MERRA/AS

The MERRA Analytic Services Project

Interim Report

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NASA Goddard Space Flight Center
April 16, 2013

Outline

Background

Accomplishments this Reporting Period

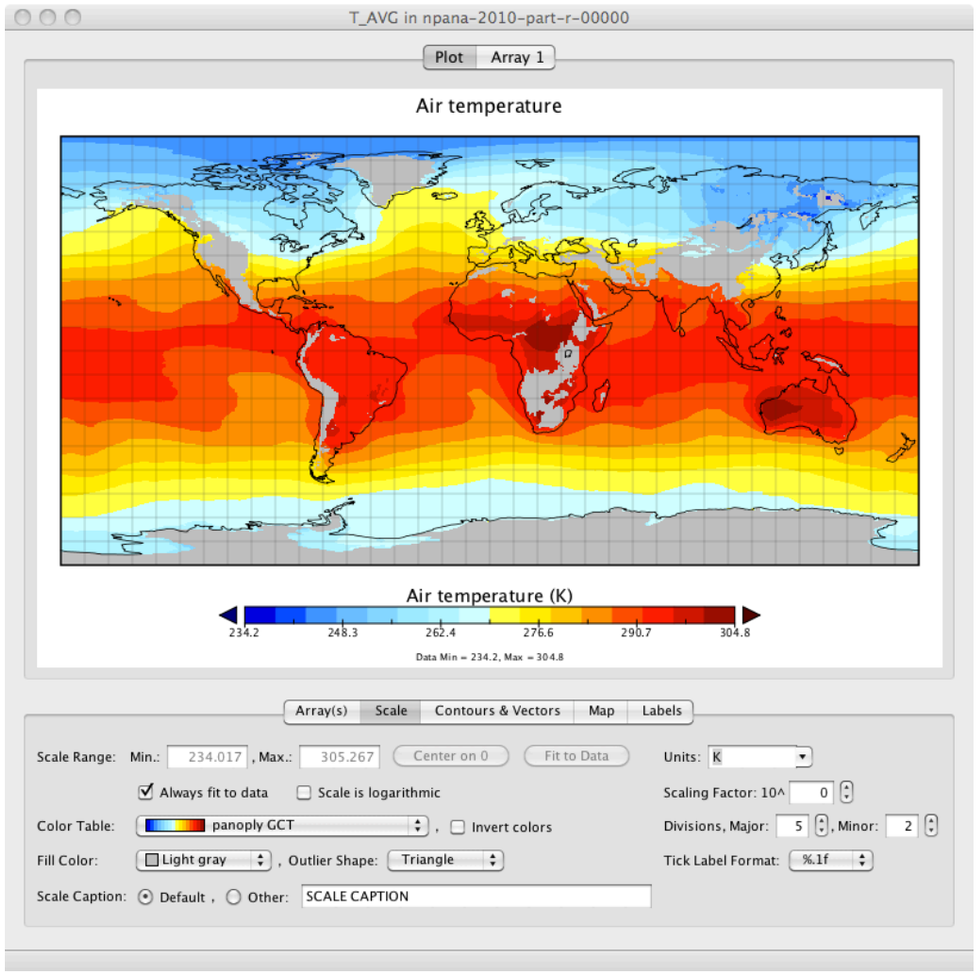
- ***MERRA/AS Cluster*** – Cluster configuration, node configuration, MERRA data, HDFS organization, and Cloudera.
- ***MERRA/AS Server*** – MapReduce analytics, sequencing/de-sequencing, canonical ops, API, and web services.
- ***Application Integration*** – Customer connections, connections to other CMAC projects, related research activities, and public outreach.
- ***Administration*** – Publications, NTRs, resource allocations, problems, recovery plans, TRL assessment, and schedule status.

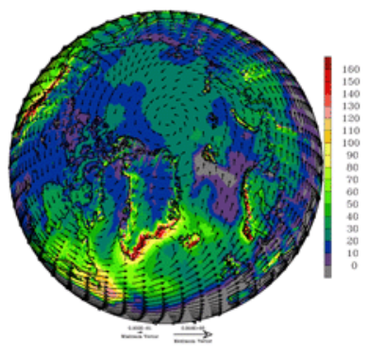
Work Plan for the Next Reporting Period

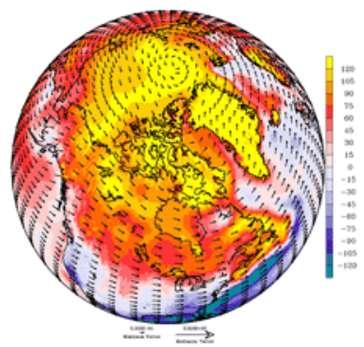
- ***MERRA/AS Cluster*** – SciDB, Impala, ECMWF, and NCEP data.
- ***MERRA/AS Server*** – Climate Data Server / MapReduce Core integration, codes set management, CDS kits, and API/Web Services public release.
- ***Application Integration*** – Complete customer connections and connections to other CMAC projects, advance related research activities and public outreach.
- ***Administration*** – Final documentation, publications and NTRs, final TRL assessment, and operational deployment.

Budget Summary / Quad Chart

Demo







Project Summary

MERRA/AS is a cyberinfrastructure resource that will ...

- Combine iRODS data grid and Hadoop MapReduce capabilities to serve MERRA analytic products ...

  ... or, specifically, we will combine iRODS-based Climate Data Server (CDS) capabilities with Cloudera MapReduce to serve MERRA analytic products;

- Store the MERRA reanalysis data collection in an HDFS to enable parallel, high-performance, storage-side data reductions;

- Manage storage-side <driver, mapper, reducer> code sets and realized objects for users; and

- Provide a library of commonly used spatiotemporal operations (canonical ops) that can be composed to enable higher-order analyses.

In addition, the project will ...

- Make available to the extended community iRODS/CDS "kits" that enable HDFS as a storage resource and MapReduce code hosting and utilities to externalize MERRA's metadata and sequence /de-sequence MERRA data; and

- Provide a preliminary evaluation of cost, performance, and usability of MapReduce in general and the system in particular.

Cover Page for Proposal Submitted to the National Aeronautics and Space Administration

NASA Proposal Number
11-CMAC11-0018

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This proposal shall be used and disclosed for evaluation purposes only, and a copy of this Government notice shall be applied to any reproduction or abstract thereof. Any authorized restrictive notices that the submitter places on this proposal shall also be strictly complied with. Disclosure of this proposal for any reason outside the Government evaluation purposes shall be made only to the extent authorized by the Government.

SECTION I - Proposal Information

Principal Investigator	E-mail Address	Phone Number
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City	State / Province	Postal Code	Country Code
Greenbelt	MD	20771	US

Proposal Title : **MERRA Analytic Services**

Proposed Start Date	Proposed End Date	Total Budget	Year 1 Budget	Year 2 Budget	Year 3 Budget
10 / 01 / 2012	09 / 29 / 2013	477,228.00	477,228.00	0.00	0.00

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH11ZDA001N-CMAC	Computational Modeling Algorithms and Cyberinfrastructure

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*
Earth Science

Date Submitted	Submission Method	Grants.gov Application Identifier	Applicant Proposal Identifier
03 / 09 / 2012	Electronic Submission Only		

Type of Application	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted
New		

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
004968611	36FC1	520734375	2A

Organization Name (Standard/Legal Name)	Company Division
NASA Goddard Space Flight Center	

Organization DBA Name	Division Number
NASA	

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SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

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Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

Authorized Organizational Representative (AOR) Name	AOR E-mail Address	Phone Number
David Leisawitz	David.T.Leisawitz@nasa.gov	301-286-0807

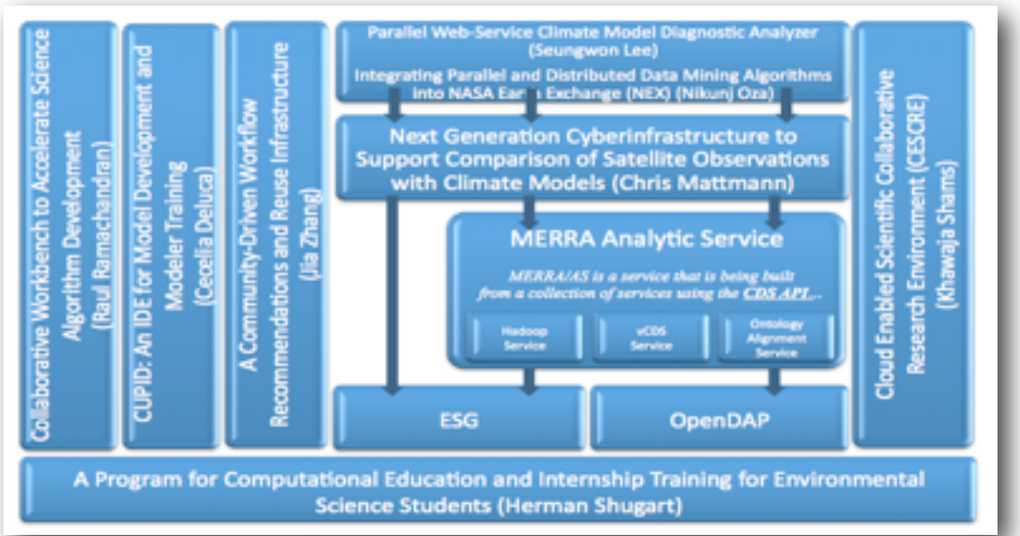
AOR Signature *(Must have AOR's original signature. Do not sign "for" AOR.)* **Date**

FORM NRESS-300 Version 3.0 Apr 09

Project Summary

Post-Award Project Extensions ...

- In response to the challenge of creating an integrated CMAC portfolio, we're using this project as the starting point for creating a Climate Data Services API and Climate Data Services Web Services;
- In response to community interest in comparing MapReduce to other Big (Science) Data technologies, we're including a SciDB version of the MERRA collection as part of the MERRA/AS testbed.
- In response to community interest, we'll provide an experimental SQL interface to the HDFS collections using Impala; and
- In support of Cristina Grieg's dissertation research, which focuses on reanalysis/observational data intercomparison, we'll incorporate on an experimental basis ECMWF and NCEP reanalysis data.



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Project Summary

Expected Outcome and Deliverables

1. ***MERRA Analytic Services*** — MERRA/AS will be a cyberinfrastructure resource that can be used to:
   - Create derived MERRA products for the OBS4MIP project and other applications, and
   - Provide a testbed for experimentation with the MapReduce paradigm of distributed, parallel storage-based computation.
2. ***Extended Climate Data Server (CDS)*** — The enhanced CDS will support the Hadoop Filesystem (HDFS) as a storage resource, MapReduce code hosting, and workflow-generated realizable objects through capabilities packaged as distributable iRODS/CDS MapReduce and MERRA Kits.
3. Preliminary evaluation of cost, performance, and usability of the system.

———

4. Climate Data Services API with MERRA/AS components.
5. MERRA/AS Web Services.
6. SciDB, Impala, and Reanalysis Intercomparison testbed enhancements.

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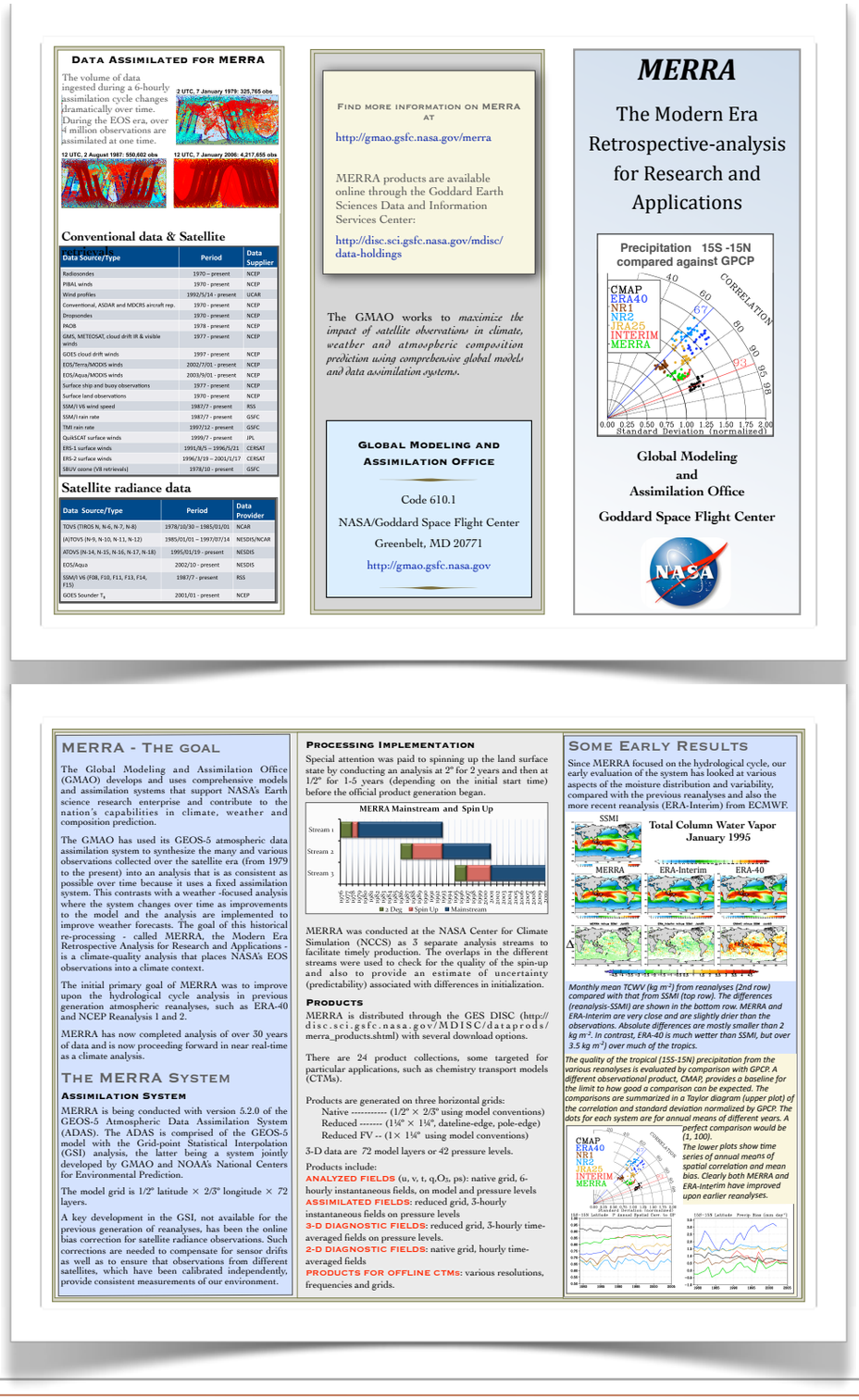
MERRA

MERRA: Modern Era-Retrospective Analysis for Research and Applications

- The MERRA reanalysis integrates observational data with numerical models to produce a global temporally and spatially consistent synthesis of 26 key climate variables.
- Spatial resolution is 1/2˚latitude × 2/3˚longitude × 72 vertical levels extending through the stratosphere.
- Temporal resolution is 6-hours for three-dimensional, full spatial resolution, extending from 1979-Present.
- ~ 200 TB, but MERRA II is on the way ...
- Subset published through ESGF for MIP activities.

