Distributed Measurements and Spacecraft Missions

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23 July 2018

ESTO
Earth Science Technology Office

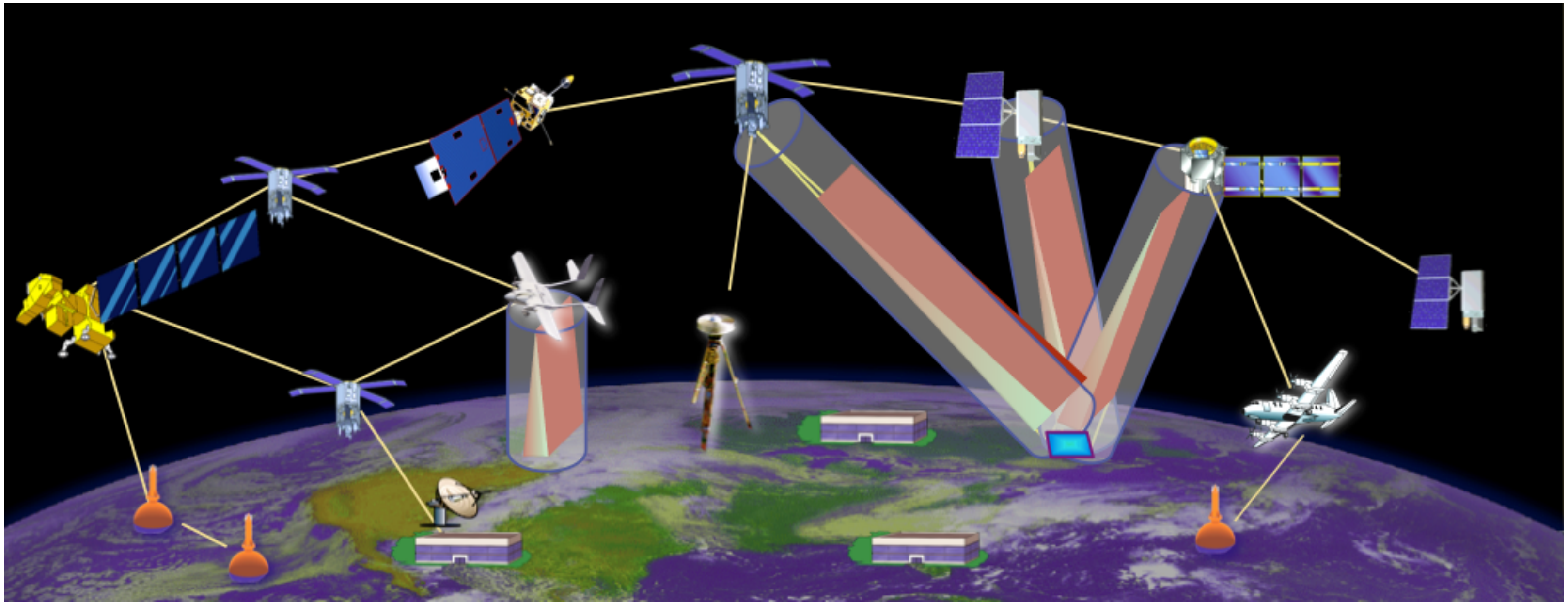
Outline

- Recent technology advances have yield new opportunities to research and applied sciences

- What can we do with the new technology that we couldn't do before?
  - New concepts for observing strategies

- What's it take to be able to realize these advances and opportunities?
  - Sociology
  - Develop New Technologies and Integration Approaches

Distributed Observing System



- Technology advances have created an opportunity to make new measurements and to continue others less costly
  - **Smallsats** equipped with steerable, science-quality instruments
  - **Machine Learning** techniques permit handling large volumes of data
  - New **computing** capabilities (GPU, Neuromorphic) for on-board data analysis
- New Observing Strategies
  - Data integrated from multiple vantage points
  - A more comprehensive picture of the physical process or natural phenomenon
  - Not all measurements are of equal value (not just global mapping missions)

