

# CMIP, CSSEF, ESGF, and BER Related Data Projects: Climate Model Analysis, Visualization, and Test Bed Efforts for Ultra-Large Data Sets

Dean N. Williams and Dave Bader on behalf of Multiple Earth System Communities and Projects  
Federated and Integrated Data from Multiple Sources

CESD Data Meeting – Infrastructure and Framework Presentation ♦ June 26, 2012



# Outline

- CMIP5 – Redefined requirements for data federation
- ESGF concept
- ESGF and CMIP
- ESGF pilot projects with ARM and CDIAC
- CSSEF
- Associated BER efforts
- Current status and near term directions
- A possible long-term vision for BER’s “Climate K-Base”

# CMIP: Experiment Design

## CMIP5: 47 models **available** from 21 centers

- CMIP = **Coupled Model Intercomparison Project**
  - Phase 1: Idealized simulations of present-day climate
  - Phase 2: Idealized simulations of future climate changes
  - Phase 3: More realistic simulations (2004 – present)
- **CMIP 5** multi-model archive expected to include
  - **3** suites of experiments
  - **24** modeling centers in **19** countries
  - **58** models
  - Total data, **~3.5 PB**
  - Replica **1 – 2 PB**
  - Derived data **~1 PB**
- **Global distribution**
- **Timeline fixed** by IPCC (2012 - 2013)
- **LLNL organizes, manages and distributes** the CMIP/IPCC (Intergovernmental Panel on Climate Change) database of climate model output

# CMIP3 archive vs. CMIP5 archive

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

**35 TB**

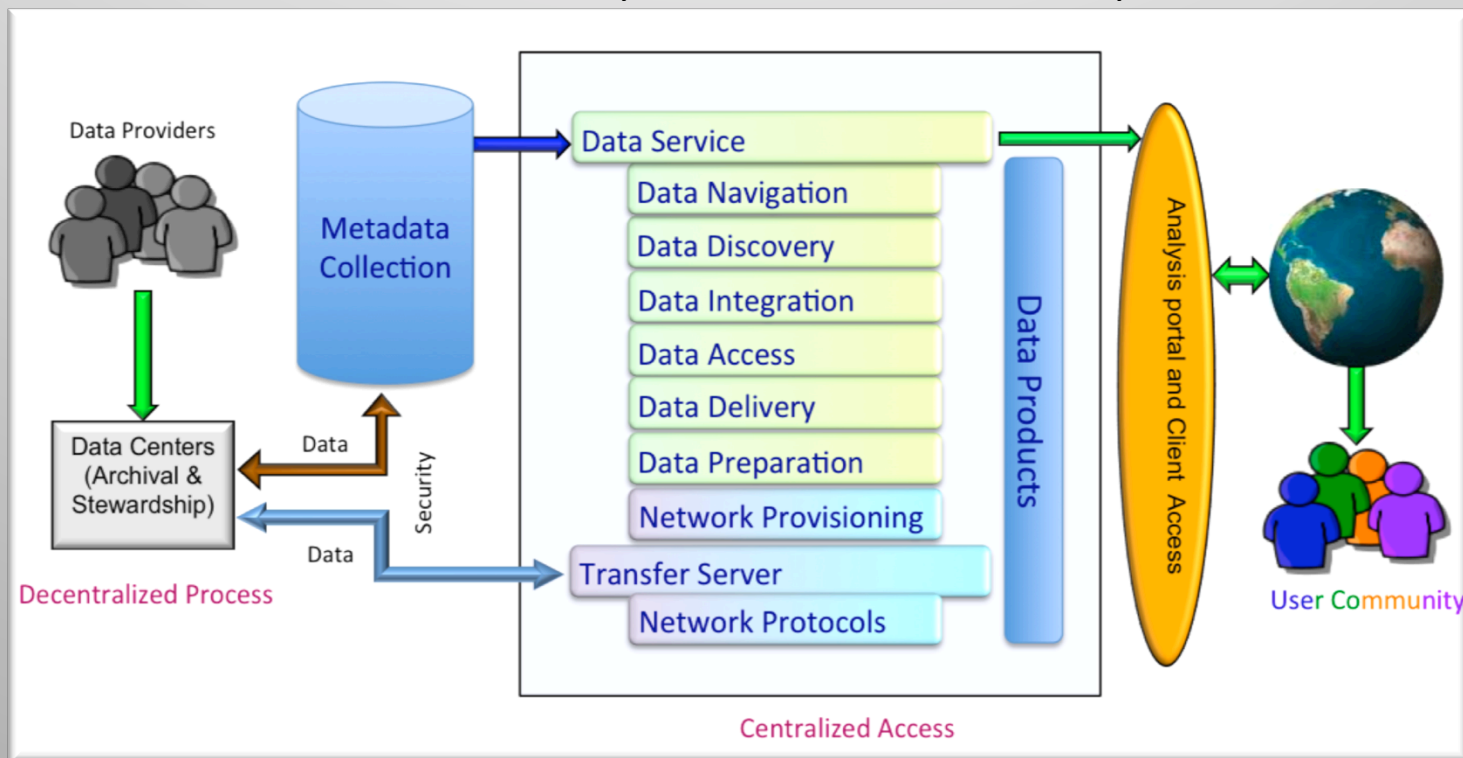
CMIP5 Modeling Centers		volume (TB)
BCC	China	51
CCCma	Canada	51
CMCC	Europe (Italy)	158
CNRM	France	71
CSIRO	Australia	81
EC-EARTH	Europe (Netherland)	97
GCESS	China	24
INM	Russia	30
IPSL	France	121
LASG	China	100
MIROC	Japan	350
MOHC	UK	195
MPI	Germany	166
MRI	Japan	269
NASA	USA	375
NCAR	USA	739
NCC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

**3.1 PB**  
**Currently 1.2 PB**

**CMIP5/CMIP3 = 10<sup>2</sup>**

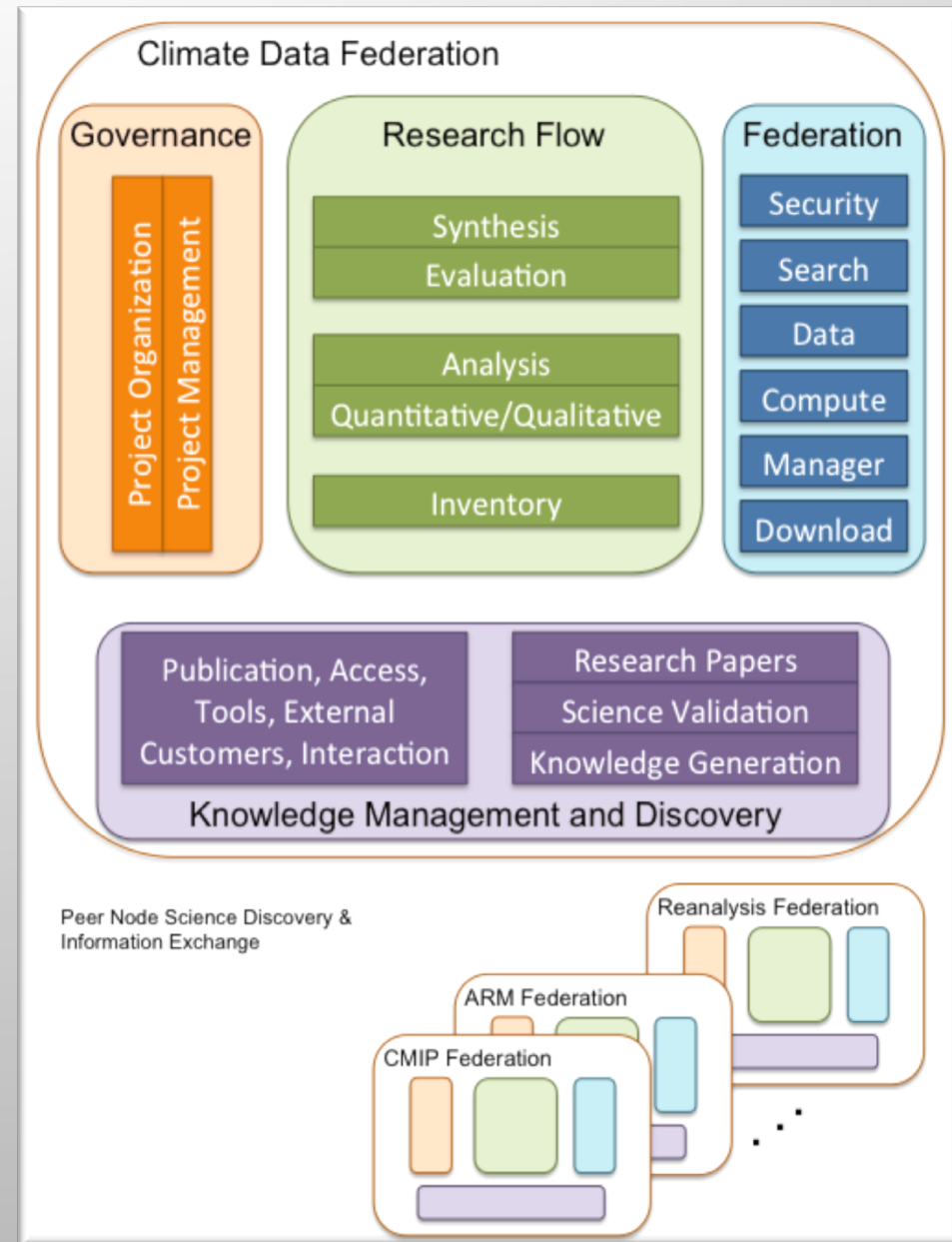
# Big Data Challenges

- **Centralized process** for CMIP3, data was **shipped to LLNL via disk**, then made available to users
  - Several weeks delay between generation of files and availability to users
  - Correction errors in data was too difficult
  - LLNL became a single point of failure (a catastrophic crash of our RAID system meant data was inaccessible for several weeks)
  - Backup was incredibly difficult, which made restoration equally as hard
- **Decentralized process** for CMIP5, a new (and **more complicated approach**) was necessary
  - Distributed data Archive
  - No single point of failure
  - Replication of heavily-used data sets
  - Data can be made available without delay and can be corrected locally