Why focus on reanalysis data?

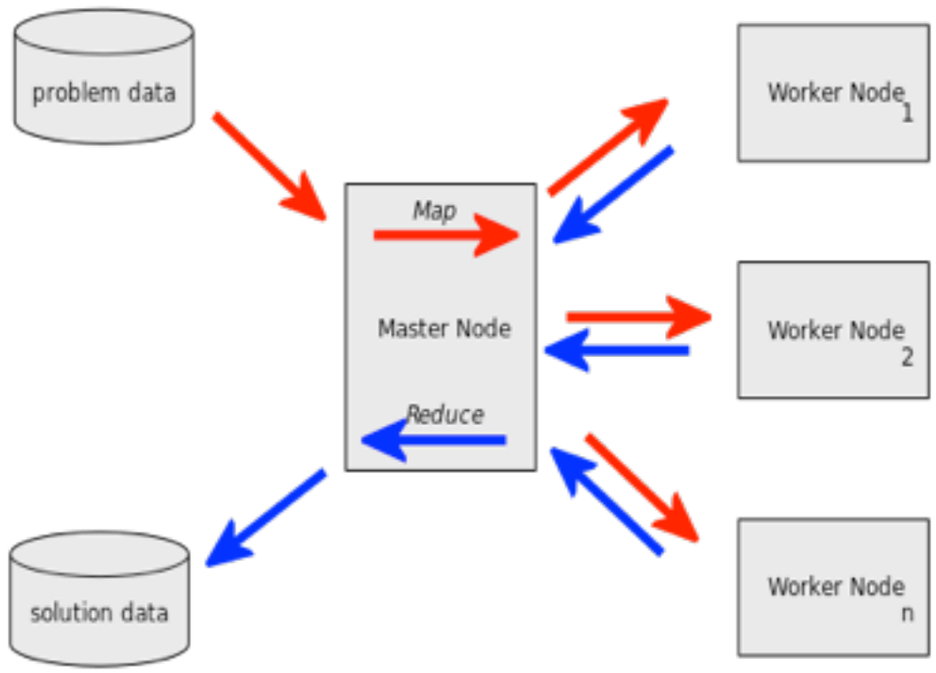
- There is an increasing demand for reanalysis data products by a large and diverse applications community representing all of NASA's Applied Sciences Program's themes: disasters, ecological forecasting, health and air quality, water resources, agriculture, climate energy, oceans, and weather.
- To be useful, climate model outputs and predictions must be made easily accessible to an expanding community of consumers, including local governments, federal agencies, and private-sector customers.



MapReduce

The Basic MapReduce Paradigm ...

- MapReduce is a framework for processing parallelizable problems across huge datasets using a large number of computers.
- Computational processing can occur on data stored either in a filesystem (unstructured) or in a database (structured).
- MapReduce can take advantage of locality of data, processing data on or near the storage assets to decrease transmission of data.
- "Map" step: The master node takes the input, divides it into smaller sub-problems, and distributes them to worker nodes. A worker node may do this again in turn, leading to a multi-level tree structure. The worker node processes the smaller problem, and passes the answer back to its master node.
- "Reduce" step: The master node then collects the answers to all the sub-problems and combines them to form the output – the answer to the problem it was originally trying to solve.

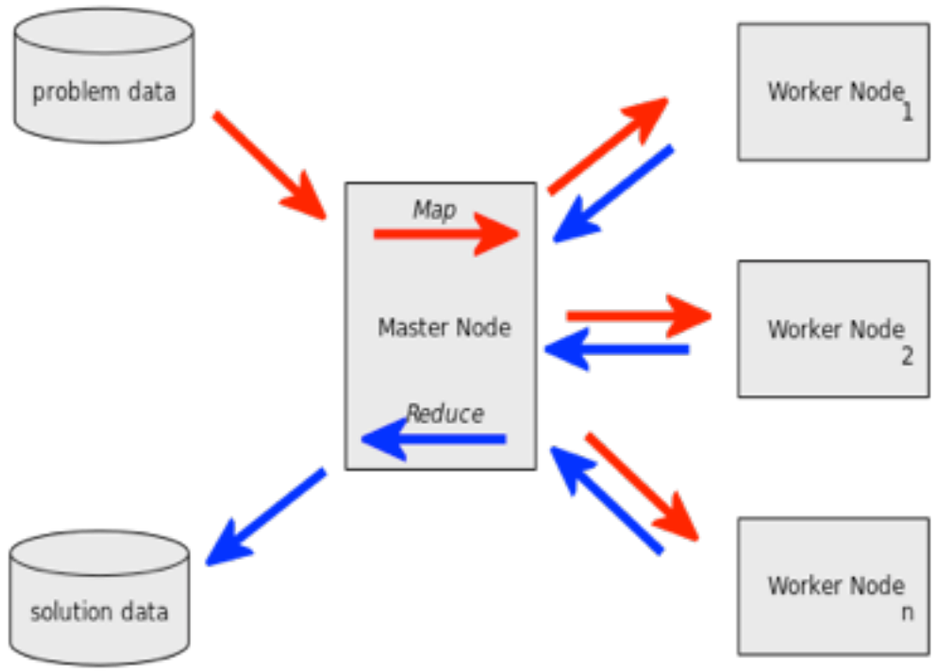


Writing a parallel-executable program has proven over the years to be a very challenging task, requiring various specialized skills. MapReduce provides regular programmers the ability to produce parallel distributed programs more easily, by requiring them to write only the simpler Map() and Reduce() functions, which focus on the logic of the specific problem at hand, while the "MapReduce System" automatically takes care of marshaling the distributed servers, running the various tasks in parallel, managing all communications and data transfers between the various parts of the system, providing for redundancy and failures, and overall management of the process ...

MapReduce

Who Uses MapReduce?

- Everybody – Amazon, Ebay (532 nodes, 5.3 PB), Facebook (1100 nodes, 8800 cores, 12/PB; 30 nodes, 2400 cores, 3 PB), Twitter, Yahoo (4500 nodes, 36 000 cores, 18 PB), University of Maryland, the NCCS, ...
- A popular free implementation is Apache Hadoop; we're working with Cloudera.



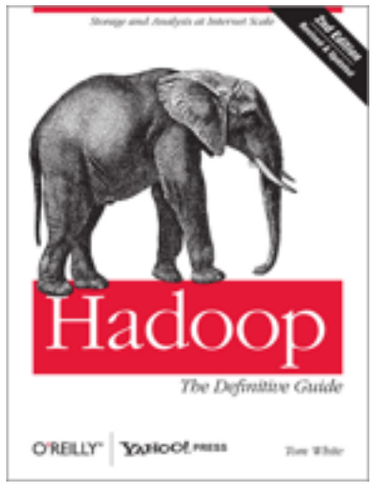
Related Projects / Software

- Avro – Data serialization system.
- Cassandra – Scalable multi-master database with no single points of failure.
- Chukwa – Data collection system for managing large distributed systems.
- Hama – Google's Pregel-like distributed computing framework based on BSP (Bulk Synchronous Parallel) computing techniques for massive scientific computations.
- Hbase – Scalable, distributed database that supports structured data storage for large tables.
- Hive – Data warehouse infrastructure that provides data summarization and ad hoc querying.
- Mahout – Scalable machine learning and data mining library.
- Apace Pig – High-level data-flow language and execution framework for parallel computation.
- ZooKeeper – High-performance coordination service for distributed applications.
- Impala - Cloudera’s open-source real-time query engine for Apache Hadoop.

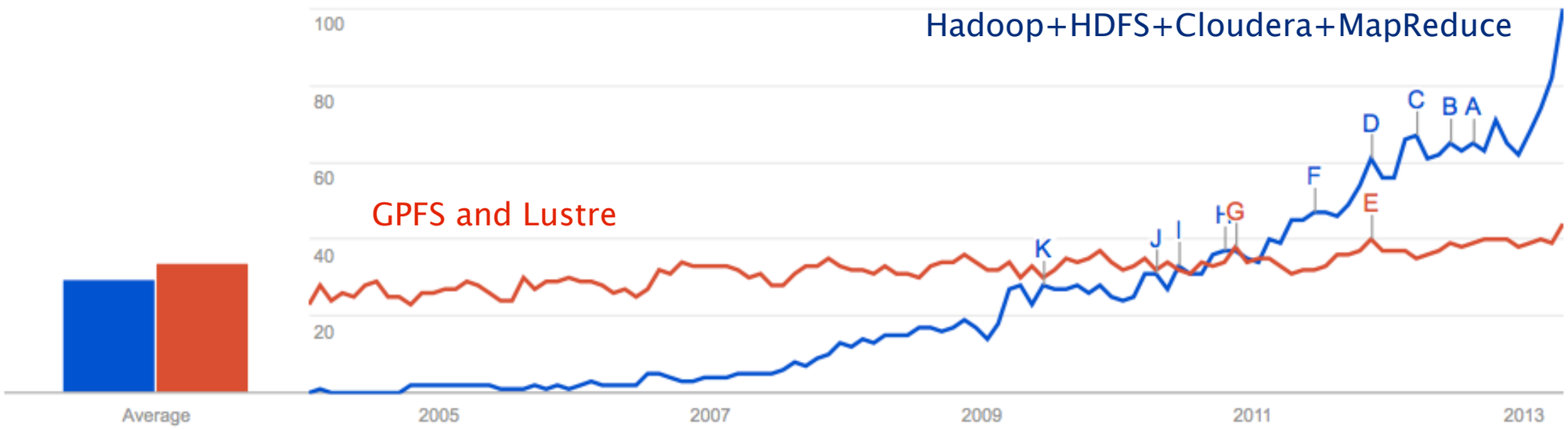
MapReduce

Is MapReduce just a fad?

- Data suggest that MapReduce is potentially a disruptive technology.
- This open source effort and the MapReduce paradigm are not likely to disappear anytime soon.
- It's great impact so far has been with textual data.
- The challenge is adapting the paradigm to complex, hierarchically-structured binary data ...



Google Trends



NCCS Analytics

Filling the Data Analysis Gap

What the NCCS Can Do to Help ...

MERRA/AS

Climate Data Server (CDS) Technology

Climate Data Services API

Analysis Nodes

...

Data Services

Analytic Services

Archive

- ~1 PB of Disk, ~25 PB of Tape.
- Slow storage designed for streaming reads and writes.

Inefficient – Users perform data analysis straight from the archive and complain that it is too slow ...

Discover Cluster

- >1 PF Peak, >25 PB of Disk.
- Fast storage designed for streaming applications.

Inefficient – Users analyze large data sets through a series of many small blocks reads and writes and complain that it is too slow ...

Accomplishments this Reporting Period

The focus has been on building the MERRA/AS cluster and developing the "MapReduce Core" ...

