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U.S. DEPARTMENT OF
ENERGY

Office of
Science

Climate Science Responds to “Big Data” Challenges: Accessing Analyzing Model Output and Observations

February 15, 2013

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On behalf of Multiple Earth System Communities and Projects



SAMS/NCAR Workshop on Massive Datasets in Environment and Climate

Overview: Bring together large volumes of diverse data

Data integrating enterprise system

Insight into big data reveals three very significant challenges:

- **Variety:** managing **complex data**, including storage and retrieval, from multiple regional and non-regional data indices, types and schemas
- **Velocity:** distributing live data streams and **large volume data** movement quickly and efficiently
- **Volume:** analyzing large-volume data (from terabytes to exabytes) in-place for **big data analytics**

Community invests in:

- **Accessing Global Information:** Accessing climate data and content information from everywhere via the web, **sensors**, and applications in an integrated and federated environment
- **Flexible Infrastructure:** Flexible automated administration, easy-to-use analytics, and virtualization at every level
- **Scalable Framework:** Big data analytics in a scalable environment with efficient parallelism, workload-optimization, and **real-time streaming process**

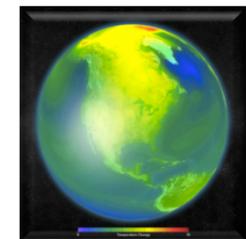
Simulation



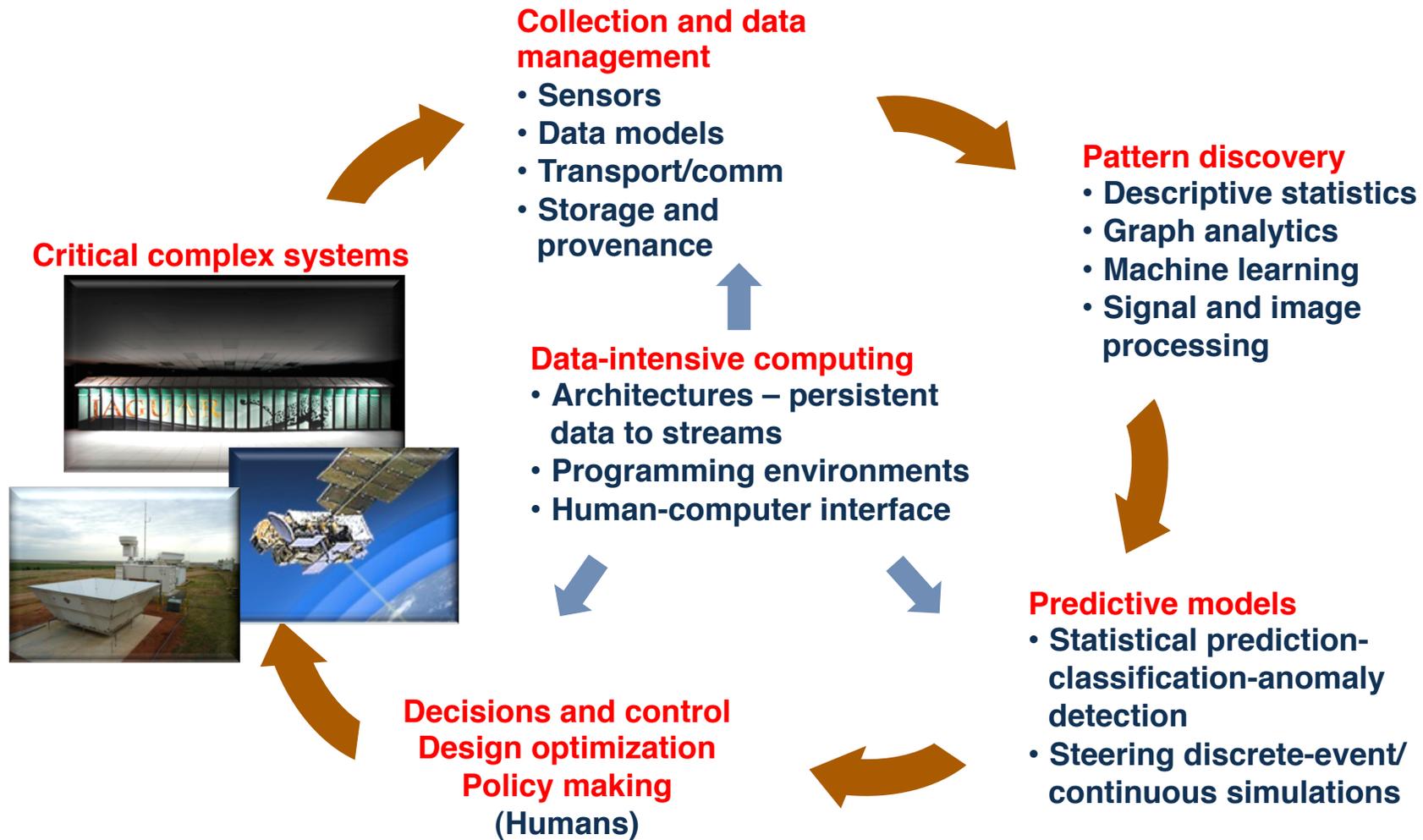
Observation



Reanalysis



Predictive analysis of complex systems



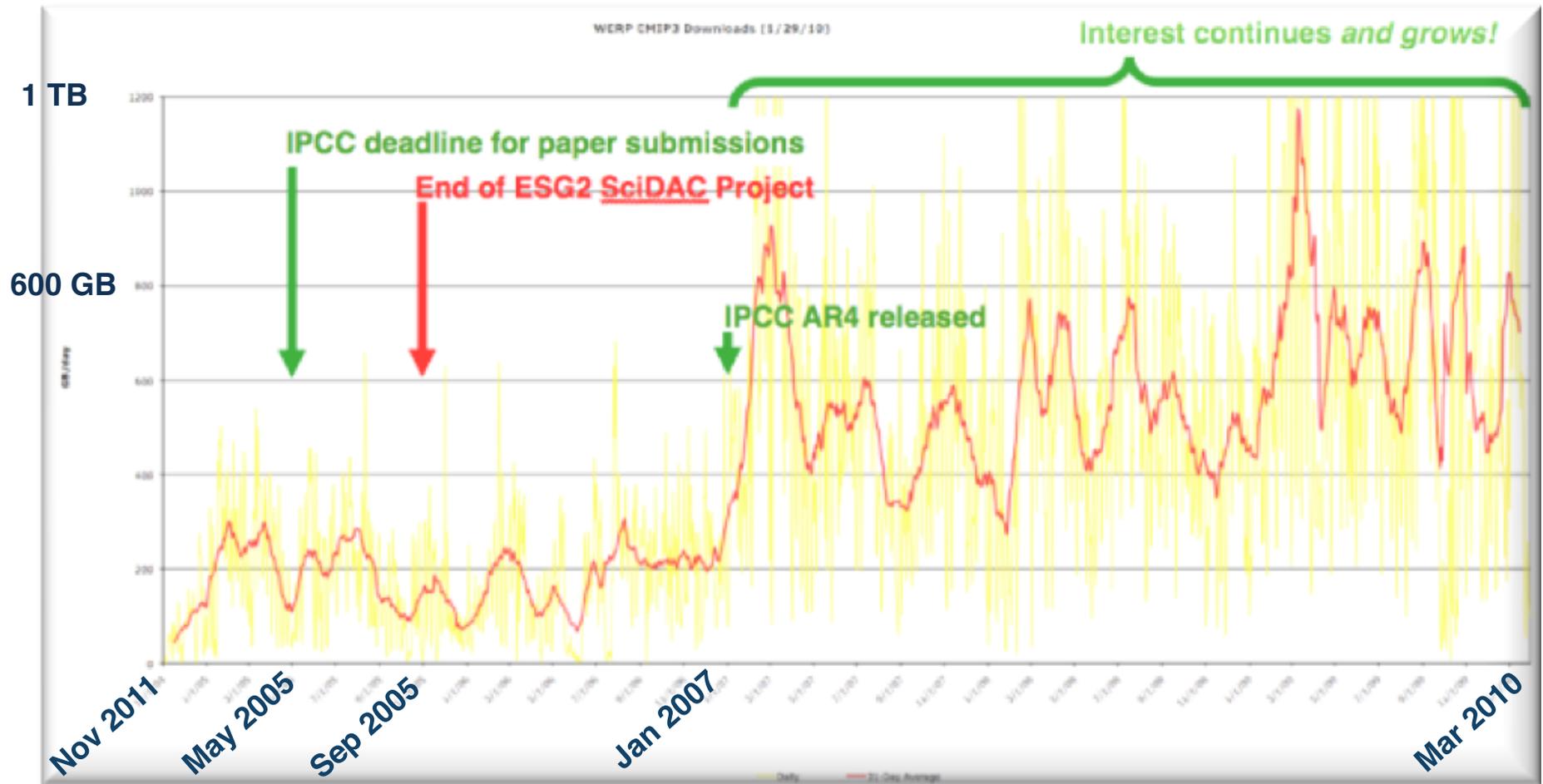
Example Project: The CMIP experiment design

CMIP5: 62 models **available** from 25 centers

- **CMIP = Coupled Model Intercomparison Project**
 - Phase 1: Idealized simulations of present-day climate (~1 Gigabyte (GB))
 - Phase 2: Idealized simulations of future climate changes (~500 GB: **CMIP2/CMIP1=500**)
 - Phase 3: More realistic simulations (2004 – present) (~35 Terabytes (TB): **CMIP3/CMIP2 = 70**)
- **CMIP 5 multi-model archive expected to include (3.5 Petabytes (PB) **CMIP5/CMIP3 = 100**):**
 - 3 suites of experiments
 - 25 modeling centers in 19 countries
 - 60+ models
 - Total data, ~3.5 PB
 - Replica 1 – 2 PB
 - Derived data ~1 PB
- **Global distribution**
- **Timeline fixed by IPCC (2012 - 2013)**
- **The community organizes, manages and distributes the CMIP/IPCC (Intergovernmental Panel on Climate Change) database of climate model output**
- **CMIP6 (350 PB – 3 EB ?)**

kilobyte (kB)	10 ³
megabyte (MB)	10 ⁶
gigabyte (GB)	10 ⁹
terabyte (TB)	10 ¹²
petabyte (PB)	10 ¹⁵
exabyte (EB)	10 ¹⁸
zettabyte (ZB)	10 ²¹
yottabyte (YB)	10 ²⁴

