



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

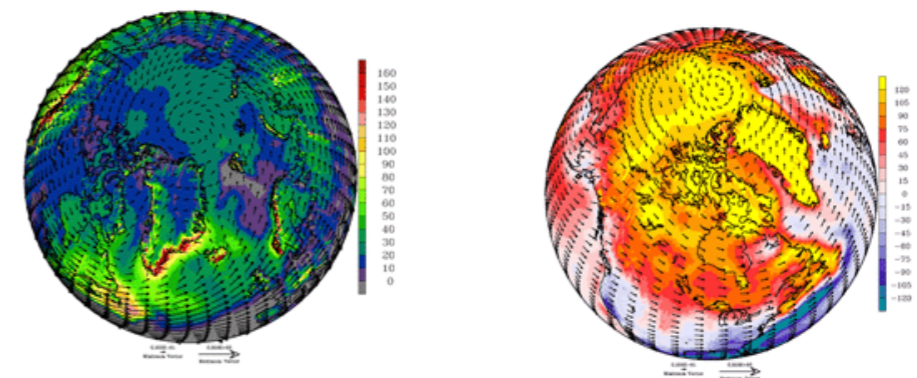
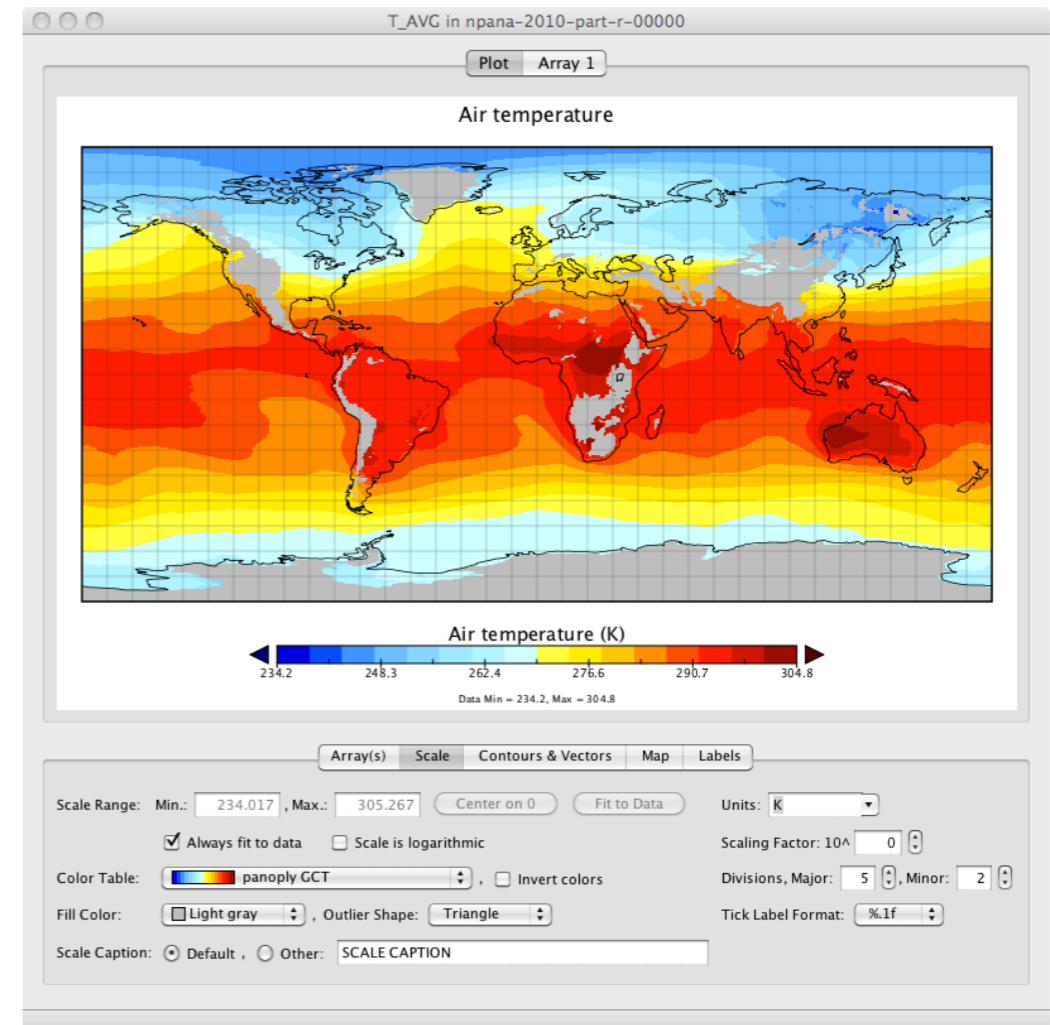
- **MERRA/AS Cluster** – Cluster configuration, node configuration, MERRA data, HDFS organization, and Cloudera.
- **MERRA/AS Server** – MapReduce analytics, sequencing/de-sequencing, canonical ops, API, and web services.
- **Application Integration** – Customer connections, connections to other CMAC 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	
NASA PROCEDURE FOR HANDLING PROPOSALS					
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 John Schnase		E-mail Address John.L.Schnase@nasa.gov		Phone Number 301-286-4351	
Street Address (1) Bldg. 28, Rm. W233A, Code 606		Street Address (2)			
City Greenbelt		State / Province MD		Postal Code 20771	Country Code US
Proposal Title : MERRA Analytic Services					
Proposed Start Date 10 / 01 / 2012	Proposed End Date 09 / 29 / 2013	Total Budget 477,228.00	Year 1 Budget 477,228.00	Year 2 Budget 0.00	Year 3 Budget 0.00
SECTION II - Application Information					
NASA Program Announcement Number NNH11ZDA001N-CMAC		NASA Program Announcement Title 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 03 / 09 / 2012		Submission Method Electronic Submission Only		Grants.gov Application Identifier	Applicant Proposal Identifier
Type of Application New	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted			
International Participation No	Type of International Participation				
SECTION III - Submitting Organization Information					
DUNS Number 004968611	CAGE Code 36FC1	Employer Identification Number (EIN or TIN) 520734375		Organization Type 2A	
Organization Name (Standard/Legal Name) NASA Goddard Space Flight Center				Company Division	
Organization DBA Name NASA				Division Number	
Street Address (1) 8800 GREENBELT RD		Street Address (2)			
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SECTION V - Certification and Authorization					
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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 David Leisawitz		AOR E-mail Address David.T.Leisawitz@nasa.gov		Phone Number 301-286-0807	
AOR Signature (Must have AOR's original signature. Do not sign "for" AOR.)				Date	

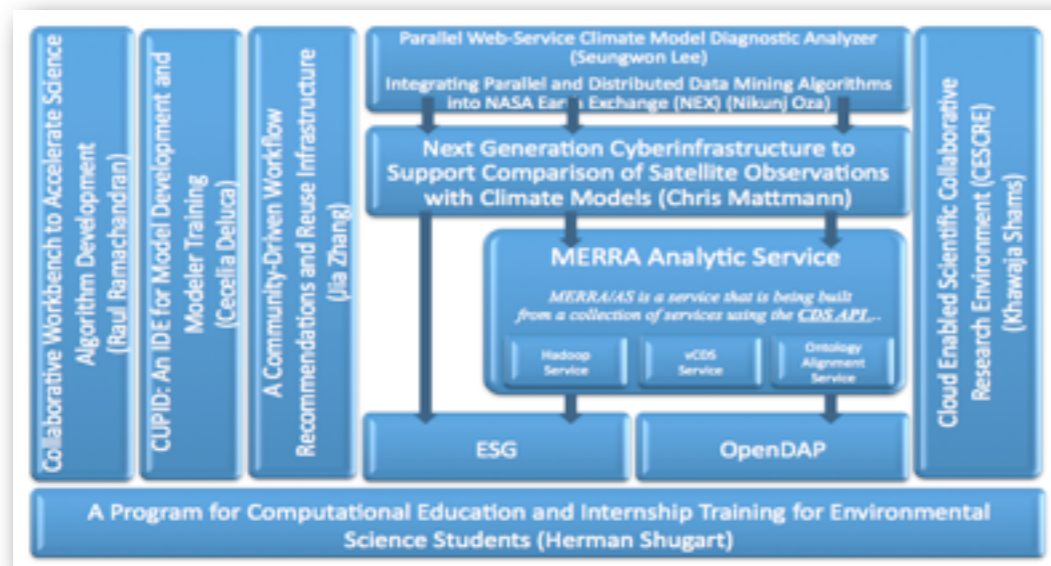
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Project Summary

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 $1/2^\circ$ latitude \times $2/3^\circ$ longitude \times 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.

DATA ASSIMILATED FOR MERRA

The volume of data ingested during a 6-hourly assimilation cycle changes dramatically over time. During the EOS era, over 4 million observations are assimilated at one time.

2 UTC, 7 January 1979: 325,765 obs
12 UTC, 2 August 1987: 559,802 obs
12 UTC, 7 January 2006: 4,217,855 obs

Conventional data & Satellite

Data Source/Type	Period	Data Supplier
Radiosondes	1970-present	NCEP
Pibal winds	1970-present	NCEP
Wind profiles	1992/93/14-present	UCAR
Conventional, ACAR and MCOIS aircraft rep.	1970-present	NCEP
Dropsondes	1970-present	NCEP
POS	1978-present	NCEP
GISL, METEOSAT, cloud drif IR & visible winds	1977-present	NCEP
GOES cloud drift winds	1997-present	NCEP
EOS/Polar/MCOIS winds	2002/03-present	NCEP
EOS/QuikSCAT winds	2002/03-present	NCEP
Surface ship and buoy observations	1977-present	NCEP
Surface land observations	1970-present	NCEP
SSM/I V6 wind speed	1987/77-present	RSS
SSM/I rain rate	1987/77-present	GSFC
TRM rain rate	1997/52-present	GSFC
QuikSCAT surface winds	1999/77-present	JPL
ERS-1 surface winds	1992/08/5 - 1996/06/23	CERSAT
ERS-2 surface winds	1996/02/10 - 2002/12/13	CERSAT
SRIV (space DB network)	1978/78-present	GSFC

Satellite radiance data

Data Source/Type	Period	Data Provider
TOVS (CHRS, N, N4, N7, N8)	1978/02/03 - 1985/03/01	NCEP
ATOV5 (N4, N10, N11, N12)	1985/01/01 - 1997/07/31	NESDIS/NCAR
ATOV5 (N14, N15, N16, N17, N18)	1995/05/19-present	NESDIS
EOS/Aqua	2002/10-present	NESDIS
SSM/I V6 (F08, F10, F11, F13, F14, F15)	1987/77-present	RSS
EOS/Sounder T ₁	2001/01-present	NCEP

FIND MORE INFORMATION ON MERRA AT
<http://gmao.gsfc.nasa.gov/merra>

MERRA products are available online through the Goddard Earth Sciences Data and Information Services Center:
<http://disc.sci.gsfc.nasa.gov/mdisc/data-holdings>

The GMAO works to maximize the impact of satellite observations in climate, weather and atmospheric composition prediction using comprehensive global models and data assimilation systems.

