Advanced Information Systems Technologies (AIST)

Machine Learning in NASA's Earth Science Division

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Outline of Talk

- Opportunities
- What’s it Going to Take
- Analytic Centers as a Framework
- Concept of Operations
- Some Experiments
- Strategy

Technology Opportunities

- Generating data and numeric output
  - Constellations of SmallSats with in situ, airborne platforms
  - Closer interaction with physical and statistical models
  - Autonomy
- Computing Capabilities
  - Public Cloud Computing
  - Quantum Computing
  - Cognitive Computing
- Exploiting Data
  - Machine Learning
  - Workflow tools, such as Notebooks
  - Integration of data into a unified picture of a natural phenomenon or physical process
  - Virtual Reality

ESTO Earth Science Technology Office

Machine Learning Hopes

- A more robust **understanding** of a natural phenomenon or physical process
  - Relying on conclusions based on 3,000 examples, not 3
  - Digest massive volumes of observational data
  - High volume output from high-resolution ES models
  - Conventional techniques drown ES researchers
- **Prediction** of future state for complex systems from observational data without a thorough understanding of complex or poorly understood underlying physics
- **Coordination** of elements of a sensor web to target transient and transitional phenomena
  - Leverage emergence of SmallSats
  - Autonomy
  - Detection of interesting features and re-tasking to observe them
- Fast, comparative **OSSEs**
  - What is the relative value of science for different Observing Systems
- **Assimilation** models which do better at washing out the experimental error while preserving features and physical anomalies
- A way to **clean up observational data** to make it easier to analyze

Lessons Learned (so far)

- ML and advanced tools are not trusted by Science Community
  - Not well understood, including which ones to use for what
  - Difficult to use
  - Don’t know who to trust
- Current crop of tools are hard to use
- Data is hard to coerce into an analyzable format
  - Finding usable data is hard (current catalogs offer limited help)
  - Large volumes of data are hard to process
  - Diverse formats, uncertainties, sources are hard to integrate
- Non-Earth Science Community is far ahead in using them
  - Financial Markets
  - Computer Security (and other security)
  - Commercial Space

What’s it Going to Take?

- **Community Acceptance** in NASA Earth Science (ES)
  - NASA Earth Scientists must understand the processes & algorithms
    - “In the field of observation, fortune favors the prepared mind.” – Pasteur
    - Collaboration among Earth Scientists, Computer Scientists and Technologists
  - Demonstration of value to the science communities
    - New Science
    - Faster Time to Science, retaining quality and understanding
    - Results backed up by confirmation with legacy techniques
    - Uncertainty Quantification
  - Engagement with NASA ES by experienced ML practitioners
- Improved **Data Usability**
  - Rapid use of the numeric results without time-delays for grooming
- **Easy to use** tools and credible results
  - Need a Framework to integrate tools, data and computation resources

A Way to Focus Technology Development

- An environment for conducting a **Science investigation**
  - Enables the confluence of resources for that investigation
  - Tailored to the individual study topic
- Harmonizes **data, tools and computational resources** to permit the research community to focus on the investigation
  - Reduce the data preparation time to something tolerable
  - Catalog of optional resources (think HomeDepot shopping)
  - Semantic-enabled catalog of resources (think Yelp) with help
  - Relevant publications
  - Provide established training data sets of varying resolution
  - Provide effective project confidentiality, integrity and availability
  - Single sign-on and unified financial tracking

Analytic Center as a Framework

User
- Project Definition
- Plan for Investigation

Project Work Environment

Data
- Catalog
- NASA DAAC
- Other US Govt
- Non-US
- Local or non-public

Tools
- Discovery & Catalog
- Work Management
- Data Interfaces
- Analytic Tools
- Modeling
- Collaboration
- Visualization
- Sharing/ Publication
- Local/custom

Computational Infrastructure
- Computing
  - Capacity
  - Capability
- Storage
- Communications

Storage
- Data Containers
- Thematic model
- Metadata/Ontology
- Resulting Products
- Published data
- Provenance

Computing
- Local systems
- High End Computing
- Cloud Computing Capability
- Quantum Computing
- Neuromorphic Computing

AC Concept of Operations

- Principles
  - Each researcher defines their own process
  - Community accepted tools allow re-use of others' work
  - Unique tools and data should be easily integrated
  - Collect publication materials as you go, in background
- Notional Process
  - PI defines hypothesis and process
  - Select framework to be used and workflow tool
  - Shop for tools, data and compute resources
  - Assemble components and verify integrity
  - Perform analysis, develop models, visualize, etc.
  - Draw conclusions and perform internal reviews
  - Enter publication process

