Operational Support of Multi-Model Data Sets

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Lawrence Livermore National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

Operations and Support Activities

CMIP archive infrastructure support

Tasks	Work Description	Effort (FTE's)				
		Software Dev.		Operations		
		Higher Priority	Lower Priority	Higher Priority	Lower Priority	In PCMDI FY14 Budget
Data Preparation	CF metadata convention support, operational website support, CMOR					0.35
Data Handling	data transport, quality control, statistical quality control, publication, replication, network, hardware, documentation, data access metrics		3.7	0.75	1.5	0.4
Help and Support	Modeling group support, support for user community		.25		0.55	
Administration & Modernization	Multi-model operational outreach, modernization, operational coordination		0.1		1.3	
Total			1.95	0.75	3.35	0.75

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Operations and Support Activities

ESGF software system support

Tasks	Work Description	Software Dev.		Operations		
		Higher Priority	Lower Priority	Higher Priority	Lower Priority	In AIMS FY14 Budget
Security *	Support configuration, security integration, data transfer tools (WGET, Globus Online, OPeNDAP, GridFTP, etc.)			0.2		
Deep Storage Access and Transfers *	Manage multiple concurrent transfers, securely replicating data via disparate networks	0.1		0.3	0.1	
LLNL	leadership, data provider, publisher, replication, UI, QC, software stack, installation, product server, certificates		3.1	0.9	2.3	1.0
User Interface *	support for ESGF web environment: registration, virtual organization, browsing and searching	0.3	0.2	0.1	0.1	
Product Service	Support for ESGF analysis and product services, dependence on the publication component		0.1	0.1	0.1	
Total		0.4	3.4	1.6	2.6	1.0

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Outline

Background and History

Operations and Support

Usage Statistics

Lessons Learned and Future Operational Support

Background, History, and the Relationship of CMIP and ESG

Background and History

International context of climate research: Coupled Model Intercomparison Projects (CMIPs)

- The Intergovernmental Panel on Climate Change (IPCC) prepares an assessment report about climate science approximately every 6 years

- This climate modeling research requires enormous scientific and computational resources
    - Involves over two dozen modeling research groups worldwide; and
    - Encourages cooperative community international research activities

- The World Climate Research Program (WCRP) serves as the primary coordinating body for this research activity.
    - The WCRP's Working Group on Coupled Modelling (WGCM) relies on the Lawrence Livermore National Laboratory (LLNL) to support these activities by coordinating and maintaining the distributed petabyte data archive.

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Background and History

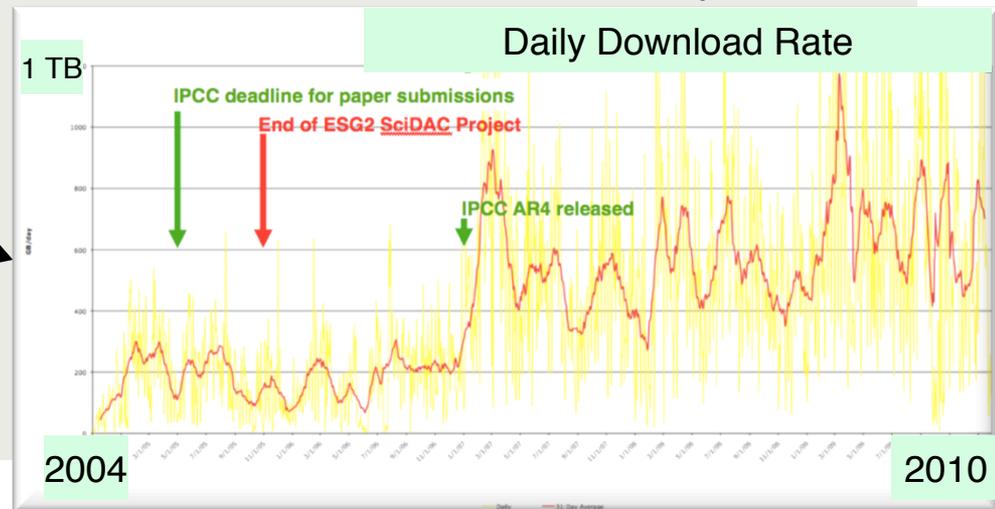## Coupled Model Intercomparison Project (CMIP) data history

- CMIP = Coupled Model Intercomparison Project
  - Phase 1: Idealized simulations of present-day climate (early 90s) (~1 Gigabyte (GB))
  - Phase 2: Idealized simulations of future climate changes (late 90s) (~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 (2010 – present) (3.5 Petabytes (PB): CMIP5/CMIP3 = 100):
  - 3 suites of experiments ("Near-Term" decadal prediction, "Long-Term century & longer), and "Atmosphere-Only")
  - 25+ modeling centers in 21 countries
  - 60+ models
  - Total data, ~3.5 PB; Replica 1.2 – 2 PB; Derived data ~1 PB
  - Driver for scale of data, global distribution
  - Timeline fixed by IPCC (September 2013)
- LLNL organizes, manages and distributes the CMIP database
- CMIP6 (2016) (350 PB – 3 EB ?)

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Background and History

Coupled Model Intercomparison Project, phase 3 (CMIP3) impact

- More than 600 journal articles published
- Nearly all the new, model-based conclusions in the IPCC's AR4
  - ~75% of the more than 100 figures in 3 major chapters of the report are based on CMIP3 results.
  - 4 of the 7 figures appearing in the "Summary for Policy Makers" are based on CMIP3
  - The multi-model perspective provided the foundation for many of the IPCC conclusions.

Interest in LLNL's CMIP3 model output archive continues unabated

(~600 GB/day downloaded)

Daily Download Rate

1 TB

IPCC deadline for paper submissions
End of ESG2 SciDAC Project
IPCC AR4 released

2004   2010

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Earth System Grid (ESG): ESG-I, ESG-II, ESG-CET

- **ESG-I** funded under DOE's Next Generation Internet (NGI), *"address the emerging challenge of climate data"*, 1999 – 2001 (ANL, LANL, LBNL, LLNL, NCAR, USC/ISI)
  - Data movement and replication; Prototype climate "data browser"; Hottest Infrastructure" Award at SC'2000.

- **ESG-II** funded under DOE's Scientific Discovery through Advanced Computing (SciDAC), *"turning climate data sets into community resources"*, 2001-2006 (ORNL addition)
  - Web-based portal, metadata, access to archival storage, security, operational services, 2004 first operational portal CCSM (NCAR), IPCC CMIP3/AR4 (LLNL); 200 TB of data, 4,000 users, 130 TB served.