Enabling Earth Science-Examples

- Improved Models that can Drive Observations
  - Integrate models with in situ, airborne and orbital instruments
  - Continuously running models direct the observation system in collecting data
- Real-time targeting of transient and transitional phenomena
  - In situ triggering of observing system
  - Train configuration prolonging observation of an event
  - Viewing an event from multiple angles
  - Autonomy in focusing the observational system on the event
- Coordinated arrays of sensors (station keeping)
  - Reduce error with statistics
  - Improve resolution with multi-node instruments in phased arrays
  - Viewing of phenomenon from multiple angles and directions

DOS Candidate Science Customers

- Hydrology
  - River flow and flooding
  - Snow fall in 3D
  - Aquifer degradation
- Weather
  - Extreme precipitation events
  - Convective weather events and lifecycle
- Cryosphere
  - Glacier change events
  - Sea Ice changes
- Urban Air Quality Events
  - At high vertical and horizontal and temporal resolution
- Biodiversity
  - Migrations
  - Invasive species
  - Transitional and transient daily phenomena
- Solid Earth and Interior
  - Landslides
  - Plate movement
  - Volcanic activity
  - Interior magma movement

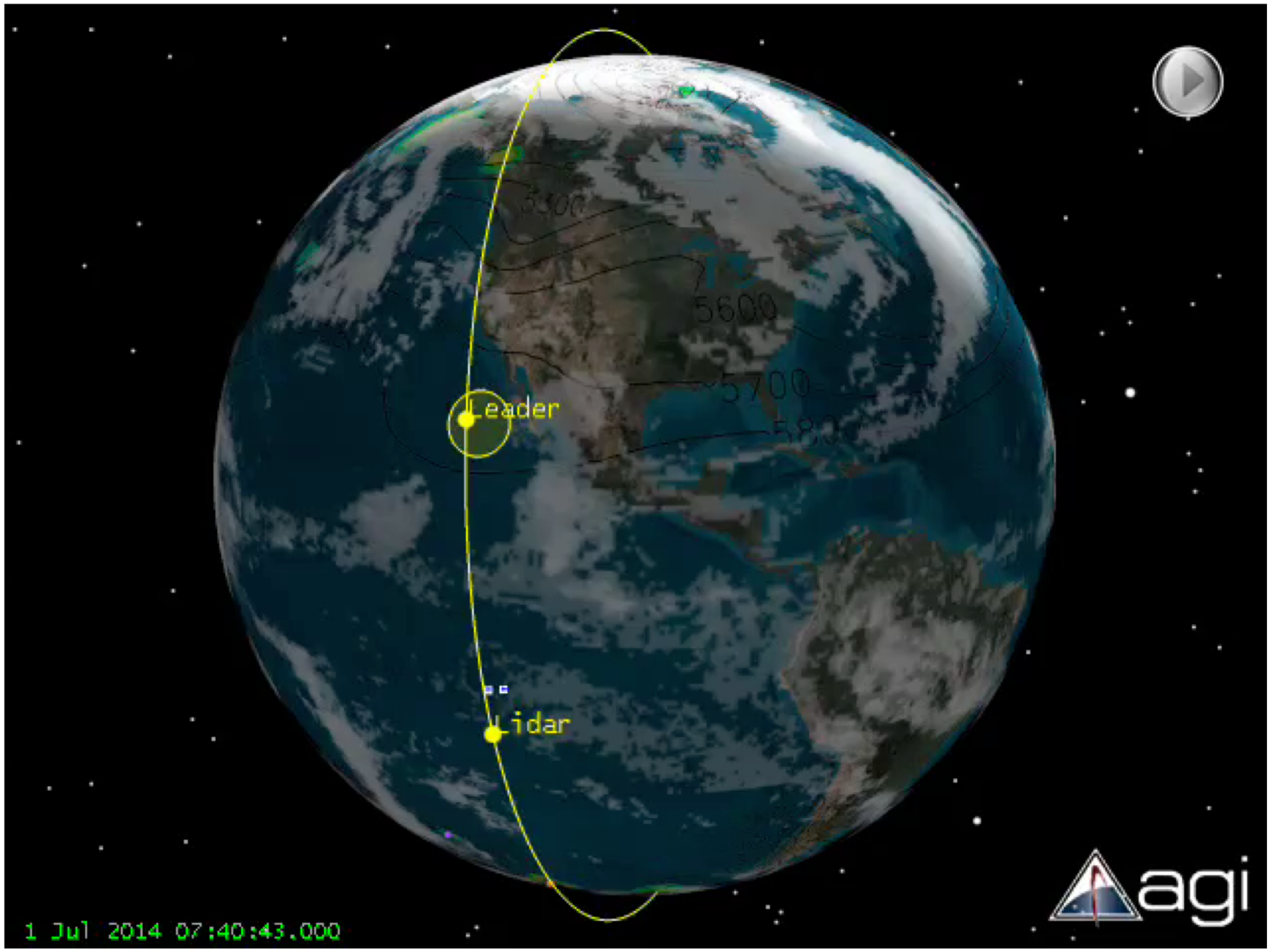
Potential Concept of Operations: Adaptive targeting with a wind lidar