GLOBAL MODELING AND ASSIMILATION OFFICE

Code 610.1
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
<http://gmao.gsfc.nasa.gov>

MERRA

The Modern Era Retrospective-analysis for Research and Applications

Precipitation 15S-15N compared against GPCP

Global Modeling and Assimilation Office
Goddard Space Flight Center

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.

MERRA - THE GOAL

The Global Modeling and Assimilation Office (GMAO) develops and uses comprehensive models and assimilation systems that support NASA's Earth science research enterprise and contribute to the nation's capabilities in climate, weather and composition prediction.

The GMAO has used its GEOS-5 atmospheric data assimilation system to synthesize the many and various observations collected over the satellite era (from 1979 to the present) into an analysis that is as consistent as possible over time because it uses a fixed assimilation system. This contrasts with a weather-focused analysis where the system changes over time as improvements to the model and the analysis are implemented to improve weather forecasts. The goal of this historical re-processing - called MERRA, the Modern Era Retrospective Analysis for Research and Applications - is a climate-quality analysis that places NASA's EOS observations into a climate context.

The initial primary goal of MERRA was to improve upon the hydrological cycle analysis in previous generation atmospheric reanalyses, such as ERA-40 and NCEP Reanalysis 1 and 2.

MERRA has now completed analysis of over 30 years of data and is now proceeding forward in near real-time as a climate analysis.

THE MERRA SYSTEM

ASSIMILATION SYSTEM

MERRA is being conducted with version 5.2.0 of the GEOS-5 Atmospheric Data Assimilation System (ADAS). The ADAS is comprised of the GEOS-5 model with the Grid-point Statistical Interpolation (GSI) analysis, the latter being a system jointly developed by GMAO and NOAA's National Centers for Environmental Prediction.

The model grid is $1/2^\circ$ latitude \times $2/3^\circ$ longitude \times 72 layers.

A key development in the GSI, not available for the previous generation of reanalyses, has been the online bias correction for satellite radiance observations. Such corrections are needed to compensate for sensor drifts as well as to ensure that observations from different satellites, which have been calibrated independently, provide consistent measurements of our environment.

PROCESSING IMPLEMENTATION

Special attention was paid to spinning up the land surface state by conducting an analysis at 2° for 2 years and then at $1/2^\circ$ for 1-5 years (depending on the initial start time) before the official product generation began.

MERRA Mainstream and Spin Up

MERRA was conducted at the NASA Center for Climate Simulation (NCCS) as 3 separate analysis streams to facilitate timely production. The overlaps in the different streams were used to check for the quality of the spin-up and also to provide an estimate of uncertainty (predictability) associated with differences in initialization.

PRODUCTS

MERRA is distributed through the GES DISC (http://disc.sci.gsfc.nasa.gov/MDISC/data-prod/merra_products.shtml) with several download options.

There are 24 product collections, some targeted for particular applications, such as chemistry transport models (CTMs).

Products are generated on three horizontal grids:

- Native ----- ($1/2^\circ \times 2/3^\circ$ using model conventions)
- Reduced ----- ($1/4^\circ \times 1/4^\circ$, dateline-edge, pole-edge)
- Reduced FV -- ($1^\circ \times 1/4^\circ$ using model conventions)

3-D data are 72 model layers or 42 pressure levels.

Products include:

- ANALYZED FIELDS** (u, v, t, q, O₃, ps): native grid, 6-hourly instantaneous fields, on model and pressure levels
- 3-D DIAGNOSTIC FIELDS**: reduced grid, 3-hourly time-averaged fields on pressure levels
- 2-D DIAGNOSTIC FIELDS**: native grid, hourly time-averaged fields
- PRODUCTS FOR OFFLINE CTMs**: various resolutions, frequencies and grids.

SOME EARLY RESULTS

Since MERRA focused on the hydrological cycle, our early evaluation of the system has looked at various aspects of the moisture distribution and variability, compared with the previous reanalyses and also the more recent reanalysis (ERA-Interim) from ECMWF.

SSM/I Total Column Water Vapor January 1995

Monthly mean TCWV (kg m^{-2}) from reanalyses (2nd row) compared with that from SSM/I (top row). The differences (reanalysis-SSM/I) are shown in the bottom row. MERRA and ERA-Interim are very close and are slightly drier than the observations. Absolute differences are mostly smaller than 2 kg m^{-2} . In contrast, ERA-40 is much wetter than SSM/I, but over 3.5 kg m^{-2} over much of the tropics.

The quality of the tropical (15S-15N) precipitation from the various reanalyses is evaluated by comparison with GPCP. A different observational product, CMAP, provides a baseline for the limit to how good a comparison can be expected. The comparisons are summarized in a Taylor diagram (upper plot) of the correlation and standard deviation normalized by GPCP. The dots for each system are for annual means of different years. A perfect comparison would be (1,100).

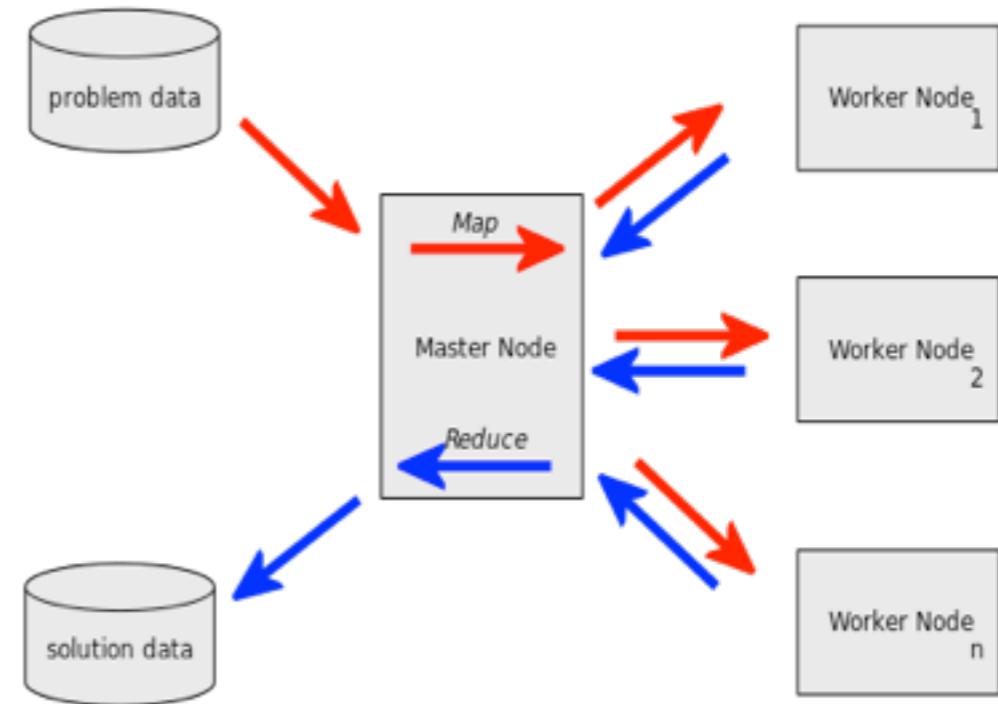
The lower plots show time series of annual means of spatial correlation and mean bias. Clearly both MERRA and ERA-Interim have improved upon earlier reanalyses.



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 ...



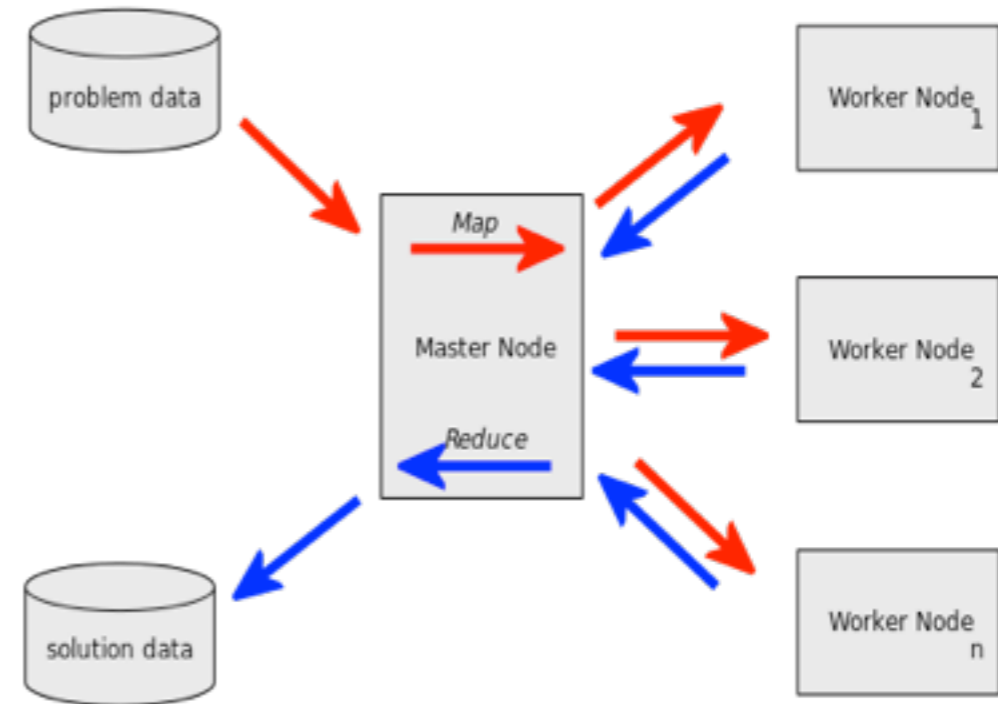
MapReduce

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.