- **ESG-CET** funded under DOE's Scientific Discovery through Advanced Computing II (SciDAC-2), *"providing climate researchers worldwide with access to: data, information, models, analysis tools, and computational resources required to make sense of enormous climate simulation and observational data sets"*, 2006 – 2011 (PMEL addition)
  - 2010 Awarded by American Meteorological Society (AMS) for leadership which led to a new era in climate system analysis and understanding.
  - CMIP3, CMIP5, CCSM, POP, NARCCAP, C-LAMP, AIRS, MLS, Cloudsat, etc.
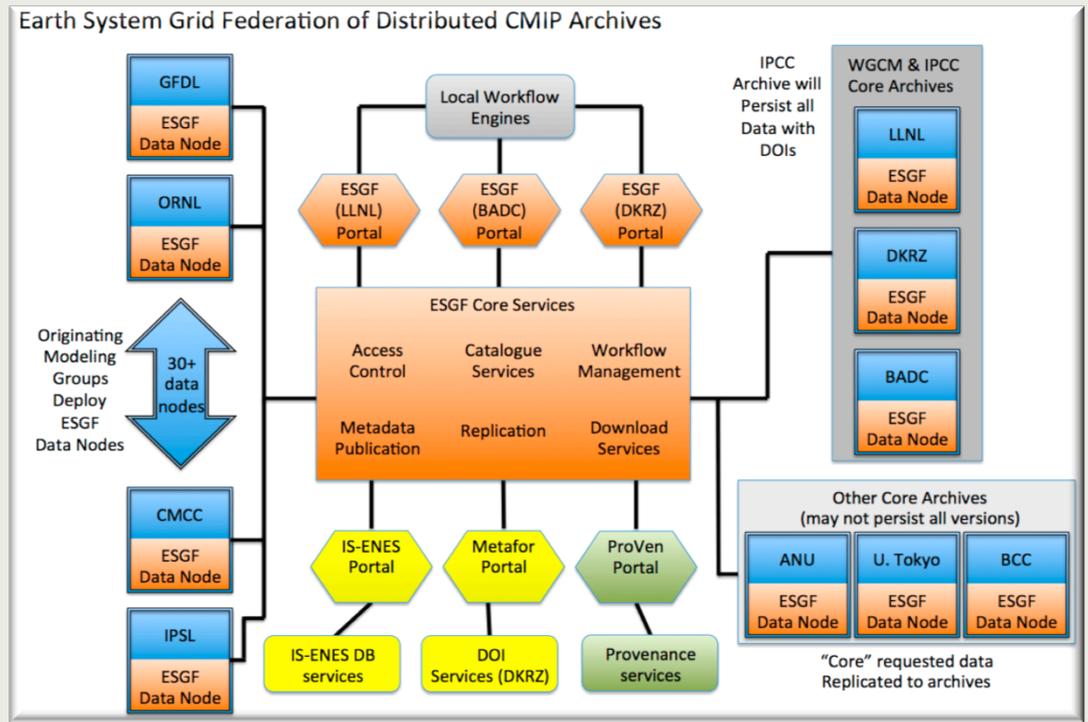 - 22,000 users, 500-800 users active per month, over 1 PB served

Background and History

Earth System Grid Federation (ESGF): 2011 - present

- ESGF multiple funding sources, "*an open consortium of institutions, laboratories and centers around the world that are dedicated to supporting research of climate change, and its environmental and societal impact*" (2011 – present)

- Historically originated from Earth System Grid project, expanded beyond its constituency and mission to include many other partners in U.S., Europe, Asia, and Australia

- Integration with many external projects: ESC, Metafor, GIP, etc.

- U.S. funding sources: DOE, NASA, NOAA, NSF

- U.S. Participants: PMEL/NOAA, LLNL/DOE, LBNL/DOE, NCAR/NSF, LANL/DOE, ORNL/DOE, ANL/DOE, JPL/NASA, GFDL/NOAA, ESRL/NOAA

- Europe: IS-ENES, BADC, UK-MetOffice, DKRZ, MPIM, IPSL, LSCE

- Asia: Univ. of Tokyo, Japanese Centre for Global Environmental Research, Jamstec, Korea Meteorological Administration

- Australia: ANU, Australian Research Collaboration Service, Government Department of Climate Change, Victorian Partnership for Advanced Computing, Australian Environment and Resource Management

- U.S. Universities: ISI/USC, Purdue University, University of Michigan, UC Davis, …

- ... and more …

ESGF — Earth System Grid Federation

Background and History

Coupled Model Intercomparison Project, phase 5 (CMIP5)

- Working with over 30 key national and international partners to establish a federated data archival and retrieval system

- LLNL is in cooperation with the IPCC Data Distribution Centre (DDC) for supporting access of impacts researchers to impacts-related variables coming out of CMIP5 model runs


Earth System Grid Federation of Distributed CMIP Archives

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Operations and Support of CMIP

http://esgf.llnl.gov

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

Operations and Support
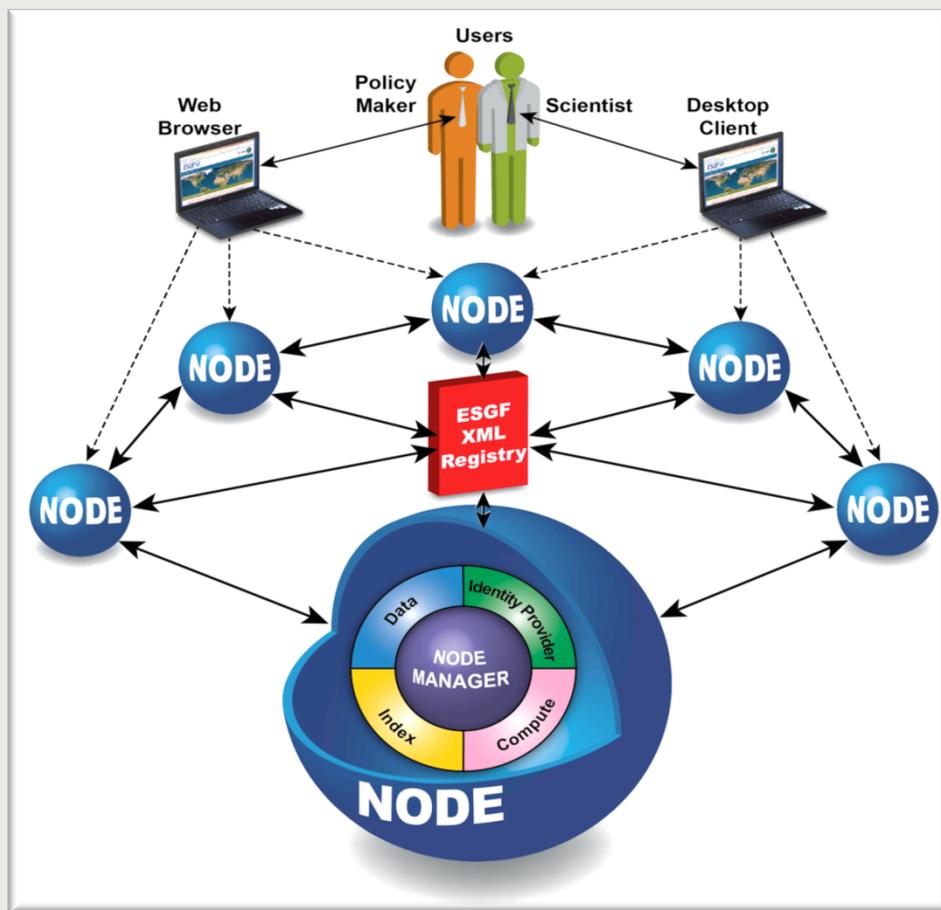
CMIP5 data processing stream

