ExArch: Climate analytics on distributed exascale data archives

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UCLA

Institut Pierre Simon Laplace

DKRZ

UNIVERSITY OF TORONTO

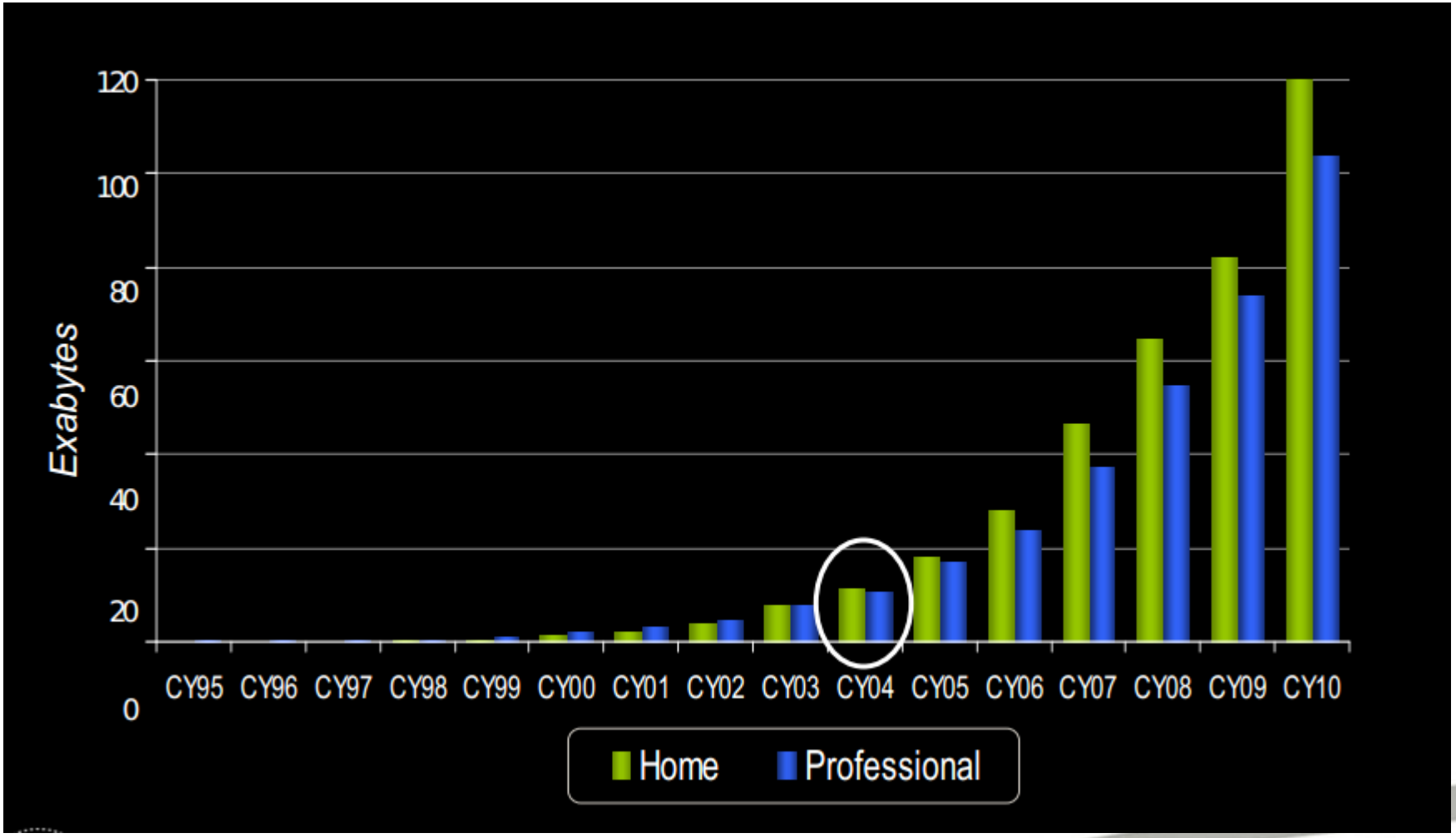
Princeton University

Centro Euro-Mediterraneo per i Cambiamenti Climatici