- *MERRA/AS Cluster* – Cluster configuration, node configuration, MERRA data, HDFS organization, and Cloudera.
- *MERRA/AS Server* – MapReduce analytics, sequencing/de-sequencing, canonical ops, API, and web services.
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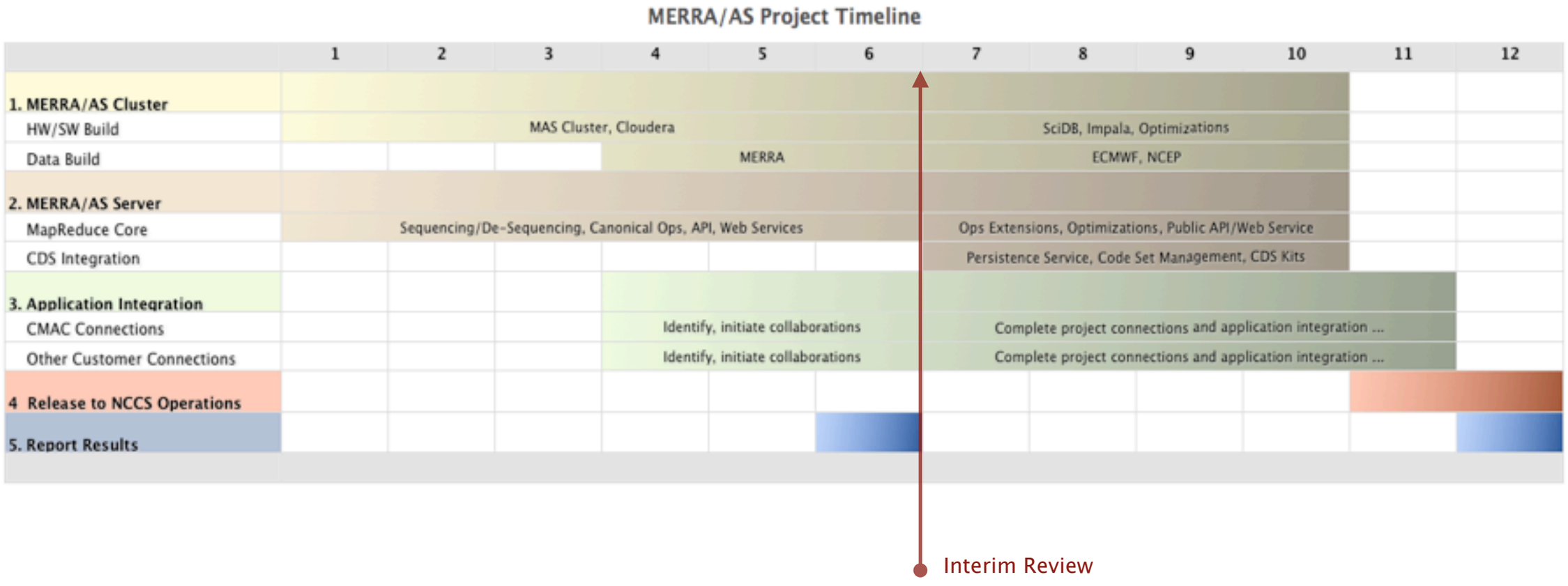
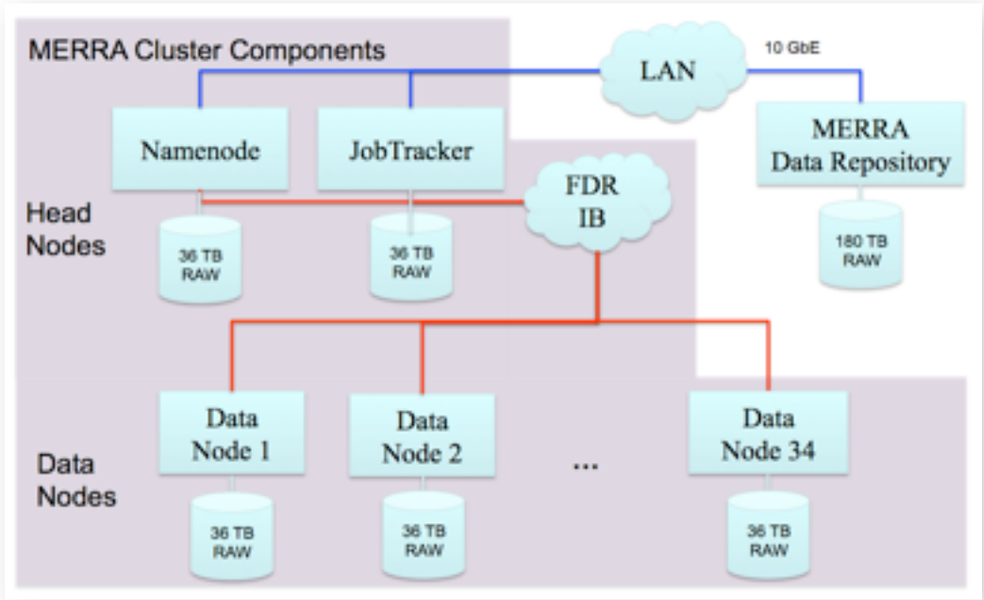
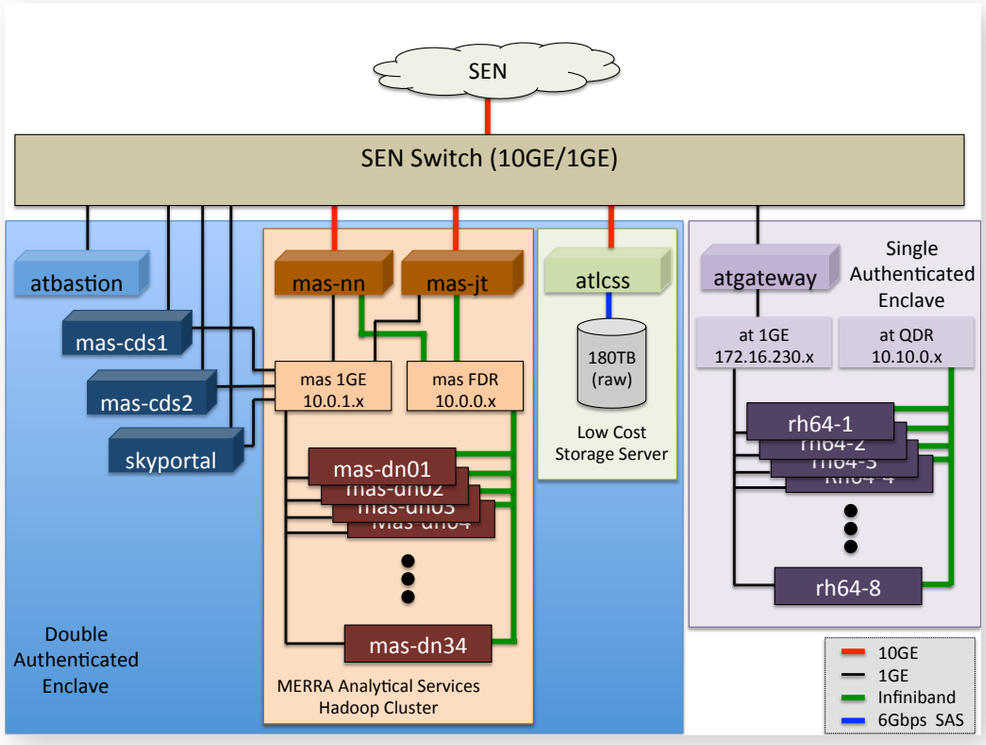


MERRA/AS Cluster

Cluster Configuration

- 36 node Dell cluster, 576 Intel 2.6 GHz SandyBridge cores, 1300 TB raw storage, 1250 GB RAM, 11.7 TF theoretical peak compute capacity.
- FDR Infiniband network with peak TCP/IP speeds >20 Gbps.





MERRA/AS Cluster

Node Configuration

- 36 node Dell cluster, 576 Intel 2.6 GHz SandyBridge cores, 1300 TB raw storage, 1250 GB RAM, 11.7 TF theoretical peak compute capacity.
- FDR Infiniband network with peak TCP/IP speeds >20 Gbps.

Component	Configuration
Node	Dell R720
Processor Type	Intel SandyBridge
Processor Number	E5-2670
Processor Speed	2.6 GHz
Cores per Socket	8
Number of Sockets	2
Cores per Node	16
Main Memory	32 GB
Storage	12 by 3 TB drives = 36 TB RAW
Interconnect	Mellanox MT27500 FDR IB
Operating System	CentOS 6.3
Kernel	2.6.32-279.5.1
Hadoop	0.20.2
Java	1.6.0_24

MERRA/AS Cluster

MERRA Data

- The GEOS-5 MERRA products are divided into 25 collections: 18 standard products, 7 chemistry products.
- Comprise monthly means files and daily files at six-hour intervals running from 1979 – 2012.
- Total size of the native, compressed NetCDF MERRA collection in a standard filesystem is ~80 TB.
- One file per day produced with file sizes ranging from ~20 MB to ~1.5 GB. Files obtained from the GES DISC.

HDFS Organization

- Native MERRA files are sequenced and ingested into the Hadoop cluster in triplicated 640 MB blocks.
- Total size of the MERRA/AS HDFS repository is ~480 TB.

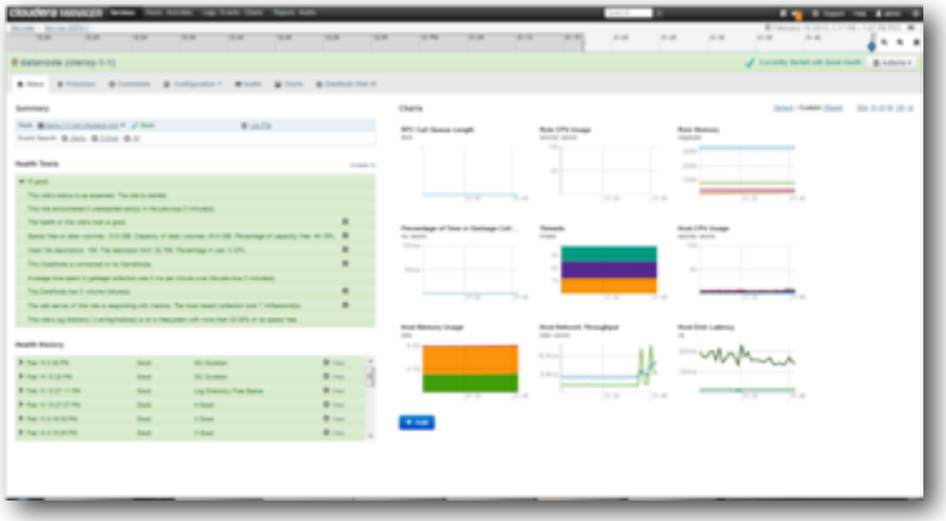
Name	Description	Size Gbytes/day // Tbytes
const_2d_asm_Nx	Constant fields	
inst6_3d_ana_Nv	Analyzed fields on model layers	0.452
inst6_3d_ana_Np	Analyzed fields at pressure levels	0.291
inst3_3d_asm_Cp	Basic assimilated fields from IAU corrector	0.231
tavg3_3d_cld_Cp	Upper-air cloud related diagnostics	0.075
tavg3_3d_mst_Cp	Upper-air diagnostics from moist processes	0.056
tavg3_3d_trb_Cp	Upper-air diagnostics from turbulence	0.147
tavg3_3d_rad_Cp	Upper-air diagnostics from radiation	0.088
tavg3_3d_tdt_Cp	Upper-air temperature tendencies by process	0.191
tavg3_3d_udt_Cp	Upper-air wind tendencies by process	0.224
tavg3_3d_qdt_Cp	Upper-air humidity tendencies by process	0.166
tavg3_3d_odt_Cp	Upper-air ozone tendencies by process	0.083
tavg1_2d_slv_Nx	Single-level atmospheric state variables	0.285
tavg1_2d_flx_Nx	Surface turbulent fluxes and related quantities	0.267
tavg1_2d_rad_Nx	Surface and TOA radiative fluxes	0.189
tavg1_2d_lnd_Nx	Land related surface quantities	0. 146
tavg1_2d_int_Nx	Vertical integrals of tendencies	1.500
inst1_2d_int_Nx	Vertical integrals of quantities	0.115
TOTAL		4.506 // 49.6

Name	Description	Size (Gbytes)
const_2d_chm_Fx	2-D invariants on chemistry grid	
tavg3_3d_chm_Fv	Chemistry related 3-D at model layer centers	0.329
tavg3_3d_chm_Fe	Chemistry related 3-D at model layer edges	0.166
tavg3_2d_chm_Fx	Chemistry related 2-DSingle-level	0.020
tavg3_3d_chm_Nv	Accumulated transport fields at layers	0.915
tavg3_3d_chm_Ne	Accumulated transport fields at edges	0.469
inst3_3d_chm_Ne	Instantaneous fields for off-line transport	0.050
TOTAL CHEM		1.949 // 21.44

MERRA/AS Cluster

Apache Hadoop / Cloudera

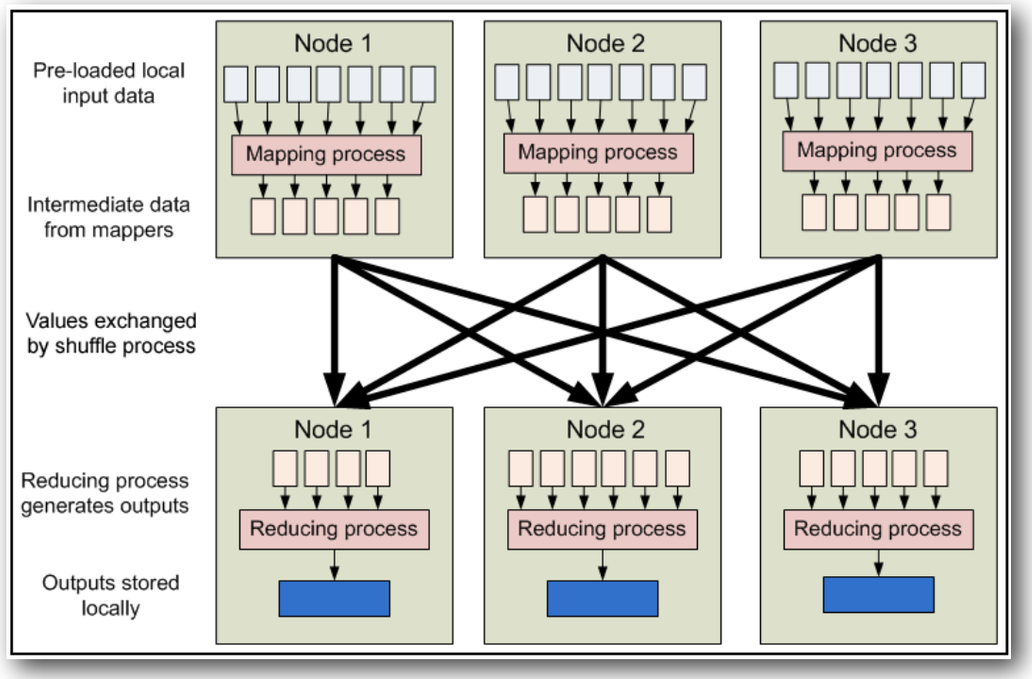
- The Apache Hadoop software library is the classic framework for MapReduce distributed analytics.
- We're using Cloudera (CDH), the 100% open source enterprise-ready distribution of Apache Hadoop.
- Cloudera is integrated with configuration and administration tools and related open source packages, such as Hue, Oozi, Zookeeper, and Impala.
- Similar to the RedHat, subscription-based model of support for Hadoop.
- Cloudera Manager Free Edition is particularly useful for cluster management, providing centralized administration of CDH.
- http://www.cloudera.com