- **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
- 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
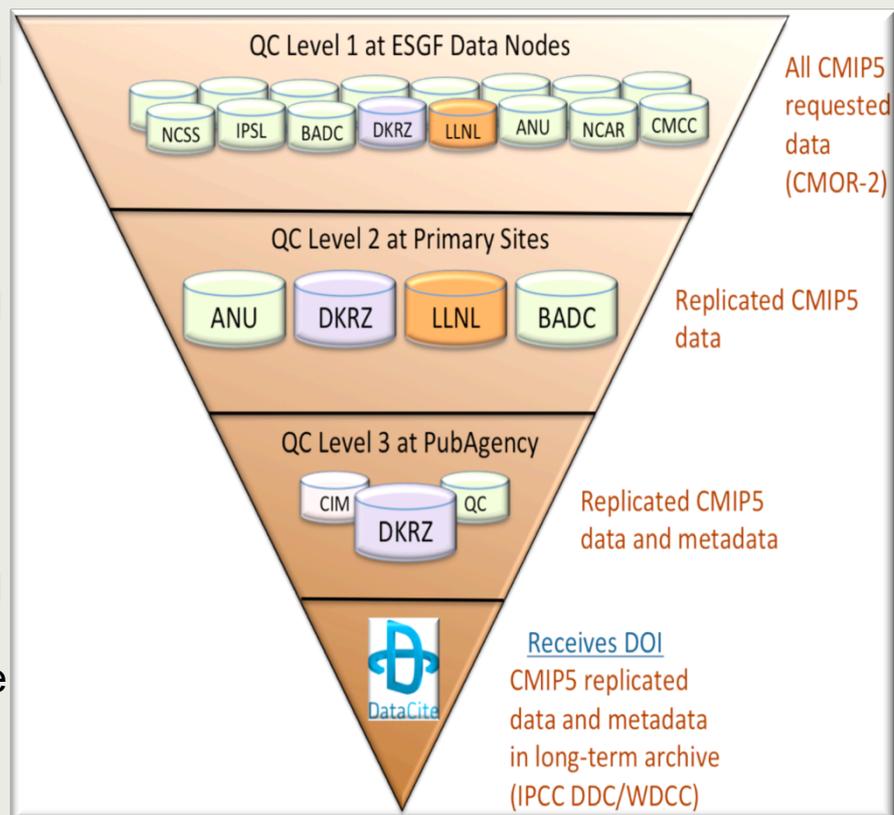
Operations and Support

ESGF software system integrates data federation services (i.e., data services)

- NetCDF Climate and Forecast (CF) Metadata Convention
  - (LibCF)
  - Mosaic
- Climate Model Output Rewriter 2 (CMOR-2)
- Regridders: 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
  UV-CDAT, Live Access Server
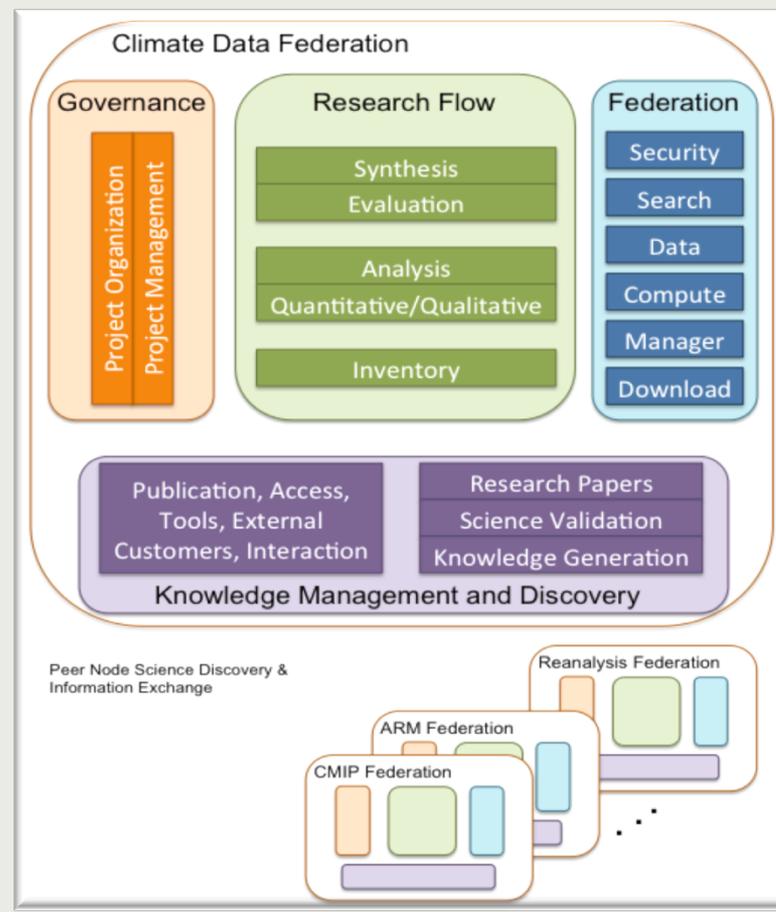
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Scaling climate applications to take advantage of increasing hardware and network bandwidth

- (1) Users communicate with ESGF front-end servers on the LLNL enterprise network via HTTP
- (2) Large data sets are made available to users via GridFTP from the CSS Data Transfer Nodes (DTNs) located in the LLNL Science DMZ
- (3) ESGF may perform analysis of raw data if requested by users through the front-end servers