Movie depicts mission CONOPS -- wind lidar working with an operational atmospheric model's first-guess field that identifies regions that are sensitive to forecast error

Spacecraft will slew toward sensitive regions and lidar is placed in a high data rate collection mode

"Leader" spacecraft is included to depict how optimization for cloud-free lines of sight could be performed

(Operational CONOPS would be more complex)



Primary Technology Needs

- Distributed Observing Strategy
  - Designing a complete architecture to create a unified picture of a physical process or natural phenomenon, not just a single mission
    - Redefine the concept of Mission
    - Forecast models as a measure of quality of understanding
    - In situ and airborne instruments as more than cal/val support
    - Integrate Non-NASA sources of data or relevant services
  - Command and control structures and tools
    - Scaling mission operations to the constellation level
    - Potential issues for traffic control in Low Earth Orbit
    - Realistic and useful computer security
    - High degrees of autonomy to be responsive to changing conditions
    - Reduce the current labor intensive operations
- Integrated Products Fusing Data from Multiple Sources
  - Precursor examples: A-train, CERES level 3
  - Techniques for continuous intercalibration
  - Continuously running research models leading to operational models

Capability Gaps

- Platforms
  - Steerable instruments with science quality measurements
  - Algorithms and control laws for steering instruments (internally and externally driven)
  - On-board processing to identify features, patterns and process complex commands
- Communications among Platforms with Low Latency
  - Improved ground station coverage and downlink capacity
  - Direct communications among platforms
  - Reduce the cost of operations
- Autonomous and Semi-autonomous Commanding
  - Control protocols and architectures
  - Integration of airborne, in situ and orbital instruments
  - Security
  - Goal-oriented mission re-planning
- Mission Design Tools
  - Systematic, not artisan
  - Model Based Systems Engineering
  - Estimate the value of science from different configurations
- Mission Operations Tools
  - Automated operations capable of managing hundreds of controllable platforms
  - Mission operations planning consoles permitting operator review of forecasted operations

Cultural Change is Needed

- Technology Community Resistance
  - Lack of familiarity and a new direction
  - Leisurely pace of technology development in Government environments
- Science Community Resistance
  - Perceived risk of new measurement techniques and unproven technologies
  - Lack of confidence
- Flight Community Resistance
  - Consider a mission to be an entire suite of observations of a phenomenon
  - New Mission Ops Model with autonomy and management
- Confidence must be built within the Science and Flight Communities
  - Conduct well designed experiments early and get a science team buy-in
  - Demonstrate components at earliest possible date and keep using them
  - Communications plan to reduce the lack of familiarity
  - INVEST experiments and demonstrations
  - Open conversation, not isolated experiments