CMIP3 (IPCC AR4) download rates in gigabytes per day



Data challenge of CMIP3 archive vs. CMIP5 archive

CMIP3 Modeling Centers		volume (GB)
BCCR	Norway	862
CCCma	Canada	2,071
CNRM	France	999
CSIRO	Australia	2,088
GFDL	USA	3,843
GISS	USA	1,097
IAP	China	2,868
INGV	Italy	1,472
INMCM3	Russia	368
IPSL	France	998
MIROC3	Japan	3,975
MIUB	Germany/Korea	477
MPI	Germany	2,700
MRI	Japan	1,025
CCSM	USA	9,173
UKMO	UK	973
Totals		34,989 (TB)

Archive size: 35 TB

CMIP5 Modeling Centers		volume (TB)
BCC	China	51
CCCma	Canada	51
CMCC	Europe (Italy)	158
CNRM	France	71
CSIRO	Australia	81
EC-EARTH	Europe (Netherland)	97
GCESS	China	24
INM	Russia	30
IPSL	France	121
LASG	China	100
MIROC	Japan	350
MOHC	UK	195
MPI	Germany	166
MRI	Japan	269
NASA	USA	375
CESM	USA	739
NCC	Norway	32
NCEP	USA	26
NIMR/KMA	Korea	14
NOAA GFDL	USA	158
Totals		3,108 (PB)

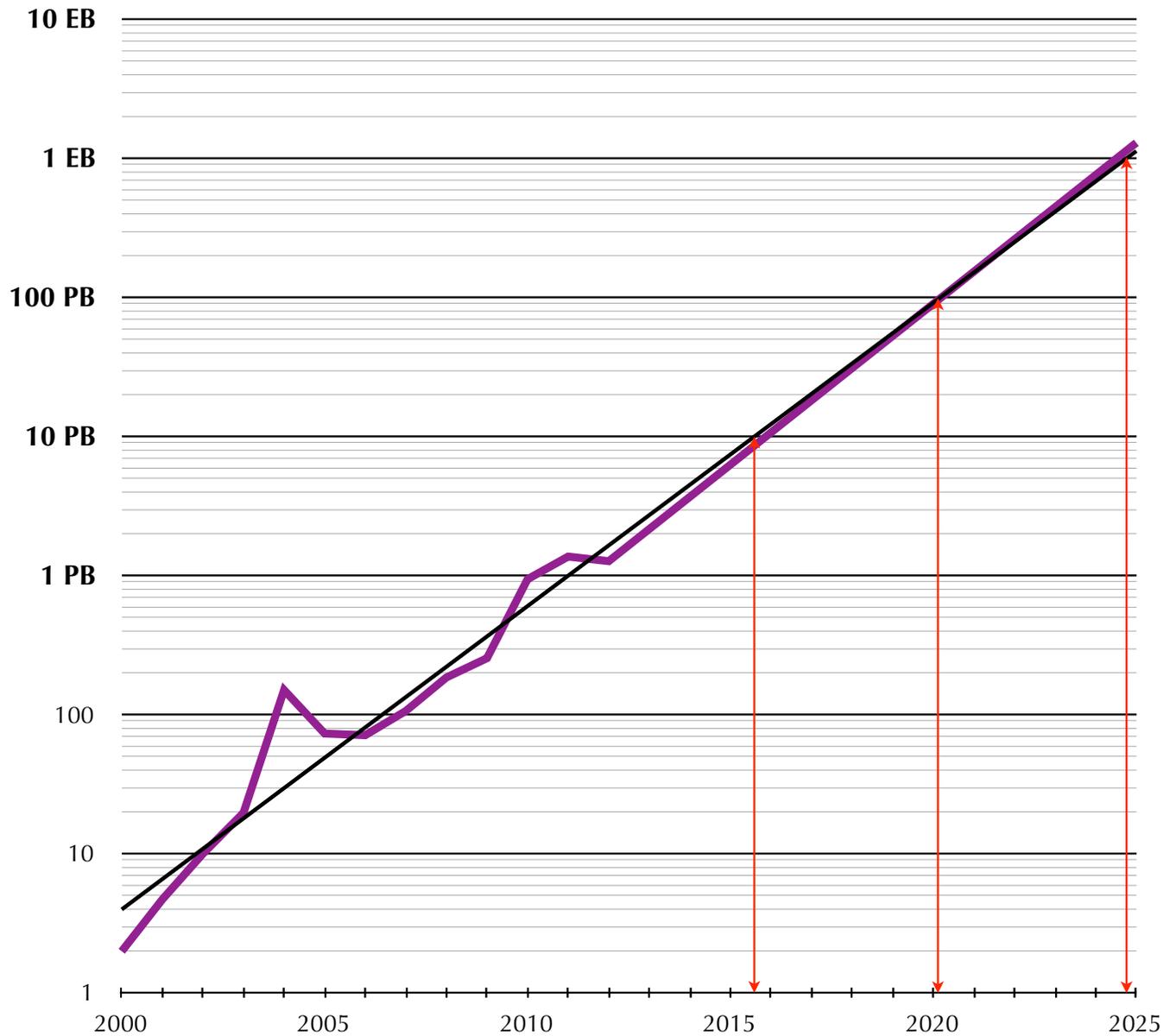
**Archive size:
currently: 1.4 PB
total: 3.1 PB by 2013**

CMIP5/CMIP3 = 10²

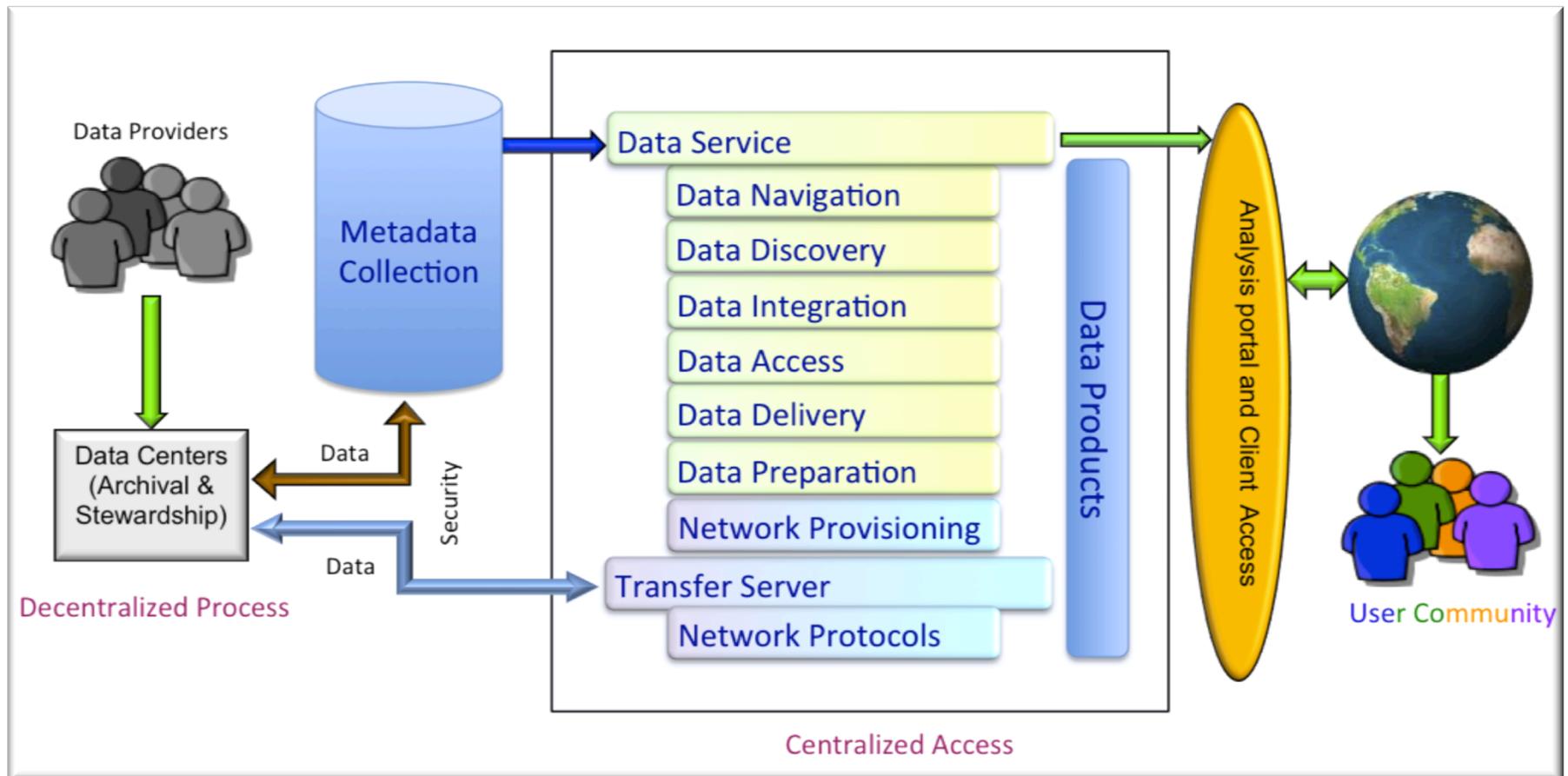
**Focus on the U.S.
climate model simulation
output.**

Projected DOE/NSF CESM output

year	total (TB)
2000	2
2001	5
2002	10
2003	20
2004	150
2005	73
2006	71
2007	106
2008	185
2009	254
2010	940
2011	1,366
2012	1,266
2013	2,158
2014	3,676
2015	6,264
2016	10,672
2017	18,184
2018	30,983
2019	52,792
2020	89,950
2021	153,263
2022	261,139
2023	444,946
2024	758,128
2025	1,291,749
2026	2,200,967
2027	3,750,154
2028	6,389,762
2029	10,887,300
2030	18,550,504