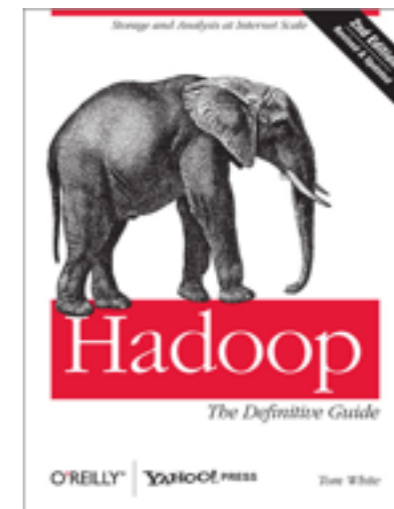
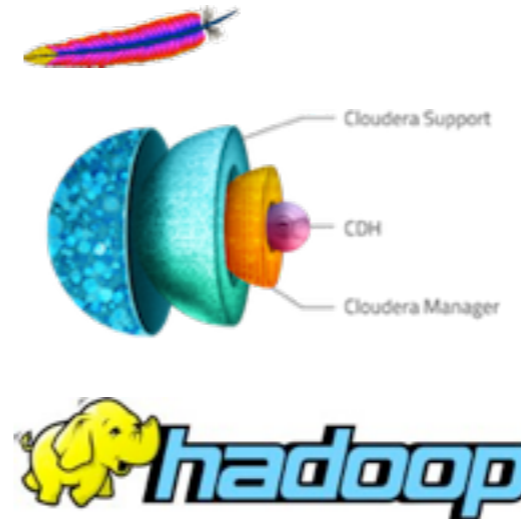




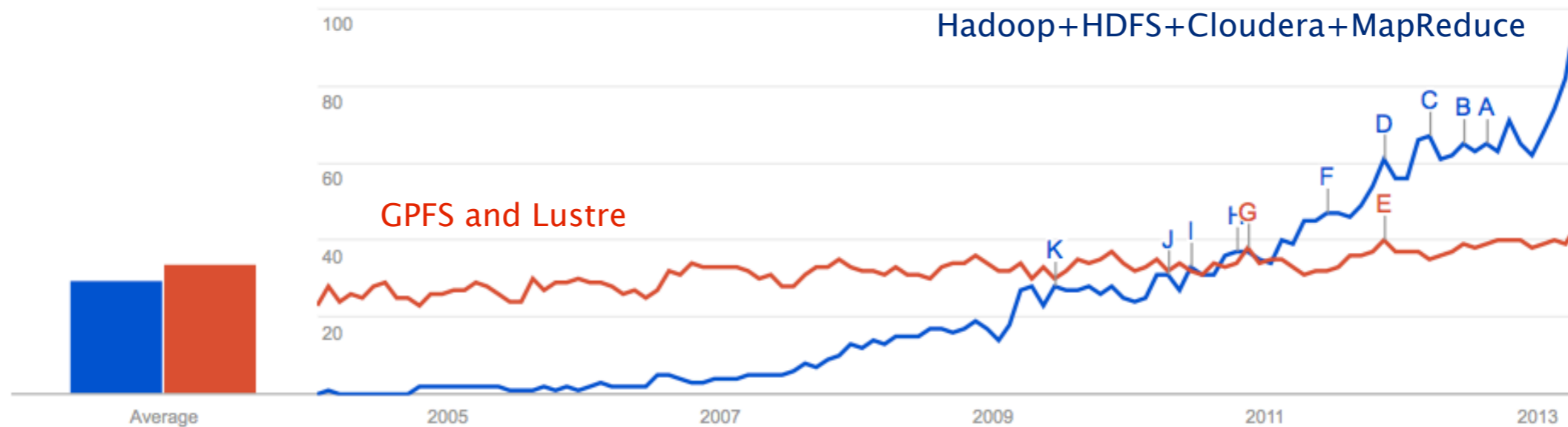
MapReduce

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



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 ...

*What the NCCS
Can Do to Help ...*

MERRA/AS

Climate Data Server (CDS) Technology

Climate Data Services API

Analysis Nodes

...

Data Services

Analytic Services



Discover Cluster

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

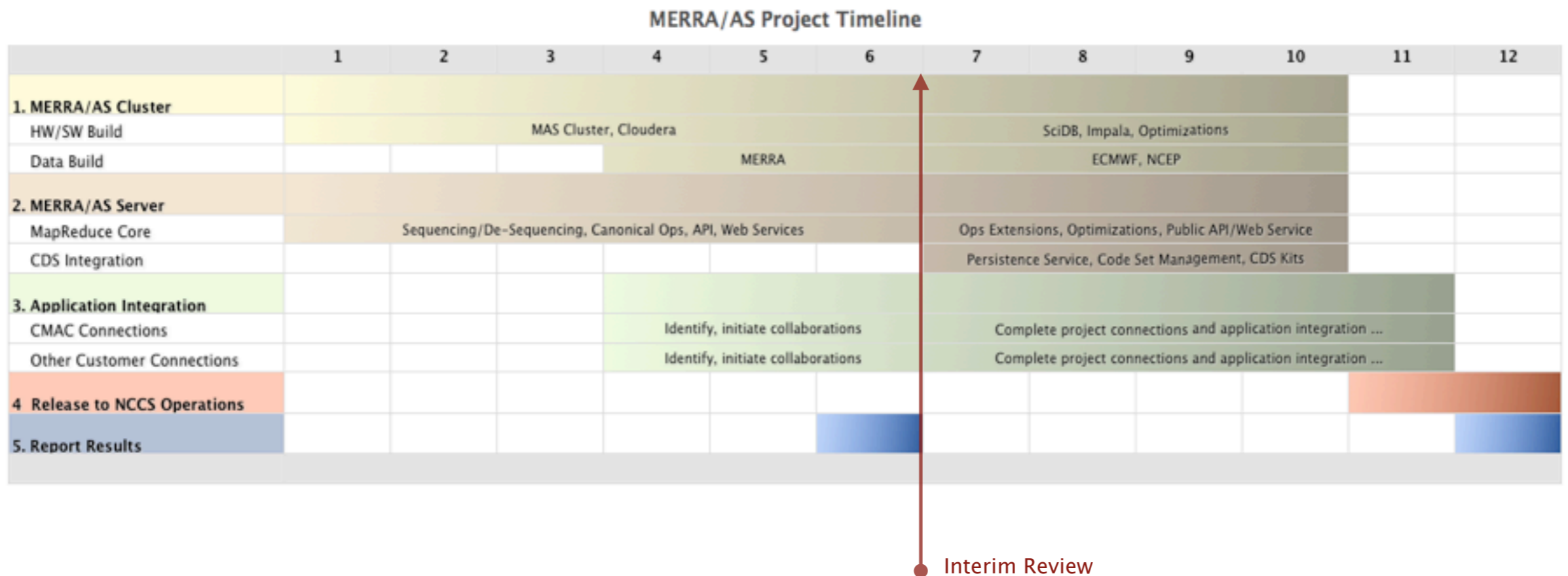
Inefficient – Users analyze large data sets through a series of many small blocks reads and writes and complain that it is too slow ...



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.
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- *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.

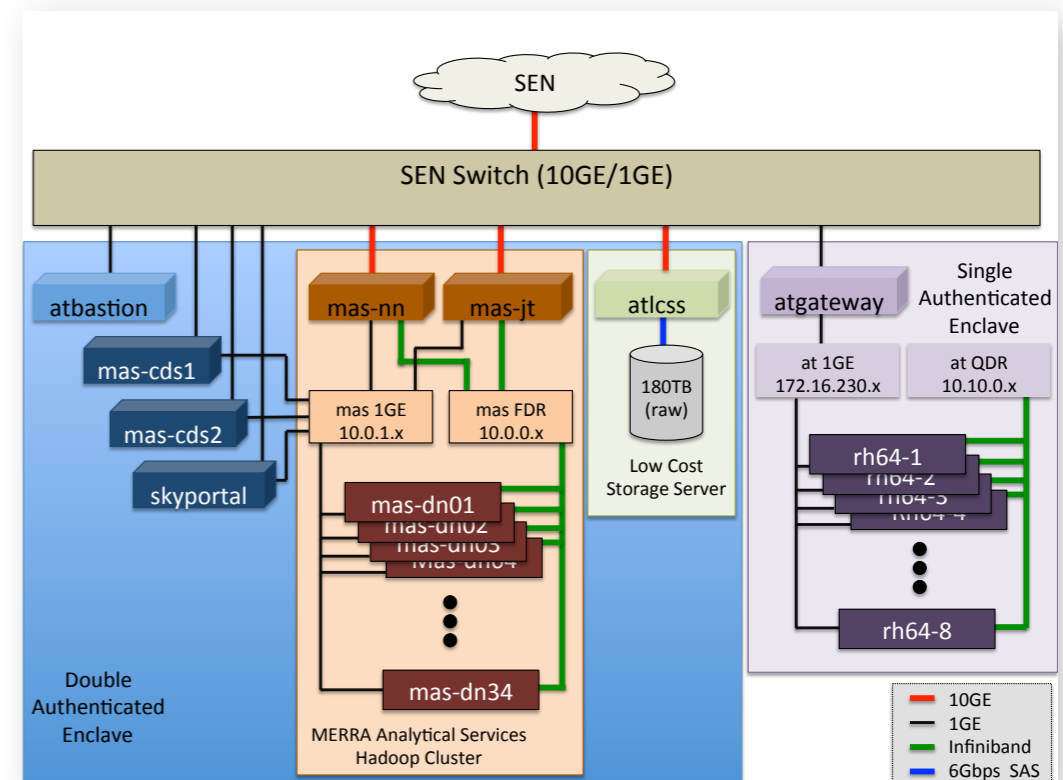
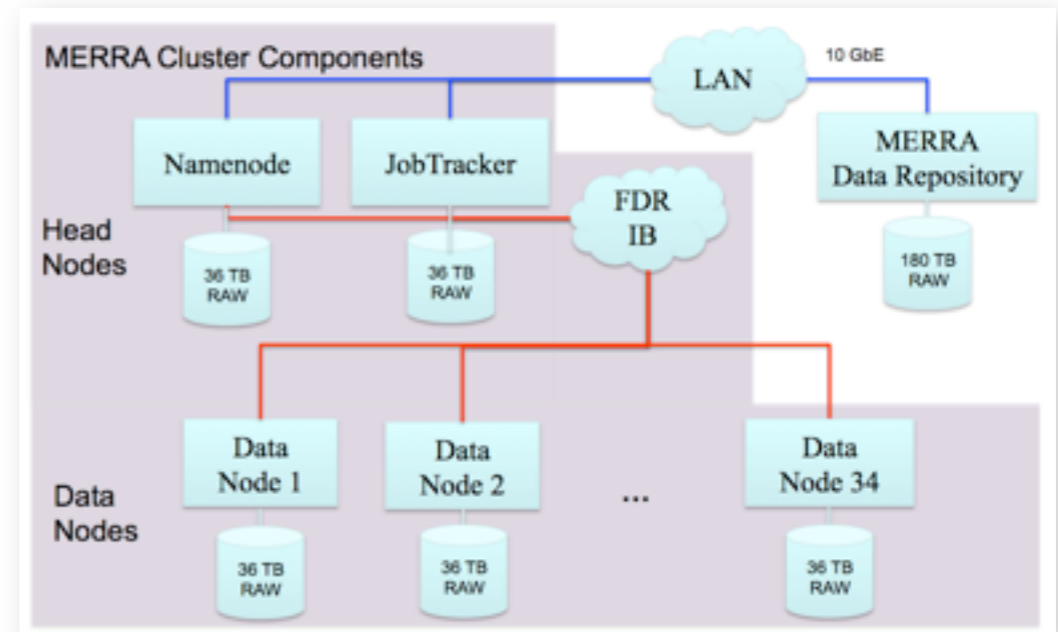