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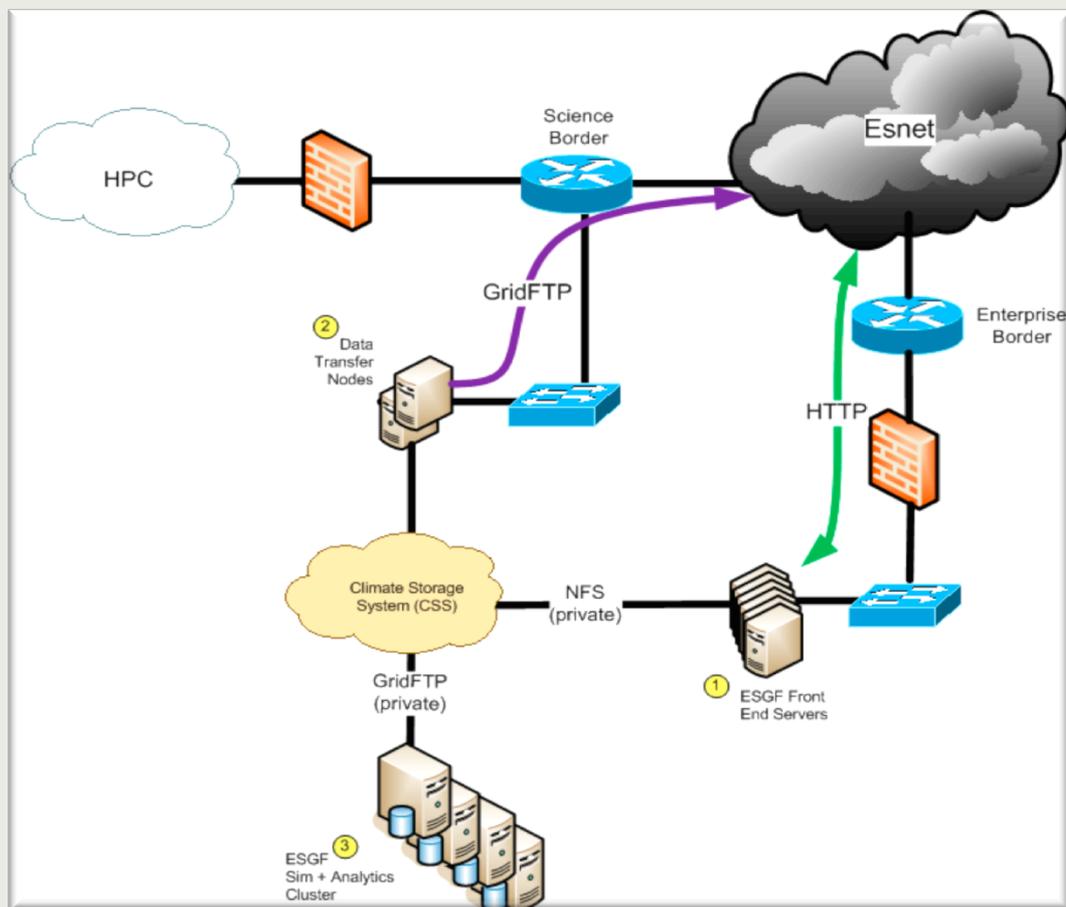
Summary of technologies most useful to ESGF

- Peer-to-peer
- Search Services
- Security Services
- User interface development
- Data Publisher
- Live Access Server (compute node)
- Data transfer (WGET, BDM, GridFTP, Globus Online, BeStMan)
- DAP Services (THREDDS Data Servers[TDS], OPeNDAP)
- Really Simple Syndication (RSS) feed
- UV-CDAT (client analysis tool access)
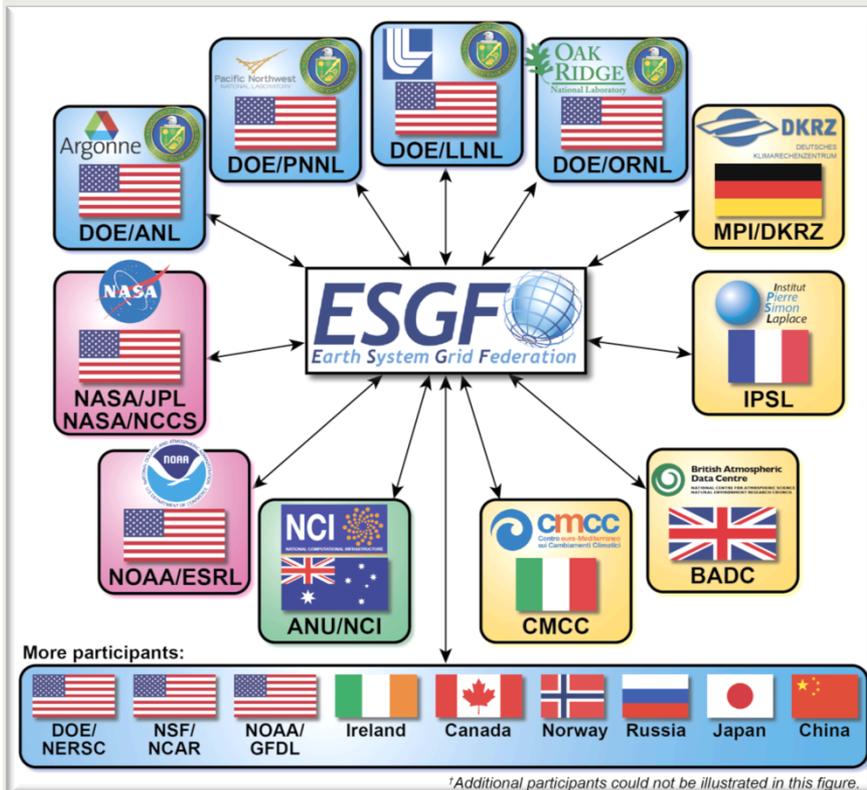- Dashboard (system monitor service)
- Replication and versioning
- Installation Script