# Data Federation Services

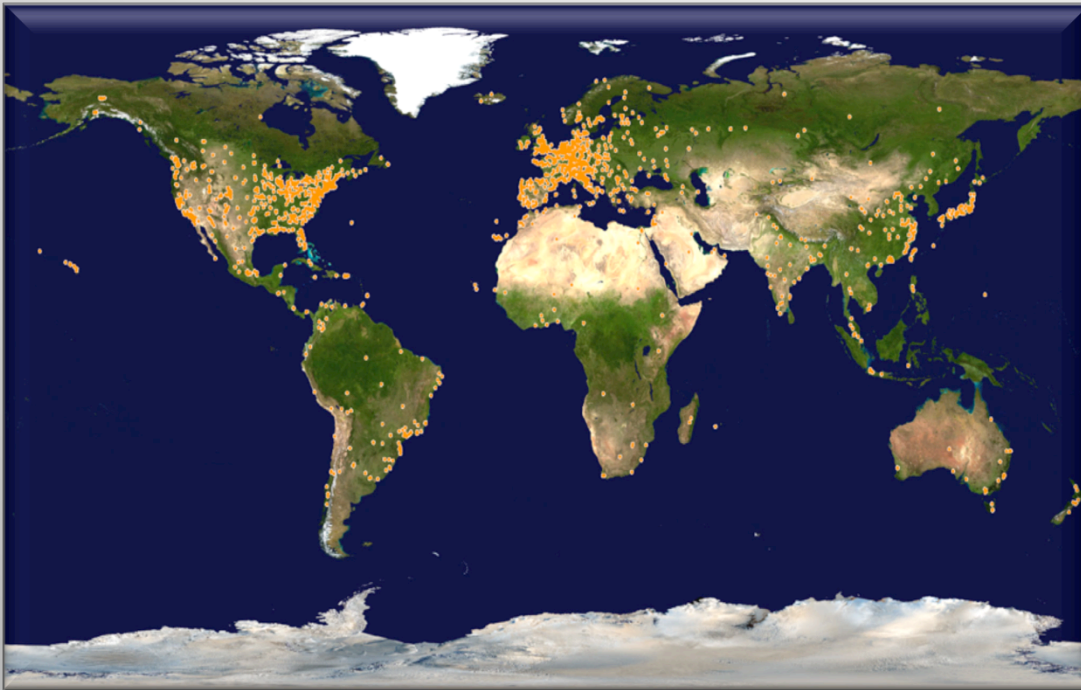
- NetCDF Climate and Forecast (CF) Metadata Convention
  - (LibCF)
  - Mosaic
- Climate Model Output Rewriter 2 (CMOR-2)
- GRIDSPEC & SCRIP
- Publishing
- Search & Discovery
- Replication and Transport
  - GridFTP, OPeNDAP, DML, Globus Online, ftp, BeSTMan (HPSS)
  - Networks
- Data Reference Syntax (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
- Product Services
  - Live Access Server, UV-CDAT
- Security



# Earth System Grid Federation (ESGF)

## Approach

Free and open consortium of institutions, laboratories and centers around the world that are dedicated to **supporting climate change research** and its environmental and societal impact.

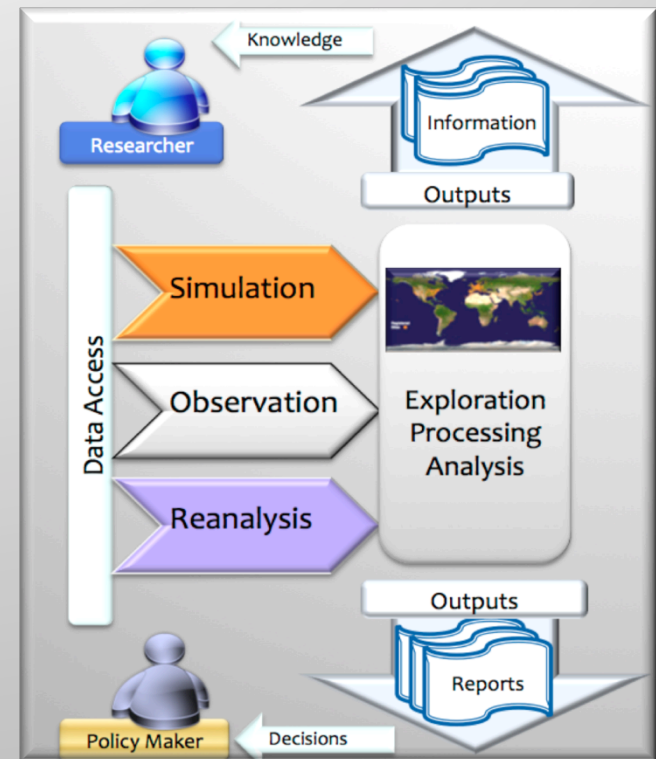


## Contributions

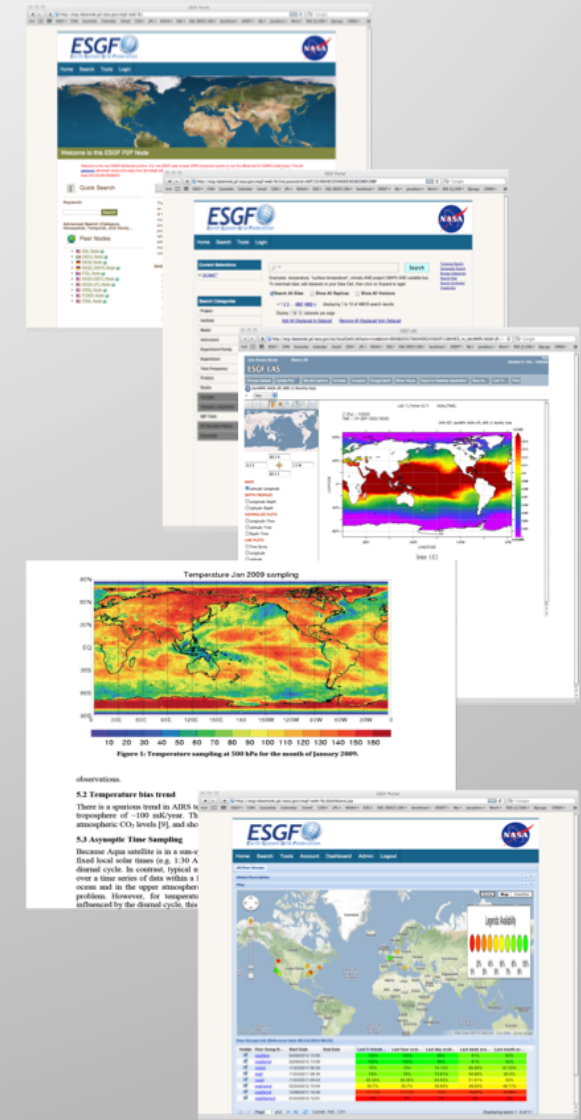
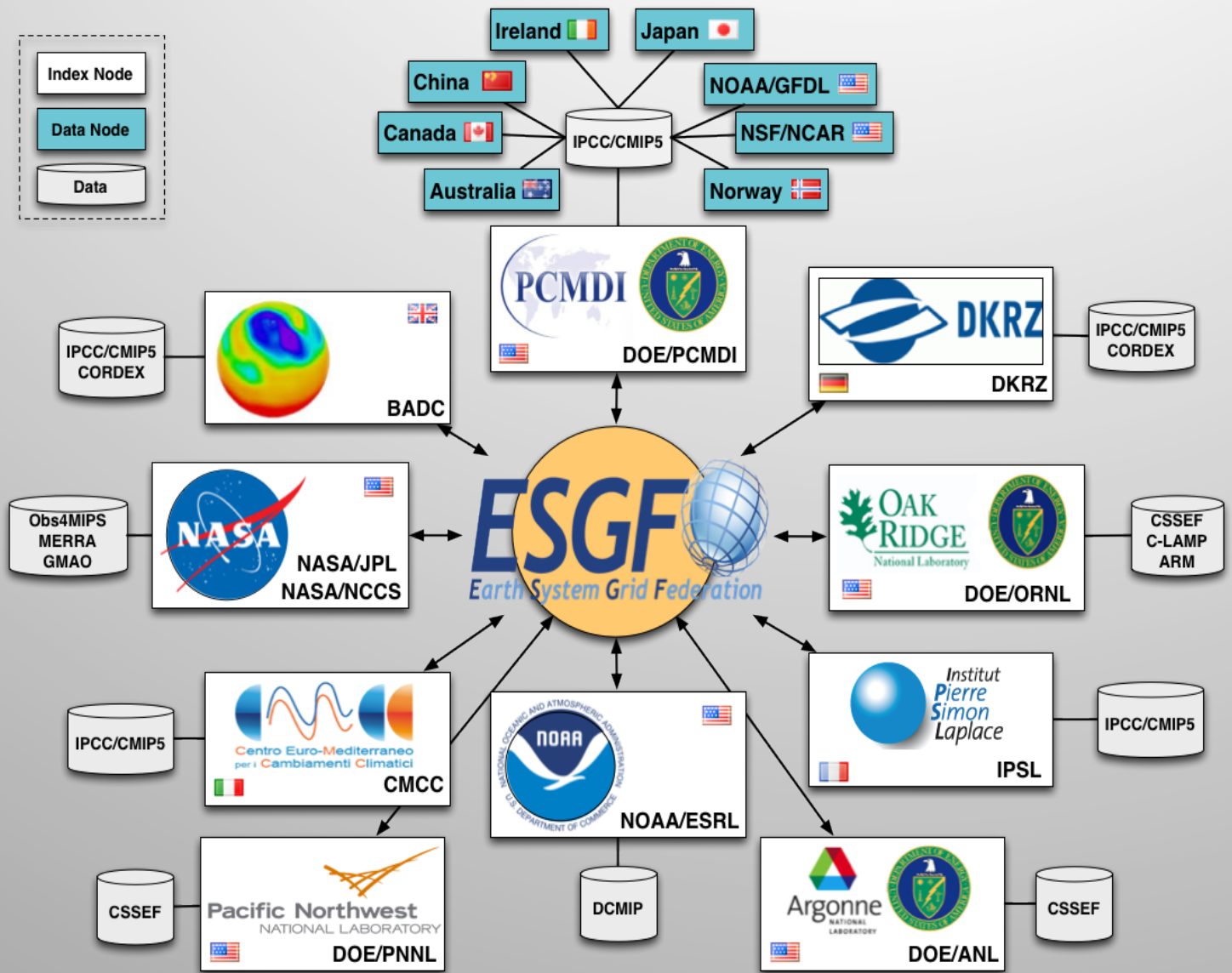
**Worldwide organizations** contributing to the ESGF efforts include: NASA's Observation Intercomparison Project (obs4MIPs); NOAA's Earth System Curator and Global Interoperability Program; EU's MetaFor and Infrastructure for the European Network for Earth System Modeling, and many more.