MERRA/AS Cluster

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
tav3_3d_cld_Cp	Upper-air cloud related diagnostics	0.075
tav3_3d_mst_Cp	Upper-air diagnostics from moist processes	0.056
tav3_3d_trb_Cp	Upper-air diagnostics from turbulence	0.147
tav3_3d_rad_Cp	Upper-air diagnostics from radiation	0.088
tav3_3d_tdt_Cp	Upper-air temperature tendencies by process	0.191
tav3_3d_udt_Cp	Upper-air wind tendencies by process	0.224
tav3_3d_qdt_Cp	Upper-air humidity tendencies by process	0.166
tav3_3d_odt_Cp	Upper-air ozone tendencies by process	0.083
tav1_2d_slv_Nx	Single-level atmospheric state variables	0.285
tav1_2d_flx_Nx	Surface turbulent fluxes and related quantities	0.267
tav1_2d_rad_Nx	Surface and TOA radiative fluxes	0.189
tav1_2d_lnd_Nx	Land related surface quantities	0.146
tav1_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	
tav3_3d_chm_Fv	Chemistry related 3-D at model layer centers	0.329
tav3_3d_chm_Fe	Chemistry related 3-D at model layer edges	0.166
tav3_2d_chm_Fx	Chemistry related 2-D Single-level	0.020
tav3_3d_chm_Nv	Accumulated transport fields at layers	0.915
tav3_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, Oozie, 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>



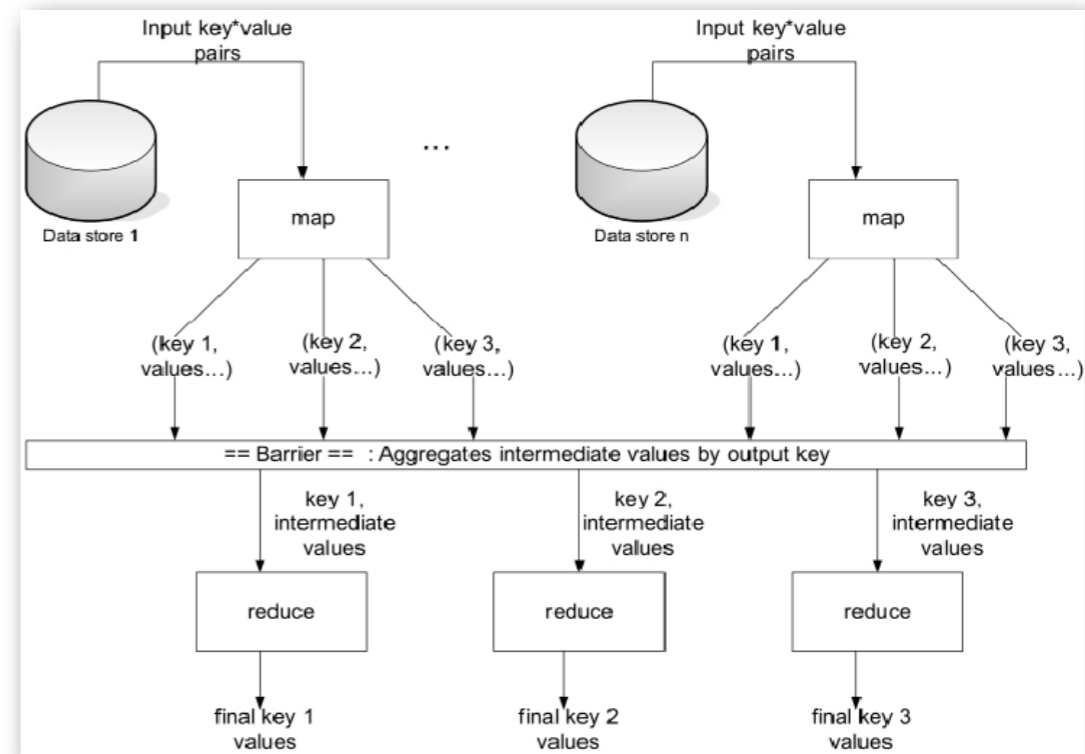
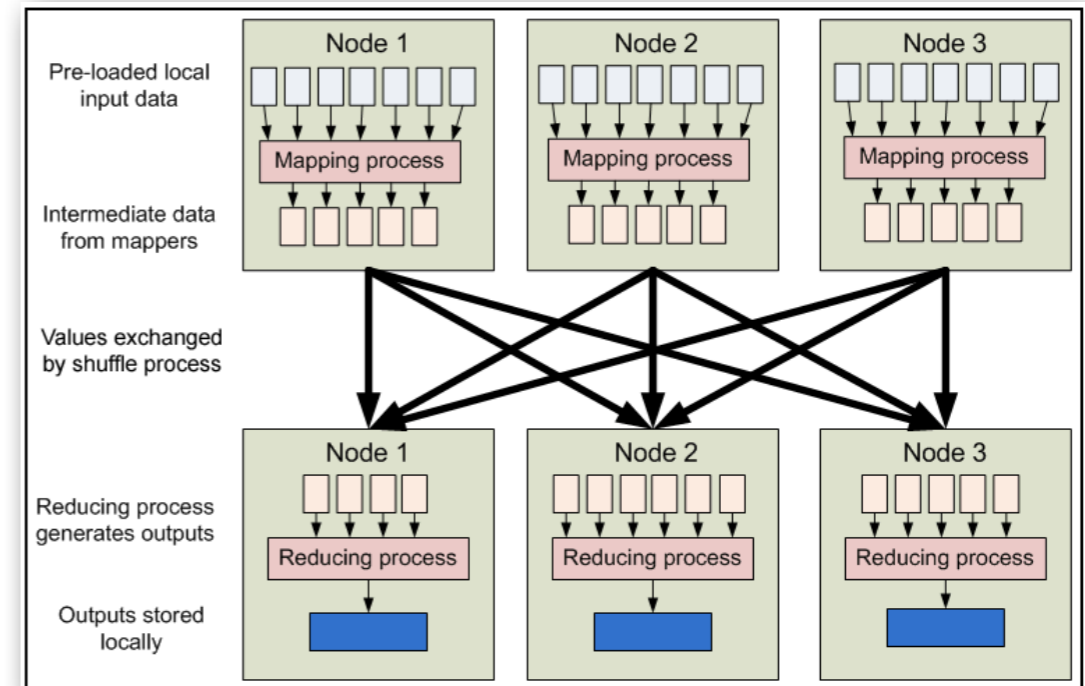
The screenshot shows the Cloudera website homepage. The top navigation bar includes 'Cloudera.com', 'Cloudera University', 'Documentation', 'Developer Community', 'Sign In', 'Register', 'Contact Us', and 'DOWNLOADS'. The main header features the Cloudera logo and the tagline 'Ask Bigger Questions'. Below the header, there is a large banner with the text 'WHAT THE ENTERPRISE REQUIRES THE PLATFORM FOR BIG DATA' and a button to 'Download the whitepaper today'. The main content area is divided into several sections: 'Ask Bigger Questions' with a description of Cloudera's open-source software, 'WHERE BIG DATA MEETS HEALTH SCIENCE' with a video thumbnail, 'GET NEXT-GENERATION DATA MANAGEMENT' with a 'NEW!' badge, 'CLOUDERA THE ULTIMATE LEADER IN SQL ON HADOOP, SAYS GIGAOM' with a 'Download the Report' button, 'CLOUDERA ENTERPRISE CORE' with a description, 'CLOUDERA ENTERPRISE RTQ' with a description, and 'INDUSTRY USE CASES' with a description. The footer includes 'WHOS USING CLOUDERA' with logos for Expedia, HOKIANTO, Experian, and JPMorgan Chase & Co., a 'Why Cloudera?' section, a 'Products' section, a 'Solutions' section, a 'Partners' section, an 'About' section, and a footer with the Cloudera logo, contact information, and legal notices.



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'.

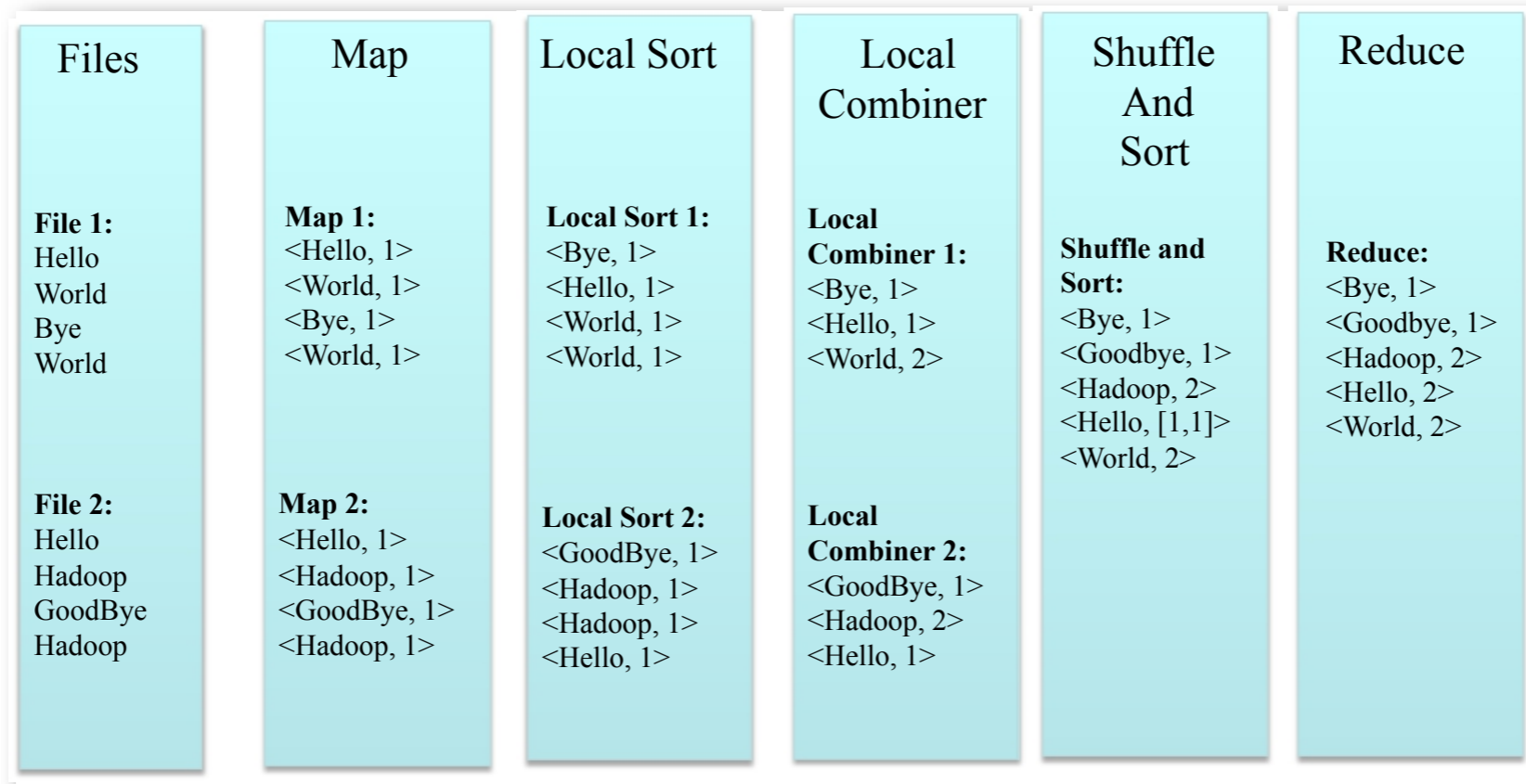




MERRA/AS Server

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 ...