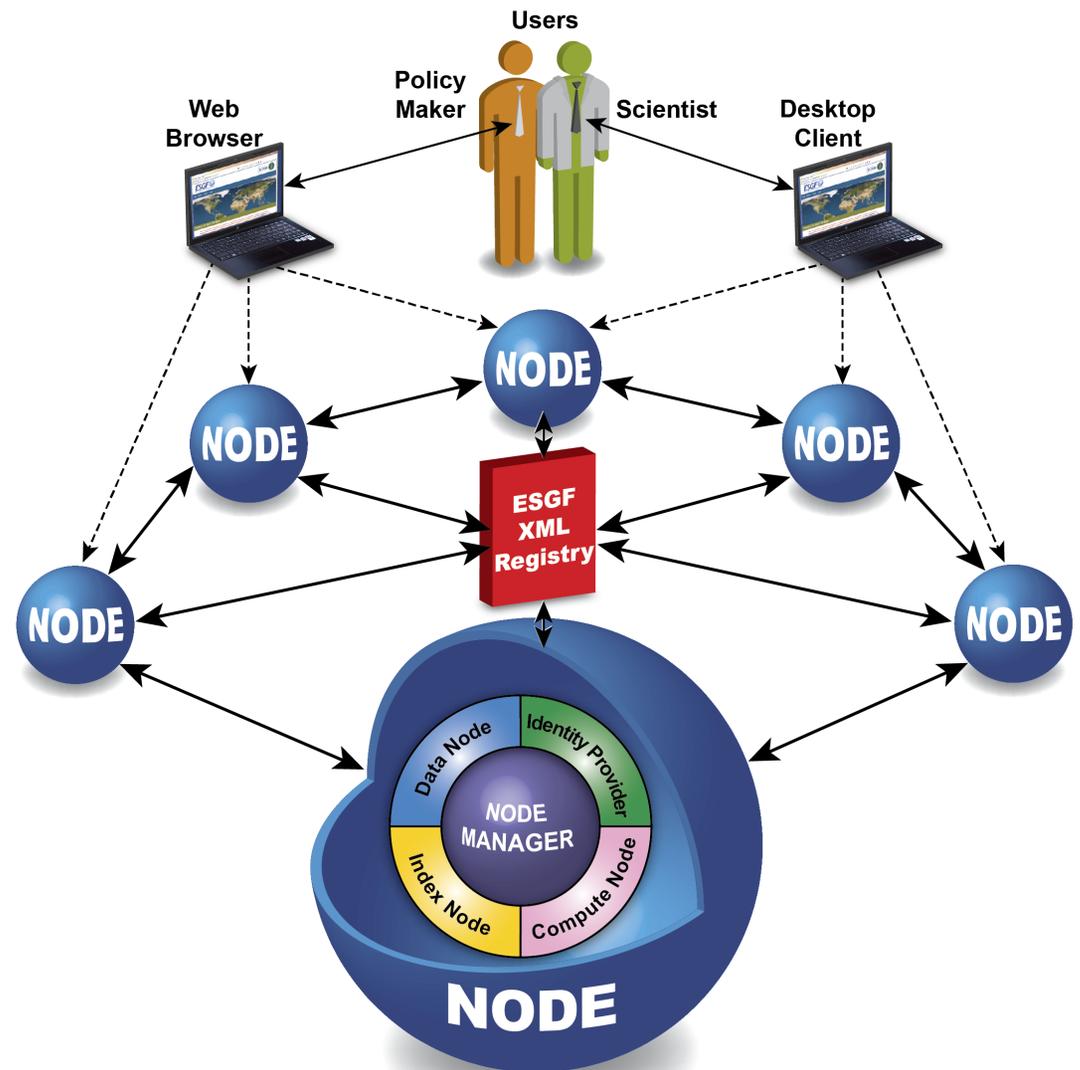


Cloud type approach for distributed data

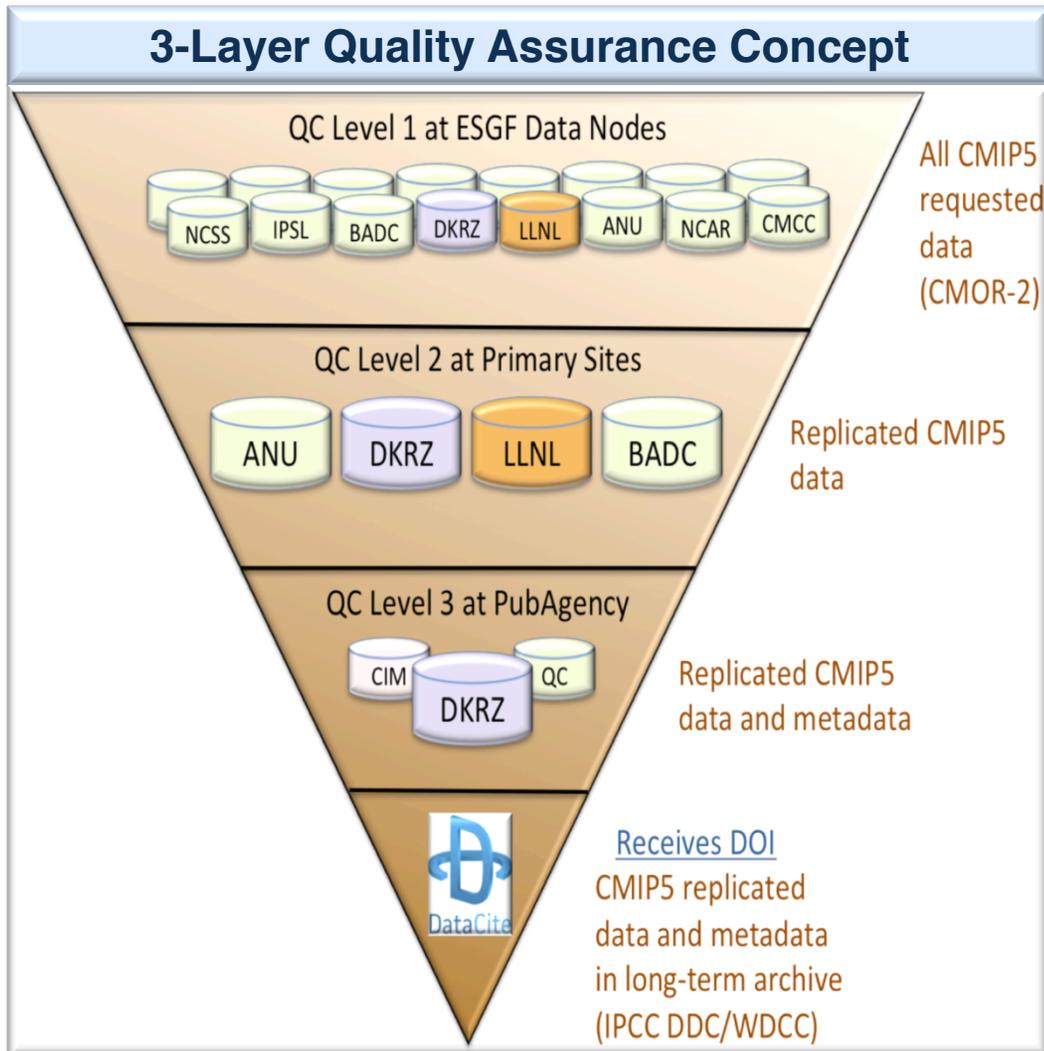


The Earth System Grid Federation (ESGF) distributed data archival and retrieval system

- Distributed and federated architecture
- Support discipline specific portals
- Support browser-based and direct client access
- Single Sign-on
- Automated script and GUI-based publication tools
- Full support for data aggregations
 - A collection of files, usually ordered by simulation time, that can be treated as a single file for purposes of data access, computation, and visualization
- User notification service
 - Users can choose to be notified when a data set has been modified



Data quality control check operations end in digital object identifiers (DOIs)

