation of mature OODT prototyped, demonstrated, and now linked to main-stream Mission libraries. Over 72,000 models/600 hits/mon.
• Multiple visualization models/tools/translators developed and demonstrated for MER, Cassini, many others.



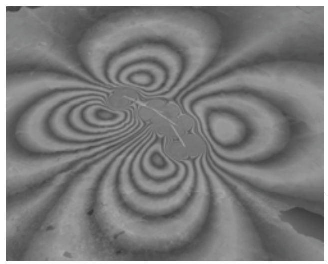




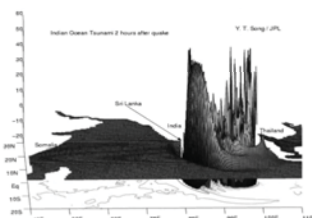
R&TD Initiative: High-Capability Computing for Engineering & Science

Science

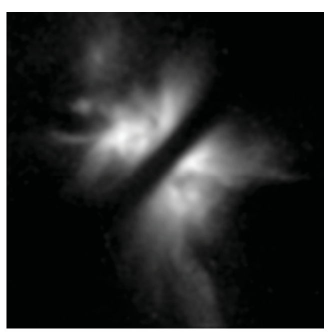
Advanced Lithospheric Deformation Modeling
PI: Jay Parker
InSAR



Earthquake-Tsunami Modeling
PI: Tony Song
Early Warning / Decision Support

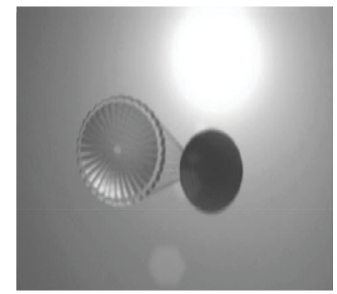


Protostellar Disk Analysis
PI: Neal Turner and Paul von Allmen
Spitzer

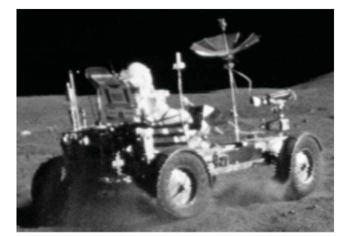


Engineering

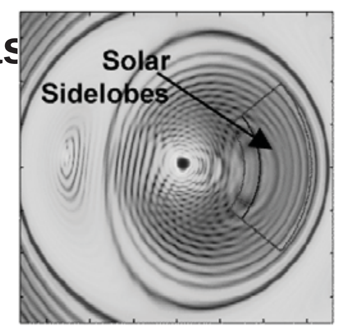
MSL Simulation Data Manager
PI: Bob Balaram
MSL



Lunar/Mars Charged-Dust Particle Interactions
PI: David Brinza
Lunar / Mars Lander Missions



Modeling of Complex Antennas
PI: Richard Hodges
Aquarius



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Current and Desired Future State of Modeling and Simulation at JPL

Models do not transfer easily or well across mission phases or projects; piecemeal validation of models

NOW

- New mission concepts are risk-managed and often incremental
- Experience is relied on to understand trades; a small number of point designs are developed
- Difficult to understand system behaviors are avoided, often via large margins
- "Test as you fly; fly as you test" - some tests may be infeasible
- Simulation-supported mission activity plan generation and validation

FORMULATION		APPROVAL	IMPLEMENTATION		
Pre-Phase A: Advanced Studies	**Phase A:** Mission & Systems Definition	**Phase B:** Preliminary Design	**Phase C:** Design & Build	**Phase D:** Assemble & Test / Launch & Operations	**Phase E:** Operations

FUTURE

- Initial validation of new mission concepts from models of new capabilities
- Systematic and thorough (quantitative) exploration of design trade space
- Targeted tests based on insights from simulations
- Validate models (assuming instrumentation) for continued and future use

Deep analyses are conducted of poorly understood (e.g., nonlinear) system behaviors

Models are shared among multiple missions, and are transferred from phase to phase; well-chosen experiments validate models

External Fact-Finding

- **Workshop**
  - A workshop was held at Caltech on March 31, 2006 to learn from external modeling and simulation experts from the following institutions:
    - Los Alamos National Laboratory
    - Caltech
    - USC Institute for Creative Technology
    - Sandia National Laboratory