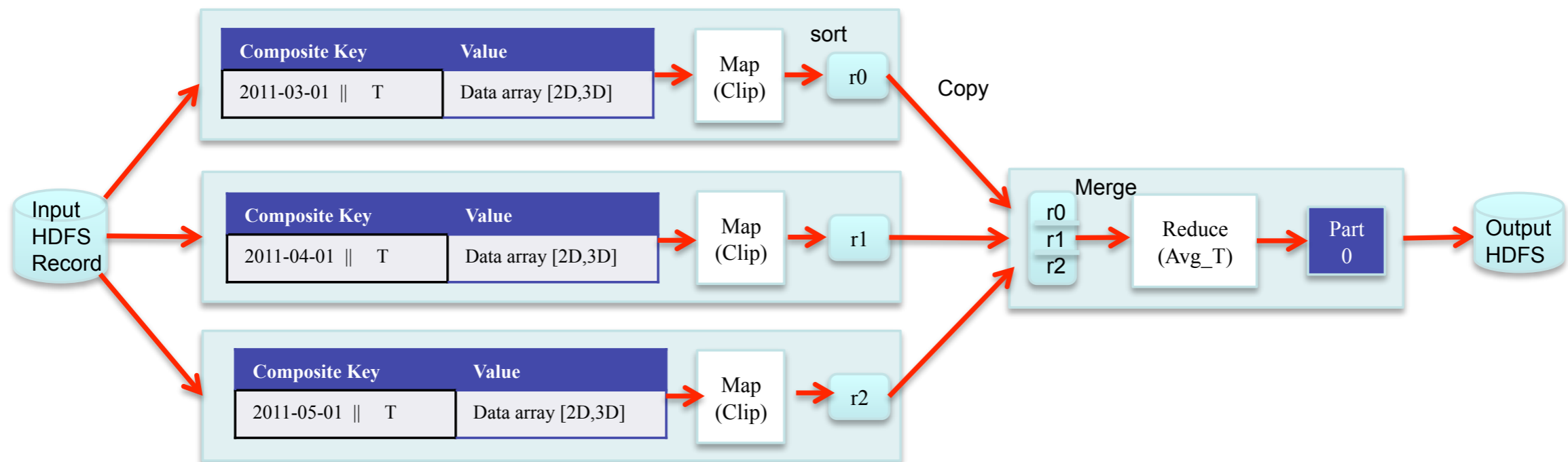




MERRA/AS Server

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

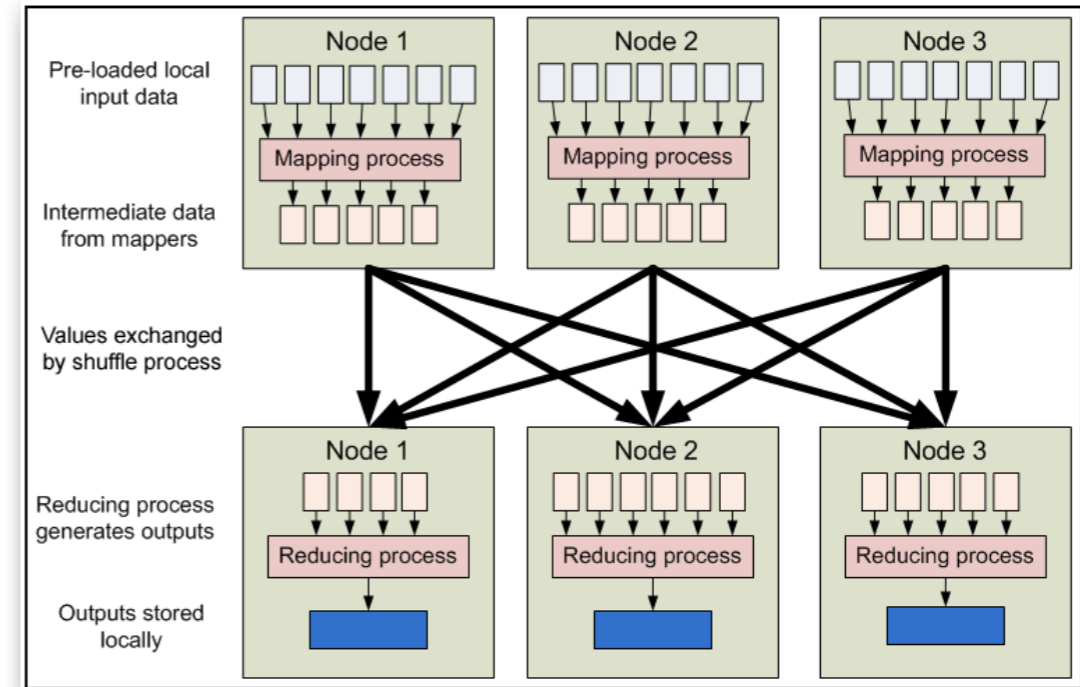
Canonical Ops Library

- 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.

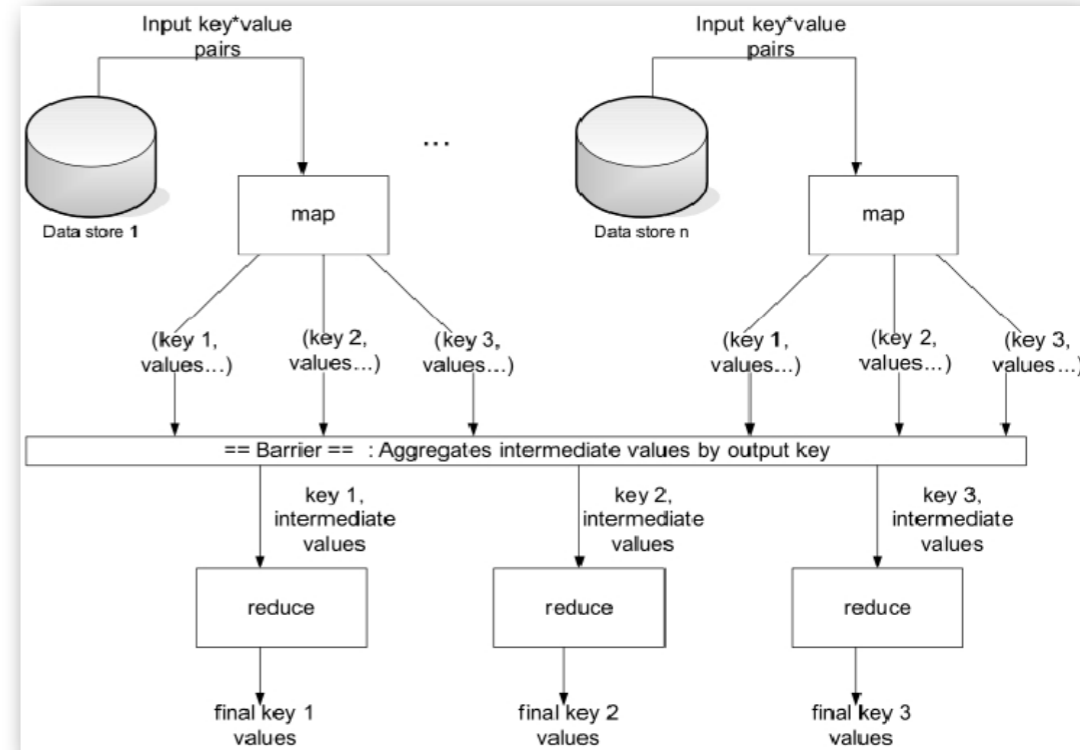


Rationale for canonical ops – Data intensive analysis workflows can be thought of as directed acyclic graphs where nodes represent computations over data and arcs the systematic steps of the analysis process.

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.





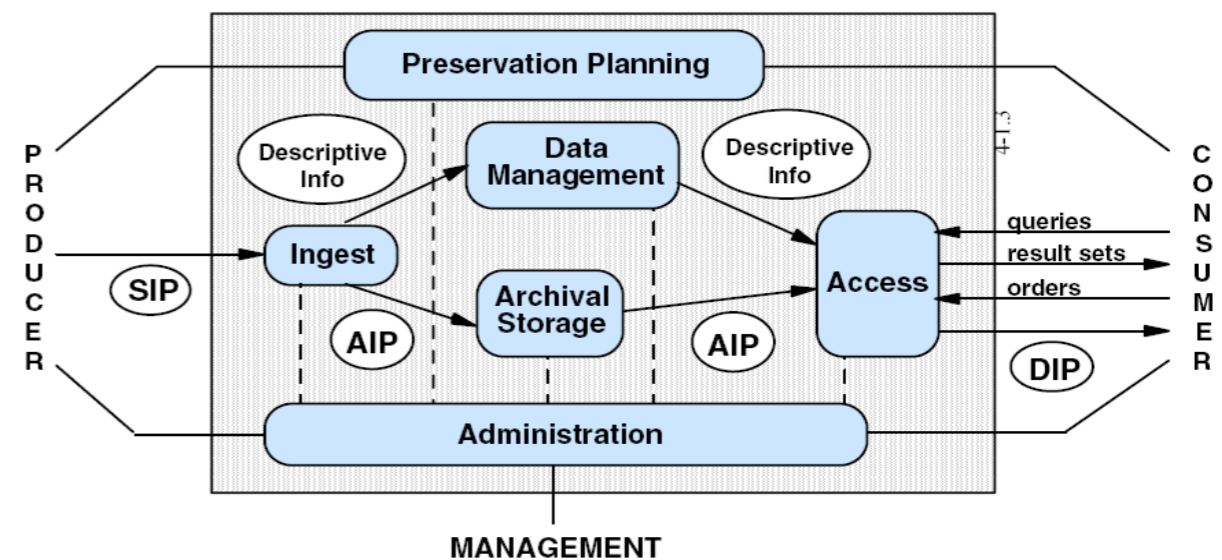
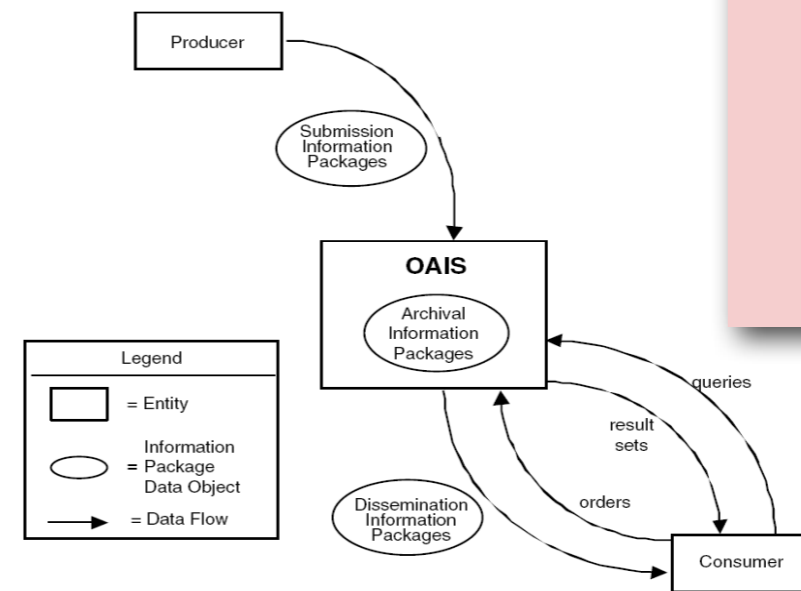
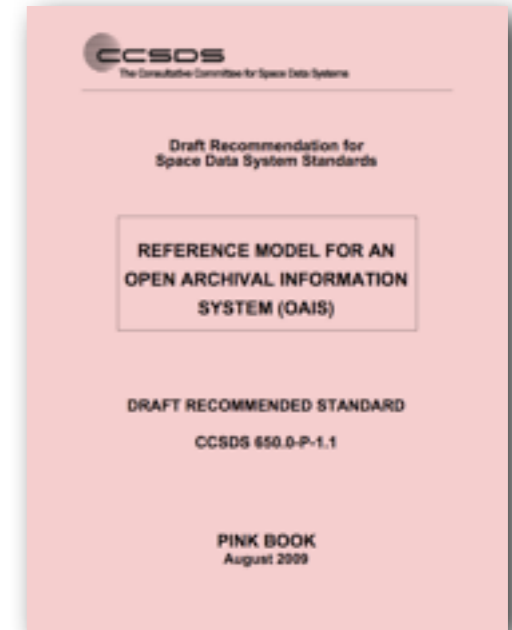
MERRA/AS Server