## History

Historically originated from the Earth System Grid (ESG) project, started in 1999, expanded beyond its constituency and mission to include many other projects and **partners in the U.S., Europe, Asia, and Australia.**

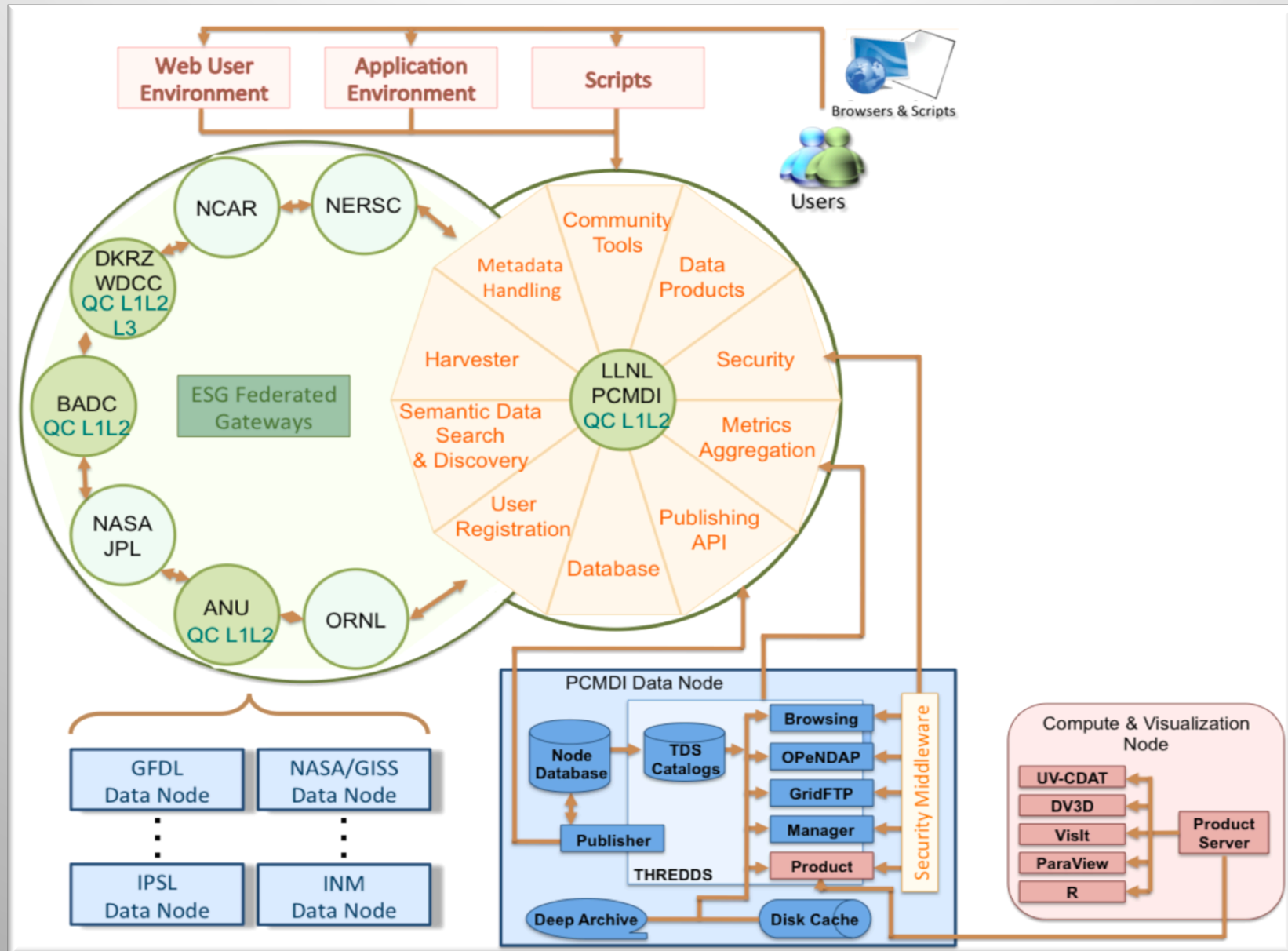


# Federated and Integrated Data from Multiple Sources



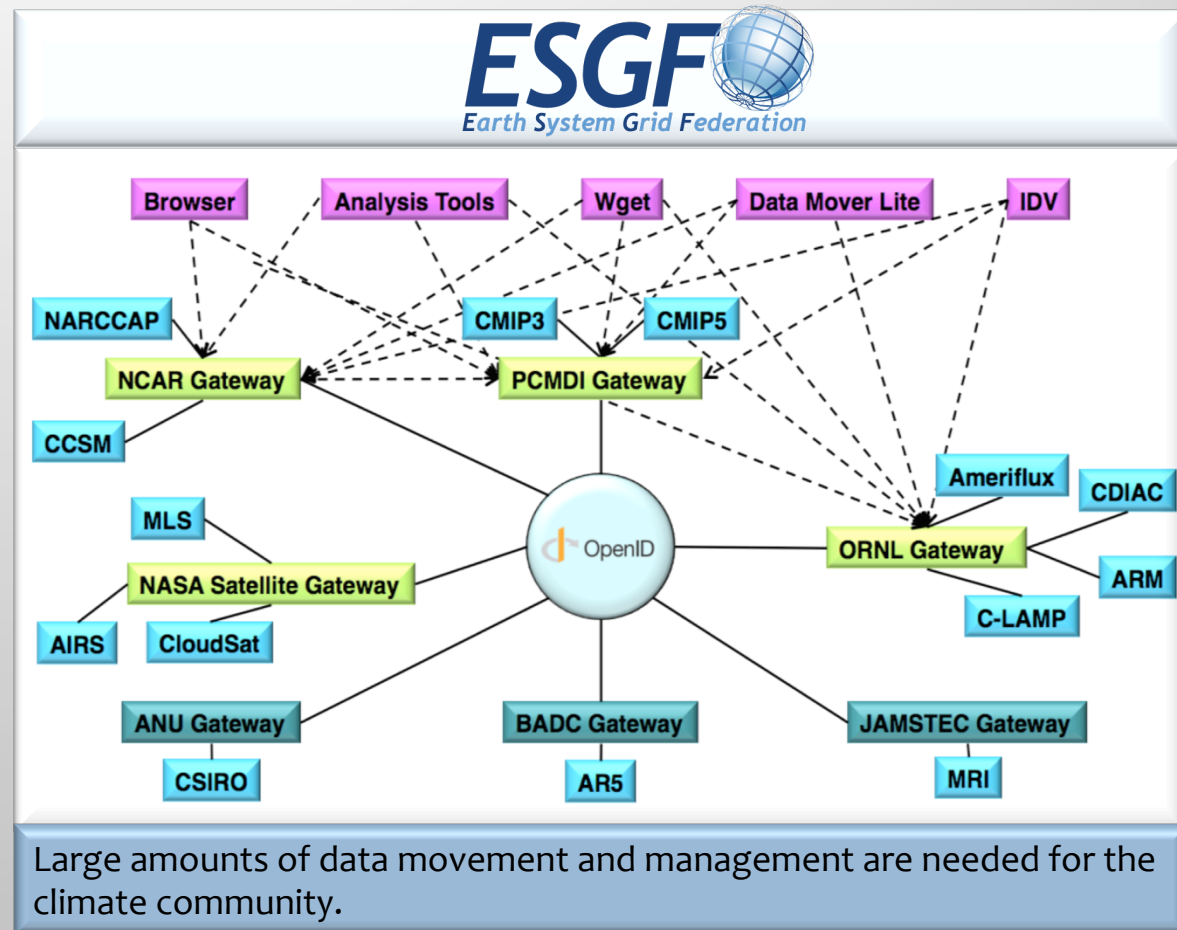


# CMIP5 Managed Distributed Archive led by the Earth System Grid Federation (ESGF)



# The 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



# ARM/CDIAC Integration with the Earth System Grid Federation (ESGF)

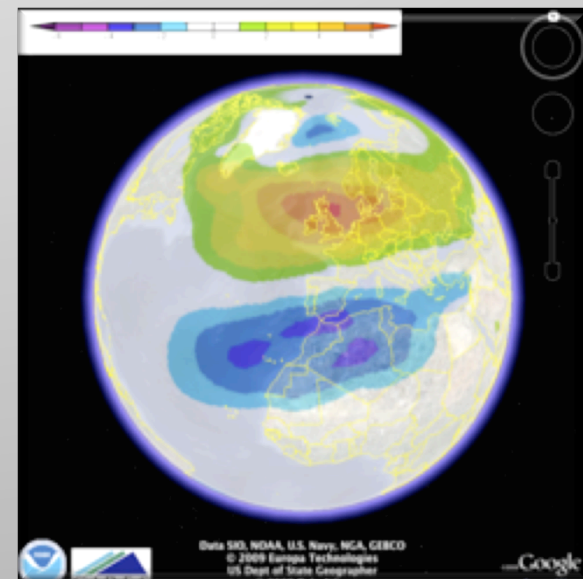
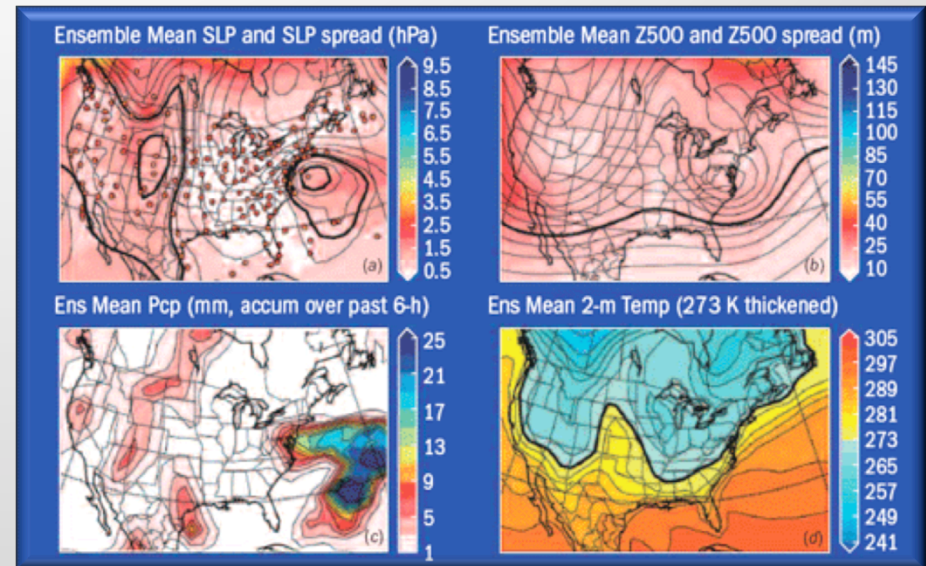
- ARM/CDIAC data set publication plan

Currently Published	To Be Published
Ameriflux	Balloon-Borne Sounding System
Fossil Fuels	Active Remotely-Sensed Cloud Locations
Obs4MIPs	Microwave Water Radiometer

- Revised workflow for seamless publication of ARM/CDIAC data sets to ESGF
  - ARM/CDIAC centers maintain a THREDDS server containing ESGF-parsable metadata catalogs of native archives
  - An ESGF “Plugin” is built containing:
    - Flexible Publication tools (**EZ-Pub**)
    - A catalog crawler for ingestion into the ESGF search index to enable data set discovery
    - Modules for data visualization, analysis, and mining
    - Security mechanisms for user authentication and verification
    - Usage metrics and statistics collectors for policy makers and administrators