ESGF Node

Software Stack

Operations and Support
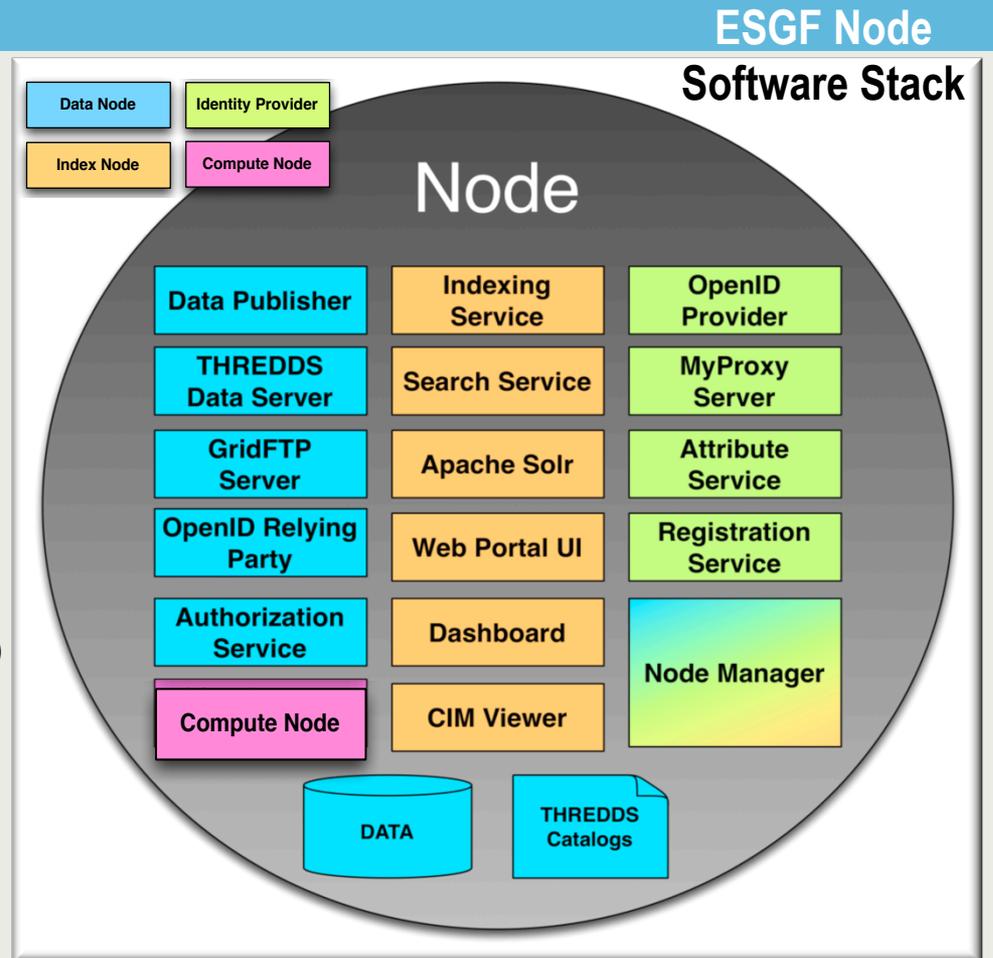
ESGF climate data holdings and growing

- Phases 3 and 5 of the Coupled Model Intercomparison Project (CMIP3 and CMIP5)
- Coordiated 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)
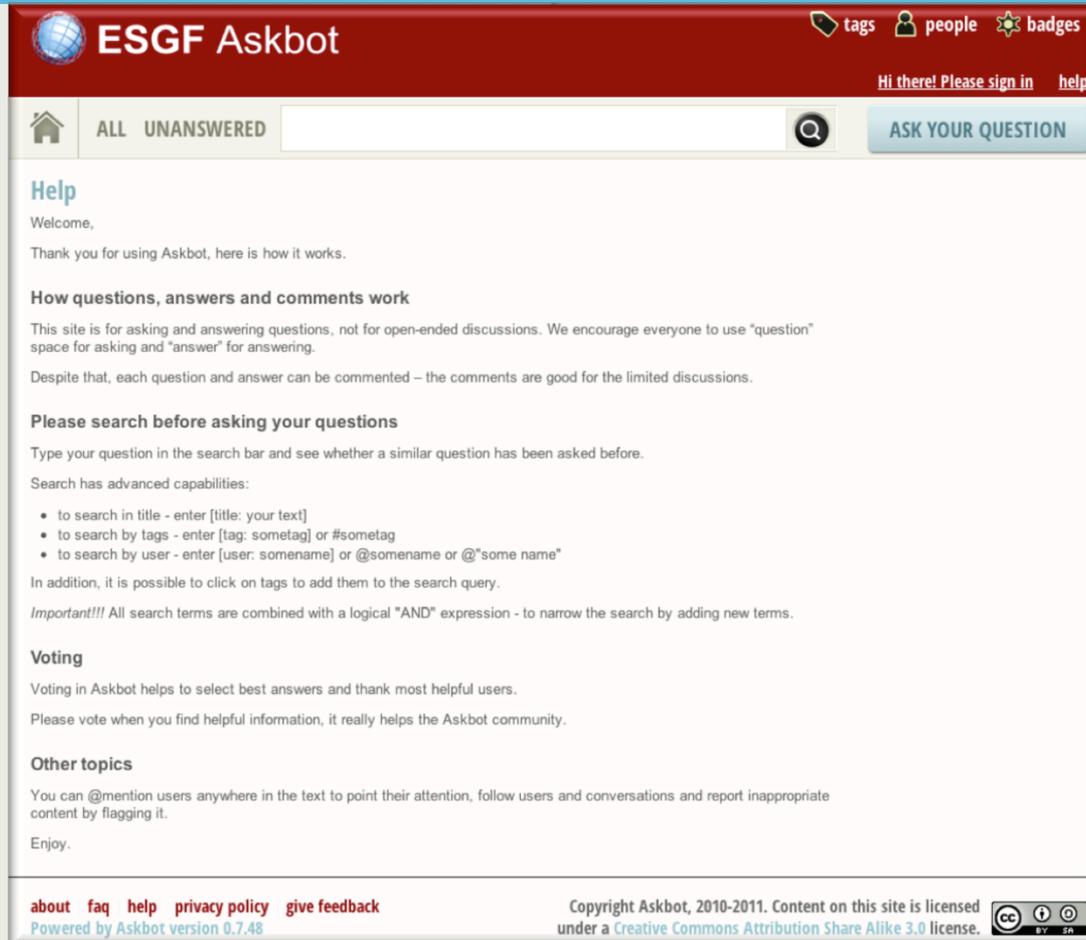- Atmospheric Infrared Sounder (AIS)
- Microwave Limb Sounder (MLS)

Current CMIP federated portals (e.g., LLNL's portal address: pcmdi9.llnl.gov)