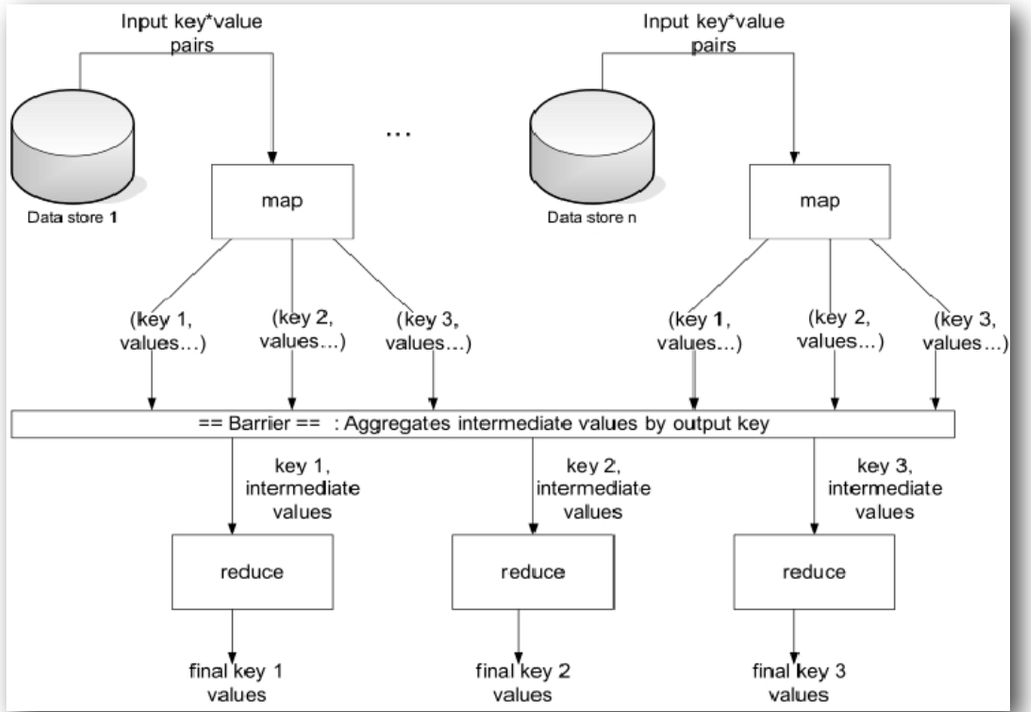


MERRA/AS Server

Hadoop MapReduce Analytics

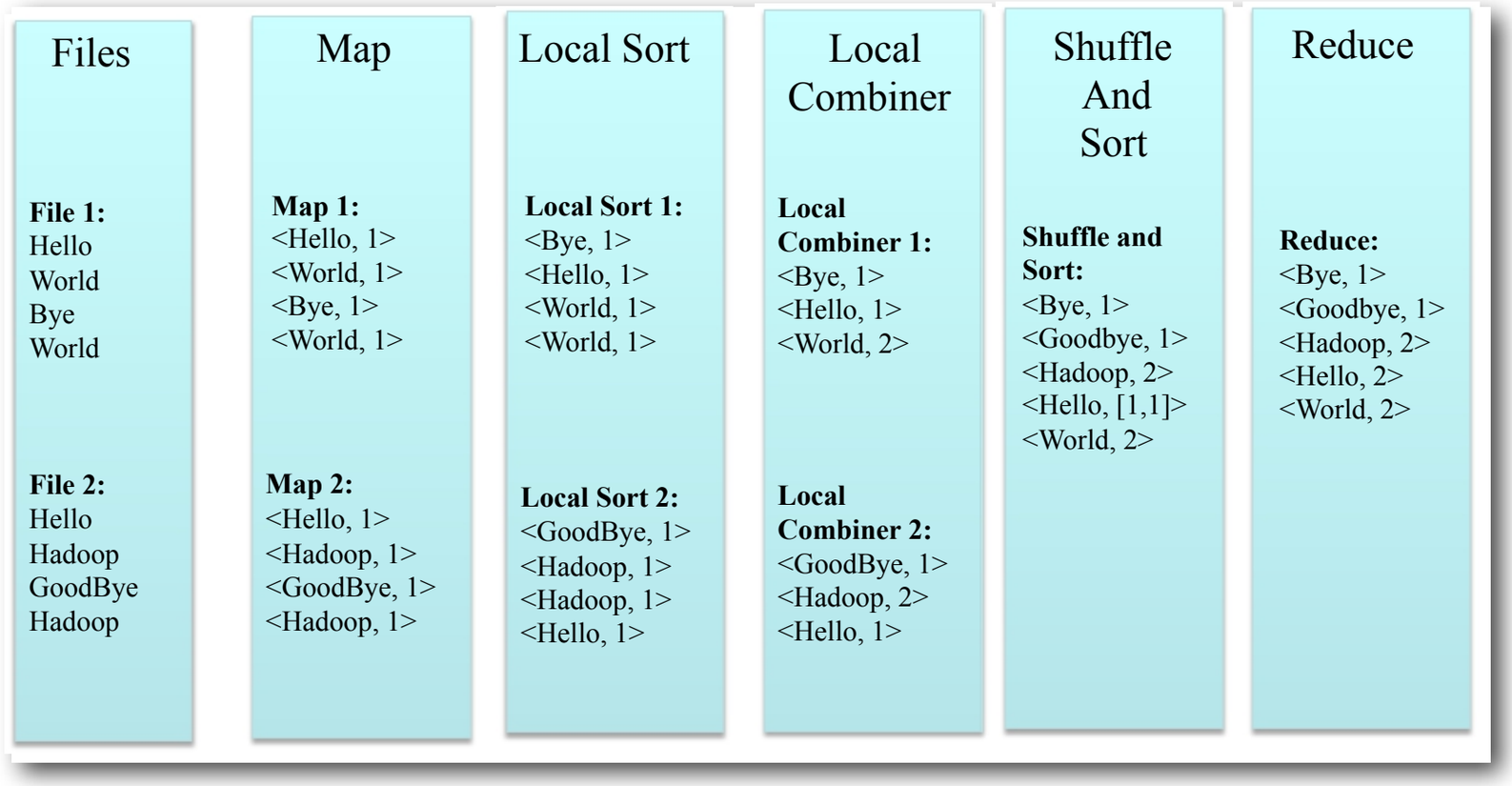
- Core Hadoop Concepts:
  - Developers write applications, not networking or low-level infrastructure;
  - Nodes perform isolated tasks without dependencies on other nodes;
  - Data is distributed in advance and computation happens where the data is.
- Hadoop Components: HDFS (Hadoop Distributed File System)
  - Data is split into blocks across multiple nodes (typically 64MB);
  - Data is replicated (3 times by default).
- Hadoop Components: MapReduce
  - Map - reads, filters, and returns key/value pairs;
  - Reduce - processes and returns key/value pairs;
  - Each Map task operates on a discrete portion of the dataset;
  - When Maps are complete, the MapReduce system distributes the intermediate data to nodes which perform the Reduce phase.
- Features of MapReduce
  - Automatic parallelization and distribution;
  - Fault-tolerance;
  - Status and monitoring tools;
  - A clean abstraction for programmers, removing ‘housekeeping’.





Hadoop MapReduce Analytics

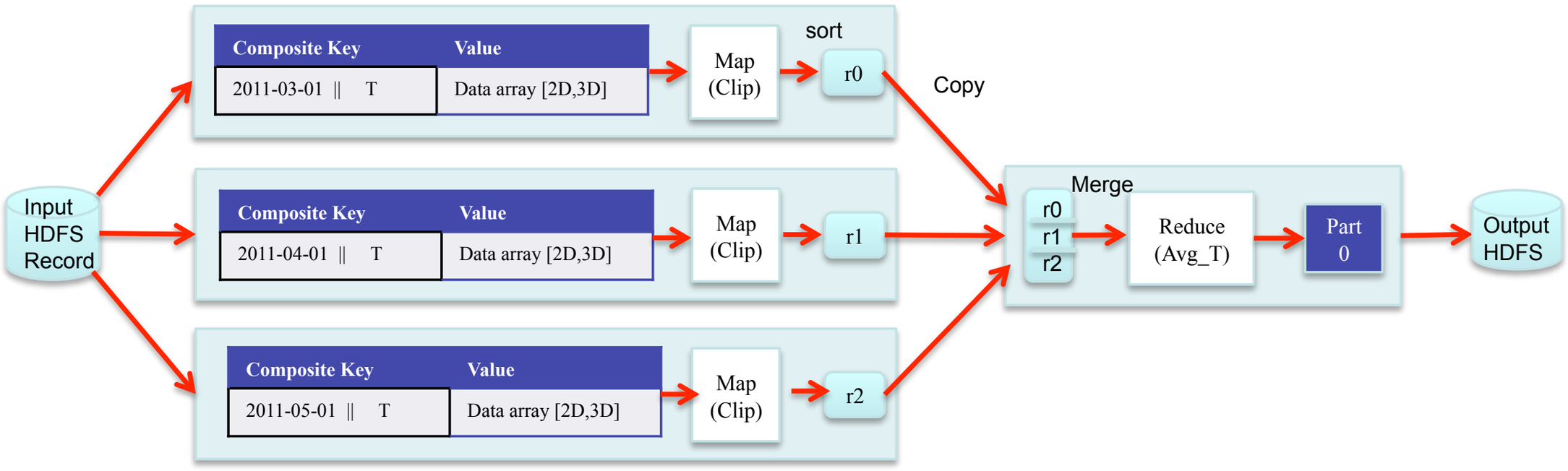
- MapReduce is an established mechanism for text processing (e.g., word count).
- In the example below, we see the workflow that counts the number of occurrences of words in two separate files:
  - The Map phase creates key/value pairs that include each unique word as a key with the number of occurrences as the value;
  - The MapReduce framework then sorts, combines, and distributes (a.k.a., shuffles) these key/value pairs for reduction;
  - The Reduce phase converts pairs with multiple values into a summary key/value pair.
- The application developer implements the Map and Reduce algorithms only.
- Text is stored in HDFS as is; however, binary data presents a challenge ...



MERRA/AS Server

Sequencing / De-Sequencing

- We're creating algorithms and utilities to move complex, multidimensional binary data into and out of the MapReduce framework.
- For MERRA, each file of native NetCDF binary data is converted into a separate sequence file to assist with metadata provenance (i.e., the sequence file is not NetCDF, but we we maintain a logical NetCDF by retaining the file's associated header information).
  - Sequence files are block-compressed in HDFS and provide direct serialization of several arbitrary data types (not just text).
- During sequencing, the data is partitioned by time, so that each record in the sequence file contains the timestamp and name of the parameter (e.g. temperature) as the composite key and the value of the parameter (which could have 1 to 3 spatial dimensions).
- The Map process filters each sequence file to capture key/value pairs that match the variable and time span of interest.
- The Reduce process calculates an average based on the input parameters (time, extents, etc.) and creates a new subset sequence file.
- The resultant sequence file is then transformed to NetCDF (or GeoTIF or any other!) format in the de-sequencing process.



MERRA/AS Server

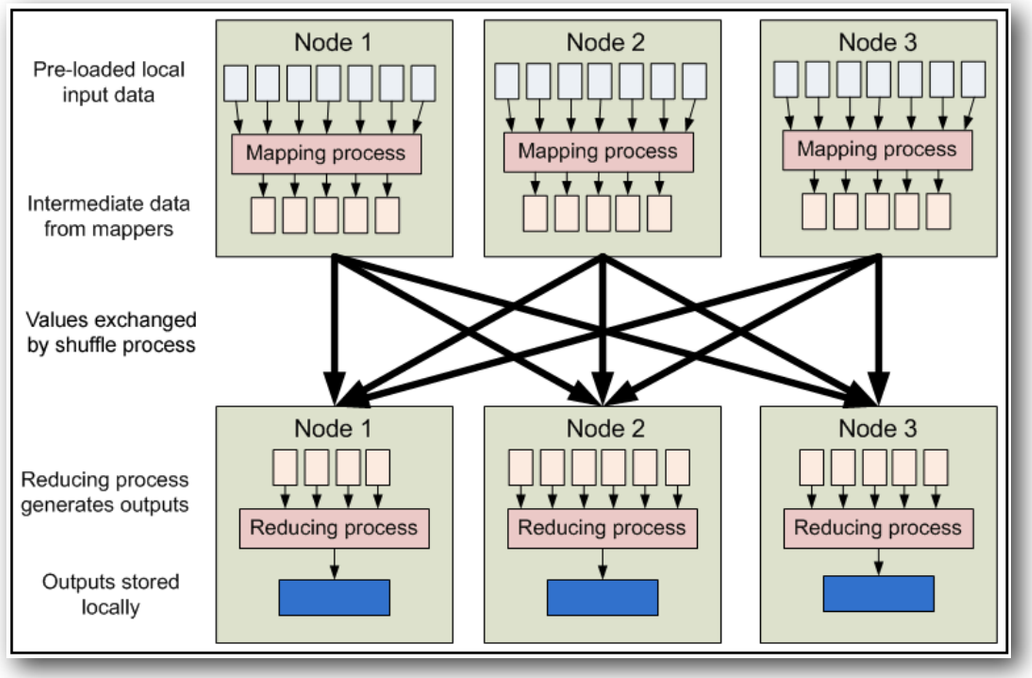
Canonical Ops Library

- We're also creating a small set of canonical near-storage, early-stage analytical operations that represent a common starting point in many analysis workflows in many domains. For example, avg, max, min, std, diff, sum operations of the general form:

  $$avg \leftarrow fn(var, (t_0,t_1), ((x_0,y_0,z_0),(x_1,y_1,z_1)))$$

  that return, in this example, the average of a variable when given a variable name, temporal extent, and spatial extent ...

- Averages over time, space, and elevation can be performed now for temperature. All other MERRA variables will ultimately be supported.