# Reanalysis Integration with the Earth System Grid Federation (ESGF)

- To enhance climate science resources, NASA Goddard Space Flight Center has agreed to host a subset of the **primary reanalysis data** on their ESGF node in a similar format to the CMIP5 archive. The ESGF node is managed by the NASA Center for Climate Simulation (NCCS).
- Participating reanalysis institutions:
  - NASA/GSFC/GMAO – MERRA
  - NOAA/NCEP – CFSR
  - ECMWF – Interim
  - JMA/JMA – 25
  - NOAA – 20CR
- Data will need to be translated to the CMIP5 **NetCDF/CF format** through the CMOR application
- <https://oodt.jpl.nasa.gov/wiki/display/CLIMATE/Sharing+Observations+for+Climate+Research>



# Climate Science for a Sustainable Energy Future (CSSEF)

## ■ Organization of model component data and scientific needs through the Earth System Grid Federation (ESGF) Peer-to-Peer (P2P) system

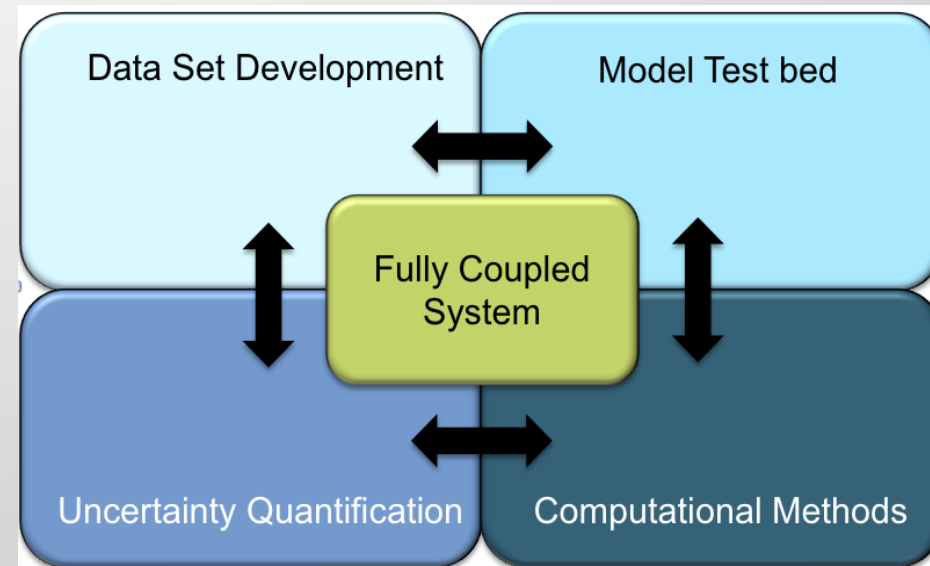
- Manage existing data and add new data to CSSEF archive
- Provenance must be documented and retained
- Stewardship and security
- Discoverability and accessibility

## ■ New paradigm

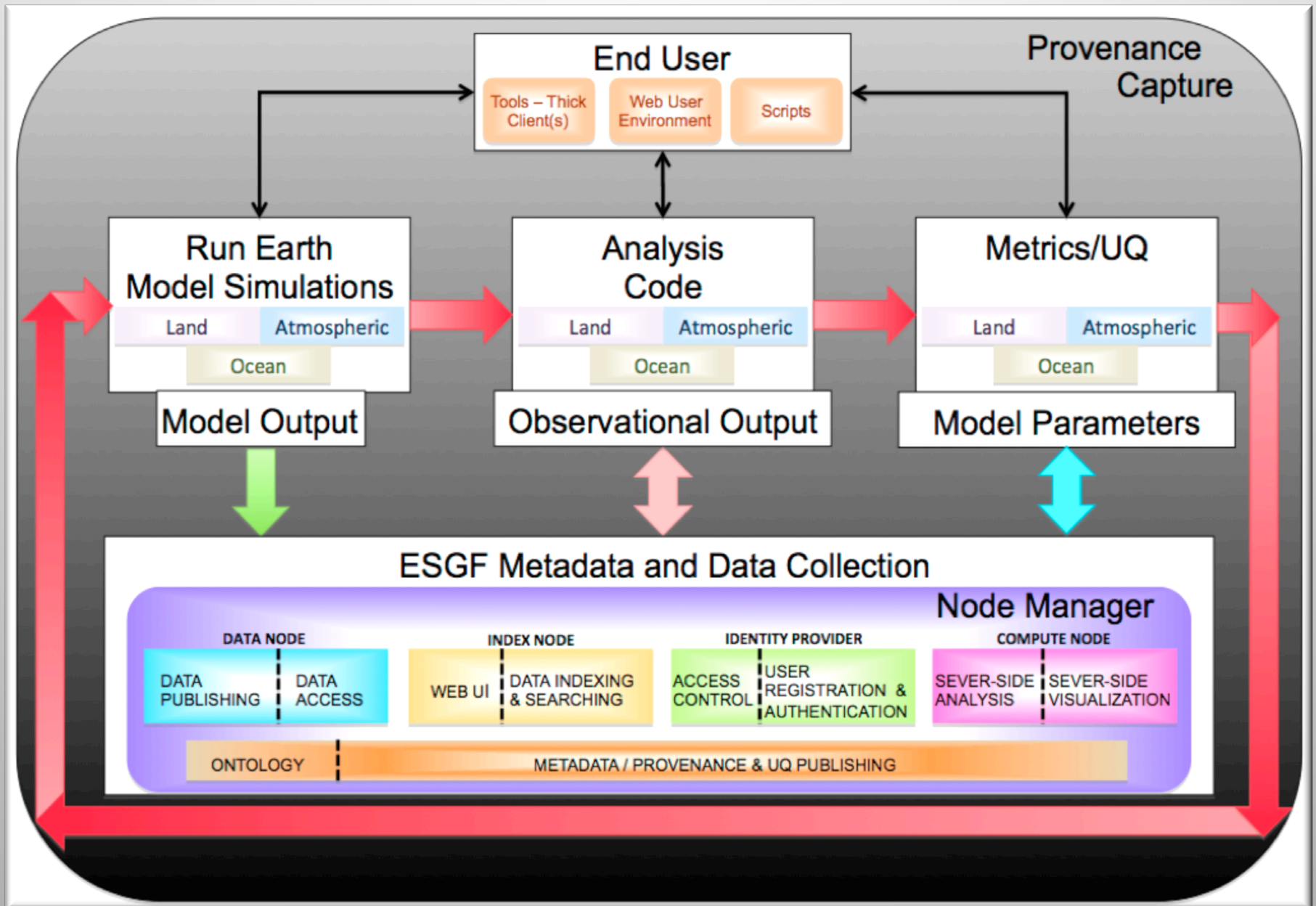
- CAM Integration
- CLM integration
- Diagnostic calculations on CAM and CLM output integration and publishing results into ESGF
- Uncertainty Quantification (UQ) calculations on CAM and CLM integration
- Distribution of workload between clients and “data engines”
- Automation and capture of workflows for reproducibility and efficiency
- Documentation of various steps; record script used for publication; note any problems encountered