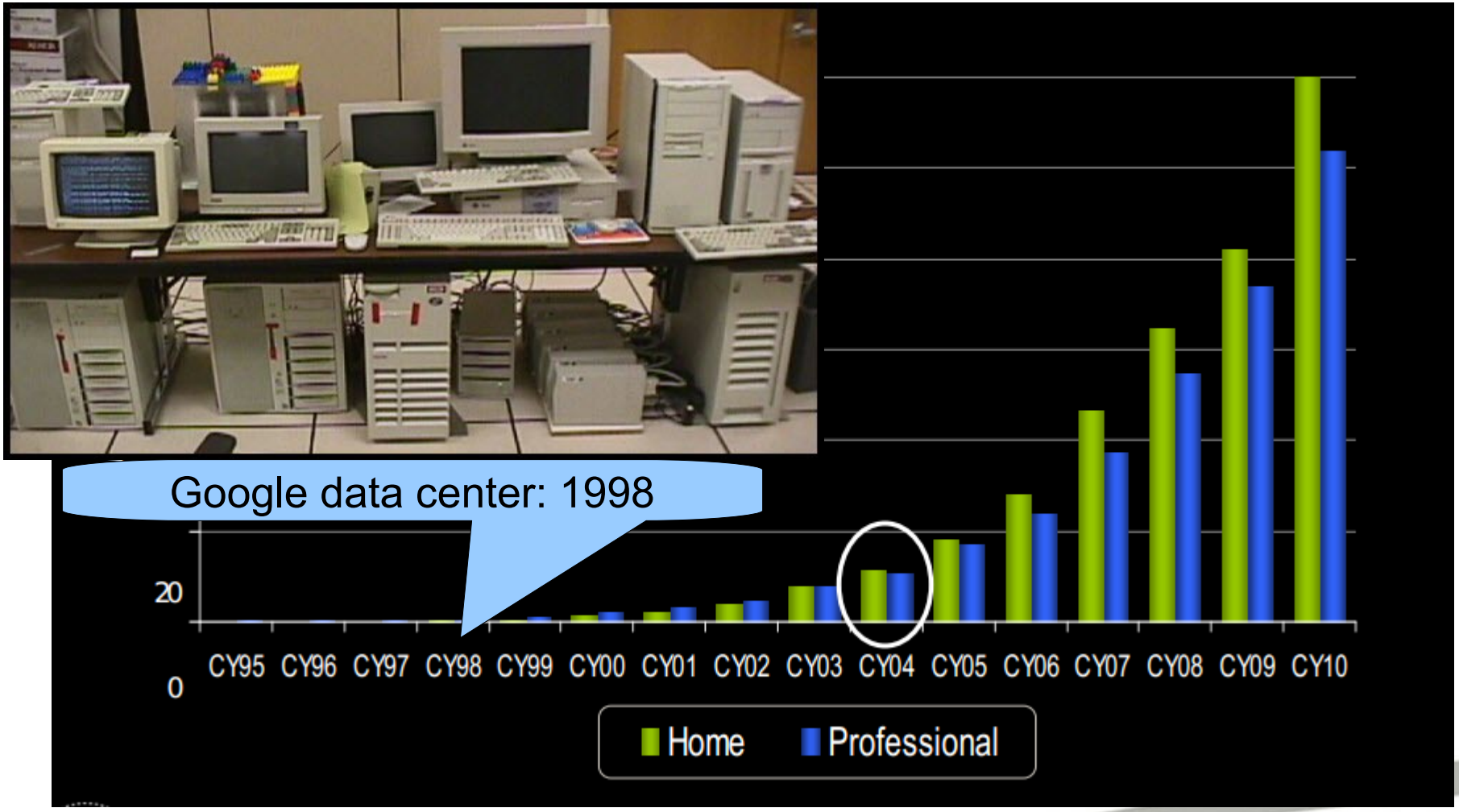
RAL Space
Harwell International Space Innovation Centre

ExArch

The project will develop a strategy, prototype infrastructure and demonstration usage examples for scientific analysis of exa-scale archives.