AIST Experiments with Analytic Centers

- Land Use and Land Change
  - NEX (NASA Ames) Rama Neimani
- Physical Oceanography
  - OceanWorks (JPL) Thomas Huang
- Tropical Cyclones and Hurricanes
  - TCIS (JPL) Svetla Hristova-Veleva
- Climate
  - Climate Model Diagnostic Analyzer (CMDA), Seungwon Lee (JPL)
  - Climate Workbench (UAH/MSFC) Manil Maskey, Chris Lynnes (GSFC)
- Communities being discussed for further experiments
  - Biodiversity
  - Hydrology
  - Atmospheric Composition
  - Cryosphere

NASA Earth Exchange (NEX) as an Analytic Center

Land Change/Use Community

- Project Definition
- Plan for Investigation

Data

- Built into website
- Dataset Sources
  - Landsat
  - Sentinel 1A
  - Modis
  - ASTER
  - TRMM
  - AVHRR
- Climate Datasets
- Land cover
- Digital Elevation Map
- STATSGO Soils
- USDA Aerial NAIP
- And others

Project Work Environment
-NEX-

Tools

- Models
  - Tops
  - Biome-BGC
  - LPJ Dynamic Global Model
- Sandbox for small scale experiments
- Analysis
  - R and python based tools
  - Matlab VIIRS HDF5 swath conversion
- Workflow: Jupyter Notebook

Computational Infrastructure

Storage

- Data Containers
- Thematic model
- Metadata/Ontology
- Resulting Products
- Published data
- Provenance

Computing

- NASA Advanced Supercomputing (NAS)
- Amazon Web Services (AWS) Public Cloud
- Ames Quantum Computer (D-wave)

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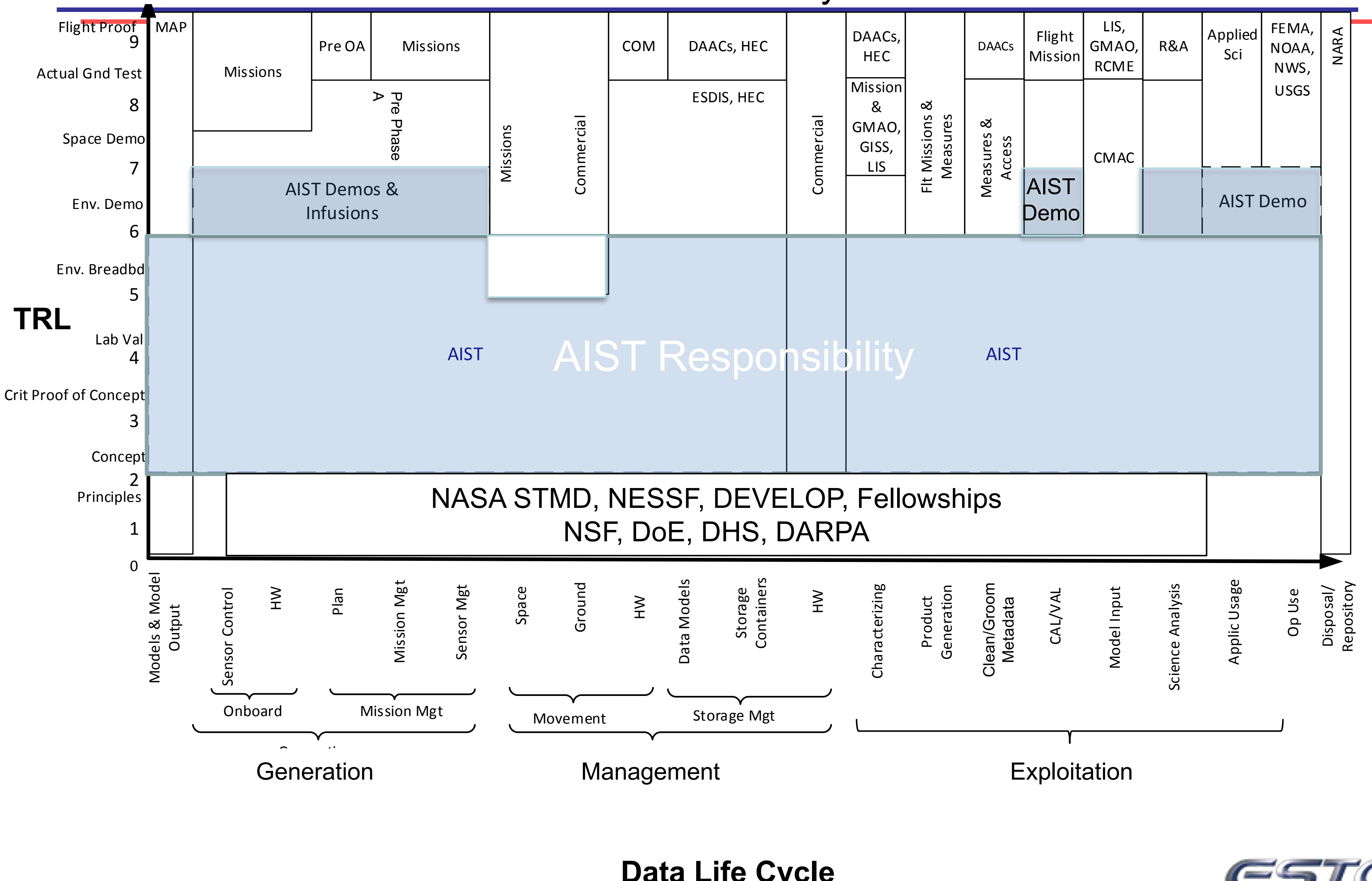
A Strategy for Introduction