Operations and Support
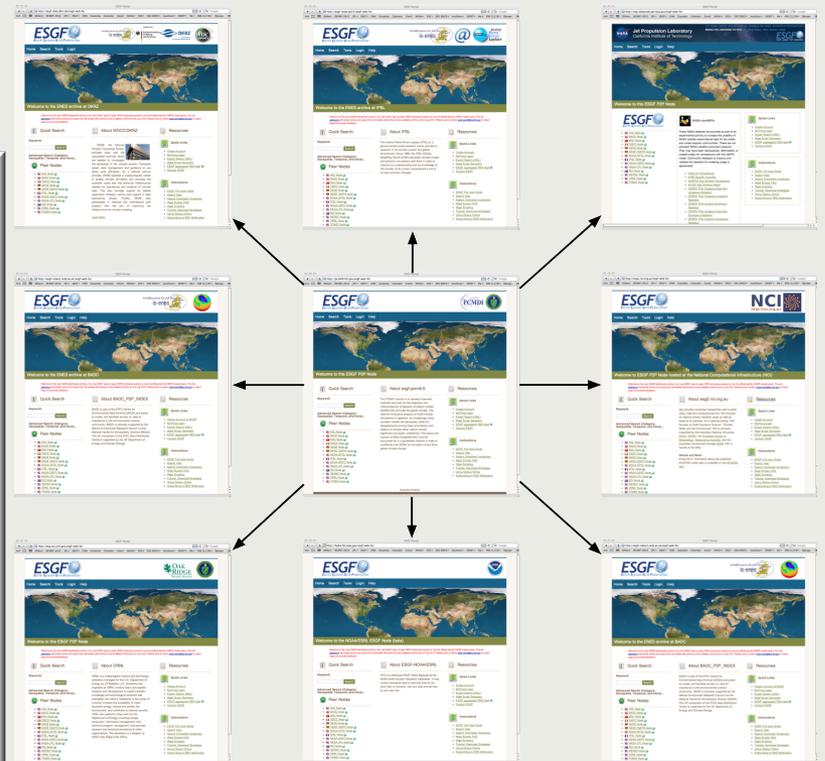
ESGF nodes deployment (map)

Operations and Support

Help desk: ESGF Askbot

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

ESGF Data Archive

ParaView Cluster
parallel processing

UV-CDAT/ESGF
UI access
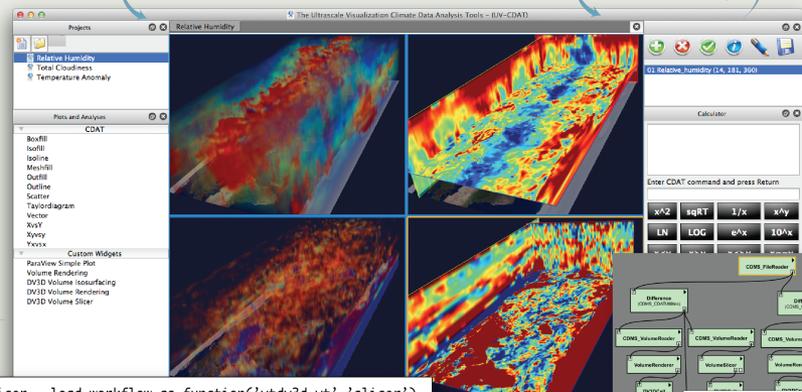
```
vslicer = load_workflow_as_function('vtdv3d.vt','slicer')
vslicer(variable='Relative_humidity')
vrender = load_workflow_as_function('vtdv3d.vt','vr')
vrender(variable='Relative_humidity')
```

Script

Workflow

Provenan...

http://uv-cdat.llnl.gov
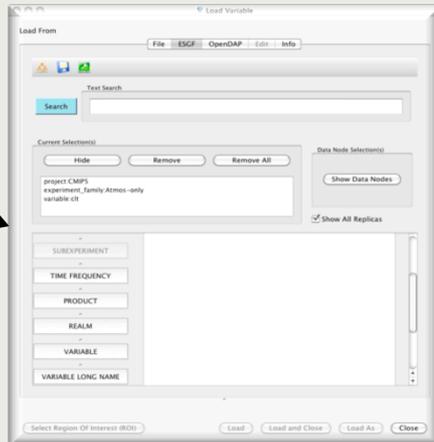
ESGF Use Statistics for CMIP5 Data Sets

Usage Statistics

Cumulative CMIP5 downloaded data from LLNL (TBs)

Cumulative CMIP5 number of distinct downloaded files
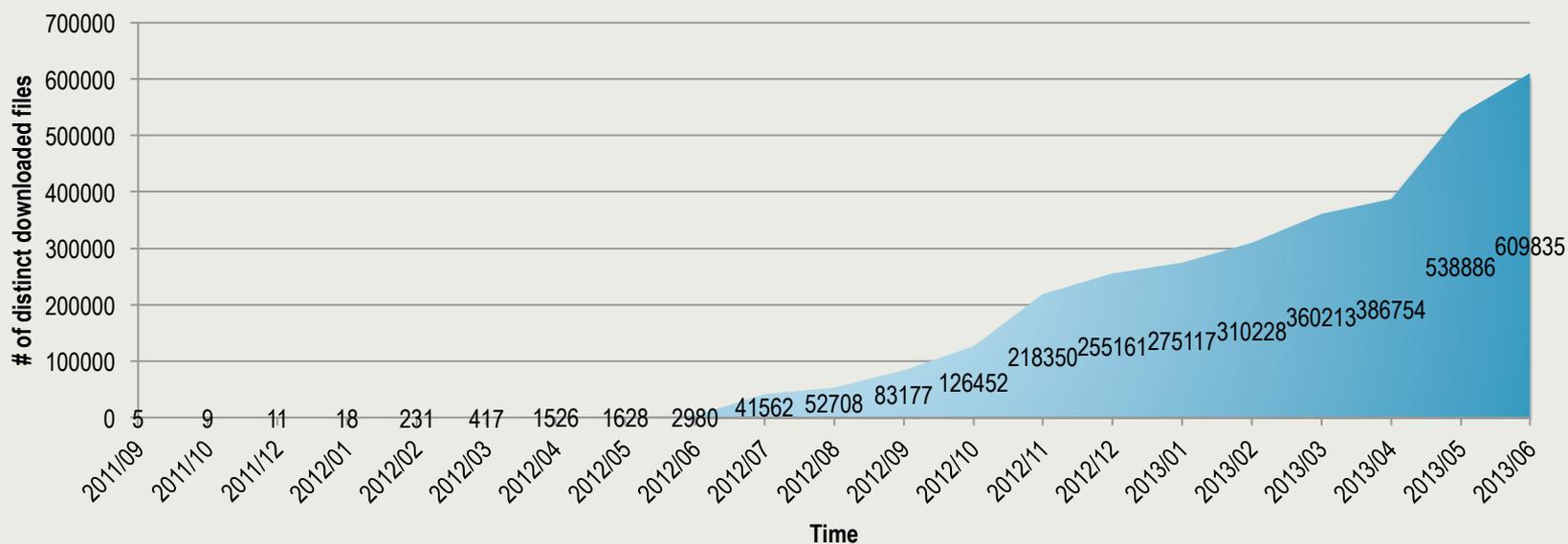
Usage Statistics