- **Common challenges in Large-Scale Modeling & Simulation**
    - Model integration (what degree of coupling is needed / feasible)
    - Software integration (interoperability between codes and tools)
    - Portability of code (across platforms / upgrades)
    - Scalability (mathematical, computational, multi-scale modeling)
    - Verification (assessment of solution accuracy of computational models)
    - Validation (accuracy of simulation results as compared to experiments)
    - Reuse (model / code libraries)
    - Institutional best practices for model use across the project lifecycle

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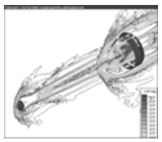
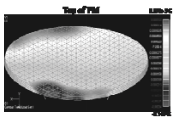
Near-Term Modeling & Simulation Tasks with Mission Impact

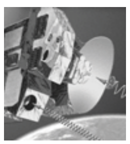
- Candidate tasks from Task Force mission investigations:



– **EDL - MSL and Beyond**
  - Terrain and sensor modeling to ensure that image-based navigation methods for pinpoint landing and hazard avoidance will work on a variety of terrain and lighting conditions



– **Large Apertures**
  - Test-analysis verification of existing cryogenic actuated mirror; demonstrate fast turn around time for design changes



– **Earth Observing Instruments**
  - Development of assimilation capabilities with support of current OSSE team to upgrade radiative transfer model to handle UV and visible

Near-term multi-mission applications

– **Venus Exploration**
  - Modeling behavior of multi-component systems (parachutes, balloons, lanyards) through multiple activities on descent will enhance proposal competitiveness

– **Comet Core Sample Return**
  - A program to develop system-level models of S/C - sampling subsystem dynamic interactions during sampling process

Near-term proposal opportunities

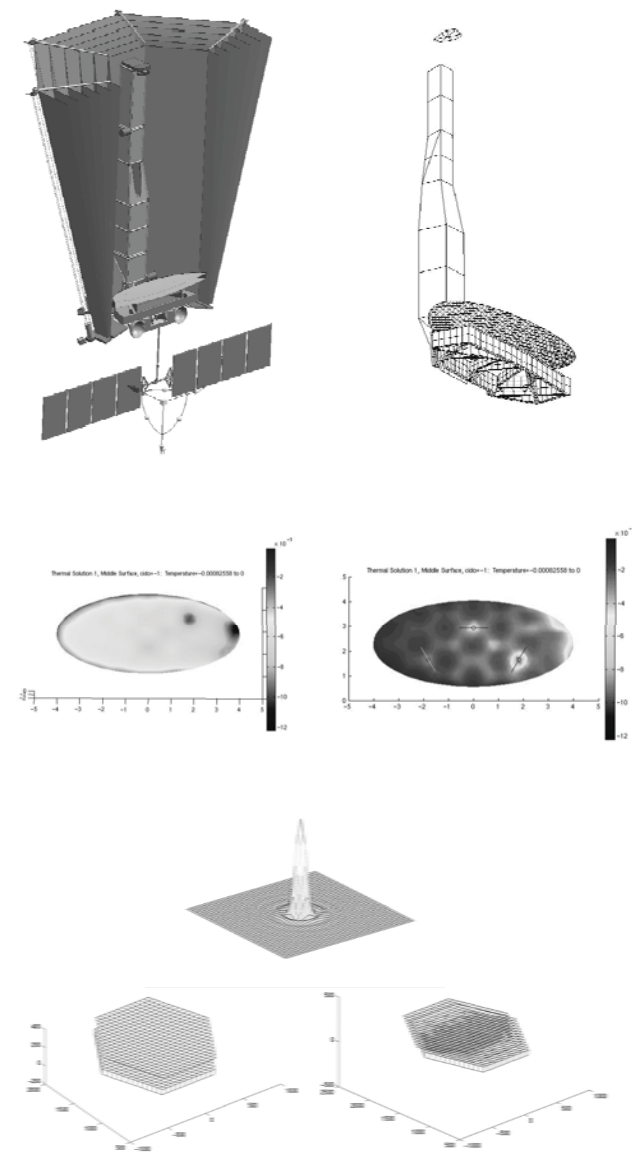
– **JUNO**
  - Improved performance and fidelity of radiation effect models on instruments, spacecraft, and telecommunications