## ■ Current projects

- Integrate current tools and approaches for test bed and refine for efficiency
- Test and build from initial subsystem



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



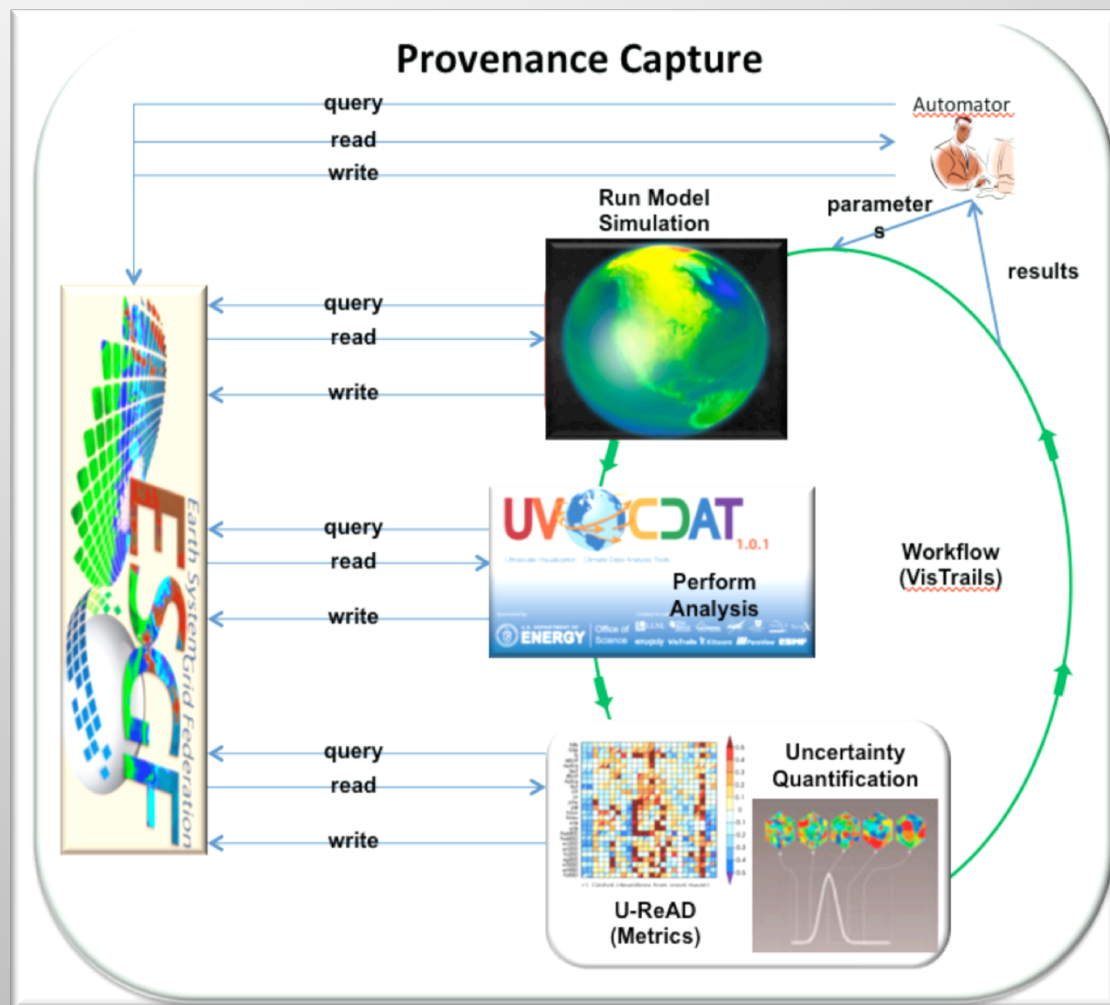
# Workflows and Provenance

## Why Use Workflows in CSSEF?

- Standardize scientific experiments, data processing, and analysis under one unified technical approach
- Workflows will work as building blocks to support more complex problems.
- Can automatically record what processes executed, what data was used, and what data resulted (**Provenance**)

## Why is provenance important?

- Without knowing the origin of published data, scientists would have no way to trust the results:
  - What version of the model was used to generate it?
  - What model forcings and parameters were used to produce this result?
  - Real world atmospheric example: LLNL and PNNL both published ARM best estimate data sets. Are they redundant, interdependent or completely independent? The historical record of how they were produced would be the only way to truly differentiate the two efforts.



# The Good, the Bad, and the Ugly

- The **data centers** have generally worked together well
  - with limited resources
  - to design and develop a distributed data archive
  - which has minimized the delay in getting data to users
- The monolithic original software structure has been completely **redesigned** by the ESG Federation
  - It's called "peer to peer" design (P2P)
  - Increased modularization will speed improvements
  - Increase flexibility will better meet the needs of a diverse user base
- The **new web-based** user interface substantially
  - Improves speed, accuracy, and flexibility of searches
  - Minimizes clicks
- It is now possible to **script downloads** without first accessing the web interface
  - "ESGF P2P release version" is used in production now and running along side the old system until the end of July."
- **Increase speed** of downloads
  - More nodes will establish gridftp servers (~10x faster than http)
  - Data will replicated at major data centers with generally better performance
- **Reduce error rates** for downloads and simplify scripting
- Make available all model and experiment **documentation**
  - Table of forcings for each model & experiment
  - Table of parent experiments and branch times for each realization
  - All information recorded through the METAFOR questionnaire



# Near Future

## *This should happen before the end of summer*

- Data error reports/notification (rudimentary pages now in place)  
<http://cmip-pcmdi.llnl.gov/cmip5/errata/cmip5errata.html>
- Service to notify users when new data sets of interest become available.
- Place to record and access CMIP5 publications (web-based form ready now)
- Citable record of CMIP5 provenance (doi assignment and other options)
- Sub-setting of files before download (and other server-side calculations) – better integration with the UV-CDAT is currently underway
- **Obs4MIPs**: An effort to make observational data that can be directly compared with CMIP5 model output
  - Promoted by Duane Waliser, Robert Ferraro, and others at JPL with cooperation from PCMDI and encouragement from the WGCM
  - Data written in same structure and format as CMIP5 model output
  - Data obtainable through ESGF (product=**Obs4MIPs**)
  - First products from NASA and from ARM now available
  - ESA and NOAA have expressed interest in contributing
  - Wiki describing Obs4MIPs now visible at: <http://obs4mips.llnl.gov:8080/wiki>
- **ANA4MIPs**: A parallel effort is underway to make reanalysis products available (currently NASA MERRA)
  - Promoted by Jerry Potter, and others at Goddard with cooperation from PCMDI and encouragement from the WGCM
  - Data written in same structure and format as CMIP5 model output
  - Data obtainable through ESGF (product=**ANA4MIPs**)

# BER Supported Data Activities

<http://uvcdat.llnl.gov>

## Ultra-scale Visualization Climate Data Analysis Tools (UV-CDAT)

- **Integrate** DOE's climate modeling and measurements archives
- Develop **infrastructure** for national and international model/data comparisons
- **Deploy** a wide-range of climate data visualization, diagnostic, and analysis tools with familiar interfaces for very large, high resolution climate data sets (**CDAT, VTK, R, VisIt, ParaView, DV3D, ...**)
- **Workflow** – data flows are directed graphs describing computational tasks
- Takes advantage of **ESGF data management**