- Focus on needs of a particular Science community
  - Data, models and tools they are comfortable with
  - Computational resources adequate to perform their investigation
  - Concept of Operations must support their work, not force a fit
  - Identify needs, lessons learned, community perceptions
  - Are there common processes that could make it easier
- NASA’s Earth Science needs **much** more exposure to Machine Learning
  - Researchers and Managers need to develop confidence in the tools
  - Outreach to the Science community
- Must be an architecture with modularity and interoperability
- Must support security
- Increase access to non-NASA data sources as well as NASA
- AIST will experiment with basic concepts as well as components

BACK UP

A View of AIST

TRL v. Data Life Cycle



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AC ConOps Detailed Sample

- PI defines the investigation to be done
  - Types of data, analysis steps, process
- Select workflow tool to manage process
  - Such as Jupyter Notebook
- Shop for data, tools and computing resources needed
  - Parameter search of known data repositories
  - Find more like…
  - Identify data from local or unpublished sources
    - Create metadata to make it usable by others, including peer review
- Integrate local data into local storage – compatiblity mode
- Retrieve remote data into local storage
  - Storage method is harmonized with known tools
  - Verifies accuracy of copy compared to repository
  - Perform incremental copy/analysis if storage limited
- Integrate local tools into work flow to interact with data and storage effectively
  - Document the tool for future reference and publication
- Massage data as required (geolocation, gridding, characteristics)
- Step through analytic steps with a limited subset of data using a limited set of processing resources
  - Visualize or analyze results until satisfied with process
- Scale up processing of entire data set
- Review results and draw conclusions
- Review AC publication package
  - Source code, tools, local data, metadata, etc.
- Submit for publication

Earth Data Analytics System (EDAS) as an Analytic Center

Climate Impact

- Project Definition
- Plan for Investigation

Data

- MERRA
- ECMWF ERA
- NOAA NCEP CFSR
- JMA JRA
- UA ERA

Project Work Environment
-NCCS-

Tools

- Earth System Grid Federation Framework
- Discovery & Catalog
- Work Management – Jupyter Notebook
- Data Interfaces - OpenDAP
- Analytic Tools: Min, max, sum, diff, average, rms,anomaly, std deviation
- Visualization using time series or spaceplot plot routines

Computational Infrastructure

Storage

- Local Sparc
- SGI Data Migration Facility

Computing

- Local systems
- High End Computing (DISCOVER)
- GSFC Science Cloud

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Tragedy,

- Large investments by DoD and IC in AI and Machine Learning have, largely, not been leveraged by NASA Earth Science
- Lack of credibility in ML by Earth Science researchers
  - Why does ML generate bogus conclusions?
    - Failure to articulate assumptions & constraints and exceeding them
    - Overtraining
    - Drift over time
    - Failure to recognize when conditions change
  - Earth Scientists have trouble understanding the technology
    - Lack of demonstration of value to motivate them
    - Lack of training in the tools and algorithms
- Partnerships among Machine Learning and Earth Science communities are slow to take root
  - Communications
  - Opportunity
  - Trust
- Data grooming takes huge amounts of time

Myths

- You can do a problem and set it aside for others to use.
  - There is no fire and forget in Earth Science
- Open source is always better than commercial software
  - GIS is a good counter-example
  - Communicating with other Agencies requires arc-GIS capability
- Data must be supplied in same form as collected
  - Stewardship is important, but not useful for analysis
  - Must be able to trace back to authoritative data
- Cannot re-use (trust) anyone else's work
  - Community acceptance and jurying could create common capabilities
  - Fix the data once and others could use it if they believe it is fixed

Analytic Center Characteristics

- Seamless integration
- Comprehensive catalog
  - Clear applicability (or not)
  - Expert system as an operator aid
- Help in using them
  - YouTube, moodle