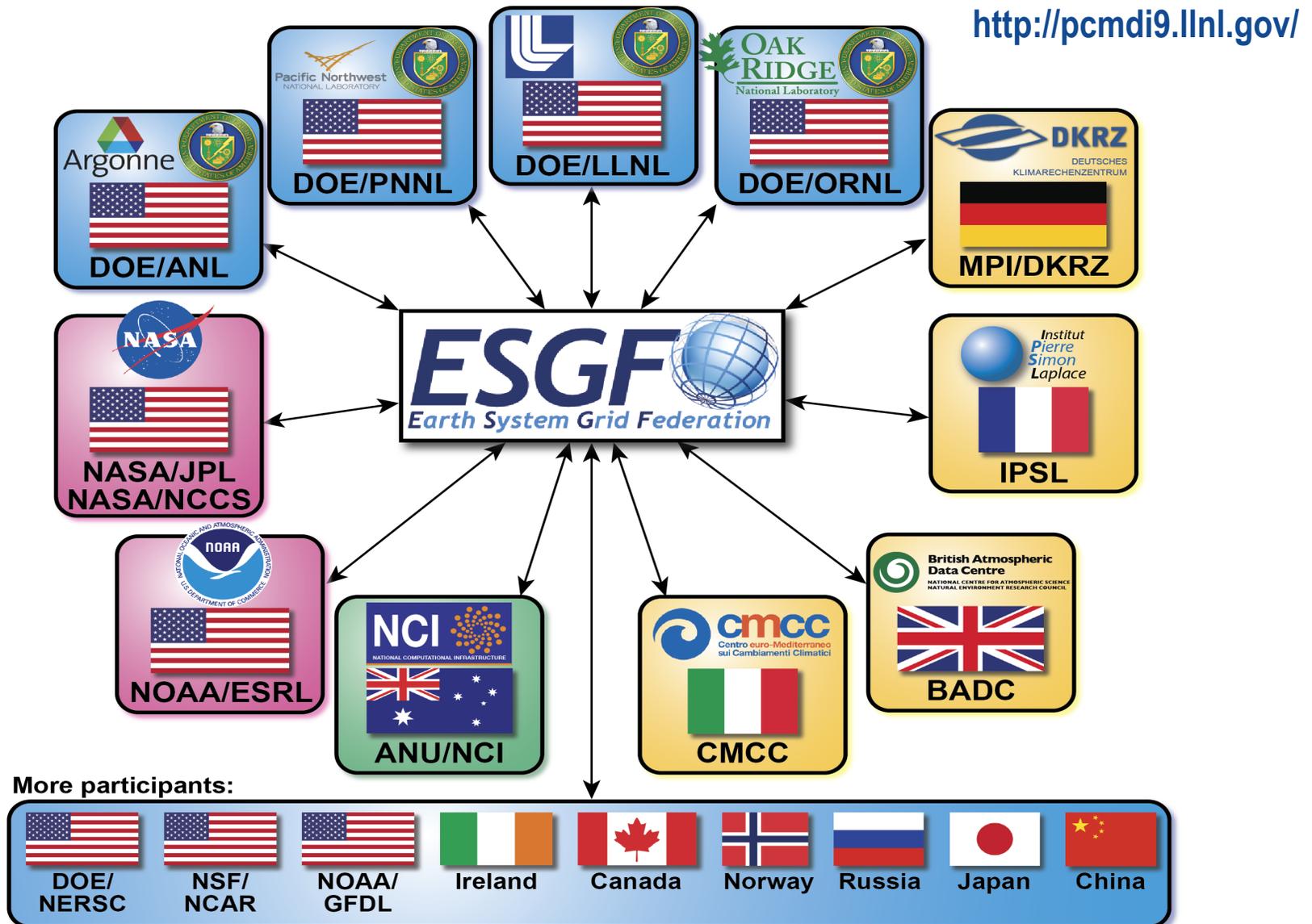


- **Publishing data** to an ESGF portal performs QC Level 1 (QCL1) check
 - QCL1 data are visible to users and are identified as QCL1 on the UI
- **DKRZ (MPI) quality control code** is run on data to perform QC Level 2 (QCL2) check
 - QCL2 data are visible to users and are identified as QCL2 on the UI
 - **Statistical quality control** – automatically identify data unusual enough to need further inspection
- **Visual inspections** are performed for inconsistencies and metadata correctness at QC Level 3 (QCL3) check
 - QCL3 data are visible to users and are identified as QCL3 on the UI
 - **Digital Object Identifiers (DOIs)** are given to data sets that pass the QCL3 check

ESGF data holdings (~2 PB)

- Phases 3 and 5 of the Coupled Model Intercomparison Project (CMIP3 and CMIP5)
- Coordinated Regional climate Downscaling Experiment (CORDEX)
- Climate Science for a Sustainable Energy Future (CSSEF)
- European Union Cloud Intercomparison, Process Study & Evaluation Project (EUCLIPSE)
- Geo-engineering Model Intercomparison Project (GeoMIP)
- Land-Use and Climate, Identification of robust impacts (LUCID)
- Paleoclimate Modeling Intercomparison Project (PMIP)
- Transpose-Atmospheric Model Intercomparison Project (TAMIP)
- Clouds and Cryosphere (cloud-cryo)
- Observational products more accessible for coupled model intercomparison (obs4MIPs)
- Reanalysis for the coupled model intercomparison (ANA4MIPs)
- Dynamical Core Model Intercomparison Project (DCMIP)
- Community Climate System Model (CCSM)
- Parallel Ocean Program (POP)
- North American Regional Climate Change Assessment Program (NARCCAP)
- Carbon Land Model Intercomparison Project (C-LAMP)
- Atmospheric Infrared Sounder (AIS)
- Microwave Limb Sounder (MLS)

ESGF is more than CMIP: federated and integrated data from multiple sources



**Additional participants could not be illustrated in this figure.*

Example ESGF web portal

ESGF Portal
[Home](#) [Search](#) [Tools](#) [Login](#) [Help](#)

Welcome to this ESGF P2P Node

ESGF Earth System Grid Federation

Quick Links

- Create Account
- MyProfile/Logout
- Expert Search (XML)
- Wget Script Generator
- ESGF aggregated RSS feed
- Contact ESGF

Instructions

- ESGF Full User Guide
- Search Help
- Search Controlled Vocabulary
- Wget Scripts FAQ
- Wget Scripting
- Tutorial: Download Strategies
- Using Globus Online
- Subscribing to RSS Notification

NASA obs4MIPs

These NASA datasets are provided as part of an experimental activity to increase the usability of NASA satellite observational data for the model and model analysis communities. These are not standard NASA satellite instrument products. They may have been reprocessed, reformatted, or created solely for comparisons with the CMIP5 model. Community feedback to improve and validate the datasets for modeling usage is appreciated.

- AIRS Air Temperature
- AIRS Specific Humidity
- AMSR-E Sea Surface Temperature
- AVISO Sea Surface Height
- CERES TOA Outgoing Clear-Sky Longwave Radiation
- CERES TOA Outgoing Longwave Radiation
- CERES TOA Incident Shortwave Radiation
- CERES TOA Outgoing Clear-Sky Shortwave Radiation
- CERES TOA Outgoing Shortwave Radiation
- MLS Specific Humidity
- MLS Air Temperature

ESGF Portal
[Home](#) [Search](#) [Tools](#) [Login](#) [Help](#)

Welcome to this ESGF P2P Node

ESGF Earth System Grid Federation

Quick Search

Keyword:

Advanced Search (Category, Geospatial, Temporal, and more)...

Peer Nodes

- AML Node
- BADC Node
- BNU Node
- CMCC Node
- DKRZ Node
- DKRZ CMIP5 Node
- NOAA-GFDL Node
- IPSL Node
- NASA-GISSC Node
- NASA-JPL Node
- NCI Node
- NERSC Node
- ORNL Node
- PCMDI Node

Resources

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ESGF Portal
[Home](#) [Search](#) [Tools](#) [Login](#)

Current Selections

- project:CMIP5

Examples: temperature, "surface temperature", climate AND project:CMIP5 AND variable:h2o
 To download data: add datasets to your Data Cart, then click on Expand or export.

Search Categories

Search All Sites Show All Replicas Show All Versions

Project: CMIP5 (55061) < 1 2 3 ... 5506 5507 > displaying 1 to 10 of 55061 search results
 Display 10 datasets per page
[Add All Displayed to Datacart](#) [Remove All Displayed from Datacart](#)

Model

Instrument

Experiment Family

Experiment

Time Frequency

Product

Results Data Cart

project:CMIP5_model:INCAR_Community_Earth_System_Model_version_1_experiment:historical_time_frequency:mon_modeling_real:atmos_ensemble:1r1p1_version:20120608
 Data Node: 16s_uscar.edu
 Version: 20120608
 Description: CESM1-FASTCHEM model output prepared for CMIP5 historical
 Further options: Add To Cart Model Metadata

project:CMIP5_model:INCAR_Community_Climate_System_Model_CCSM_version_4_experiment:RCP8_5_time_frequency:mon_modeling_real:atmos_ensemble:1r1p1_version:20120620
 Data Node: 16s_uscar.edu
 Version: 20120620
 Description: CCSM model output prepared for CMIP5 RCP8.5
 Further options: Add To Cart Model Metadata

ESGF LAS

Choose dataset: Update Plot

obs4MIPs NASA-CF5 MODIS L3 Monthly Data

Time: 16-MAR-2000 12:00

Plot showing a spatial distribution of data over the Atlantic Ocean region, with a color scale from 20 to 80.

Apply analysis

US Department of Commerce NOAA | OAR | PMEL | Contacts | Privacy Policy | Disclaimer | mailto:

ESGF Portal
[Home](#) [Search](#) [Tools](#) [Account](#) [Dashboard](#) [Admin](#) [Logout](#)

Peer Group: esgf-prod

Peer Group Maps

Availability Registered Users Node Type

Map showing global distribution of nodes with a legend for Availability, Registered Users, and Node Type.

Hosts List (Reference date 08/24/2012 13:14:09)

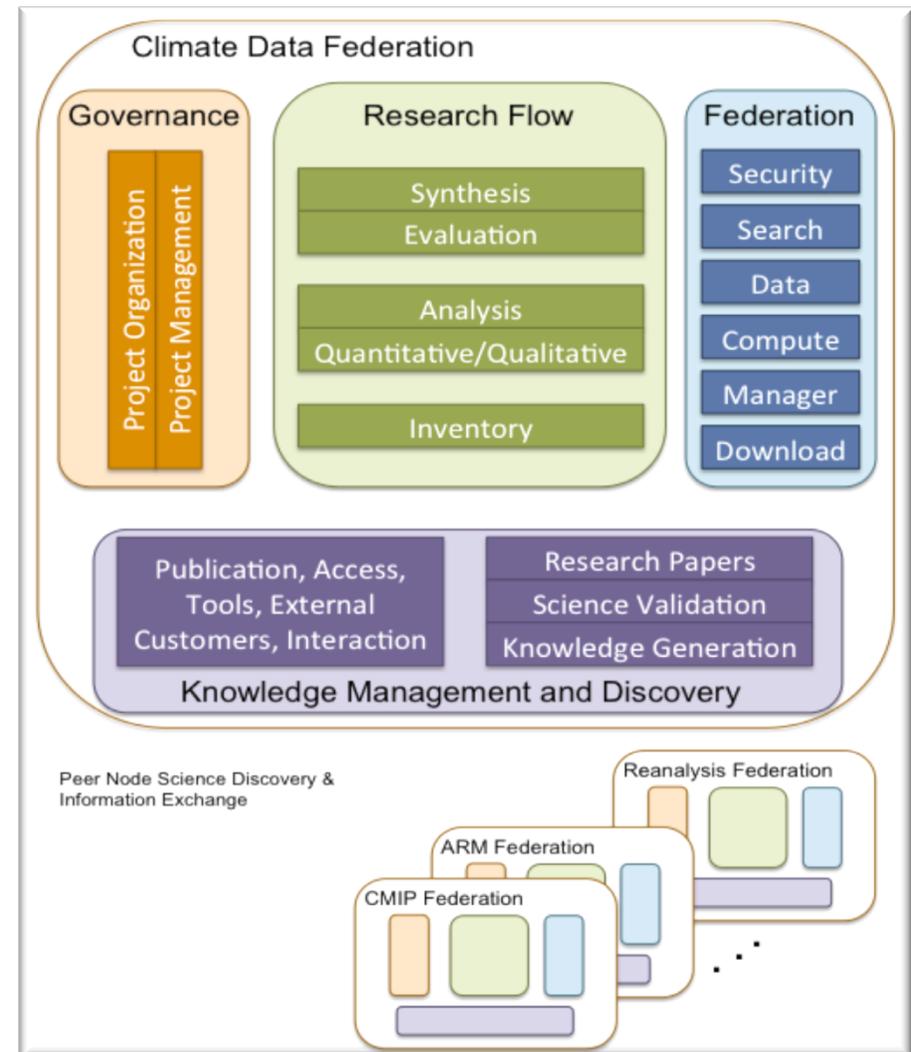
Visible	Alias	Host Name	Last 5 minutes a...	Last hour availa...	Last day availa...	Last week avail...	Last month avail...
<input checked="" type="checkbox"/>	pcmdi9.llnl.gov	198.128.245.161	100%	100%	100%	100%	100%
<input checked="" type="checkbox"/>	pcmdi9.llnl.gov	198.128.245.159	100%	100%	100%	100%	100%
<input checked="" type="checkbox"/>	bnml-ppoc-ar5.llnl.gov	136.172.30.9	100%	100%	100%	99%	99%
<input checked="" type="checkbox"/>	esgdata.pfsl.noaa.gov	140.208.31.117	100%	100%	88%	99%	99%
<input checked="" type="checkbox"/>	esg01.nersc.gov	128.95.80.79	100%	100%	100%	99%	99%
<input checked="" type="checkbox"/>	esg103.arcc.ucla.edu	210.21.240.163	100%	100%	100%	99%	99%
<input checked="" type="checkbox"/>	vesa.llnl.gov/vech	128.104.53.4	100%	100%	100%	99%	99%
<input checked="" type="checkbox"/>	norstone-isd-bnl.gov	129.241.21.139	100%	100%	100%	99%	99%