## Visual Data Exploration & Analysis of Ultra-large Climate Data

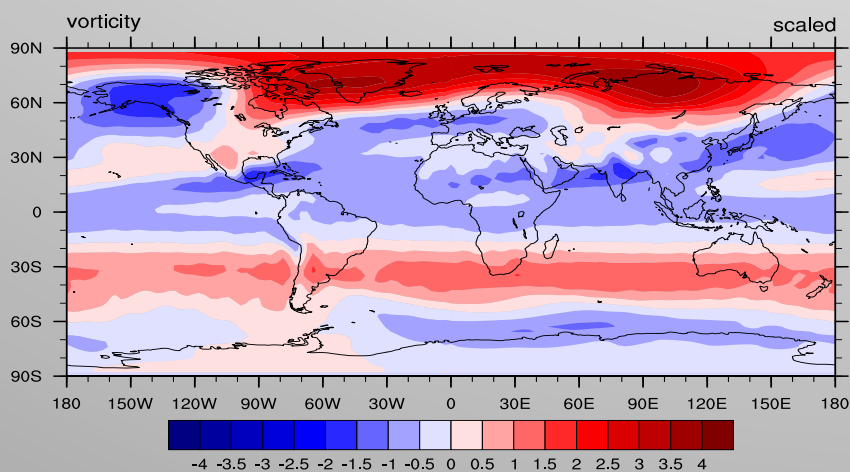
- **Climate applications**, in which specific case studies aimed at answering climate change questions will provide the science drivers for technology development;
- **Technology adaptation**, where applied research is performed to extend existing technologies to meet the needs of the science drivers; and
- **Software engineering and integration** is carried out to deliver working tools to the climate community.



# BER Supported Data Activities

## Parallel Analysis Tools and New Visualization Techniques for Ultra-Large Climate Data Sets

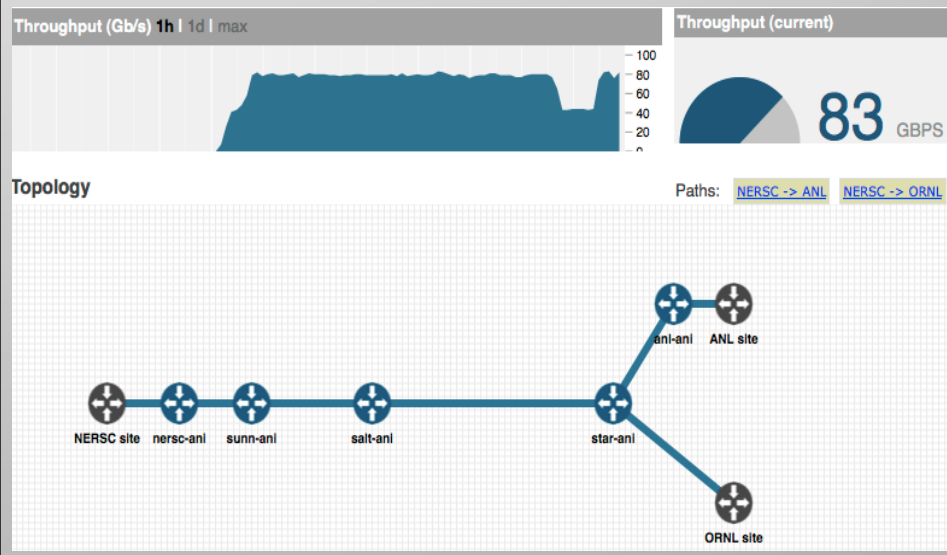
- Speed up current diagnostics (e.g the CESM-CAM atmospheric model diagnostics) with **task parallelism**
- Create a **data-parallel version** of the NCAR Command Language (NCL) analysis and visualization package.
- Build a new library: ParCAL – Parallel Climate Analysis Library.
- Use existing software technology (MOAB, PnetCDF, Intrepid).
- **ParNCL** (built with ParCAL) will allow users to run their NCL scripts unaltered.
- Explore news ways of doing 3D visualization of climate data



## Climate100: Scaling Climate Applications to 100 Gbps Network

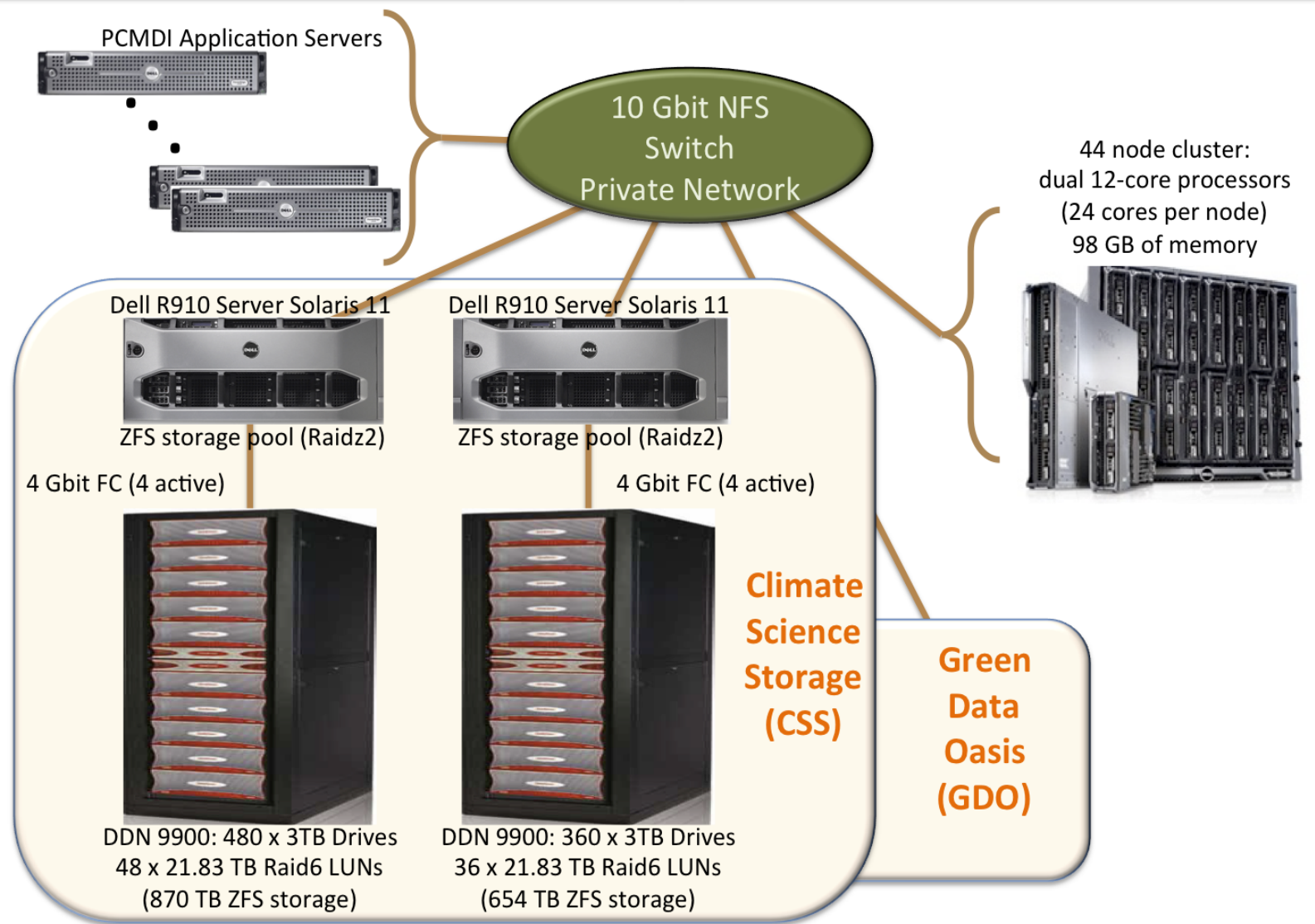
- Total size of data is **increasing**.
- There are **many files**, relatively small files, in climate data sets.
- It requires **efficient methods** to fully utilize the underlying network infrastructure with limited resources.
- **Averaging 83Gbps** on average over TCP connections.
- The 100Gbps network is in the testing phase. (Expected to be in production by the end of 2012.)