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.

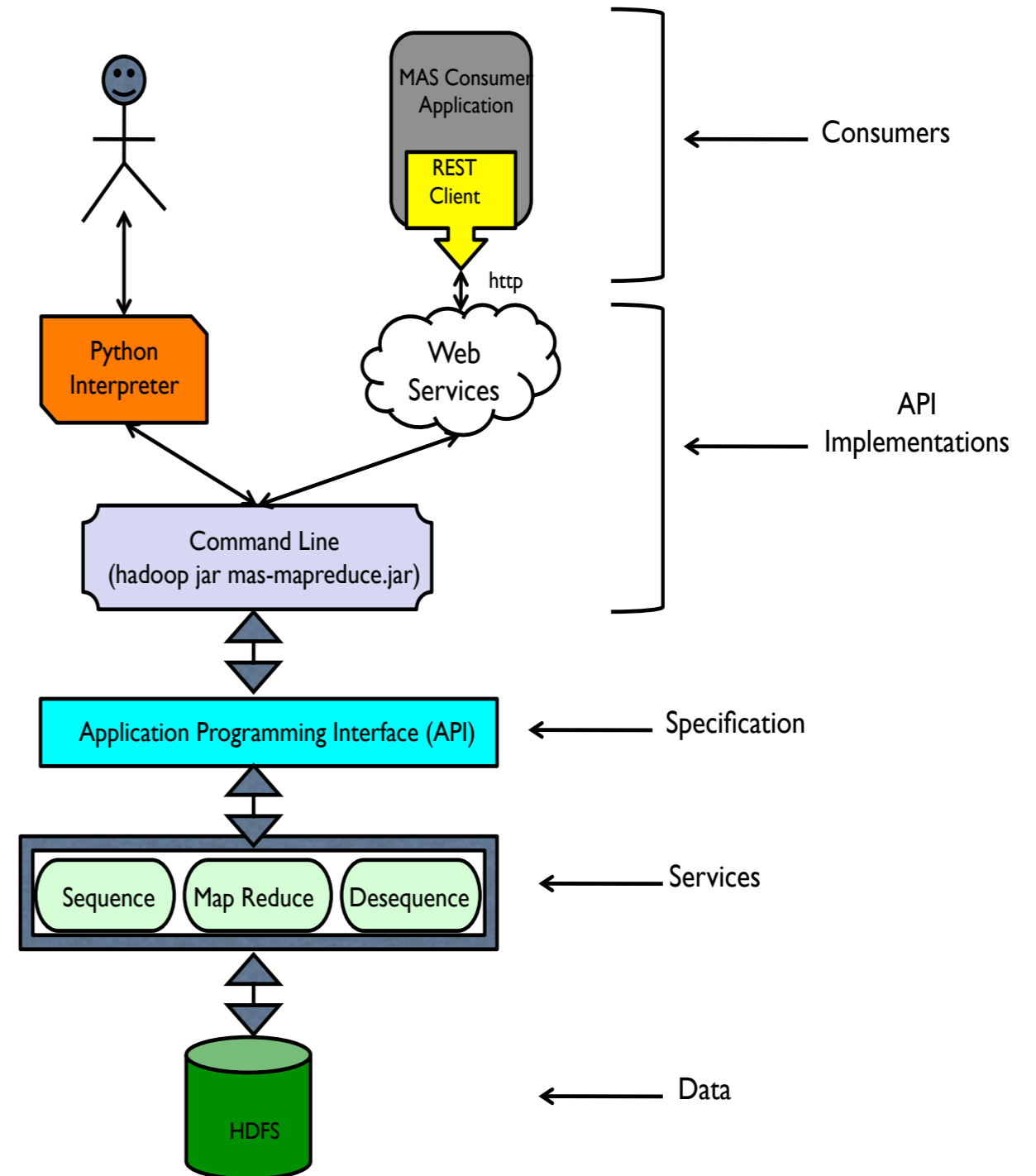
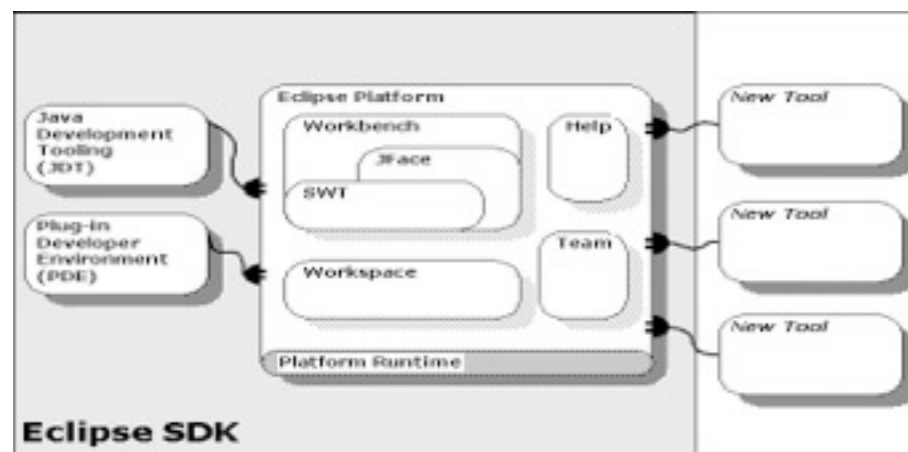




MERRA/AS Server

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 ...





MERRA/AS Server

Sample CDS Use Cases

- A data producer **Executes()** the Hadoop sequence service that generates sequence files
- A data producer **Ingests()** 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()** the MapReduce code using the code hosting service
- A scientist **Orders()** 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()** 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()** 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):

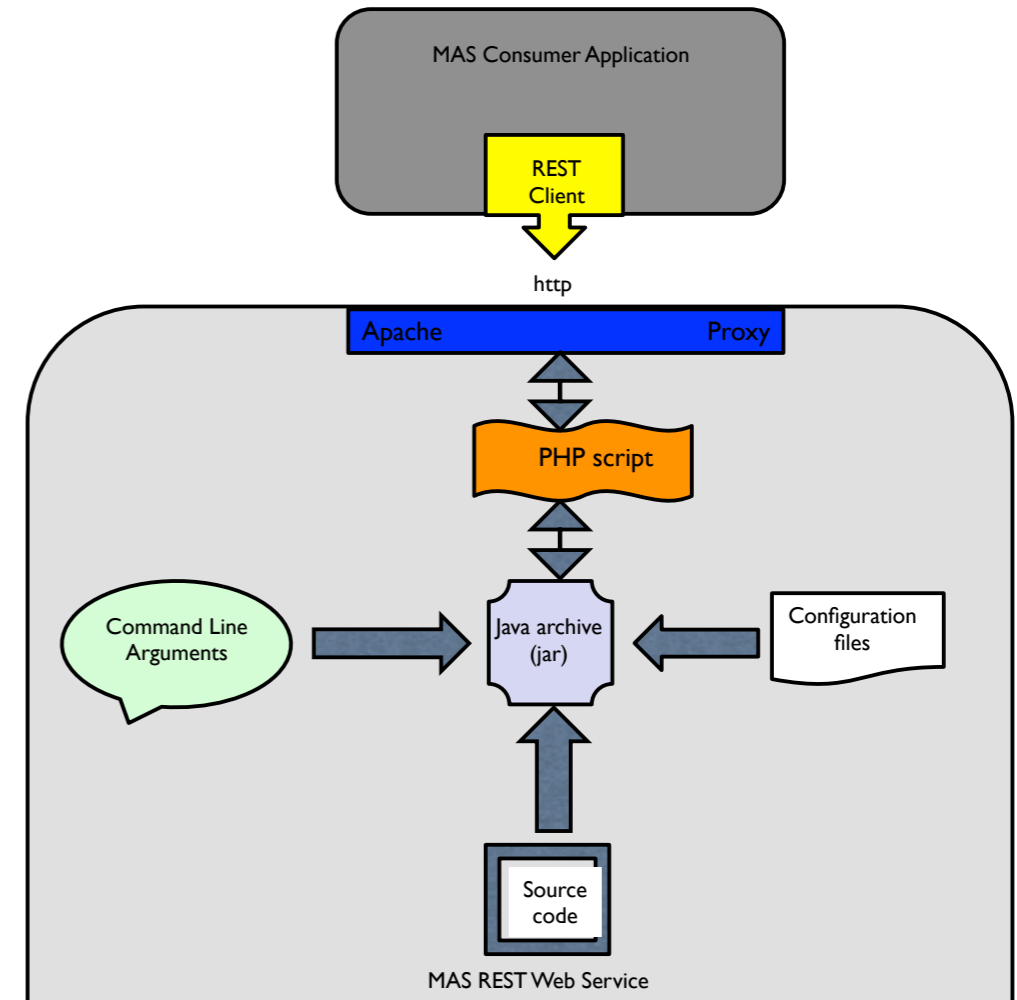
```
$ download(MAS, h654c35c-f223-4787-a947-8787f532d3fe)
$ AverageTemperatureByTimeSpanAndStep!MERRA!/home/gtamkin/m/out
```




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 Server

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](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