ESTO Distributed Testbed

- Not a single facility, rather a collaboration among a wide range of participants
  - Each has something to contribute
  - Each could benefit by experimenting in the open (non-proprietary)
  - Emulated in situ, airborne and orbital assets
- Funded to conduct early-stage experiments and demonstrations
  - Competitively selected
  - Agree to commitment to making contribution available
- Governance
  - Self-managed, prioritzied and coordinated
  - Lifetime expected 5 years
  - Annual Review
- Types of testing initially
  - Remote operation of instruments among different parties at different sites
  - Deconflict commands and schedules
  - Block-chain distributed ledger applications
  - Protocol for quick reaction agreement to share facilities
    (think seconds instead of months)
  - Control and Monitor system needs
- Demonstrate some specific science use cases
  - Emulate several science missions with different science communities
- Elevate at least two nodes into space (Compete in INVeST Program)
  - Impact of latency, international agreements, etc.,
  - Perform experiments to debug, revise, estimate performance and demonstrate integration

Technologies to be Considered

- Autonomy in flight control and operations
  - UAV swarms have developed relevant capabilities
  - Automated ground stations (SSC, KSC)
- Security
  - Blockchain automated service contracts
- Mission Planning and Science Value
  - TAT-C (**MO4.R8.5)**
  - Joel Johnston's Modular OSSE (**TH3.R2.1)**
- In situ measurements
  - SoilSCAPE (Moghaddam, USC)
- Modeling
  - GSFC Land Info System (LIS) (Peters-Lidard, Kumar, Clark)
  - NASA NU-WRF
- Data fusion into a single data product
  - OLYMPUS metadata from data extractor (Huffer)

Backup

Studies: Assessing Science Value of an Observing System

- Recent and current projects
  - Weather OSSE (GMAO/McCarty, Bob Atlas)
  - Hydrology and Mass Change (GSFC/Peters-Lidard)
  - Snow (UMd/Forman) (w/Jared Entin)
  - General purpose modular OSSE (Johnson/OSU)

- Need for improvements to Science value assessments
  - Reduce cost and turnaround time compared to conventional OSSE
  - Interface with model-based engineering tools for mission design
  - Ensure simulation includes all data sources

- Study Objective
  - Definitize need statement for improving effectiveness of OSSEs to be used in 2017 Decadal Survey

Simulating Observations from Future Observing Systems

- An **Observing System Simulation Experiment (OSSE)** is an experiment designed to assess the potential impact of planned missions on Numerical Weather Prediction. OSSEs, now widely used, were pioneered at NASA by Dr. Robert Atlas.
- OSSEs help quantify the potential benefits of an observing system before it is designed, built and launched into orbit.
- Trade-offs in instrument or orbital configurations and methods of assimilating a new type of observing system can be determined by an OSSE and ultimately result in both time and cost savings.

•A **Nature Run (NR)** is a high resolution long integration from a state-of-the-art numerical weather prediction model.

•It acts as a proxy atmosphere for OSSE's from which synthetic observations from existing and future observing systems are derived.

•It is also used as the verification or truth data set when evaluating assimilations and forecasts which use the synthetic observations.

•Available Nature Runs include: fvGCM, T511 and WRF-ARW.

Recent AIST Projects
Distributed Observing System

SWOS Element	Project	Contact	Status
Data Comm Model	Land Info System for SMAP & AirMoss (SoilSCAPE)	Dr. Mahta Moghaddam, USC	Aug 2012 to Jan 2017
OSSE Capability	NASA GMAO OSSE Capability	Dr. Tsengdar Lee, NASA HQ	Feb 2015 to Feb 2017
Instrument Control	Optimizing the Pointing of Narrow FoV Instruments	Dr. Sreeja Nag, Bay Area Environmental Resch Inst	Mar 2016 to Dec 2016
Instrument Control	Model-predictive Control Architecture for Optimizing Earth Science Data Collection	Mike Lieber, Ball Aerospace	Apr 2015 to Mar 2017
Mission Planning	Tradespace Analysis Tool for Design of Distributed Missions	Dr. Jacqueline LeMoigne-Stewart, GSFC	Aug 2015 to Aug 2017
On-board computing	SpaceCubeX: Hybrid Flight Architecture	Dr. Matthew French, USC	Feb 2015 to Feb 2017
On-board computing	High Performance Space Computer	Dr. Rich Doyle, JPL	Jan 2013 to Oct 2019
Mission Planning	Feasibility Studies of Quantum Annealing Algorithms	Dr. Milt Halem, UMBC	May 2015 to May 2017