<https://sdm.lbl.gov/climate100>



# BER Funded Climate-science Storage System with Scalable Compute Clusters

ESnet 100 Gbps Internet



# BER “Climate K-Base”: Bring Together Large Volumes of Diverse Data to Generate New Insights

## 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 zettabytes) in-place for **big data analytics**

BER 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**

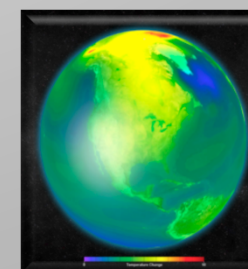
### Simulation

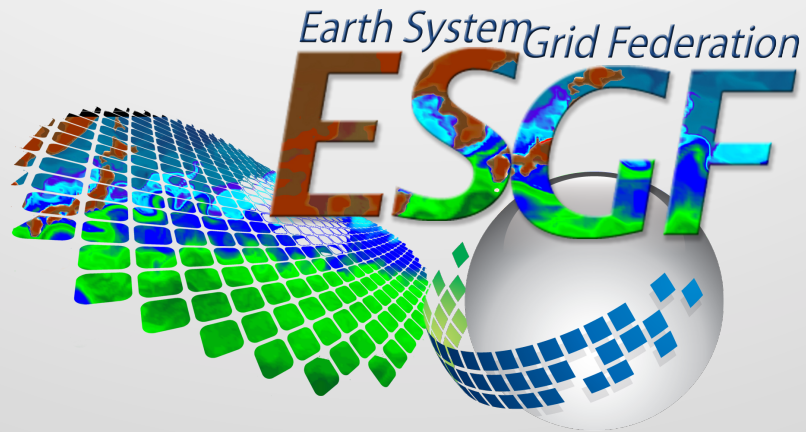


### Observation



### Reanalysis





# BACKUP SLIDES



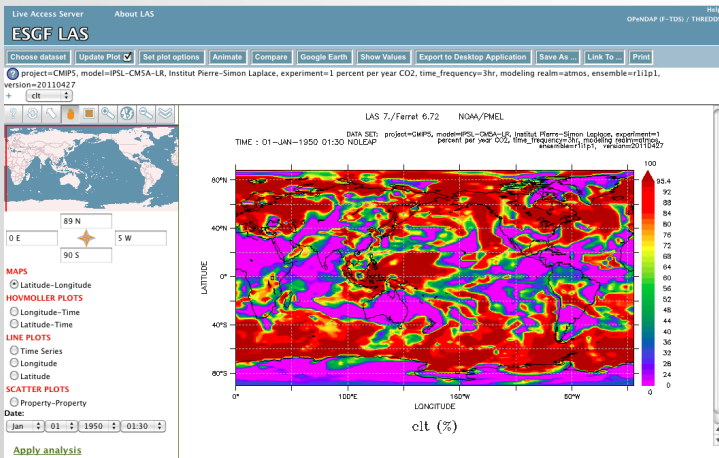
# ESGF Web Front-End

<http://pcmdi9.llnl.gov>

The screenshot shows the ESGF Portal homepage. At the top, there are logos for ESGF (Earth System Grid Federation) and PCMDI. Below the logos is a navigation bar with links for Home, Search, Tools, and Login. A large satellite-style map of the world is featured prominently. Below the map, a green banner reads "Welcome to this ESGF P2P Node". A red text box contains a welcome message for the new CMIP5 distributed archive. The main content area is divided into three columns: "Quick Search" with a keyword input field and a search button; "About esgf-pcmdi-9" with a paragraph describing the PCMDI mission; and "Resources" with a "Quick Links" section containing links like "Create Account", "MyProxyLogon", and "Expert Search (XML)". A "Peer Nodes" section lists various participating institutions with their respective flags. At the bottom, there is a footer with user information and links to privacy policy and contact.

The screenshot shows the ESGF Portal search results page. The top navigation bar is identical to the homepage. The main content area features a search bar with a "Search" button. Below the search bar, there are "Current Selections" (showing "No search criteria selected") and "Search Categories" with a list of project names and their counts: CCSM (2793), CMIP5 (47748), CORDEX (7), CSSEF (4), GeoMIP (263), LUCID (124), NARCCAP (109), PCM (489), PMIP3 (30), TAMIP (1152), TEST (15), cloud-cryo (10), cordex (57), euclipse (1), and geomip (23). There are also sections for "Institute", "Model", "Instrument", "Experiment Family", "Experiment", "Time Frequency", "Product", "Realm", "Variable", "Variable Long Name", "MIP Table", "CF Standard Name", and "Ensemble". A "Data Cart" section is visible at the bottom right. The footer contains user information and links to privacy policy and contact.

# ESGF Web Front-End



CIM Viewer v0.7.1 - CMIP5 Experiment - 1pctCO2

Model Experiment

CMIP5 Experiment - 1pctCO2

Overview Requirements CIM Info

**Short Name** 1pctCO2  
**Long Name** 1 percent per year CO2  
**Description** Idealized 1pct per year increase in atmospheric CO2 to quadrupling.  
**Rationale** Diagnostic experiment for understanding the long-term simulations. Evaluate model response without complications of aerosols, land-use change etc.

Documents : 2 Current Document : CMIP5 Experiment - 1pctCO2

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**ESGF** Earth System Grid Federation

Home Search Tools Account Logout

Current Selections

- remove all
- (x) project:CMIP5
- (x) model:GFDL-ESM2G
- (x) experiment:1pctCO2
- (x) time\_frequency:mon
- (x) variable:cit

Search

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

Search All Sites  Show All Replicas  Show All Versions

< 1 > displaying 1 to 2 of 2 search results Add All to Datacart Remove All from Datacart

Display 10 files per page

Search Categories

- Project
- CMIP5 (2)
- Institute
- NOAA GFDL (2)
- Model
- GFDL-ESM2G (2)
- Instrument
- Experiment Family
- Experiment
- 1pctCO2 (2)
- Time Frequency
- mon (2)
- Product
- output1 (2)
- Realm
- atmos (2)
- Variable
- cit (2)
- Variable Long Name
- MIP Table
- Amon (2)
- CF Standard Name
- Ensemble
- r11p1 (1)
- r11p2 (1)

Results Data Cart

project=CMIP5,model=GFDL-ESM2G,Geophysical Fluid Dynamics Laboratory,experiment=1 percent per year CO2,time\_frequency=mon,modeling\_realm=atmos,ensemble=r11p1,version=20120412  
 Data Node: esgdata.gfdl.noaa.gov  
 Version: 20120412  
 Description: NOAA GFDL Geophysical Fluid Dynamics Laboratory CMIP5 AR5  
 Further options: Add To Cart Visualize and Analyze Model Metadata

project=CMIP5,model=GFDL-ESM2G,Geophysical Fluid Dynamics Laboratory,experiment=1 percent per year CO2,time\_frequency=mon,modeling\_realm=atmos,ensemble=r11p2,version=20120412  
 Data Node: esgdata.gfdl.noaa.gov  
 Version: 20120412  
 Description: NOAA GFDL Geophysical Fluid Dynamics Laboratory CMIP5 AR5  
 Further options: Add To Cart Visualize and Analyze Model Metadata

download/analysis/information

User: https://pcmdi9.llnl.gov/esgf-dp/openid/williams13 | ESGF P2P Version 1.3.2-55-g337b708-devel | Privacy Policy & Legal Notice | Contact ESGF

**ESGF** Earth System Grid Federation

Home Search Tools Account Logout

Current Selections

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- (x) project:CMIP5
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Search

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Search All Sites  Show All Replicas  Show All Versions

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Display 10 files per page

Search Categories

- Project
- Institute
- Model
- Instrument
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- Experiment
- Time Frequency
- Product
- Realm
- Variable
- Variable Long Name
- MIP Table
- CF Standard Name
- Ensemble

Results Data Cart

Show all  Filter over search constraints Show initial 10 files Remove All WGET All Selected

cmip5.output1.NOAA-GFDL-GFDL-ESM2G.1pctCO2.mon.atmos.Amon.r11p1.v20120412esgdata.gfdl.noaa.gov (Total Number of Files: 2360) Expand | WGET | Globus Online | Remove

cmip5.output1.NOAA-GFDL-GFDL-ESM2G.1pctCO2.mon.atmos.Amon.r11p2.v20120412esgdata.gfdl.noaa.gov (Total Number of Files: 3540) Expand | WGET | Globus Online | Remove

Download apps

User: https://pcmdi9.llnl.gov/esgf-dp/openid/williams13 | ESGF P2P Version 1.3.2-55-g337b708-devel | Privacy Policy & Legal Notice | Contact ESGF



# ESGF Web Front-End

**Geospatial Search**

Search Type:  Encloses  Overlaps

Enter address:

Clear Markers

[1] lat 43.38, lon -87.98  
[2] lat 34.59, lon -104.76

Define Area:  Square  Circle

**Geospatial Search**

**ESGF Dashboard**

Account Dashboard Admin Logout

Visible Alias Host Name Last 5 minutes a... Last hour availa... Last day availabi... Last week availa... Last month availa...

**ESGF LAS**

Choose dataset Update Plot Set plot options Animate Compare Google Earth Show Values Export to Desktop Application Save As Link To Print

obs4MIPs NASA-GSFC MODIS L3 Monthly Data

ct

TIME : 16-MAR-2000 12:00

DATA SET: obs4MIPs NASA-GSFC MODIS L3 Monthly Data

99.99

80°N

40°N

0°

40°S

80°S

50°E 150°E 110°W 10°W

ct (%)

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**ESGF Desktop Environment**