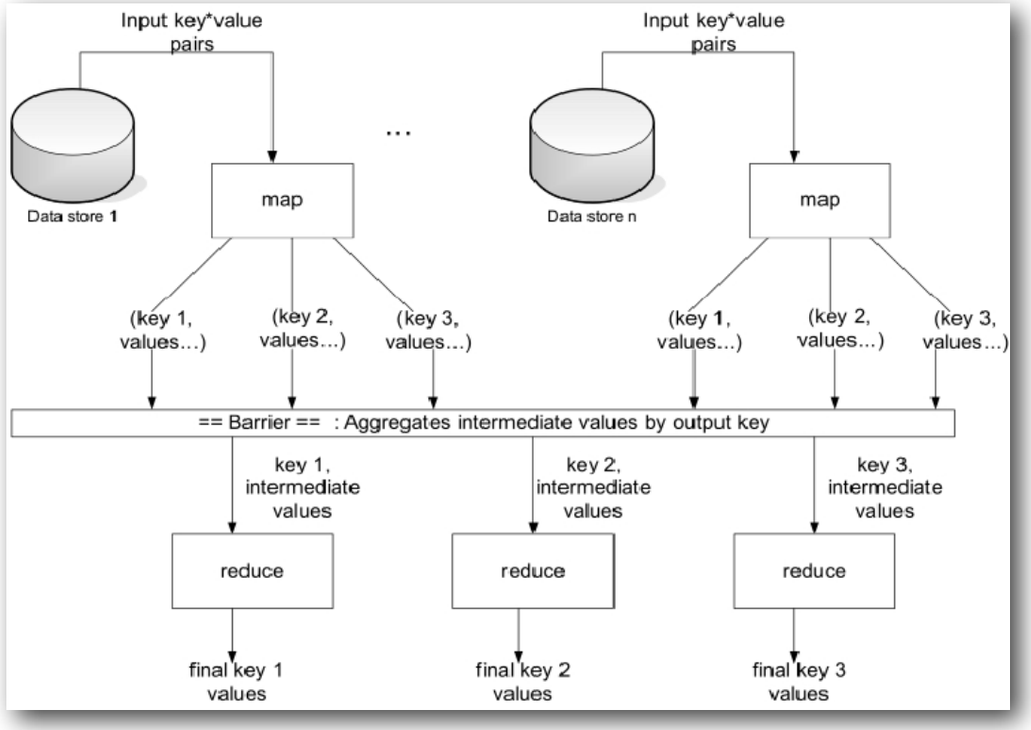


Rationale for canonical ops *– Data intensive analysis workflows can be thought of as directed acyclic graphs where nodes represent computations over data and arcs the systematic steps of the analysis process.*

These workflows bridge between the largely unstructured mass of archived scientific data and the highly structured, tailored, reduced, and refined analytic products that are used by individual scientists and form the basis of intellectual work in the domain.

In general, the initial steps of an analysis, those operations that first interact with a data repository, tend to be the most general, while data manipulations closer to the client tend to be the most specialized to the individual, to the domain, or to the science question under study. The amount of data being operated on also tends to be larger on the repository-side of the workflow, smaller toward the client-side end products.

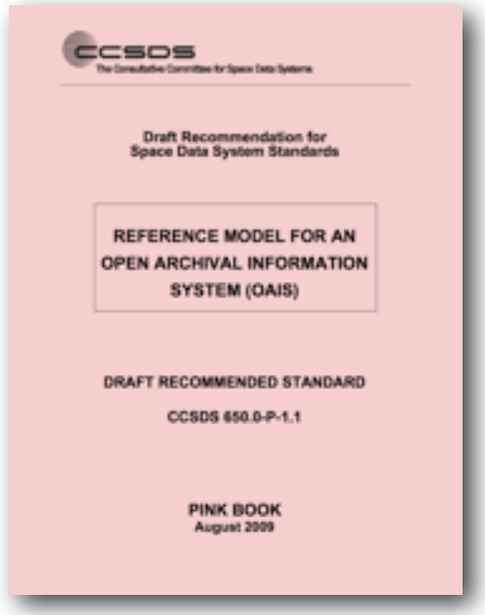
This stratification can be exploited in order to optimize efficiencies along the workflow chain. MapReduce, for example, seeks to improve efficiencies of the near-archive operations that initiate workflows.

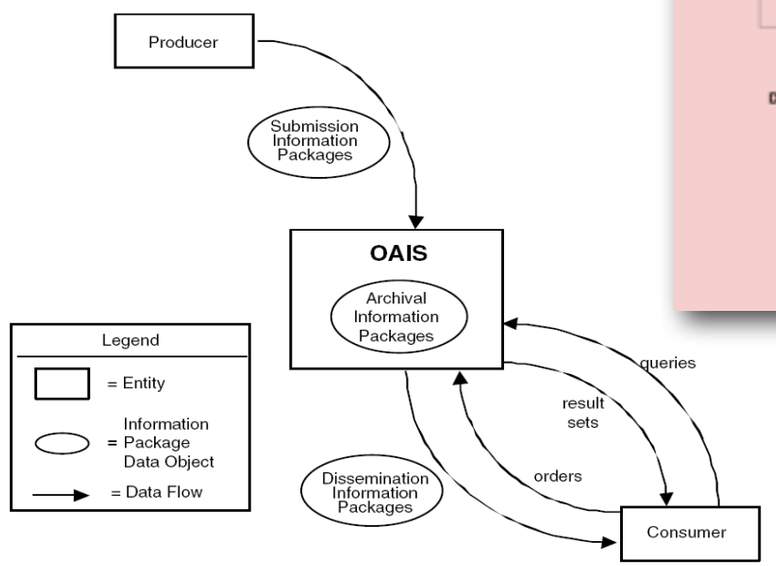


MERRA/AS Server

Climate Data Services API

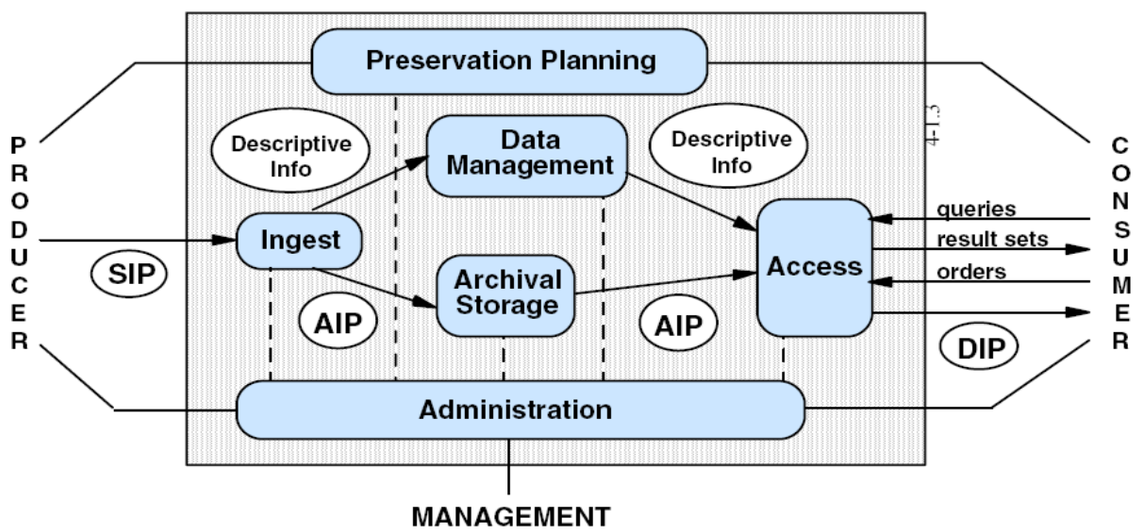
- The MERRA/AS project is the starting point for development of the NASA Climate Data Services (CDS) Application Programming Interface (API).
- MapReduce functionality will be the first service exposed through the CDS API.
- The CDS API leverages the Open Archival Information System (OAIS) reference model.
- Built around six basic methods.





CDS API Method Overview

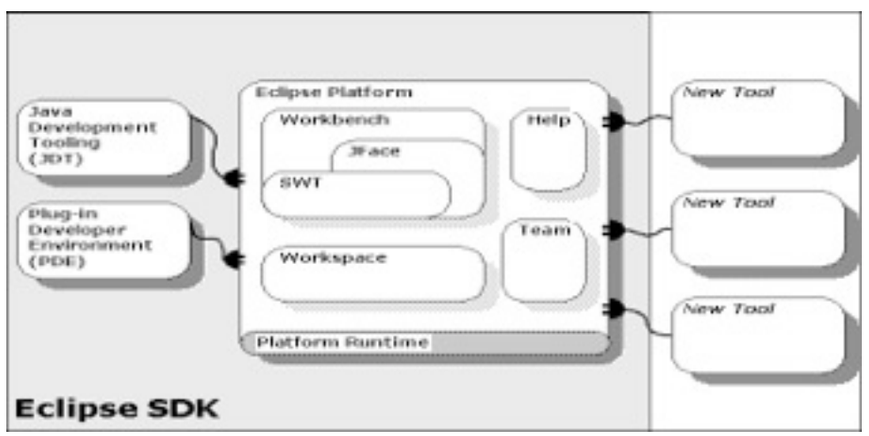
- ***Ingest*** – Submit/register a Submission Information Package (SIP).
- ***Query*** – Retrieve data from a pre-determined service request (synchronous).
- ***Order*** – Request data from a pre-determined service request (asynchronous).
- ***Download*** – Retrieve a Dissemination Information Package (DIP).
- ***Status*** – Track progress of service activity.
- ***Execute*** – Initiate a service-definable extension. Allows for parameterized growth without API change.

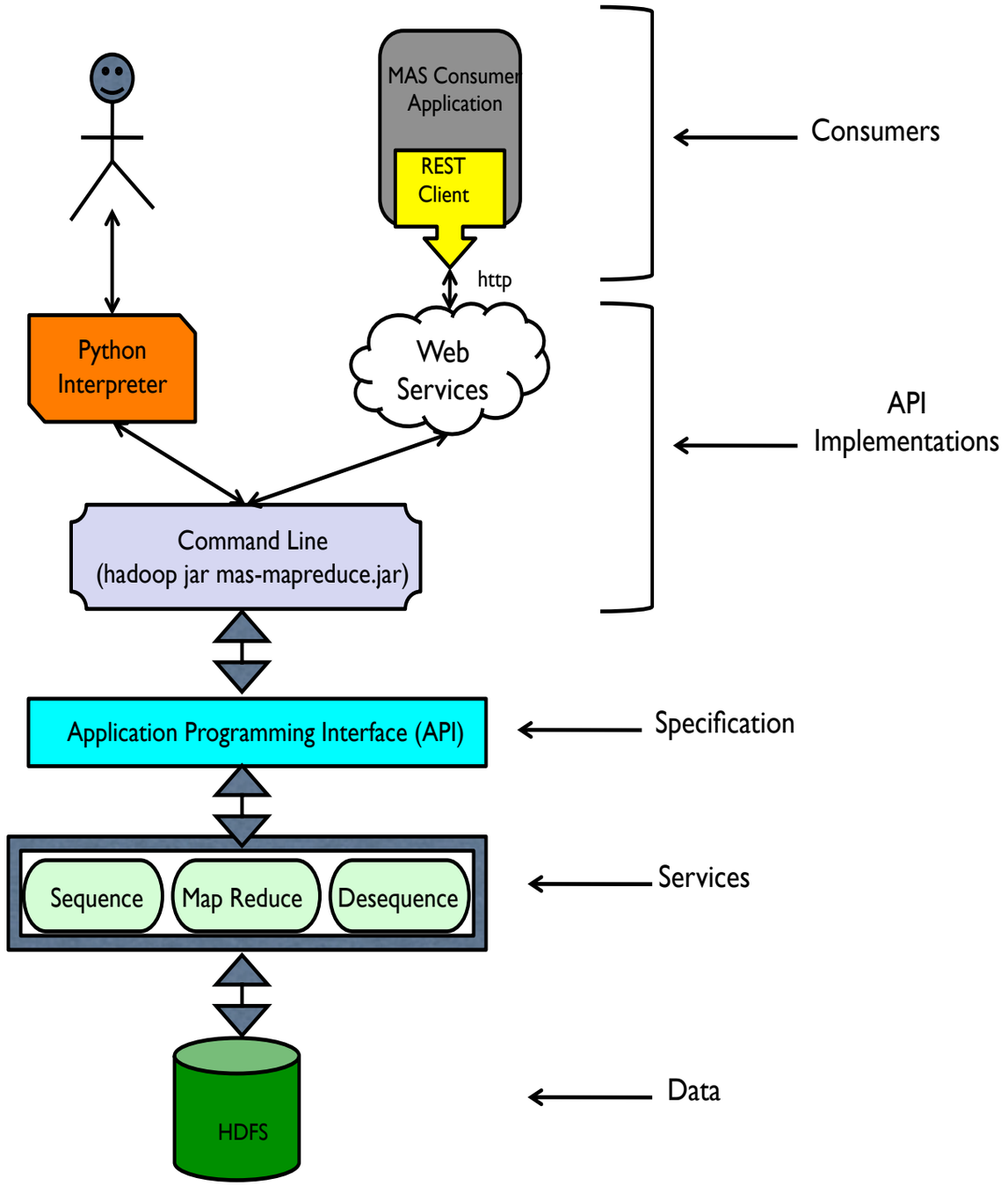


MERRA/AS Server

CDS API Services Architecture

- The CDS API is a logical abstract specification that can be implemented and exposed via various technologies *(e.g., command line, python interpreter, web services, web application interface, and methods library)*.
- Said another way, the API is implemented by applications that expose Climate Data Services according to the operations and primitives defined in the specification.
- The API provides a consistent means for consumers to access Climate Data Services.
- The Command Line Interpreter and associated utilities target humans that dynamically invoke CDS services *(or use scripts to combine services to build more complex functionality)*.
- Web Services target consumer applications.
- And the Methods Library can be used to build plug-in modules to Eclipse and related IDEs ...