Geo-distribution related to the users that have downloaded CMIP5 data sets from pcmdi9 (~2000 IPs in total)
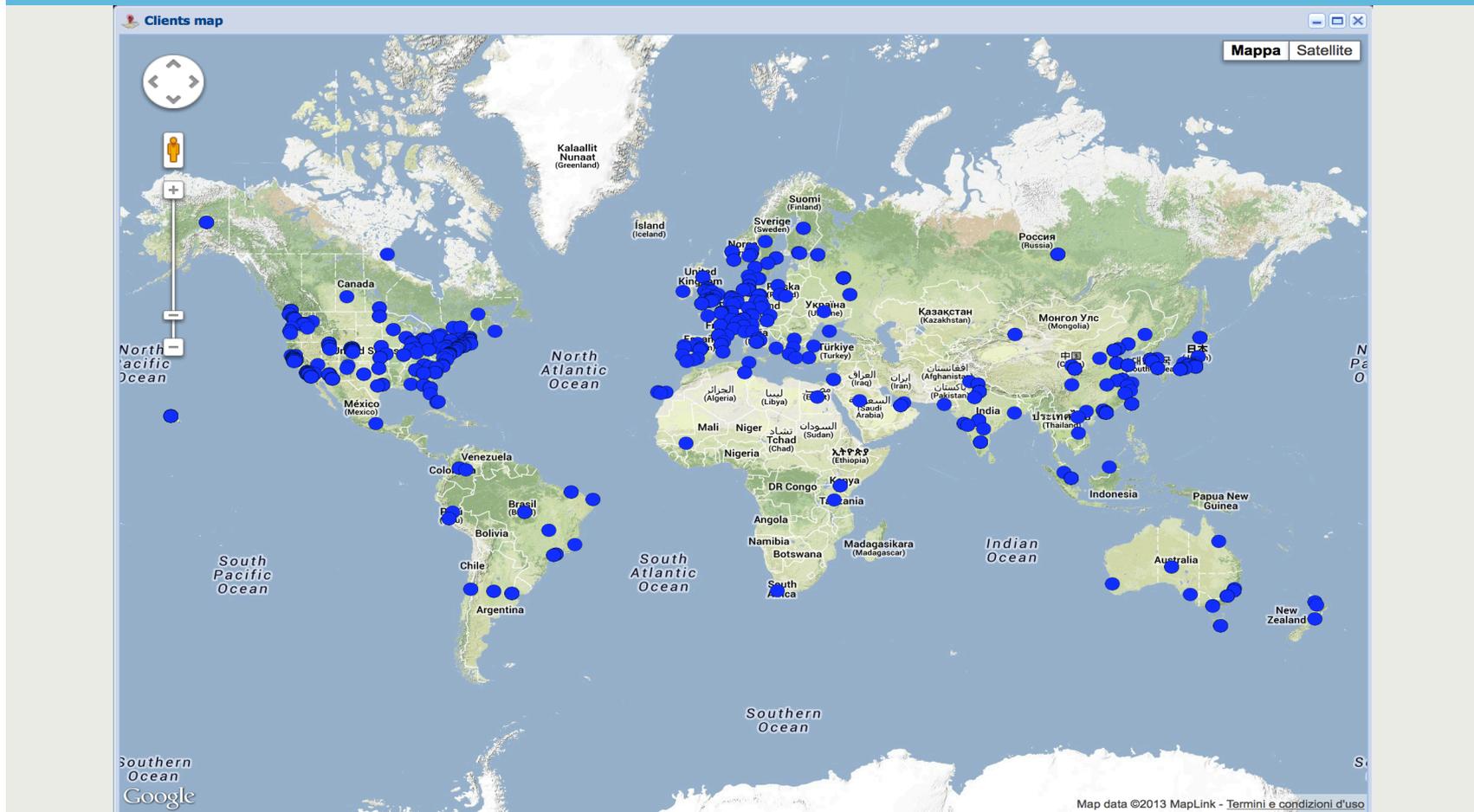
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User distribution percentage by country (~2000 distinct IPs in total)

Client distribution (%) by continents (2000 distinct IPs in total)

Africa 0.61%
No-resolv 1.56%
Australia 2.00%
Asia 27.89%
America 47.44%
Europe 20.50%

Legend:
- America
- Europe
- Asia
- Australia
- Africa
- No-resolv

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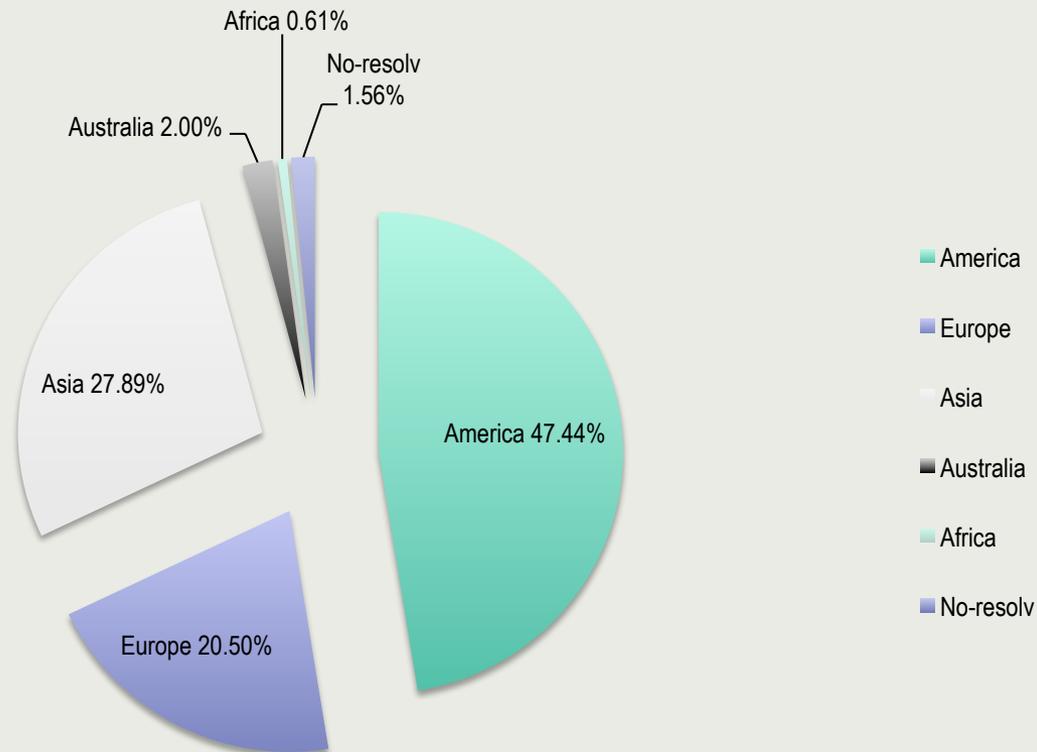
Usage Statistics