Page 1 of 4 Update XML CSV Displaying topics 1 - 8 of 29

<http://pcmdi9.llnl.gov/>

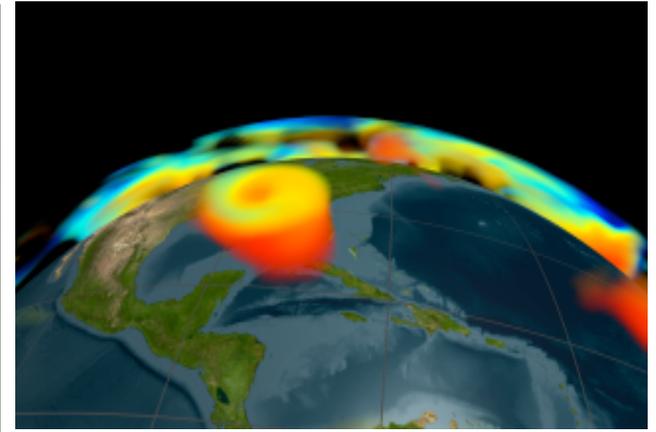
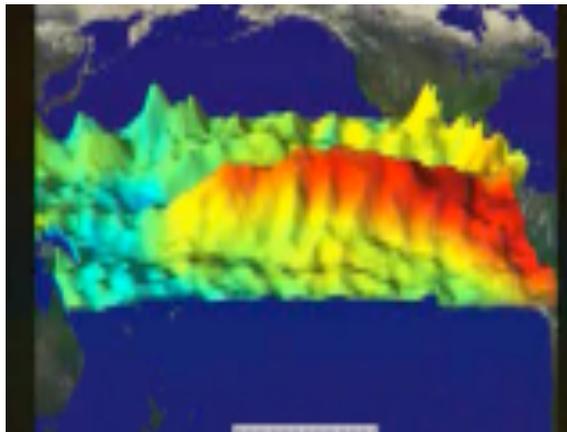
ESGF software system integrates data federation services

- NetCDF Climate and Forecast (CF) Metadata Convention
 - (LibCF)
 - Mosaic
- Climate Model Output Rewriter 2 (CMOR-2)
- Regriders: GRIDSPEC, SCRIP, & ESMF
- Publishing
- Search & Discovery
- Replication and Transport
 - GridFTP, OPeNDAP, DML, Globus Online, ftp, BeSTMan (HPSS)
 - Networks
- Data Reference Syntax (DRS)
- Common Information Model (CIM)
- Quality Control
 - QC Level 1, QC Level 2, QC Level 3, Digital Object Identifiers (DOIs)
- Websites and Web Portal Development
 - Data, Metadata, Journal Publication Application
- Notifications, Monitoring, Metrics
- Security
- Product Services
 - Live Access Server, UV-CDAT



Advanced analytics, informatics, and visualization for scientists

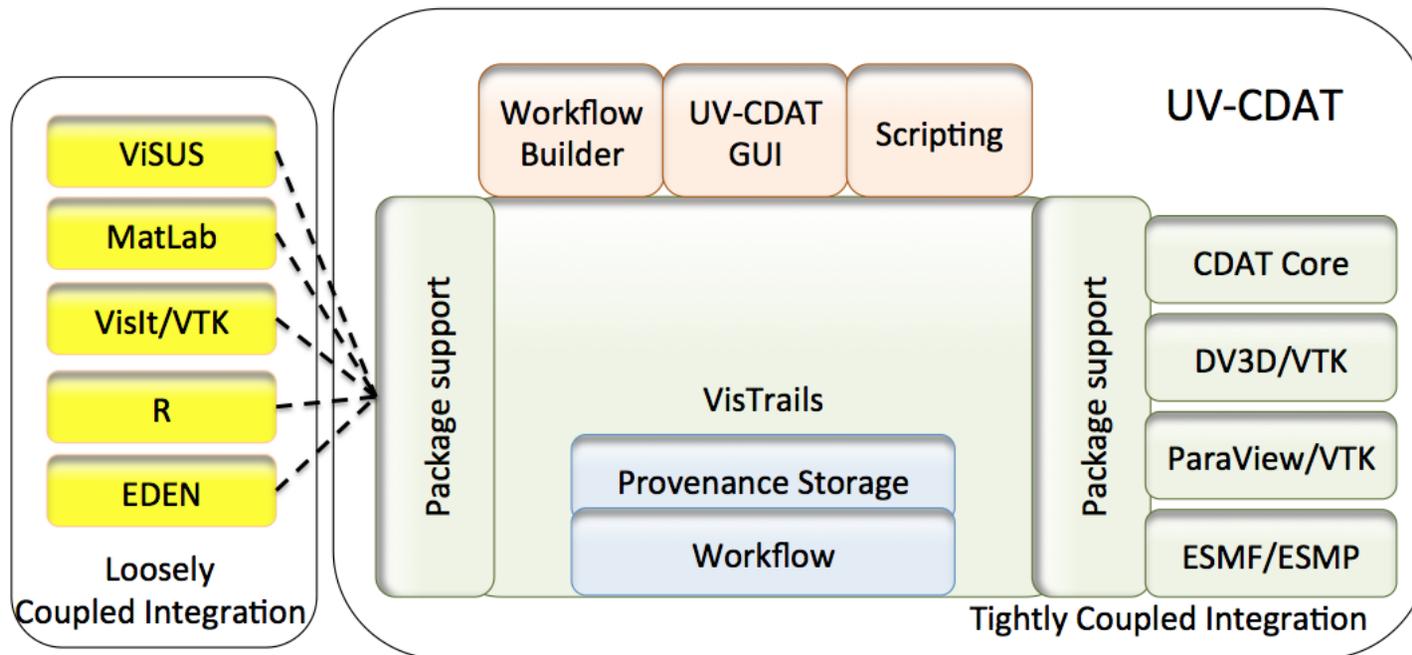
- Analysis and visualization is a key aspect of scientific analysis and discovery
- Advanced interactive visualization is rarely used by scientists
- Interfaces too complex, pickup too costly
- Interactive climate visualization requires:
 - Intuitive interfaces
 - Seamless integration with high performance analysis workbenches
 - Parallel streaming visualization pipelines



Background and introduction

<http://uv-cdat.org/>

- What is **UV-CDAT**:
 - ❑ A seamless environment for open-source data analysis and visualization packages



- What is **UV-CDAT** purpose:
 - ❑ Bring together robust tools for climate data processing
 - ❑ Integration heterogeneous data sources (e.g., simulations, observation, re-analysis)
 - ❑ Local and remote data access and visualization
 - ❑ Reproducibility