Sample CDS Use Cases

- A data producer ***Executes()****s* the Hadoop sequence service that generates sequence files
- A data producer ***Ingests()****s* MERRA data, initiating the service that loads sequence files into HDFS
- A scientist calls ***Query()*** to determine which MERRA operations (e.g., average) and parameters (e.g., surface pressure, temperature, etc.) are available from the data
- A developer ***Ingests()****s* the MapReduce code using the code hosting service
- A scientist ***Orders()***s seasonal average surface pressure for 2006-2009 with a time step of 3, initiating the MapReduce job
- A scientist monitors job progress using ***Status()*** until the job is complete
- A scientist ***Downloads()*** the results of the MapReduce job

CDS API Method Detail - Query

- The Query method executes a predefined service request that returns data in an XML instance package that conforms to a predefined standard schema
- Arguments
  - **service**: The name of the target service. For example: *MAS*
  - **request**: The name of the query to be processed. For example, *GetAvailableOperatorsByParameter* (queries supported by MAS Service)
  - **parameters:** 1 or more parameters of the format (name!value).
- Returns (resultSet or fault)
  - **resultSet**: query results in XML format ***- OR –***
  - **fault:** Error code (e.g., E_InvalidParameter)
- Example
  - `$ query(MAS, GetAvailableOperatorsByParameter, parameter!temperature)`
- Response

```
<temperature>
   <operator>average</operator>
   <operator>standard deviation</operator>
</temperature>
```

CDS API Method Detail - Ingest

- The Ingest method provides a generic way of providing submission information packages (SIP) to a service provider.
- Arguments
  - **service**: The name of the target service. For example: *HADOOP*
  - **operation**: An identifier that indicates the specific processing for the SIP. For example, *Put,* (operations supported by the HADOOP Service)
  - **SIP**: Submission information package (name!type!content)
  - **sessionId**: Optional session ID for the SIP if the operation is a result of a previous transaction (e.g., ingest parts of a single collection through multiple calls).
- Returns (sessionId!sessionStatus!sessionStatusDetail)
  - **sessionId**: Session id
  - **sessionStatus:** One word status of the session (e.g., Received, Completed, Failed)
  - **sessionStatusDetail**: Description of the session (e.g., “Ingest failed due to insufficient HDFS storage space”)
- Example
  - `$ ingest(HADOOP, Put, MERRAMonth0109!MERRA!/home/gtamkin/m/01/09)`

SIP

CDS API Method Detail - Order

- The Order Method places an order for a predefined service request that does not return instantaneous results. Queries will be handled asynchronously with this method.
- Arguments
  - **service**: The name of the target service. For example: *MAS*
  - **request**: The name of the query to be processed. For example, *GetAverageTemperatureByTimeSpanAndStep* (orders supported by MAS Service)
  - **parameters:** 1 or more parameters of the format (name!value).
- Returns (sessionId!sessionStatus!sessionStatusDetail)
  - **sessionId**: session id. A unique UUID that is used to retrieve session status (e.g., f654c35c-f223-4787-a947-8787f532d3fe)
  - **sessionStatus:** One word status of the session (e.g., Received, Completed, Failed)
  - **sessionStatusDetail**: Description of the session (e.g., “Order failed due to lack of privileges”)
- Example
  - `$ order(MAS, GetAverageTemperatureByTimeSpanAndStep, step!3, startDate!200202, endDate!200708)`

MERRA/AS Server

CDS API Method Detail - Download

- The Download method provides a means for retrieving packages associated with a sessionId from a service provider. In a typical asynchronous transaction, such as those associated with Order, this method obtains results from a service request.
- Arguments
  - **service**: The name of the target service. For example: *MAS*
  - **sessionId**: Session ID for the order.
  - **DIP**: Optional dissemination information package (name!type!content). When this parameter is empty, all packages associated with the supplied sessionId are returned. When a package name is specified within the DIP parameter, the service provider returns only the associated package.
- Returns
  - **DIP**: Requested dissemination information package
- Example
  - `$ download(MAS, f654c35c-f223-4787-a947-8787f532d3fe)`

CDS API Method Detail - Execute

- The Execute method implementation is optional for service providers. It is a service extension mechanism that allows a service provider to offer additional services that are accessed in a common way.
- Arguments
  - **service**: The name of the target service. For example: *iRODS*
  - **methodName**: The name of the method to be processed. For example, *ApplyDataRetentionPolicyToData* (methods supported by iRODS Service)
  - **parameters:** 1 or more parameters of the format (name!value).
- Returns (sessionId!sessionStatus!resultSet)
  - **sessionId**: session id.
  - **sessionStatus:** One word status of the session (e.g., Received, Completed, Failed)
  - **resultSet**: execute results in XML format
- Example
  - `$ execute(IRODS, ApplyDataRetentionPolicyToData, dataType!MERRA)`
- Response

```
f654c35c-f223-4787-a947-8787f532d3fe!Completed!<resultSet>327 files
   removed 4 TB freed</ResultSet>
```

CDS API Method Detail - Status

- Status is a method for session tracking. Once initiated, a session enters into different processing stages. The Status method offers the client a way of querying the current state of the session.
- Arguments
  - **sessionId**: Session ID.
- Returns (sessionId!sessionStatus!sessionStatusDetail)
  - **sessionId**: Session id
  - **sessionStatus:** One word status of the session (e.g., Processing, Completed, Failed)
  - **sessionStatusDetail**: Description of the session (e.g., "MapReduce job in progress")
- Example
  - `$ status(f654c35c-f223-4787-a947-8787f532d3fe)`
- Response

```
f654c35c-f223-4787-a947-8787f532d3fe!Processing!MapReduce job in
   progress
```

CLI Session – Query for Available Operations

- The scientist calls ***Query()*** to determine which MERRA operations (e.g., average) and parameters (e.g., surface pressure, temperature, etc.) are available from the data:

```
$ query(MAS, GetAvailableOperatorsByParameter, parameter!temperature)
$ <temperature>
$    <operator>average</operator>
$    <operator>standard deviation</operator>
$  </temperature>
```

MERRA/AS Server

CLI Session – Query for Available Operations

- The scientist calls ***Query()*** to determine which MERRA operations (e.g., average) and parameters (e.g., surface pressure, temperature, etc.) are available from the data:

```
$ query(MAS, GetAvailableOperatorsByParameter, parameter!temperature)
$ <temperature>
$    <operator>average</operator>
$    <operator>standard deviation</operator>
$  </temperature>
```

CLI Session – Order MapReduce Job

- The scientist ***Orders()***s seasonal average surface pressure for 2006-2009 with a time step of 3, initiating the MapReduce job (responses are in bold italics):

```
$ order(MAS, GetAverageTemperatureByTimeSpanAndStep, step!3, startDate!
200202, endDate!200708)
$ h654c35c-f223-4787-a947-8787f532d3fe

$ status(h654c35c-f223-4787-a947-8787f532d3fe)
$ h654c35c-f223-4787-a947-8787f532d3fe!Processing!MapReduce job in
progress

$ status(h654c35c-f223-4787-a947-8787f532d3fe)
$ h654c35c-f223-4787-a947-8787f532d3fe!Completed!MapReduce job completed
successfully
```

CLI Session – Ingest MapReduce Job

- The developer ***Ingests()***s the MapReduce code (responses are in bold italics):

```
$ ingest(CHOST, Put, MERRAASService!MERRA!/home/gtamkin/m/
HadoopTest.jar)
$ i654c35c-f223-4787-a947-8787f532d3fe

$ status(i654c35c-f223-4787-a947-8787f532d3fe)
$ i654c35c-f223-4787-a947-8787f532d3fe!Completed!MapReduce job ingested
successfully
```

CLI Session – Download Job Results

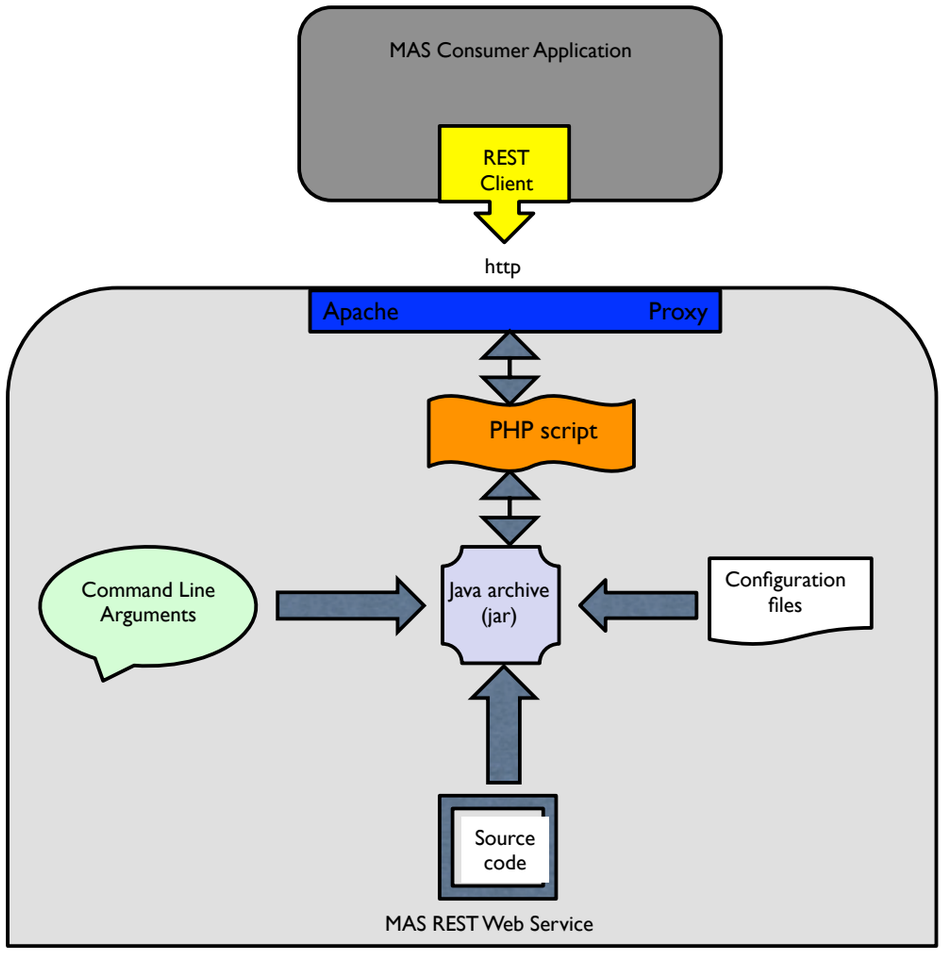
- The scientist ***Downloads()*** the results (e.g., part-r-00000) of the MapReduce job (responses are in bold italics):

```
$ download(MAS, h654c35c-f223-4787-a947-8787f532d3fe)
$ AverageTemperatureByTimeSpanAndStep!MERRA!/home/gtamkin/m/out
```

MERRA/AS Server

MERRA/AS Web Service

- This is the project's initial exposure point for client applications that wish to consume MERRA/AS results.
- We're using a Representational State Transfer (REST)-style architecture, which is based on a client server model and a set of principles describing how standards can be used to develop web services.
- REST is the predominant web API design model supporting these key goals:
  - Scalability of component interactions (allows intermediaries like firewalls and proxies without changing the interface);
  - Generality of interfaces (access paradigm consistent across services);
  - Independent deployment of components (implementations can change without changing the interfaces); and
  - Intermediary components to reduce latency, enforce security and encapsulate legacy systems (e.g., load-balance requests without consumer knowledge).
- A concrete implementation of a REST Web service uses HTTP methods explicitly, is stateless, exposes directory structure-like URIs, and transfers XML, JavaScript Object Notation (JSON), or both.
- REST services were chosen to support access to the Climate Data Services API in part because HTTP is a flexible industry standard protocol.



- Available now internally, ready for external beta testing pending this interim review and discussions ...