ESGF registered CMIP5 users distributed (table)

About 6000 on pcmdi9
(about 7200 esgf-prod)

Host Name	City	Registered Users
pcmdi9.llnl.gov	Livermore	5977
esgf-data.dkrz.de	Hamburg	769
esg-datanode.jpl.nasa.gov	Sylmar	128
dev.esg.anl.gov	Lemont	62
esgf-node.ipsl.fr	Paris	58
esgf-index1.ceda.ac.uk	Appleton	30
esgf.nccs.nasa.gov	Huntsville	27
esgdata.gfdl.noaa.gov	Princeton	25
euclipse1.dkrz.de	Hamburg	20
adm07.cmcc.it	Salento	18
pcmdi11.llnl.gov	Livermore	17
esg.bnu.edu.cn	Beijing	14
esg01.nersc.gov	Berkeley	11
esg.ccs.ornl.gov	Oak Ridge	6
cmip5.bnu.edu.cn	Beijing	2
esg-dn1.nsc.liu.se	Linköping	2
wawona.ca.sandia.gov	Livermore	1
esgnode2.nci.org.au	Canberra	1
esgfvm3.llnl.gov	Livermore	1
esgf-data1.ceda.ac.uk	Appleton	1
vesg.ipsl.polytechnique.fr	Palaiseau	0
esg.lasg.ac.cn	Beijing	0
cmip3.dkrz.de	Hamburg	0
esgf-dev.dkrz.de	Hamburg	0
vesg.ipsl.fr	Paris	0
esgdata1.nccs.nasa.gov	Huntsville	0
bmbf-ipcc-ar5.dkrz.de	Hamburg	0

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Usage Statistics

Users distribution by identity provider

Pie chart with labels:
- 0.08%
- 0.08%
- 0.61%
- 0.23%
- 0.08%
- 0.08%
- 0.92%
- 0.15%
- 0.61%
- 0.54%
- 2.68%
- 1.07%
- 6.90%
- 0.08%
- 2.84%
- 14.18% — CMIP3
- 68.89% — CMIP5

Legend:
- euclipse1.dkrz.de
- esg-dn1.nsc.liu.se
- ceda.ac.uk
- dev.esg.anl.gov
- esg-datanode.jpl.nasa.gov
- esg-gateway.jpl.nasa.gov
- esg-vm-demo02.ccs.ornl.gov
- esg.ccs.ornl.gov
- esg.nci.org.au
- esg1-gw.pnl.gov
- esg2.nci.org.au
- esgf-data.dkrz.de
- esgf-node.ipsl.fr
- ipcc-ar5.dkrz.de
- pcmdi3.llnl.gov
- pcmdi9.llnl.gov
- www.earthsystemgrid.org

Lessons Learned and Future Operational Support

Future Operations and Support

Lessons learned

- ESGF infrastructure is under constant requirements to improve and adapt
- ESGF must continue to rely on careful integration of already proven technologies and applications that have been developed by teams over the course of many years (e.., Solr, TDS, UV-CDAT, HTTP, OPeNDAP, SSL,…)
- Promote participation and involvement by a large community of stakeholders, managers, and engineers, through an open source, meritocracy based system (not dissimilar to the principles promoted by the Apache Software Foundation, for example)
- Establish a governance model from the very beginning, in order to represent the interests of all stakeholders, prioritize requirements, and guide the overall system development
- Avoid single points-of-failure in the engineering workforce
- Large infrastructure like ESGF should consider scalability as one of its major requirement (e.g., data discovery, movement, processing, etc. testing should be scaled to 10 to 100 times the current amount of data)
- Funding is always a struggle (U.S. and EU agencies tend to fund innovative research and new ideas and less prone to support ongoing successful projects such as ESGF)

Future Operations and Support

Governance of ESGF

- **Steering Committee:** Funding agencies and stakeholders responsible for providing resources
- **Executive Committee:** Overall responsibility for meeting sponsors, stakeholders, and community needs and prioritizing work
- **Technical Committee:** Responsible for the development of the system architecture, the management of the development lifecycle and scheduling releases
- The executive and technical committees are responsible for setting release contents and reporting what was actually delivered in the releases to the community.

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Future Operations and Support

Distributive technologies that need more research for ESGF use

- Machine learning for pattern discovery and prediction
- Decision analytics based on the quantification of uncertainties
- Streaming analysis, visualization and sensors simulation
- Full suite of server-side analysis and visualization
- Hadoop and distributed computing
- Cloud computing installation and VMs
- Streaming clients for data download
- Research possible alternative search technologies such as NoSQL and MongoDB
- Research alternative communication protocols to P2P
- Scalable semantic technologies
- Research quality control checking on the data
- Digital Object Identifiers (DOIs)
- Server-side data reduction and calculations
- Workflow and provenance

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Future Operations and Support

Funding of ongoing operational and software support for CMIP and climate science data capabilities is a critical issue

- Software and Model Archive Federated Data System Components have been developed entirely as 3-5 year R&D projects through support from BER and ASCR.

- Over the last few years, we were generously given additional support by BER.

- The current budget for AIMES under the SFA provides only one FTE of support.

- From the charts estimate that multiple FTE's are needed:

  – CMIP community outreach and engagement
    - participation metadata standards definition committees
    - Collaboration and infrastructure design and deployment with other BER and USGCRP climate data centers

  – Operational support of the ESGF-based CMIP model data distribution system
    - Ongoing ESGF software support
    - Assistance to modeling centers for software deployment and maintenance

  – Maintenance of CMIP replicated data archive housed at LLNL

  – Servicing requests driven by the DOE, CMIP, and the research community

  – …..

Questions and Discussion