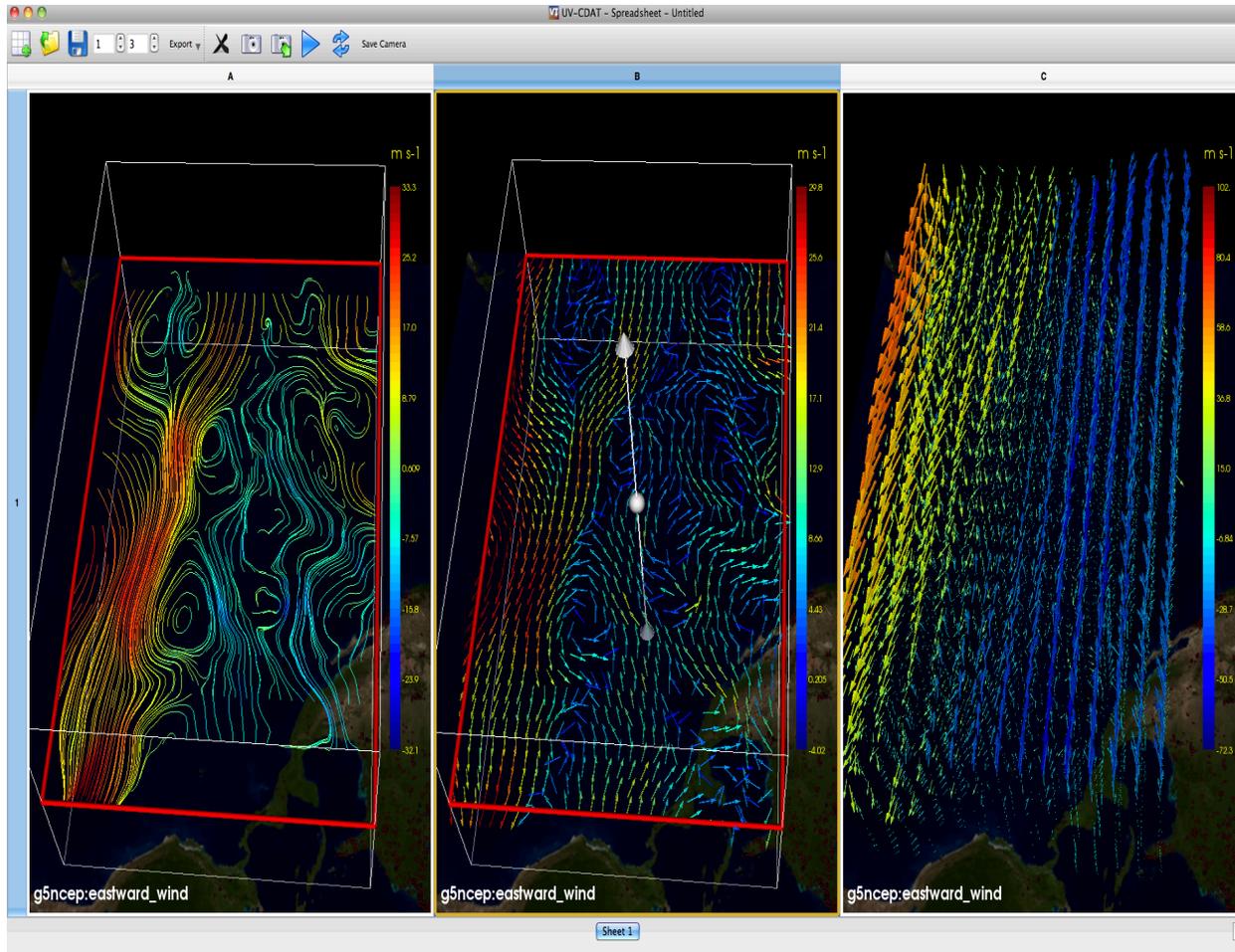
Interactive visualization and analysis

- Drag-and-drop variable and plots to create visualizations.
- Each plot has many user-friendly configuration options.

The screenshot displays the UV-CDAT software interface. The main workspace is divided into two sections. The top section, labeled 'A', contains the text "Drag and drop 2 variable(s) here" and "Plot: Contoured Volume Slicer". The bottom section contains the text "Drag and drop a variable here" and "Drag and drop a plot type here". On the left side, there is a "Plots and Analyses" panel with a list of visualization options including DV3D, Contoured Volume Slicer, Data Point Cloud, Demo 1, Glyph Array Slicer, Glyph Volume Plot, Hovmoller Slicer, Hovmoller Volume, Scalar Plot, Streamline Slicer, Textured Volume IsoSurface, Vector Plot, Volume IsoSurface, Volume Rendering, and Volume Slicer. Below this list are sections for Matplotlib, PVClimate, and VCS. On the right side, there is a "Variables" panel showing a list of variables and a "Calculator" panel with a grid of mathematical functions and operators. The calculator grid includes buttons for x^2, sqrt, 1/x, x^y, LN, LOG, e^x, 10^x, x<y, x>y, x<>y, x==y, SIN, ARCSIN, COS, ARCCOS, TAN, ARCTAN, STD, ABS, REGRID, MASK, GET_MASK, and GROWER. At the bottom of the calculator are buttons for Clear, Del, Enter, Plot, and a numeric keypad.

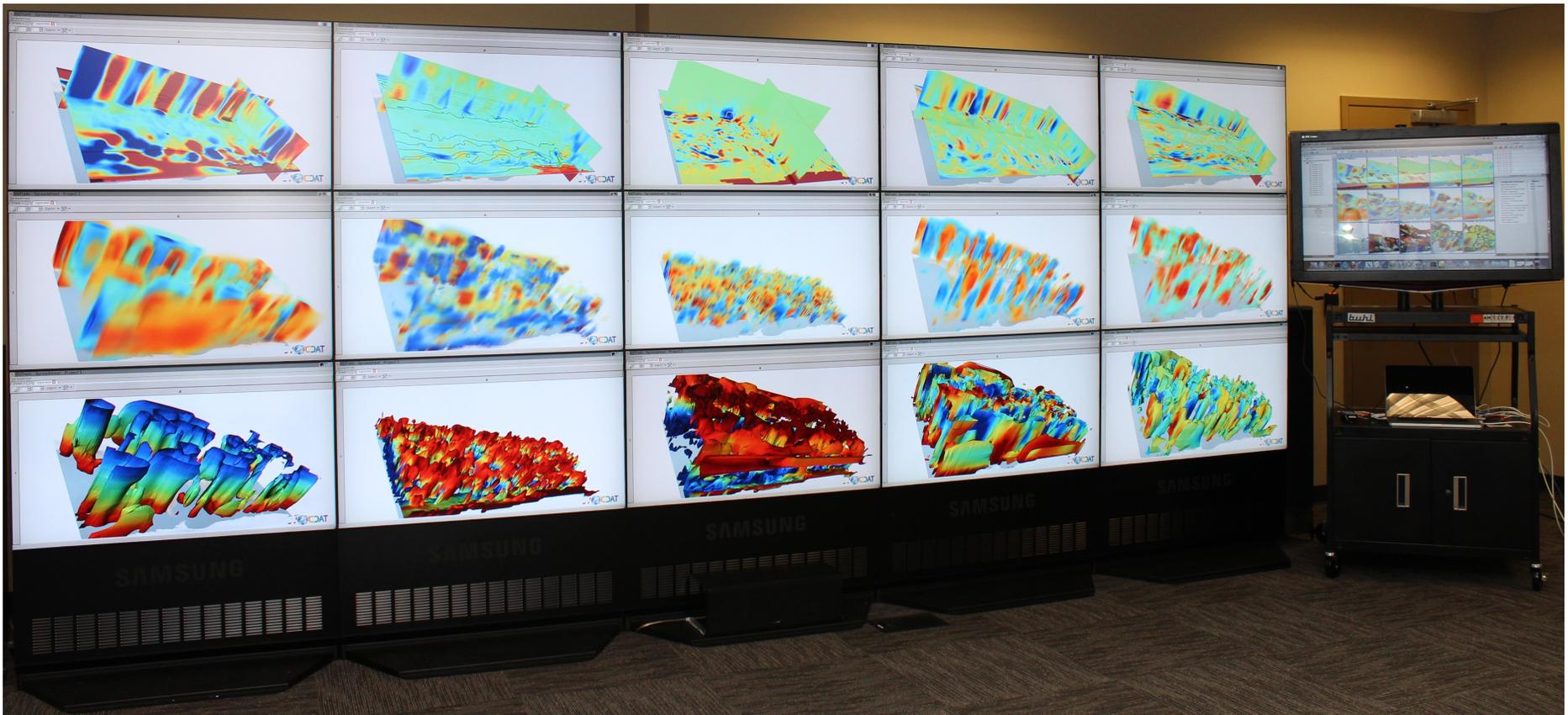
Vector plots

- Facilitates the visualization of 3D vector fields
- Utilizes streamlines on slices, glyphs on slices, or glyph volumes



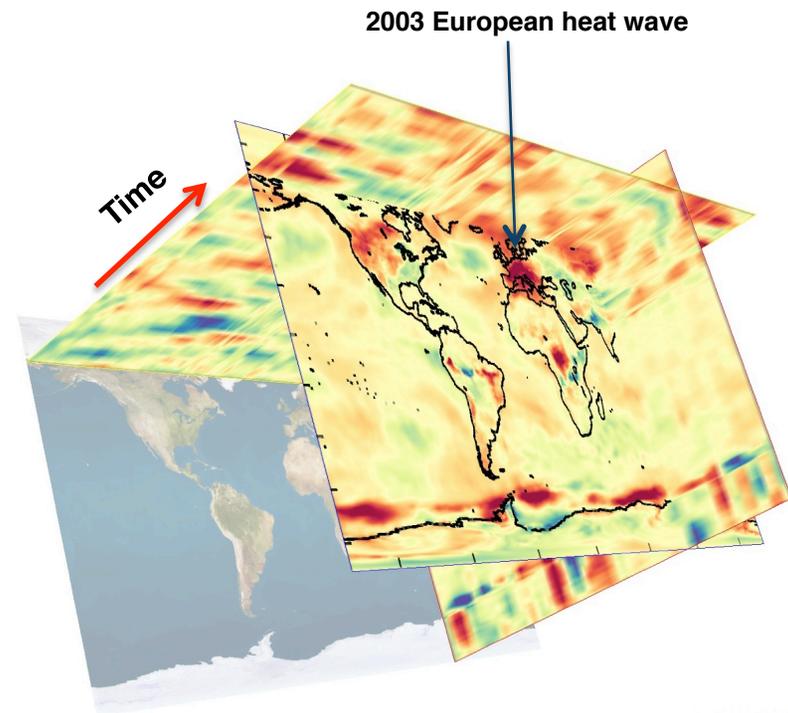
Interactive hyperwall visualization

- Uses parallelism to address data complexity
- UVCDAT runs on each display node (full-res 1-cell hyperwall display)
- UVCDAT runs on control node (low-res 15-cell touchscreen display)
- Control node interactions broadcast to all hyperwall nodes



Using UV-CDAT's 2D and 3D Capabilities to Explore Explore Time Series Data

- Demo using DV3D to examine 2-meter temperature from MERRA reanalysis
 - Use of a “3D Hovmöller” to explore anomalies
 - Basic attribution of extreme heat waves
 - Use of 250 mb meridional wind anomaly to identify stationary Rossby Waves
 - Identification of possible new planetary wave
- Demo of 3D slicer to examine Hurricane Sandy (October 2012)