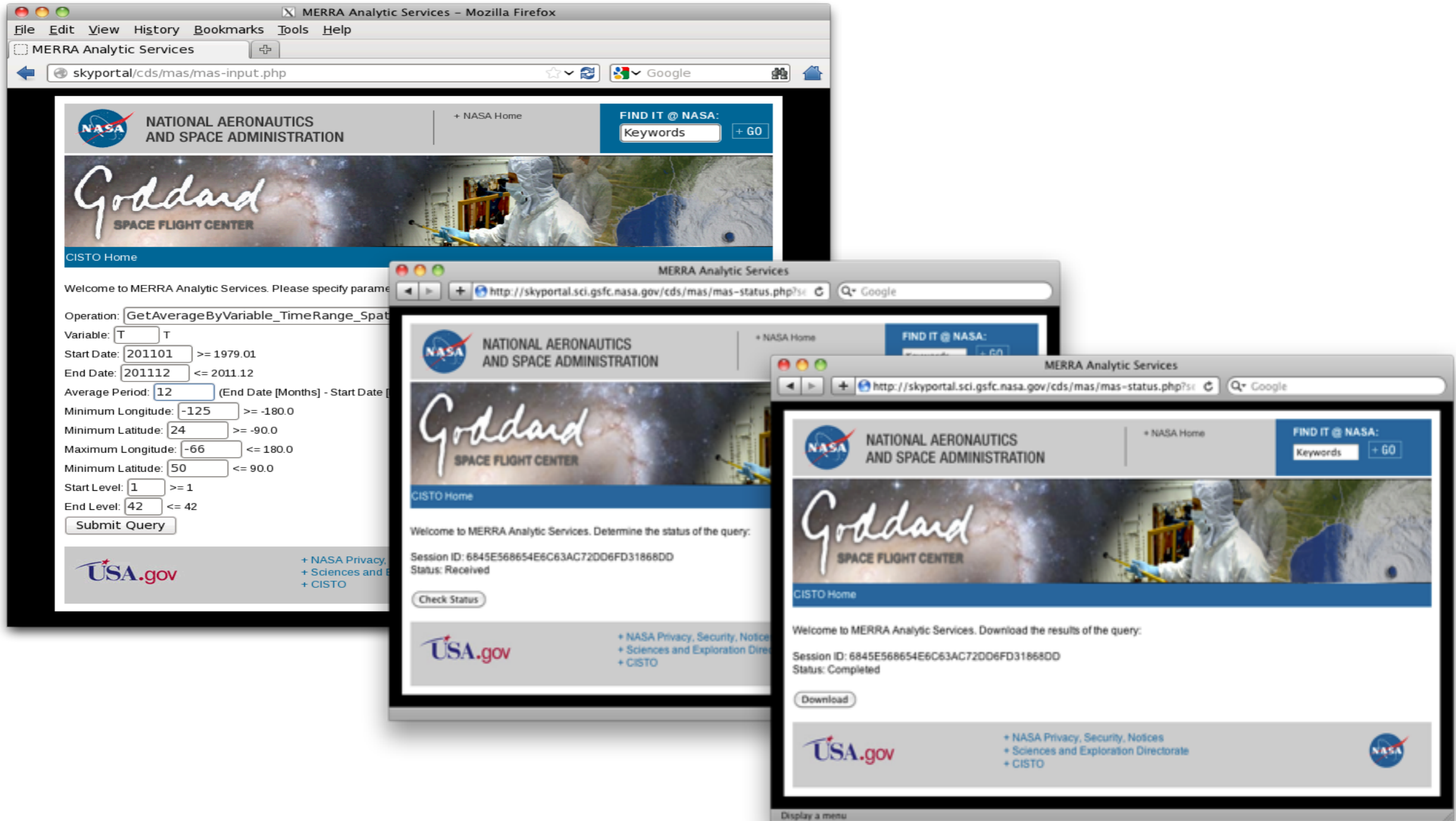
Response (File Download)



MERRA/AS Server

MERRA/AS Graphical User Interface (GUI)

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



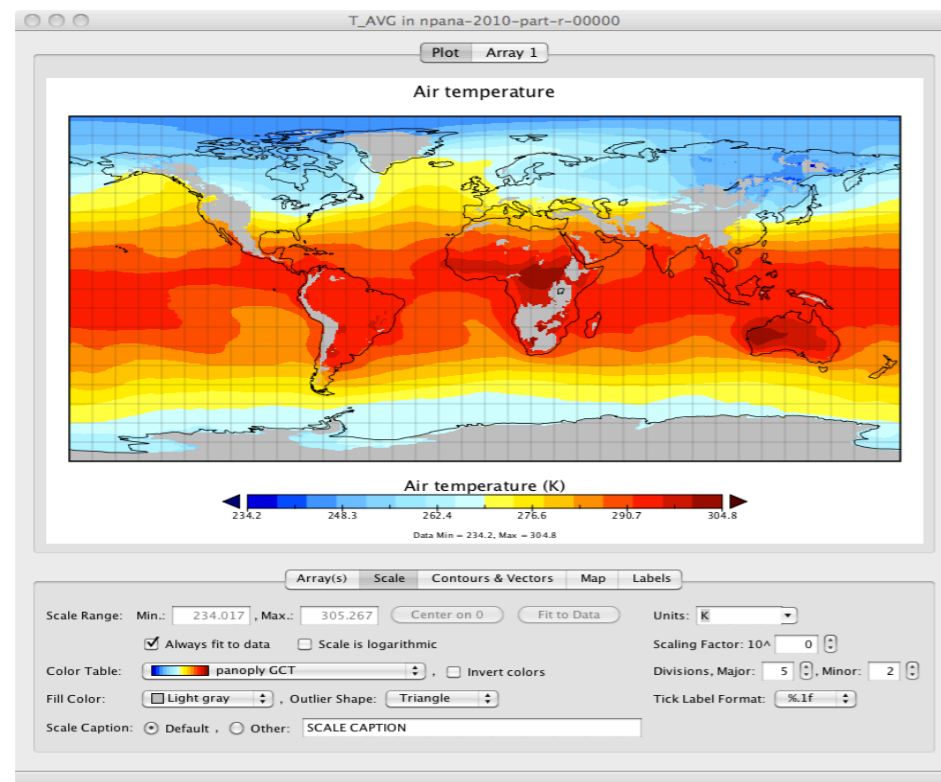


MERRA/AS Server

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 vice 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.

- *NetCDAveragerMapper* — 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.
- *NetCDAveragerReducer* — 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.

RECOVER
"Rehabilitation Capability Convergence for Ecosystem Recovery"
A NASA/DOI National Wildfire Applied Sciences Project

John Schnase, Roger Gill,
Mark Carroll, Akiko Elders, and Molly Brown

Keith Weber, George Haskett,
and Tess Gardner

NASA Goddard Space Flight Center
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Pocatello, ID 83209