– **Lunar Impactor (follow-on)**
  - Model plume and effects of SMART-1 impact in Aug 2006 and validate impact event models

Future proposal opportunities

New R&TD Task: Integrated Modeling and Simulation of Large Apertures (IMSLA)

- Integrated tool operates on single model for thermal, structural, optical analysis and controls
- Fully adaptive transient analyses, coupled with structural, optical metrics
- Both serial and highly parallel implementation, model size limited only by available parallel computing resources
- Open architecture to accommodate any analysis domain and rapid proto-typing of new features
- Double precision for all floating point data
- Data-driven design, fully-parameterized code base
- Integrated tool with built-in design sensitivity, efficient optimization strategies



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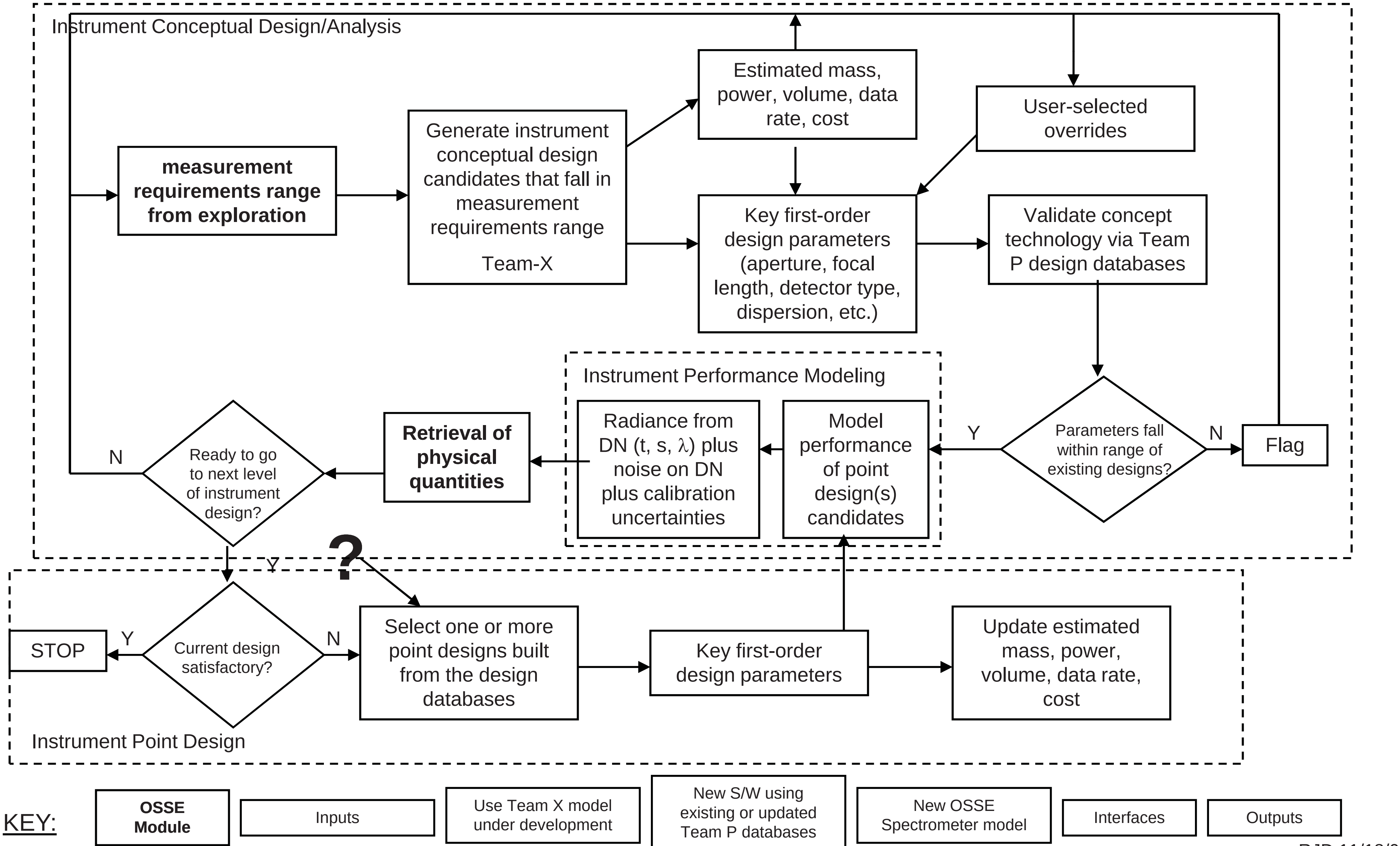
New R&TD Task: Observing Systems Simulation Experiments (OSSE)