Spatio-temporal pipeline: UV-CDAT use case 1

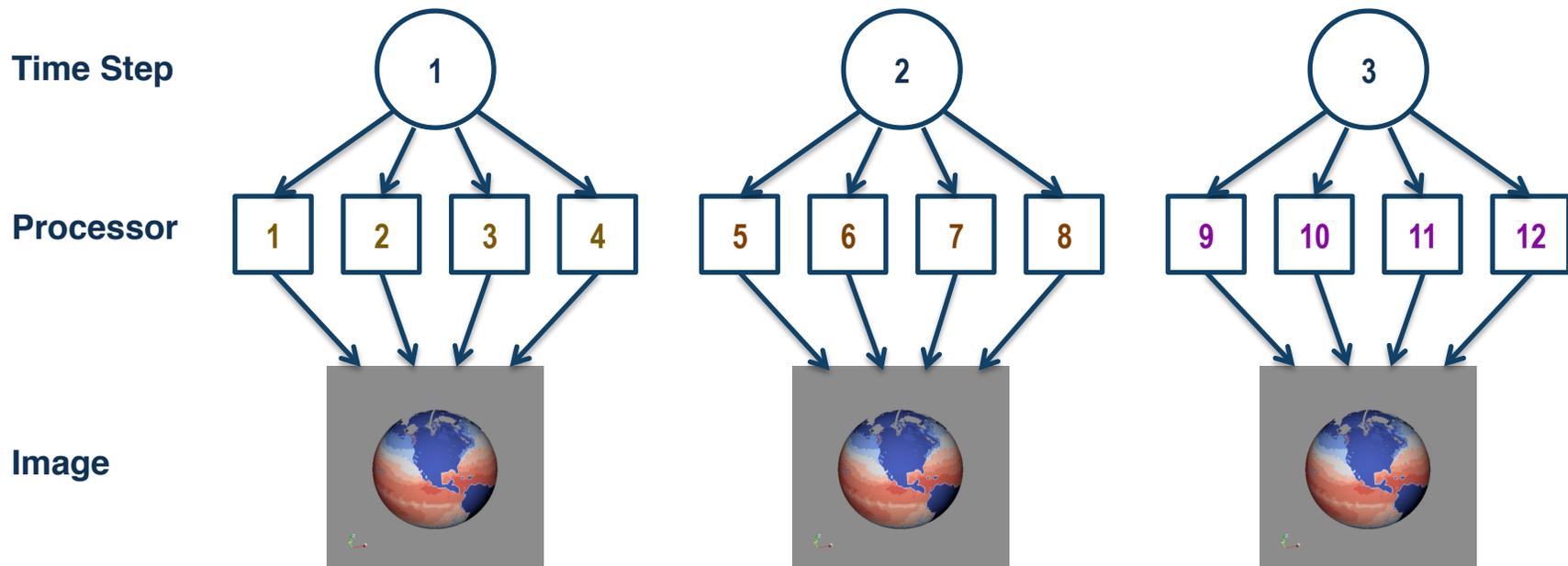
Use Case 1: High spatial resolution, high temporal resolution, image sequence production

Problem

Large datasets exist with many **timesteps and high temporal resolution**. UV-CDAT must be capable of handling these datasets. Existing tools do not support high temporal resolution well.

Solution

Added capability within UV-CDAT ParaView to partition within time to allow for **multiple timesteps to be processed in parallel**. Processors are divided into “time compartments”, and each file is processed by a time compartment.



Use Case 1 performance results: Mustang tests

Number of Timesteps	Number of Processes (P)	Time Compartment = P (seconds)	Time Compartment = 8 (seconds)
2	16	46.96	21.76
4	32	81.84	21.47
8	64	159.77	21.16
16	128	235.61	26.85
32	256	1,103.00	23.13
64	512	2,365.89	25.02
128	1024	8,128.92 (~2 hrs)	30.15
256	2048	28,862.55 (~8 hrs)	62.83

- Measured on Mustang supercomputer, 8 cores per node
- Each time step is 1.4 GB
- Panasas parallel file system
- Testing having all processors read each time step versus having eight processors read each time step

Spatio-temporal pipeline: UV-CDAT use case 2

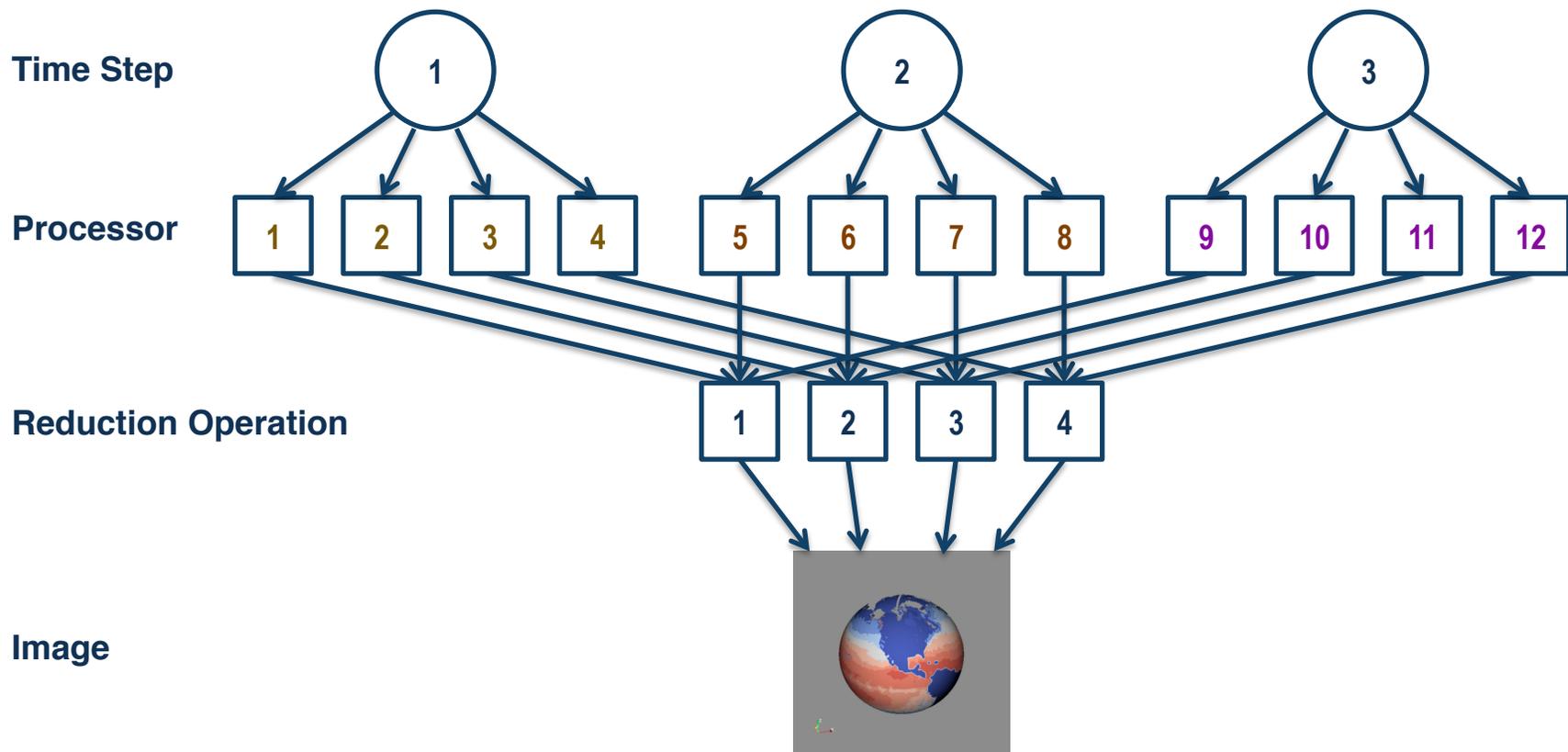
Use Case 2: High spatial resolution, high temporal resolution, time average

Problem

Multiple timesteps need to be averaged together to produce a data product based on the results.

Solution

Added capability within UVCDAT ParaView to take multiple timesteps and **compute various statistics** (average, min, max, standard deviation) using the spatio-temporal pipeline.



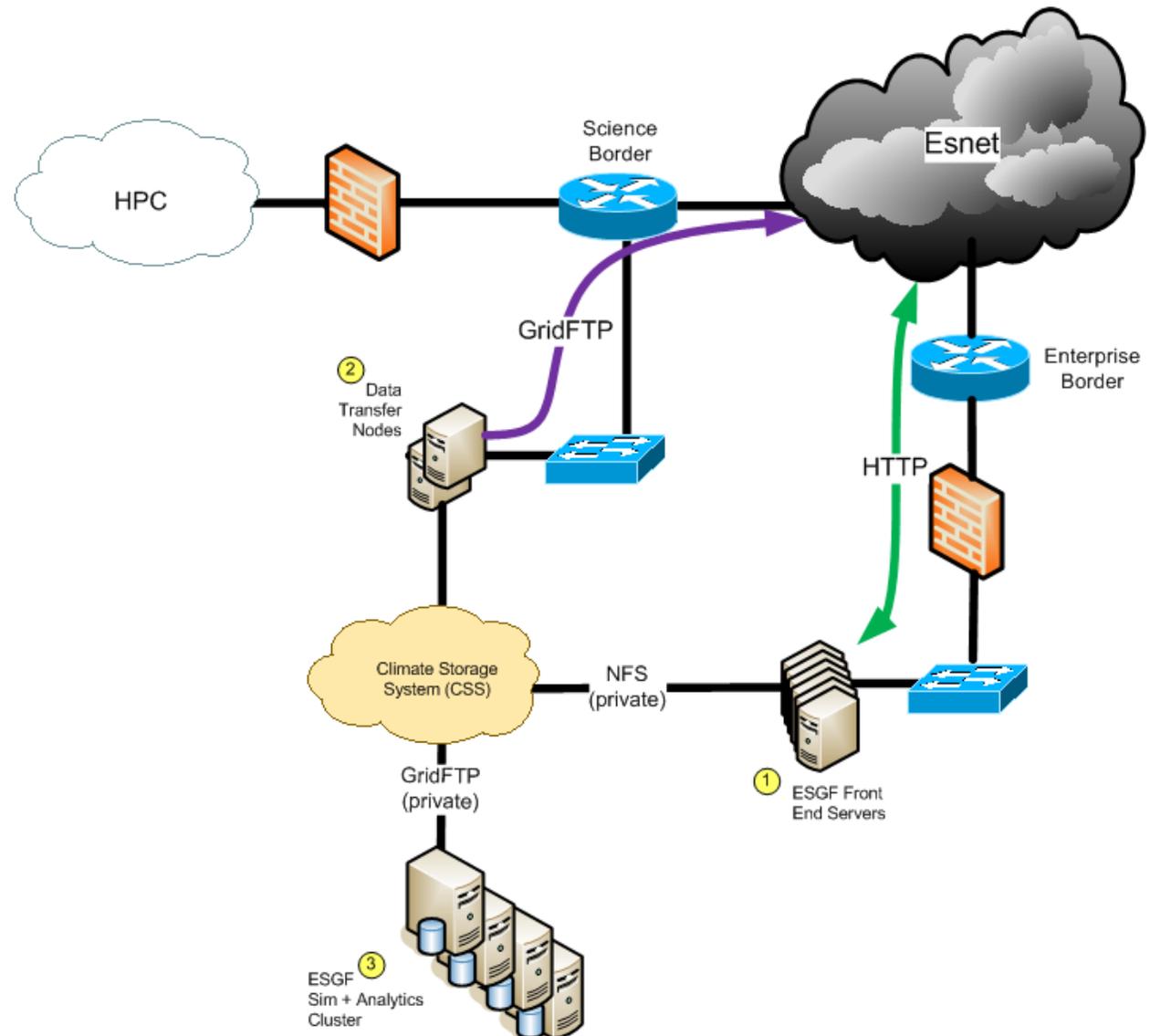
Use Case 2 performance results: Hopper tests