MERRA/AS Web Service – Endpoint

REST Service API (URL Conventions adhere to CDS API terminology):
http://<ip:port>/cds/<service>/<primitive>/<service_request>?<parameters> // order, query
http://<ip:port>/cds/<service>/<primitive>/<optional operation>?<parameters> // ingest, execute

The consumer Orders()s average temperature for time range [Jan. 2011-Dec. 2011] within Continental US for all vertical levels:

_____

http://skyportal.sci.gsfc.nasa.gov/cds/mas/order.php?GetAverageByVariable_TimeRange_SpatialExtent_VerticalExtent&variable_list=T&operation=avg&start_date=201101&end_date=201112&avg_period=12&min_lon=-125&min_lat=24&max_lon=-66&max_lat=50&start_level=1&end_level=42

```
<Response>
   <sessionId>h654c35c-f223-4787-a947-8787f532d3fe</sessionId>
   <sessionStatus>Received</sessionStatus>
   <sessionStatusDetail>Map Reduce job submitted at Wed Apr 17 13:17:06 EDT 2013</sessionStatusDetail>
</Response>
```

_____

http://skyportal.sci.gsfc.nasa.gov/cds/mas/status.php?session_id=h654c35c-f223-4787-a947-8787f532d3fe

```
<Response>
   <sessionId>h654c35c-f223-4787-a947-8787f532d3fe</sessionId>
   <sessionStatus>Completed</sessionStatus>
   <sessionStatusDetail>Map Reduce job completed successfully prior to Wed Apr 17 13:19:32 EDT 2013</
   sessionStatusDetail>
</Response>
```

_____

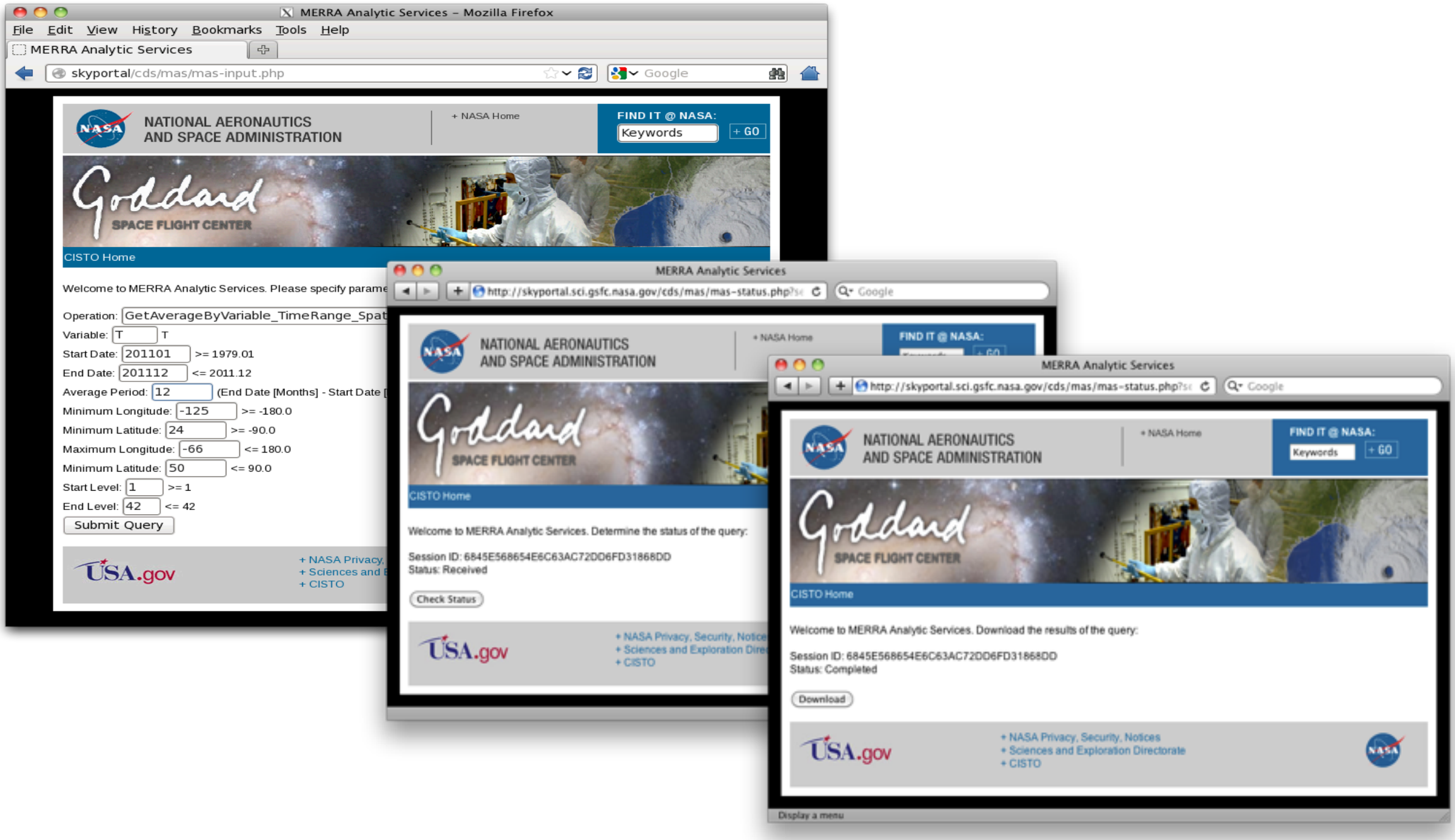
http://skyportal.sci.gsfc.nasa.gov/cds/mas/download.php?session_id=h654c35c-f223-4787-a947-8787f532d3fe

Response (File Download)

MERRA/AS Server

MERRA/AS Graphical User Interface (GUI)

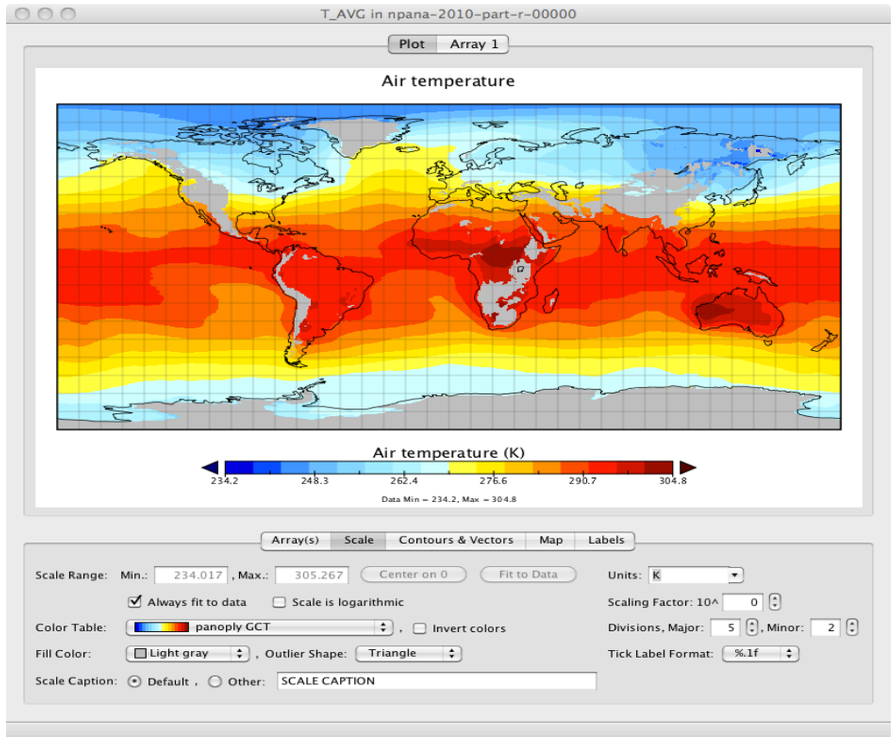
http://skyportal.sci.gsfc.nasa.gov/cds/mas/mas-input.php



MERRA/AS Server

Code Modules

- There's a substantial code ecosystem behind the averaging operation. Lines of code per logical module is as follows:
  - Core 2617
  - Sequencer 824
  - De-sequencer 808
  - MapReduce 1138
  - Avg Op 234 (Mapper 89, Reducer 145)
  - **Total** **5621 <==**



NetCDF Sequencing Common Classes — These are wrapper classes that would be used to contain the NetCDF data in a form that can be read and written to sequence files.

- *NetCDFCompositeKey* — This is the key object used by both the sequencer and the application. The key uses the field name and the date-time from the NetCDF file. This allows <key, value> pairs to be sorted by time and grouped by field.
- *NetCDFSequenceFileRecord* — This is the main data class. A record contains the main field variable, along with any other variables that were associated with this field from the NetCDF file. It also stores the essential metadata associated with the variable. It contains methods that convert NetCDF variable Java objects into this record object.
- *NetCDFSequenceFileVariable* — Contains the data and metadata/attributes from a NetCDF variable. This class also contains multiple convenience routines for accessing the data.
- *NetCDFSequenceFileAttribute* — Attributes are metadata associated with a variable. The sequence variable class uses this class to store variable attributes.

NetCDF Sequence Application Classes — These are the main sequencing and de-sequencing application classes. These rely on the common sequence classes to translate NetCDF files to sequence files and vise versa.

- *NetCDFSequenceFileGenerator* — This class opens, reads, and translates input NetCDF files into Hadoop Map files (sequence files with indexing). It uses the NetCDFCompositeKey class to construct keys, and classes from the common sequence directory to construct values. The values are serialized using a library called Kryo that packs Java objects into byte arrays.
- *SequenceToNetCDF* — Output from a MapReduce program is itself a sequence file. This class converts sequence file results into a NetCDF file to return to the MERRA/AS server.

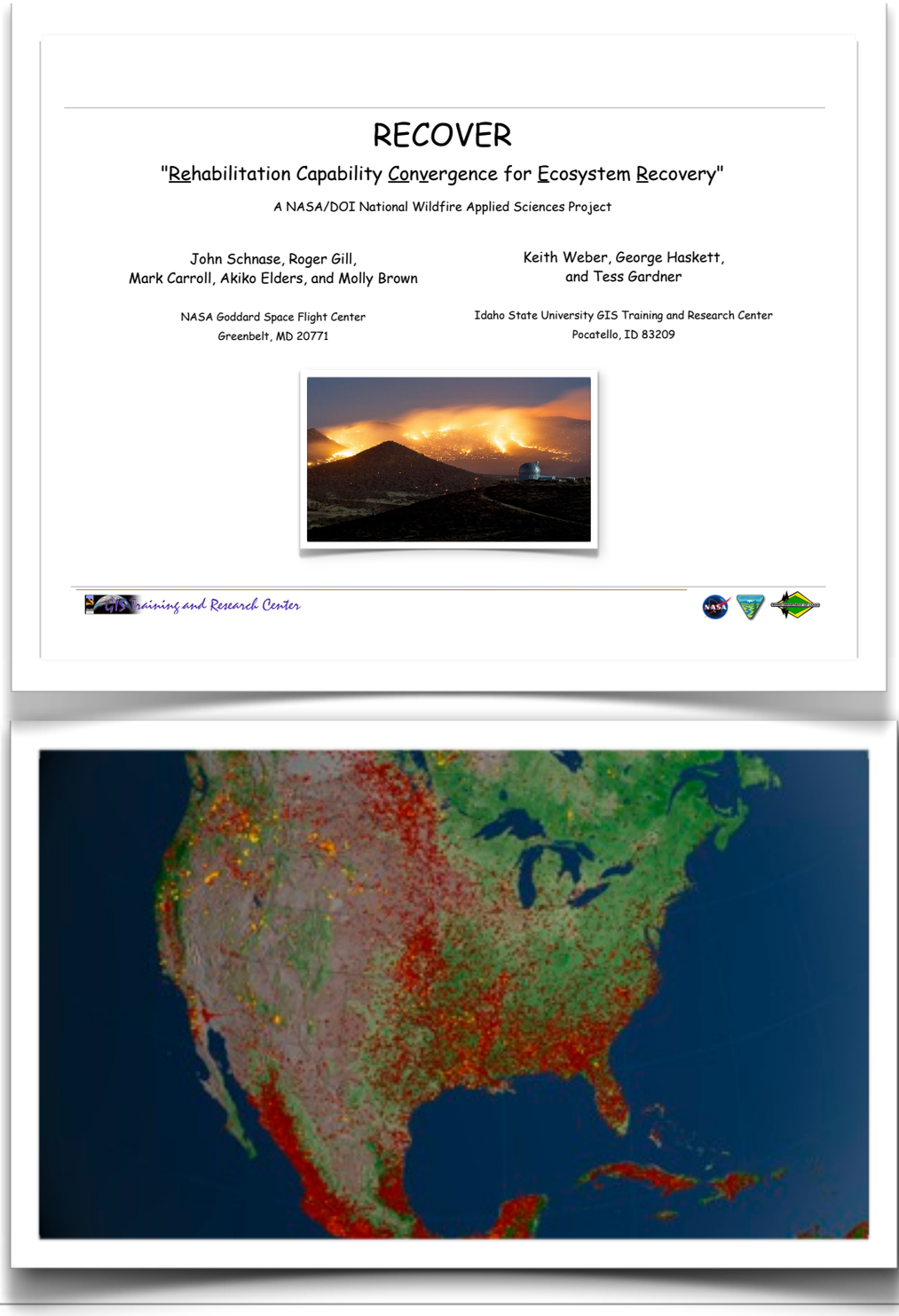
Ops Library Classes — As part of the MERRA/AS delivery, we will begin a library of these basic operations. These canonical ops will provide a template for users as they begin their exploration of MapReduce analytics and will be useful in their own right as steps in larger analyses.

- *NetCDFAveragerMapper* — This code basically compares the current <key, value> pair to the criteria for what fields to process (in this case a simple average). Any field that does not match is rejected. Fields that are accepted are passed on to the reducer.
- *NetCDFAveragerReducer* — Upon receiving all the <key, value> pairs from the mapper, this routine goes through the grouped and ordered <key, value> pairs and performs the averaging operation based on the specified time period. When a time period has been processed, a new <key, value> pair is created and written out to disk.