Dave Aune, Seagate (presentation at LLNL, August 2008)



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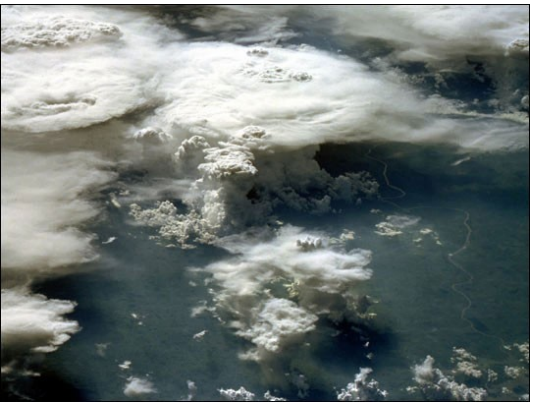
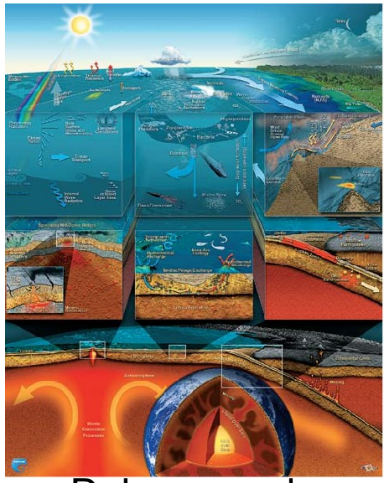
Climate Science drivers



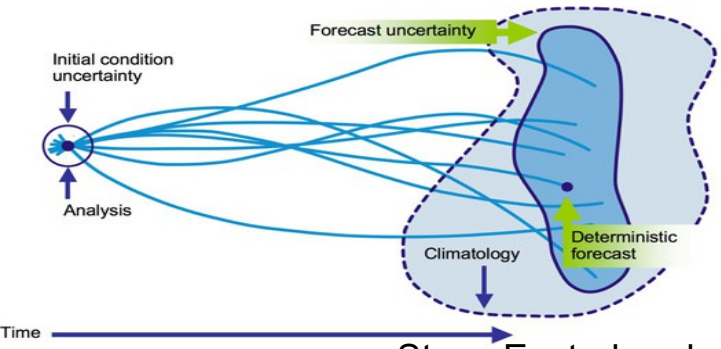
Earth Science Image Analysis Lab.

Greater precision;
Increased complexity;
Improved quantification of uncertainty;
Bridging scientific communities:

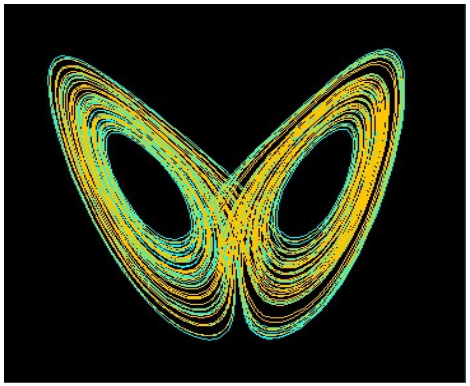


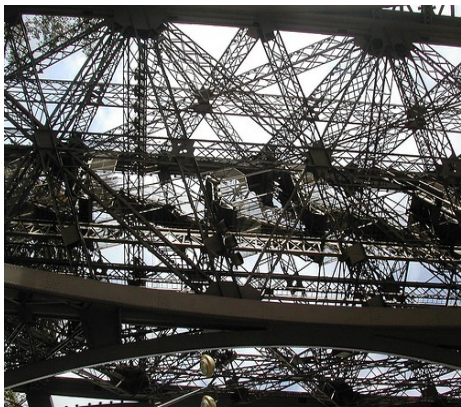
Delaney and Barga (2010)

All in the context of increasing societal relevance.



Steve Easterbrook





What is special about exa-scale?

How should the climate modelling community use a thousandfold increase in computer power?
Short answer: 3-fold increase in horizontal, vertical and temporal resolution, plus a 3 fold increase in ensemble size and number of model variables ==> 700-fold increase in computational requirements.

But: we are not going to have a thousand-fold increase in manpower to look at the results: how do we structure the analysis to allow research and prompt distribution of results.

Take the compute to the data – but how?

(1) System: Programming libraries which access data repositories more efficiently;

(2) Archive: Flexible range of standard operations at every archive node;

(3) Portal: Well documented workflows supporting specialist user communities implemented on a server with high speed access to core archives;

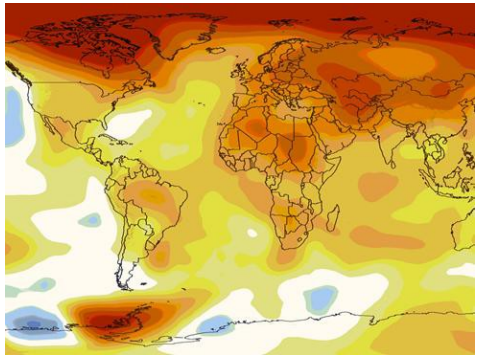
(4) User: Well packaged systems to increase scientific efficiency.