Time Compartment Size	Total Time (seconds)
1	145
2	278
12	93
48	151
96	244
240	525
480	1204

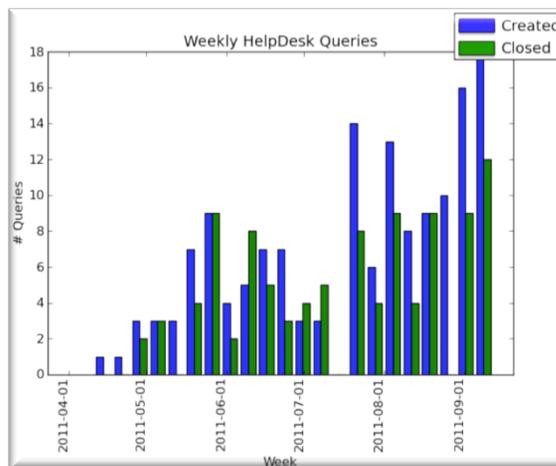
- **Measured on Hopper supercomputer**
- **480 cores, 20 nodes**
- **Analysis of Michael Wehner's climate data**
- **324 timesteps, total data size is 20 GB**
- **Calculate yearly statistics from monthly data**
 - **Min, max, average, standard deviation**
- **Lustre parallel file system**

ESGF/UV-CDAT integrated with the hardware and network

- 1 Users communicate with ESGF front-end servers via HTTP
- 2 Large data sets are made available to users directly from the Climate Storage System (CSS) via vsftp and GridFTP
- 3 Through UV-CDAT, ESGF will perform analysis of raw data if requested by users through the front-end servers to the analysis (hadoop) cluster

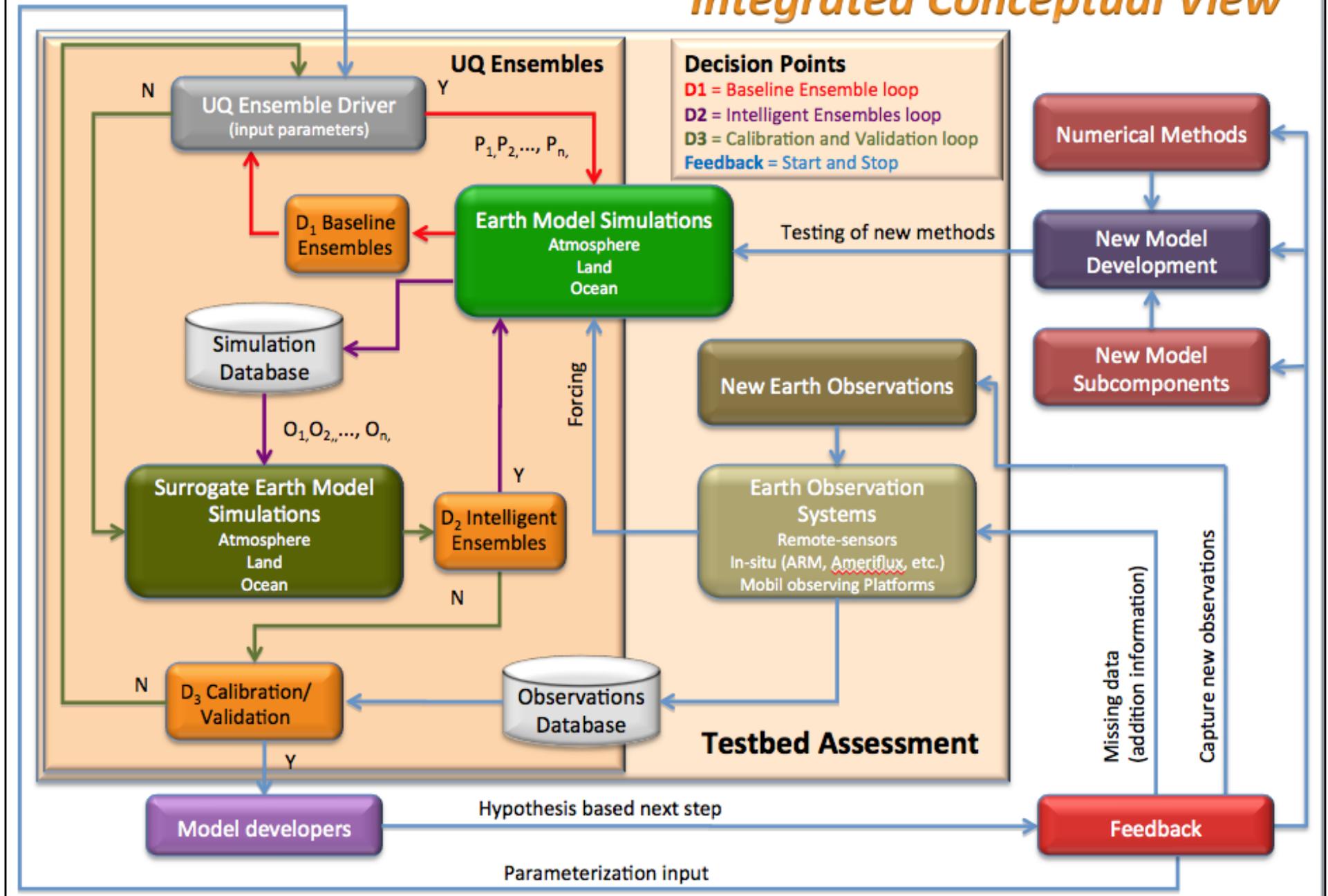


ESGF's and UV-CDAT multiple collaborations

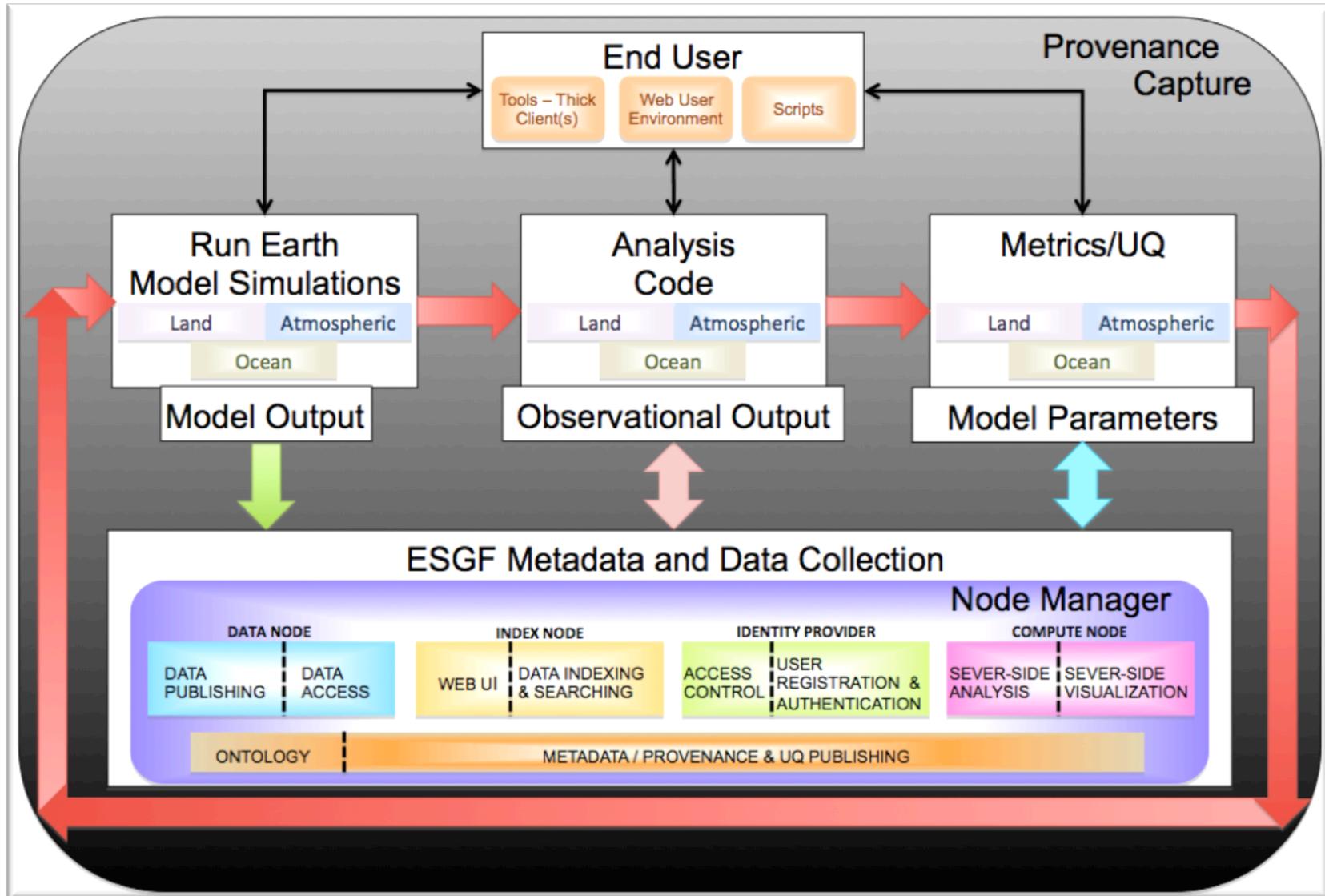


Climate Science for a Sustainable Energy

Integrated Conceptual View



High-level Conceptual View of CSSEF Test Bed Architecture and Workflow



Questions and discussion