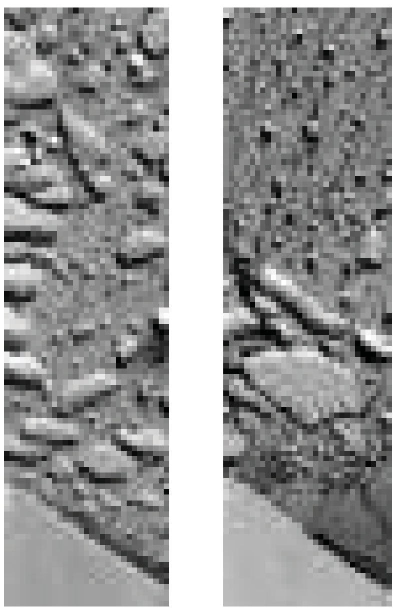
RJD 11/18/06

Onboard Science Data Analysis

Objective

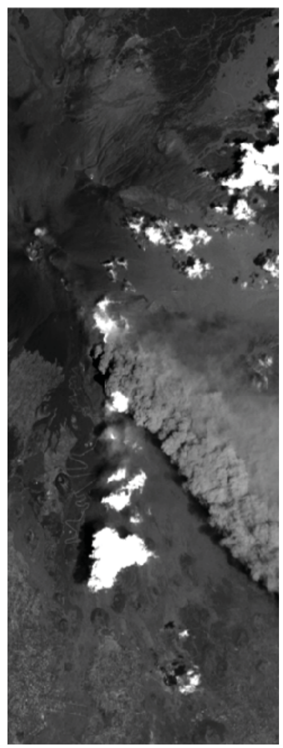
To increase science return by determining high priority science data for downlink and identifying dynamic science events

Change Detection



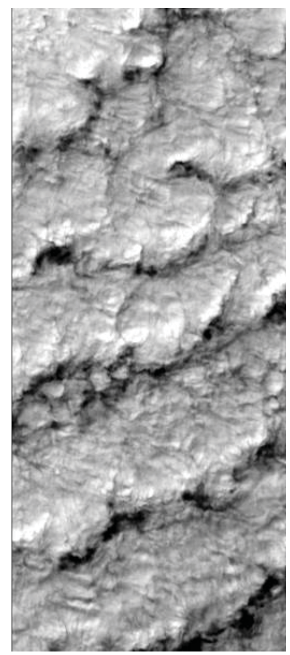
Sea ice breakup

Feature Detection

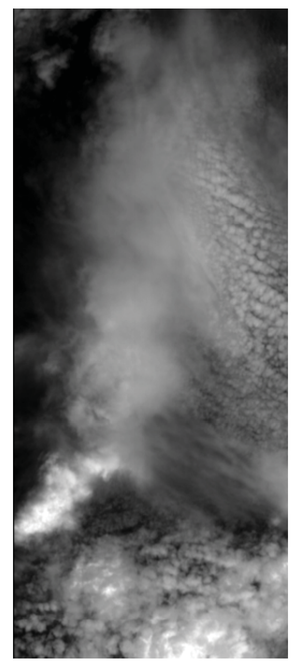


Volcanic eruption

Data Quality Control



Cloudy



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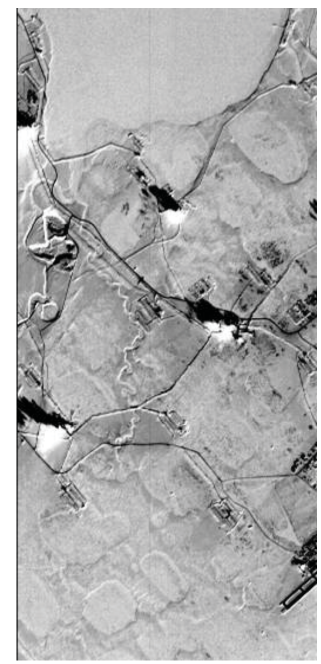