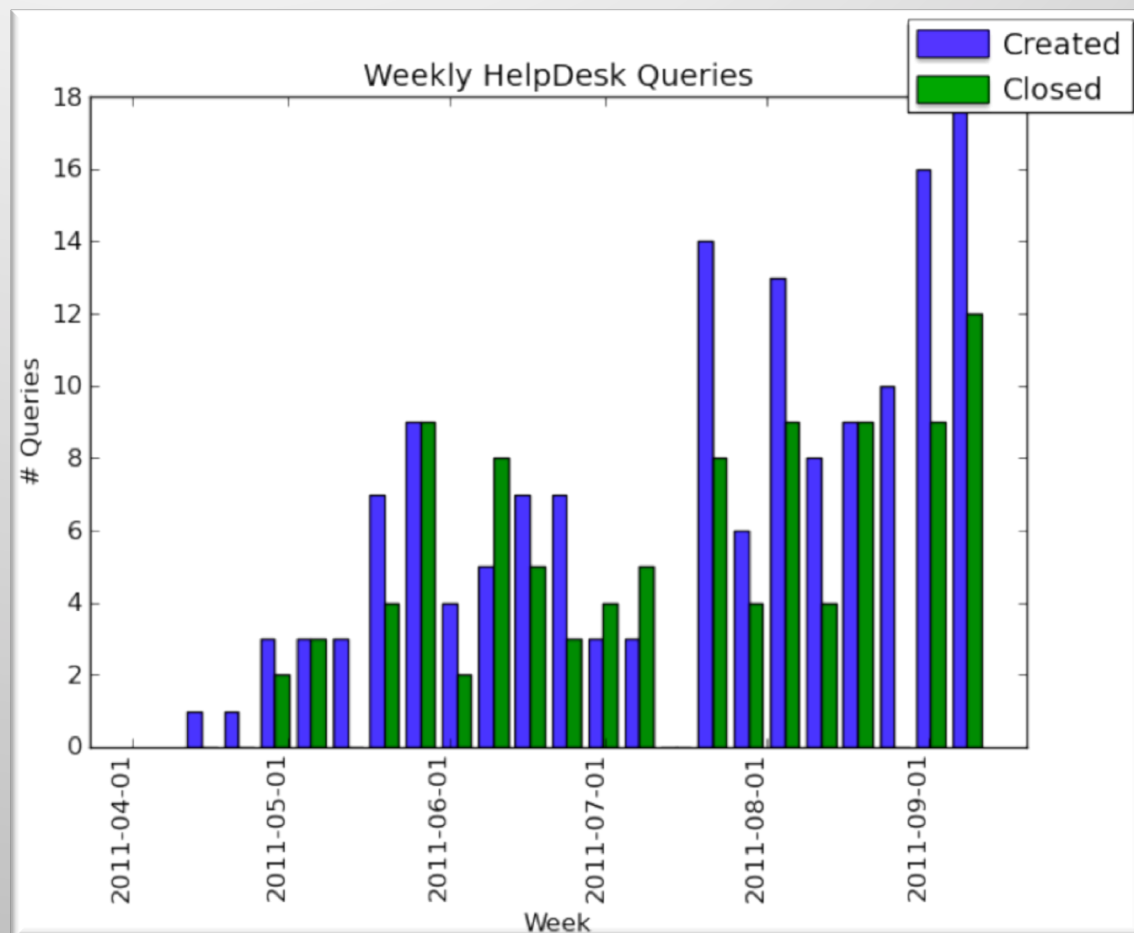
Global Online Setup for Use in the Earth System Grid Federation

Using Global Online in the Earth System Grid Federation

Setup Global Online Account

# ESGF Help Desk Weekly Traffic

- About half of these queries come directly to [cmip5-helpdesk@stfc.ac.uk](mailto:cmip5-helpdesk@stfc.ac.uk) and the other half to the esg-support mailing list [esgf-user@lists.llnl.gov](mailto:esgf-user@lists.llnl.gov)
- Questions that are resolved are placed on the **ESGF FAQ** list
- **Scientists** at PCMDI/LLNL, BADC, and DKRZ are charged with addressing CMIP5 data questions
- **Technical staff** at LLNL, BADC, DKRZ, NCAR, and JPL are charged with addressing ESGF system questions



# Publication Web Application

- Web based submission** of citations to database
- Capture tags** to enable contextual search, the tags include
  - Keywords
  - Funding
  - Data used (model, experiment, variable, time frequency)
- Submission page differentiate with the **journal type**
  - The types are: journal, book, proceeding, presentation, technical report
- Editable database** entry
  - Enable search of all submitted publications, update, change or add keywords
- Admin page for **editing** or removing publications

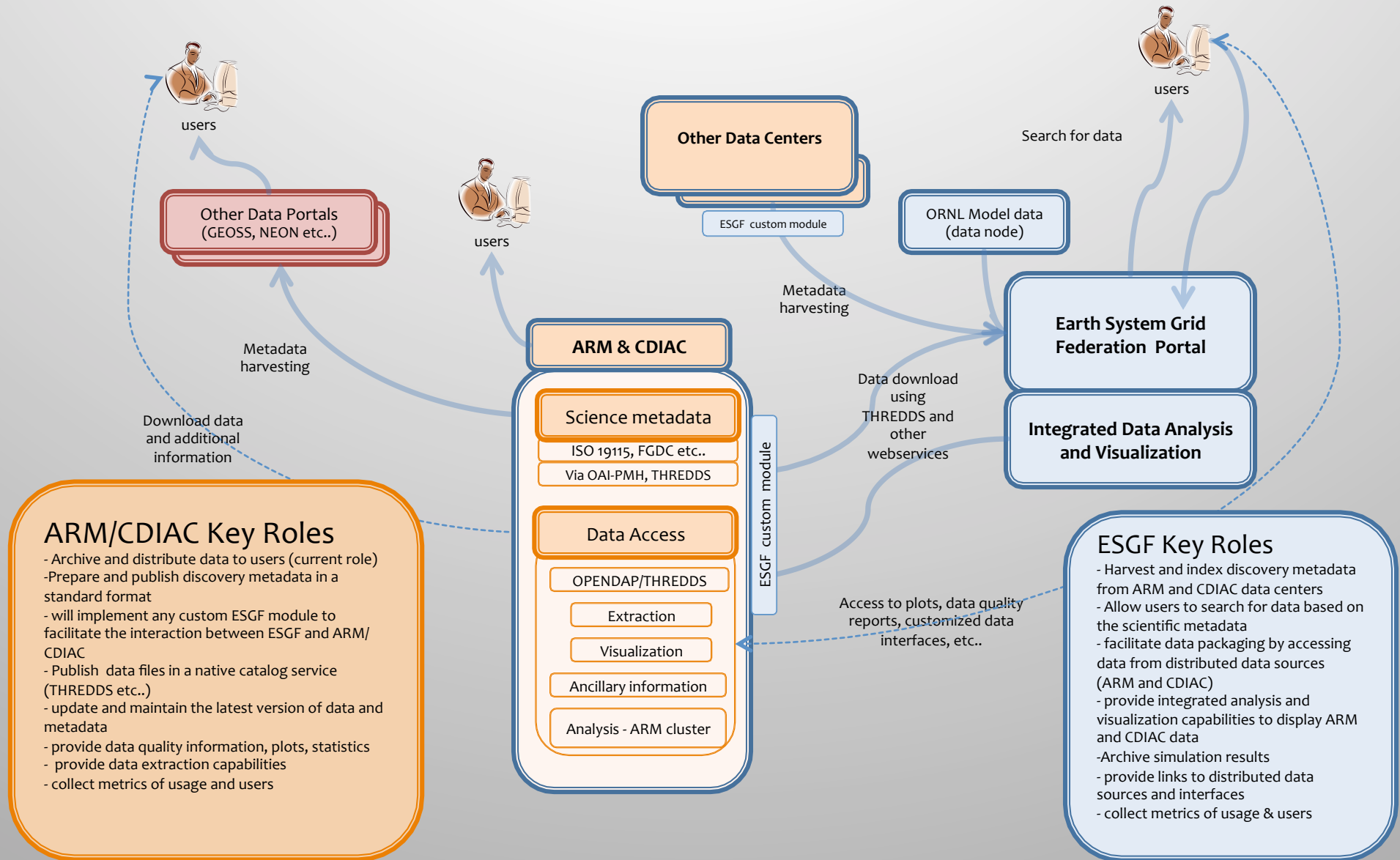
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Last Name	First Name	Middle Initial	Delete	Order
Andrews	Timothy		X	1
Gregory	Jonathan	M	X	2
Webb	Mark	J	X	3
Taylor	Karl	E	X	4

Edit	Author	Article Title
Edit	Taylor Karl, Stouffer Ronald, Meehl Gerald,	An overview of CMIP5 and the experiment design
Edit	Andrews Timothy, Gregory Jonathan, Webb Mark, Taylor Karl,	Forcing, feedbacks and climate sensitivity in a new models

List

# ESGF – ARM and CDIAC Publication Architecture



# Ultra-large Climate Data Analysis and Visualization

## UV-CDAT Displaying CDAT, DV3D, ParaView, VisIt, and R

<http://uvcdat.llnl.gov>

The screenshot displays the VisIt software interface with several panels and windows:

- Projects Panel:** Shows a project named 'Project 1\*' with a 'Sheet 1' containing several 'untitled\*' files associated with different axes (A1, B1, B2, C1, C2, A2).
- Spreadsheet Panel:** Displays a spreadsheet with columns A, B, and C. Column A shows a 2D heatmap of data with axes 'lat (degrees\_north)' and 'lon (degrees\_east)'. Column B shows a 2D heatmap with a color scale. Column C shows a 3D visualization of a globe.
- Variables Panel:** Lists various variables such as 'pr (7300, 64, 128)', 'v (2, 80, 97)', 'u (2, 80, 97)', 'clt (120, 46, 72)', 'ta (11, 17, 73, 144)', 'precip (217, 288)', 'temp (217, 288)', and 'TEMP (42, 2400, 3600)'. It also includes a 'Calculator' window with a complex script for parameter changes and aliases.
- Plots and Analyses Panel:** Lists various plot types including 'DV3D', 'PVClimate', 'PV Climate Plot', 'VCS', 'VisIt', 'Contour Plot', 'Extreme Value Analysis Plot', and 'Pseudocolor Plot'.
- Visualizations:**
  - VisIt:** A 2D heatmap visualization of climate data.
  - CDAT:** A 2D heatmap visualization of climate data with a color scale.
  - DV3D:** A 3D visualization of a globe showing climate data.
  - ParaView:** A 3D visualization of a globe showing climate data.
  - CDAT:** A 2D heatmap visualization of climate data with a color scale.
  - R:** A 2D heatmap visualization of climate data with a color scale.

# Layered Data Distributed Open Architecture