Application Integration

Customer Connections

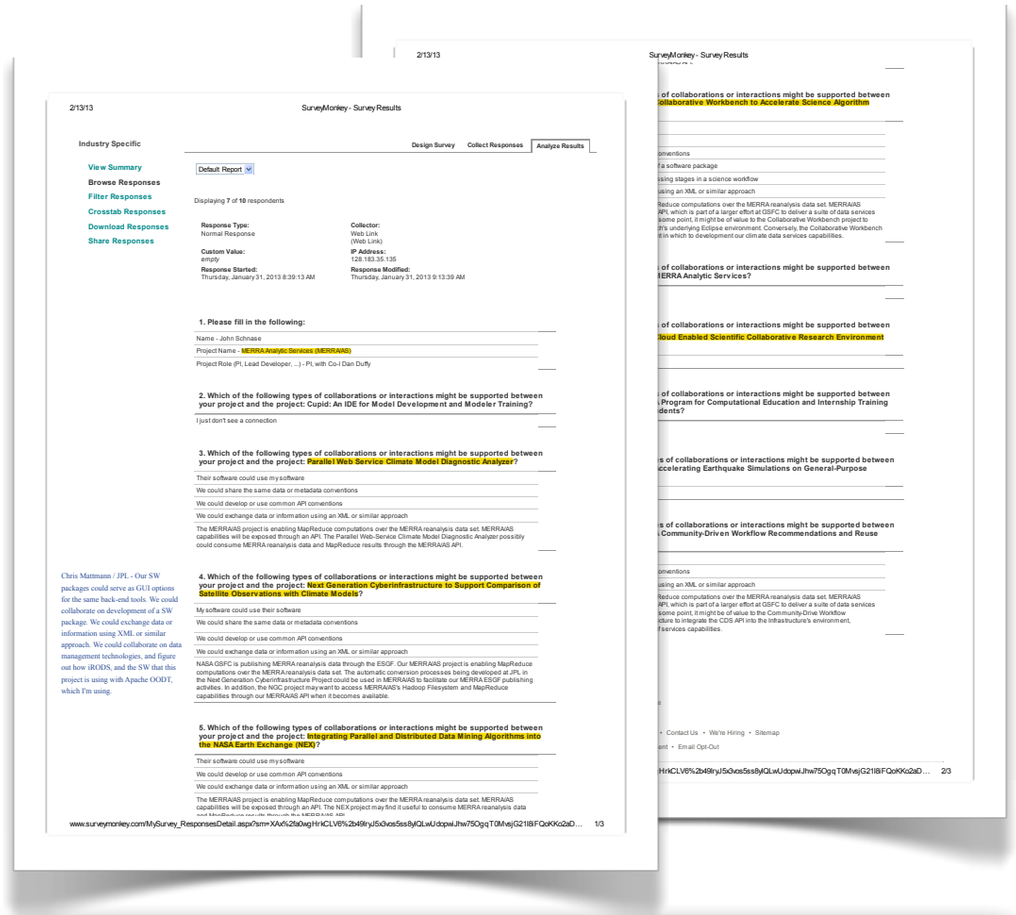
- NASA ASP A.35 Wildland Fires RECOVER project.
  (Keith Weber, John Schnase, Molly Brown)
  - Post-wildfire decision support system for Burned Area Emergency Response (BAER) Plan development. Partners include Bureau of Land Management, USDA Forest Service, Idaho Department of Lands, and the National Interagency Fire Center.
  - iRODS- and Amazon Cloud-based RECOVER Server performs real-time data aggregation from diverse collections – to include MERRA and SMAP.
- NSF DataNet Federation Consortium
  - Science cyberinfrastructure initiative focusing on engineering and hydrology. Partners include UNC, RENCI, Research Data Alliance, DataOne, and EUDAT.
  - Hydrology and the iRODS integration of diverse hydrological and atmospheric data sets a major focus – to include MODIS and MERRA products.
- SIGClimate
  - NASA, NOAA, UNC, DOI, DOE effort to improve government and private sector sharing of climate data management information and technologies and to improve access to climate data.
  - NCDC / NCCS / RENCI iRODS Testbed being designed now, with possible connection to NFS DNFC ...
- Others include: GSFC / LARC iRODS Testbed, CSC Climate Edge product line, Applied Science and Terrestrial Ecology Program climate adaptation projects, Direct Readout Laboratory Climate Data Records (CDRs), and NCA modelers.



Application Integration

Connections to Other CMAC Projects

- Rama Nemani / NEX Project
  - Climate Data Services preparing to deliver ~18TB of downscaled MODIS data to ARC. We're in active discussions with Rama about how to use the iRODS-based Climate Data Server technology to facilitate transfers and make MERRA data available to NEX.
- Chris Mattman / NexGen Cyberinfrastructure Project
  - Climate Data Services providing Chris/JPL with CMIP Data Conversion Software that will allow observational data to be converted to CMIP5 format for IPCC/ESGF publication. This capability will be integrated into the MERRA/AS in the next phase of this project
  - We've also discussed potential sharing of JPL GUIs and GSFC's CDS API between these projects.
- Other potential linkages to be developed are API-facilitated data sharing with Lee, Oza, and Ramachandran's projects.



Related Research Activities

- Cristina Grieg's dissertation research
  - Cristina's dissertation research is focusing on reanalysis data intercomparison, observational/reanalysis data intercomparison, and storage optimizations for reanalysis data and associated analytics.

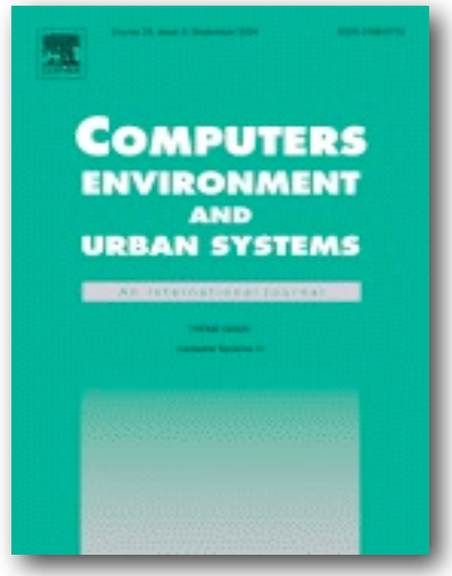
Administration

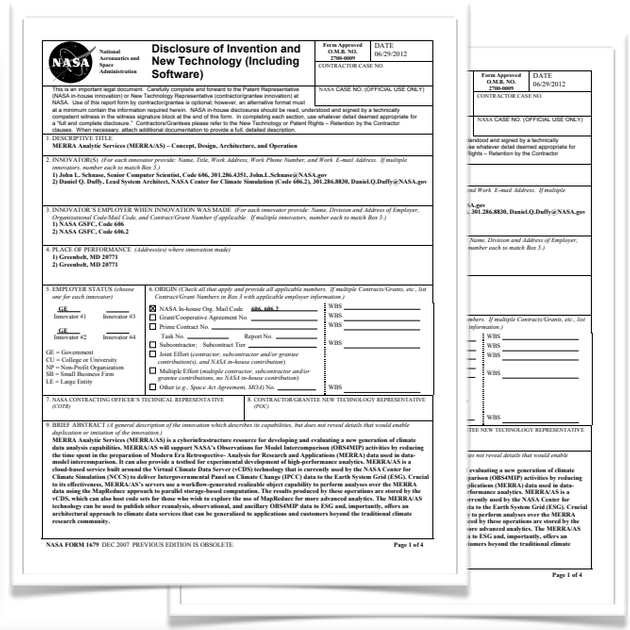
Communications

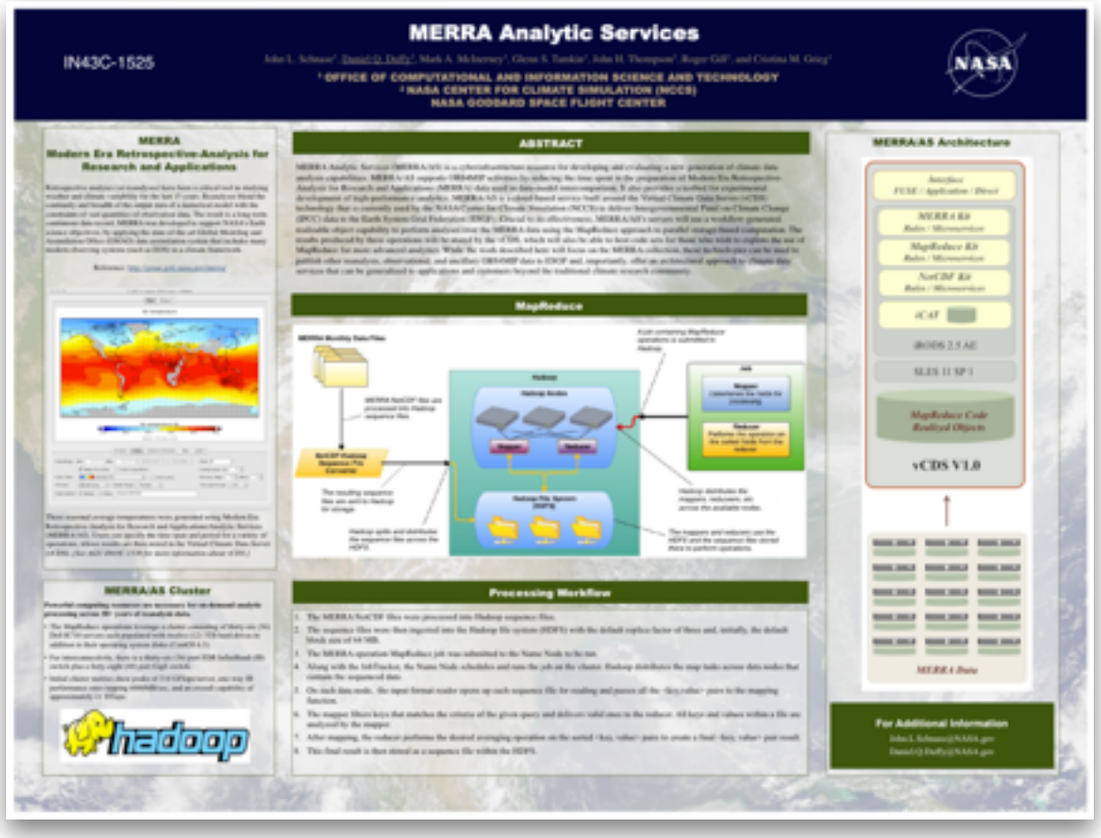
- Posters / Presentations
  - Schnase, J.L., Duffy, D.Q, McInerney, M.A., Tamkin, G.S., Thompson, J.H., Gill, R., & Grieg, C. *MERRA Analytic Services*. AGU Fall Meeting, December 3-7, 2012, San Francisco, CA.
  - Tamkin, G.L., Schnase, J.L., and Duffy, D.Q. Next Generation Climate Data Services: MERRA Analytics. Supercomputer 2012 Conference (SC12), November 10-16, 2012, Salt Lake City, UT.
- Papers
  - Schnase, J.L., Duffy, D.Q, McInerney, M.A. Tamkin, G.S., Nadeau, D., Thompson, J.H., Sinno, S.,Luczak, E., Gill, R., & Grieg, C. MERRA Analytic Services. In: *Computers, Environment, and Urban Systems – Special Issue on Big Data and Scientific Cloud Computing*. (In prep.)
  - Other venues: IEEE Special Issue on Big Data, iRODS Users Group Conference, ...

New Technology Reports (NTRs)

- *MERRA Analytic Services (MERRA/AS) – Concept, Design, Architecture, and Operation.* (Submitted 06/29/2012)
- *MERRA Analytic Services (MERRA/AS)* – Application Programming Interface . (In prep.)







Administration

Resource Allocations

- The MERRA/AS cluster cost $350K.
- Labor is being charged to the remaining $150K: Glenn Tamkin (Technical Lead), with Denis Nadeau, Hoot Thompson, Scott Sinno, Ed Luczak, Mark McInerney, Dan Duffy, and John Schnase.

TRL Assessment / Schedule Status

- Aggregate $TRL_{in} = 3$ *(Analytical and experimental critical function proof-of-concept.)*

  Aggregate $TRL_{out} = 6$ *(Subsystem prototyping demonstration in a relevant end-to-end environment.)*
- First half of the project is on schedule ...

Problems / Recovery Plans

Issue	Potential Problems	Recovery Plans
Architecture	The user-facing front-end data portal orchestrates jobs on the remote cluster; variability on performance and where results are stored have been observed.	Expose web service on cluster name node directly to eliminate the extra layer of network traffic.
Performance / Consistency	Job run-time is based on a variety of variables, causing ad-hoc [within limits] completion times.	Provide an asynchronous download capability via API to avoid synchronous time-outs; use Cloudera optimizations to increase Hadoop throughput.
Software Stack	Hadoop and 3rd party offerings are constantly changing due to the rapid evolution of the technology.	Freeze the software ecosystem on the most mature offerings at the expense of integrating the latest functionality. Avoid reliance on version-specific features in preparation of migration by leveraging mainstream core features versus custom.
Hardware	Data nodes may fail, jeopardizing the success of MapReduce jobs.	Replicate the data three times across the data nodes and utilize Hadoop's failover capability to move processing to a working node.

Work Plan for the Next Reporting Period

The focus in the next half of the project will be on CDS integration, application integration, public release of the API and associated web services, and operational deployment of MERRA/AS ...

- *MERRA/AS Cluster* – SciDB, Impala, ECMWF, and NCEP data.
- *MERRA/AS Server* – Climate Data Server / MapReduce Core integration, codeset management, CDS kits, and API/Web Services public release.
- *Application Integration* – Complete customer connections and connections to other CMAC projects, advance related research activities and public outreach.
- *Administration* – Final documentation, publications and NTRs, final TRL assessment, and operational deployment.

MERRA/AS Project Timeline

	1	2	3	4	5	6	7	8	9	10	11	12
1. MERRA/AS Cluster												
HW/SW Build	MAS Cluster, Cloudera						SciDB, Impala, Optimizations					
Data Build				MERRA			ECMWF, NCEP					
2. MERRA/AS Server												
MapReduce Core	Sequencing/De-Sequencing, Canonical Ops, API, Web Services						Ops Extensions, Optimizations, Public API/Web Service					
CDS Integration							Persistence Service, Code Set Management, CDS Kits					
3. Application Integration												
CMAC Connections				Identify, initiate collaborations			Complete project connections and application integration ...					
Other Customer Connections				Identify, initiate collaborations			Complete project connections and application integration ...					
4 Release to NCCS Operations												
5. Report Results												

Interim Review

MERRA/AS Server

Next Phase Activities

- Climate Data Server / MapReduce Core Integration
  - Goal is to create a capacity for MapReduce code set management and the management of results produced by job runs.
  - Requires the integration of the iRODS-based Climate Data Server (CDS) technology.
  - Best understood as a service extension. For example, a "Persistence Service" (PS) where one can submit a MapReduce <driver, mapper, reducer> program or API-facilitated script and manage realized objects.

    ingest (PS, MR_SIP, ...) - save a program or script
    order (PS, MR_AIP, ...) - create a realized object
    download (PS, MR_DIP, ...) - get a realized object

  - We want to be able to provide storage-proximal MapReduce analyses as a service – possibly to outside customers who wish to run proprietary codes and manage proprietary results ...
- Operational Deployment
  - Deliver Cluster/MapReduce/Persistence aggregate capability at "mission qualified" TRL 8.
  - Deliver iRODS/CDS MapReduce and MERRA "Kits" and RENCI E-iRODS plug-in extensions.
  - Deliver MERRA/AS components of the NASA Climate Data Services API and associated web services.
  - Deliver related documentation, publications, presentations, NTRs, etc.