Clear

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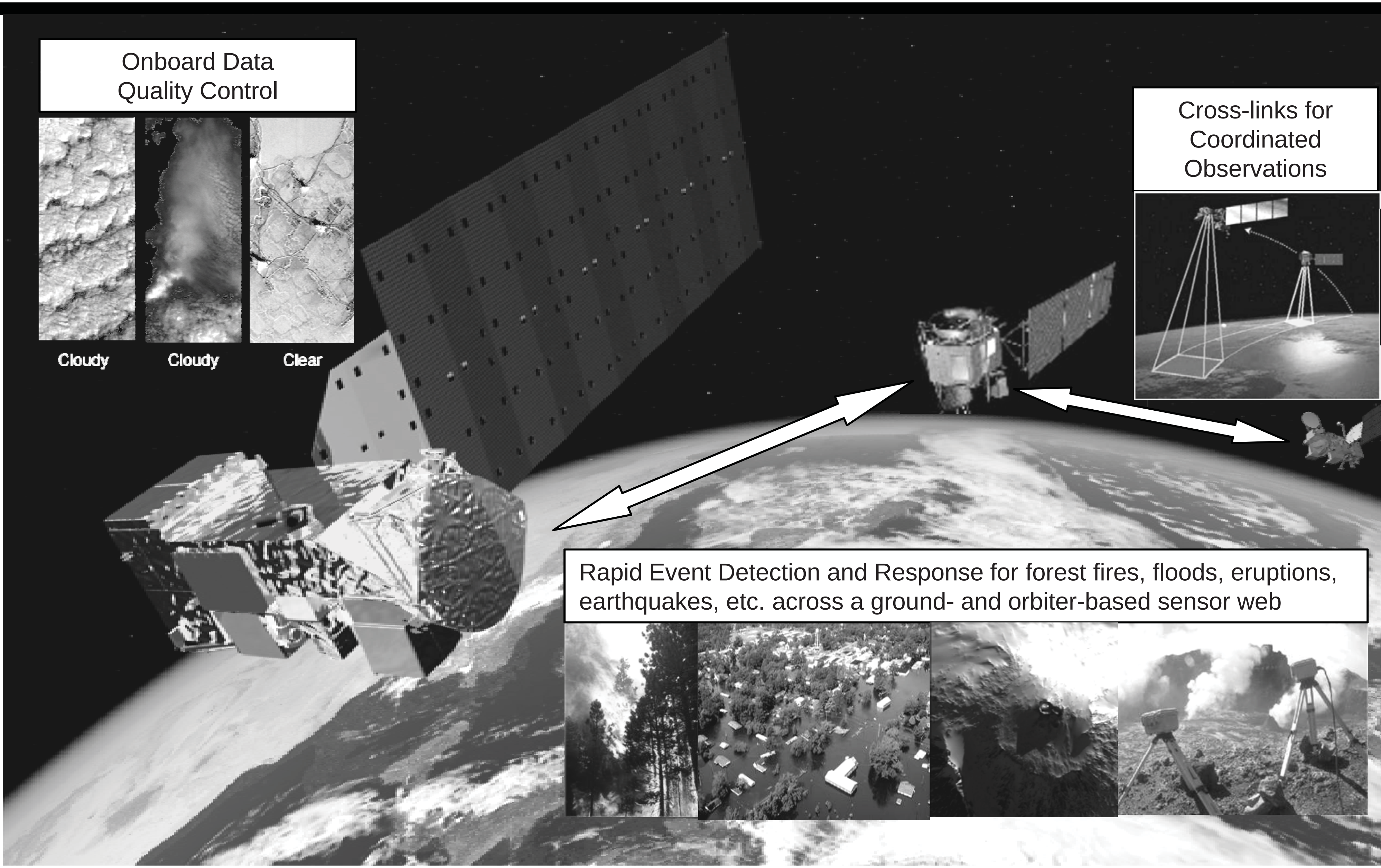
Space Networking Scenario: Coordinated Science Operations



RJD 11/18/06

What are the outstanding computational needs and challenges in this [your] field?