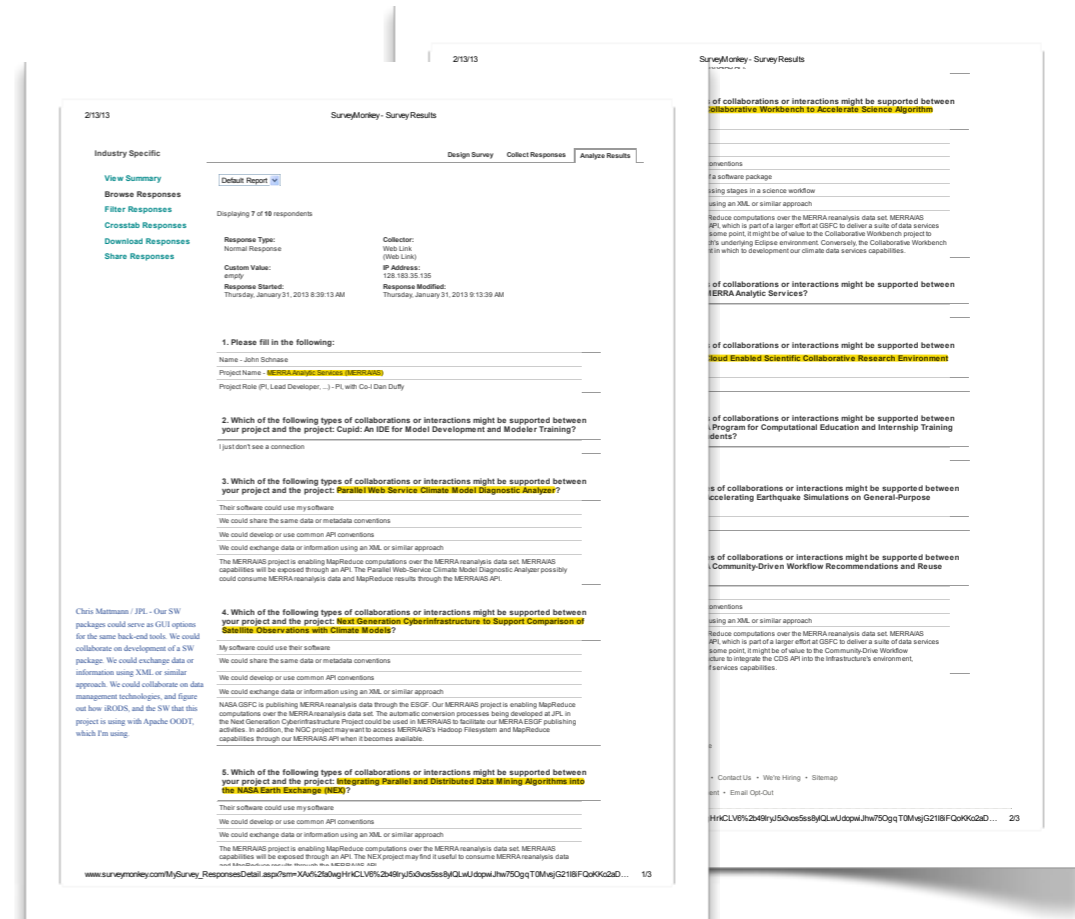




Application Integration

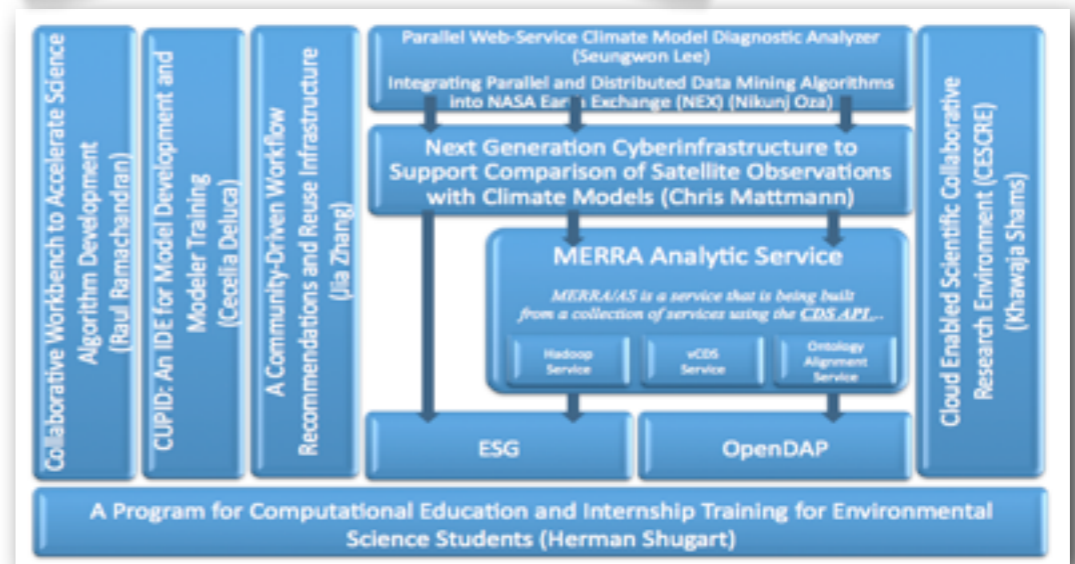
Connections to Other CMAC Projects

- 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

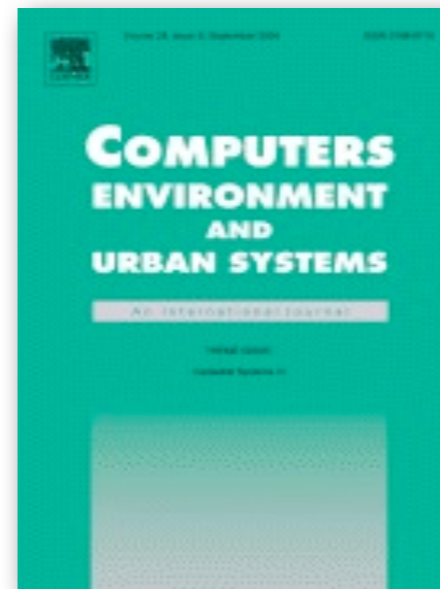
- Schnase, J.L., Duffy, D.Q, McInerney, M.A., Tamkin, G.S., Thompson, J.H., Gill, R., & Grieg, C. *MERRA Analytic Services*. AGU Fall Meeting, December 3-7, 2012, San Francisco, CA.
- Tamkin, G.L., Schnase, J.L., and Duffy, D.Q. Next Generation Climate Data Services: MERRA Analytics. Supercomputer 2012 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.)



National Aeronautics and Space Administration		Disclosure of Invention and New Technology (Including Software)		Form Approved OMB No. 2700-0002	DATE 06/29/2012
This is an important legal document. Carefully complete and forward to the Patent Representative (NASA In-house inventor) or New Technology Representative (contractor/government inventor) at NASA. Use of this report form by contractors is optional. However, an alternative format must be submitted to the Patent Representative (NASA In-house inventor) or New Technology Representative (contractor/government inventor) at the end of this form. In completing each section, use whatever detail deemed appropriate for "full and complete disclosure." Contractors should refer to the "Patenting of Patent Rights - Notification by the Contractor" document. When necessary, attach additional documentation to provide a full, detailed description.		NASA CASE NO. (OFFICIAL USE ONLY)		CONTRACTOR CASE NO.	
1. DISCOVERABLE TITLE		MERRA Analytic Services (MERRA/AS) – Concept, Design, Architecture, and Operation		Form Approved OMB No. 2700-0002	DATE 06/29/2012
2. INVENTOR(S) (For each inventor provide: Name, Title, Work Address, Work Phone Number and Work E-mail Address. If multiple inventors, number each to match Box 2.)		1) John L. Schnase, Senior Computer Scientist, Code 686, 281.286.4351, John.L.Schnase@NASA.gov 2) David Q. Duffy, Lead System Architect, NASA Center for Climate Simulation (Code 686.2), 281.286.8838, David.Q.Duffy@NASA.gov		CONTRACTOR CASE NO.	
3. INNOVATOR/EMPLOYER WHEN INNOVATION WAS MADE (For each inventor provide: Name, Division and Address of Employer, Organizational Code/Mail Code, and Contract Grant Number if applicable. If multiple inventors, number each to match Box 2.)		1) NASA GSFC, Code 686.2 2) Greenbelt, MD 20771		NASA CASE NO. (OFFICIAL USE ONLY)	
4. PLACE OF PERFORMANCE (Address(es) where innovation made)		1) Greenbelt, MD 20771		Name, Division and Address of Employer (number each to match Box 2.)	
5. EMPLOYER STATUS (check one for each inventor)		6. RIGHTS (check all that apply and provide all applicable numbers. If multiple Contracts/Grants, etc., list Contract/Grant Numbers in Box 3 with applicable employer information.)		Form Approved OMB No. 2700-0002	
a) <input type="checkbox"/> NASA In-house Oig. Mail Code: 686.486.2		WBS		DATE 06/29/2012	
b) <input type="checkbox"/> Grant/Cooperative Agreement No.		WBS		CONTRACTOR CASE NO.	
c) <input type="checkbox"/> Prime Contract No.		Report No.		NASA CASE NO. (OFFICIAL USE ONLY)	
d) <input type="checkbox"/> Task No.		Subcontract, Subcontract No.		Form Approved OMB No. 2700-0002	
e) <input type="checkbox"/> Joint Effort (contract, subcontractor and/or grantee contribution) and NASA In-house contribution		Multiple Effort (multiple contractor, subcontractor and/or grantee contribution, and NASA In-house contribution)		DATE 06/29/2012	
f) <input type="checkbox"/> Other (e.g., Space Act Agreement, MSA) No.		WBS		CONTRACTOR CASE NO.	
7. NASA CONTRACTING OFFICER'S TECHNICAL REPRESENTATIVE (PTO)		8. CONTRACTING OFFICER'S NEW TECHNOLOGY REPRESENTATIVE (PTO)		Form Approved OMB No. 2700-0002	
9. BRIEF ABSTRACT (A general description of the invention which abstracts its essential features, but does not reveal details that would enable duplication or imitation of the invention.)		10. FULL ABSTRACT (A general description of the invention which abstracts its essential features, but does not reveal details that would enable duplication or imitation of the invention.)		Form Approved OMB No. 2700-0002	
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NASA FORM 1476 DEC 2007 PREVIOUS EDITIONS IS OBSOLETE.		Page 1 of 4		Form Approved OMB No. 2700-0002	

MERRA Analytic Services
IN43C-1525
John L. Schnase, David Q. Duffy, Mark A. McInerney, Glenn S. Tamkin, John H. Thompson, Roger Giff, and Christine M. Chang
OFFICE OF COMPUTATIONAL AND INFORMATION SCIENCE AND TECHNOLOGY
NASA CENTER FOR CLIMATE SIMULATION (NCCS)
NASA GODDARD SPACE FLIGHT CENTER

ABSTRACT
MERRA Analytic Services (MERRA/AS) is a cyberinfrastructure resource for developing and evaluating a new generation of climate data analysis capabilities. MERRA/AS will support NASA's Observations for Model Intercomparison (OBAMIP) activities by reducing the time spent in the performance of Model Intercomparison (MIP) activities. MERRA/AS is a cloud-based service built around the National Climate Data Service (NCDS) technology that is currently used by the NASA Center for Climate Simulation (NCCS) to deliver Interoperational Panel on Climate Change (IPCC) data to the Earth System Grid (ESG). Critical to its effectiveness, MERRA/AS serves as a workflow-oriented environment for performing analyses over the MERRA data using the MapReduce approach to parallel storage-based computation. The results produced by these operations are stored by the NCDS, which can also host code for those who wish to explore the use of MapReduce for more advanced analysis. The MERRA/AS technology can be used to publish other reanalysis, observational, and auxiliary OBAMIP data to ESG and, importantly, offers an architectural approach to climate data services that can be generalized to applications and customers beyond the traditional climate research community.

MERRA/AS Architecture
Analysis FEED Application (Client)
MERRA AS
MapReduce AS
NCDS AS
vCDS V1.0
MERRA AS

Processing Workflow
1. The MERRA/AS job was processed into Hadoop requests.
2. The requests (job) were then requested into the Hadoop file system (HDFS) with the default replication factor of three and, initially, the default block size of 64 MB.
3. The MERRA/AS operation MapReduce job was submitted to the Name Node in the cluster.
4. Along with the job, the Name Node schedules and sends the job to the cluster. Hadoop distributes the map tasks across data nodes that contain the requested data.
5. On each data node, the request handler opens up each request file for reading and passes all the "key-value" pairs to the mapping function.
6. The mapper (block) that matches the criteria of the given query and delivers valid data to the reducer. All keys and values within a file are shuffled by the mapper.
7. After mapping, the reducer performs the desired averaging operation on the sorted "key-value" pairs to create a final "key-value" pair result.
8. This final result is then stored as a response file within the HDFS.



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.

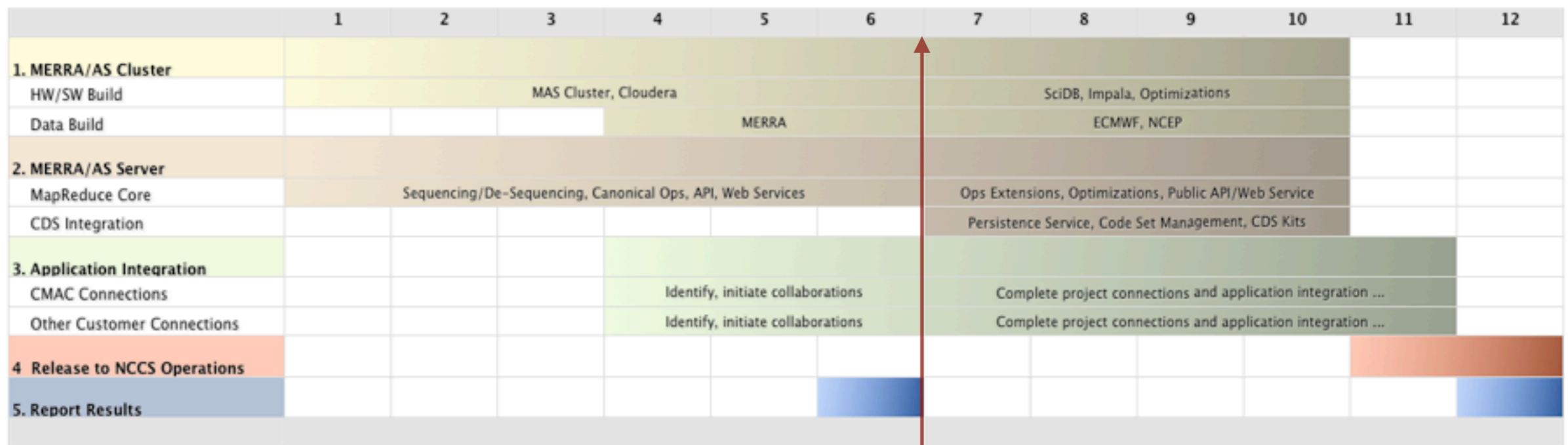


Work Plan for the Next Reporting Period

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



● 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.