Design Exploration

- Determining the optimality of a proposed system design, along with design parameter sensitivity
- "Visualization" techniques for search methods in design optimization
- Making design exploration tools friendly to the end-user (system engineer or domain expert)

Physics- Based Modeling

- Most large apertures can not be fully tested on the ground and rely on simulation, requiring a thorough quantification of margins and uncertainties using systematic parameter variation and optimization techniques
- Current commercial tools are black boxes, they can not be extended or customized and are hard to integrate with in-house tools

Model Validation

- Validation of models (e.g., EDL) for space-unique environments. How do you validate something that can only be tested in space, and where you don't get the space system back for testing after the fact?

Computing Architectures

- Need high-performance distributed flight computing architectures optimized for memory-intensive applications, and exploiting alternate approaches to fault tolerance

Can they be stated in general terms, and possibly be very similar (or even isomorphic) to challenges faced by other disciplines?

Design Exploration

Certainly, many design optimization techniques are general-purpose, but we are lacking the ability to predict which techniques (or family of techniques) is most likely to provide leverage in a given domain

Physics-Based Modeling

- Structural dynamics, CFD, electro-magnetics, and multi-body dynamics have similar issues
- Most definitely since they contain the core elements common to geophysical modeling

Validation of Models

- The nuclear weapons community is typically faced with similar problems

Computing Architectures

- Extreme aspects of space environment (radiation, temperature, power) have been obstacles to leveraging industry solutions

What are some specific techniques/tools/results/experience from your field which you suspect may be usable elsewhere?

Design Exploration

Search techniques, gradient-based approaches, simulated annealing, evolutionary computing…

Physics-Based Modeling

- Parallelization techniques, assuming that a client server architecture and inherently parallel data structure is in place
- Element libraries if finite element or finite volume techniques are used, assuming that an API for elements is in place
- Scripting capability of high level algorithms (Matlab, Python) which allows easy customization and integration of other software packages

Validation of Models

- Nuclear stockpile stewardship, commercial space systems, MDA, ...

Computing Architectures

- Necessity has forced finding practical solutions to e.g., autonomous space systems applications, despite impoverished flight computing environments

Are there any such in other fields, which you think you could use?

Design Exploration

Possibly, although the general techniques are fairly well-known.

Physics-Based Modeling

- CACR's ASC work in CFD and Fluid-structure interaction
- Any numerical libraries, eg PETSc
- Any element and material models from universities and other NASA centers
- We are incorporating some lessons learned from JPL flight projects algorithm development

Validation of Models

- Unknown. A survey should be performed

Computing Architectures

- DoD likely facing similar challenges for space computing applications

What do YOU think are the core intellectual issues in the emerging new scientific methodology based on computation?

Design Exploration

- Of greatest value would be an ability to analyze the structure / topology of a given design space to predict which techniques are likely to be most useful.

Physics-Based Modeling

- Provide a software platform for multi-physics which is general purpose, can be extended easily, can handle small and large models and is scalable on parallel hardware
- Verification of in-house software compared to commercial software
- Sustainability of in-house software (maintenance and quality assurance) compared to commercial software
- Better education in computational mechanics and numerical methods, critical assessment of simulation techniques is missing in engineers fresh from school

Validation of Models

- Correct sensor placement with minimal impact on the overall space system design. Using sensors for double or triple duty, eg, validating more than one model. All while conserving overall mass and resource utilization impact to space system design.

Computing Architectures

- Algorithm-based approaches to fault tolerance -- detecting and managing errors informed by knowledge of intent and nature of the computation

Other strategic issues you consider important in this context?

Design Exploration

- Concurrent science-engineering exploration and design is key.
- We don't know yet whether we can use this system eventually for [detailed] design, because a lot depends on how well one can model performance.

Physics-Based Modeling

- Infusion of new technologies beyond the commercial offerings is difficult in a production environment like JPL.
- Continuing education of mid and end career engineers in new simulation techniques is necessary.
- Integration of components with the right level of maturity and fidelity is critical.

Validation of Models

- A model is considered validated when it could be used as a one for one substitute for a physical testbed (which doesn't usually exist in the usual context in this situation).

Computing Architectures

- Space computing, with its special requirements, is a niche market for the computing industry

End of File