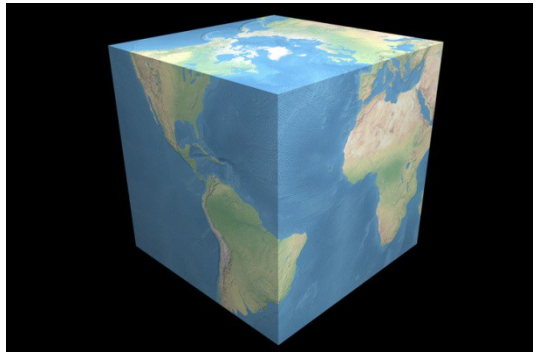
(5) Pre-computed products.

CMCC parallel data analytics framework

*The **CMCC parallel data analytics framework** addresses scientific data analysis challenges at large scale*

*Several use cases focusing on **massive data reduction**, **statistical analysis**, **data slicing/dicing** have been defined jointly with climate scientists and tested on **CMIP5 datasets***



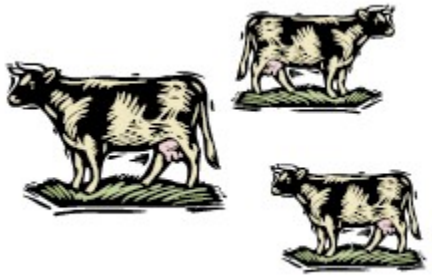


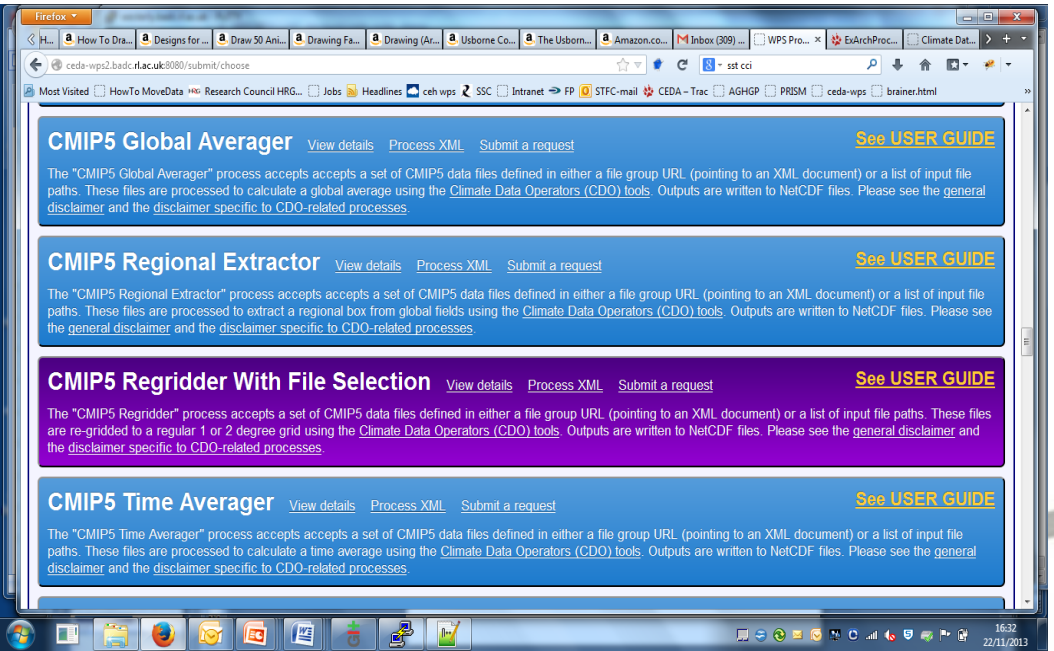
*The framework integrates **scientific numerical libraries, provides array-based support and adopt parallel paradigms***

Taking the processing to the archive – BADC

CEDA OGC Web Services

Implementing around 100 processing operations through the Climate Data Operators library

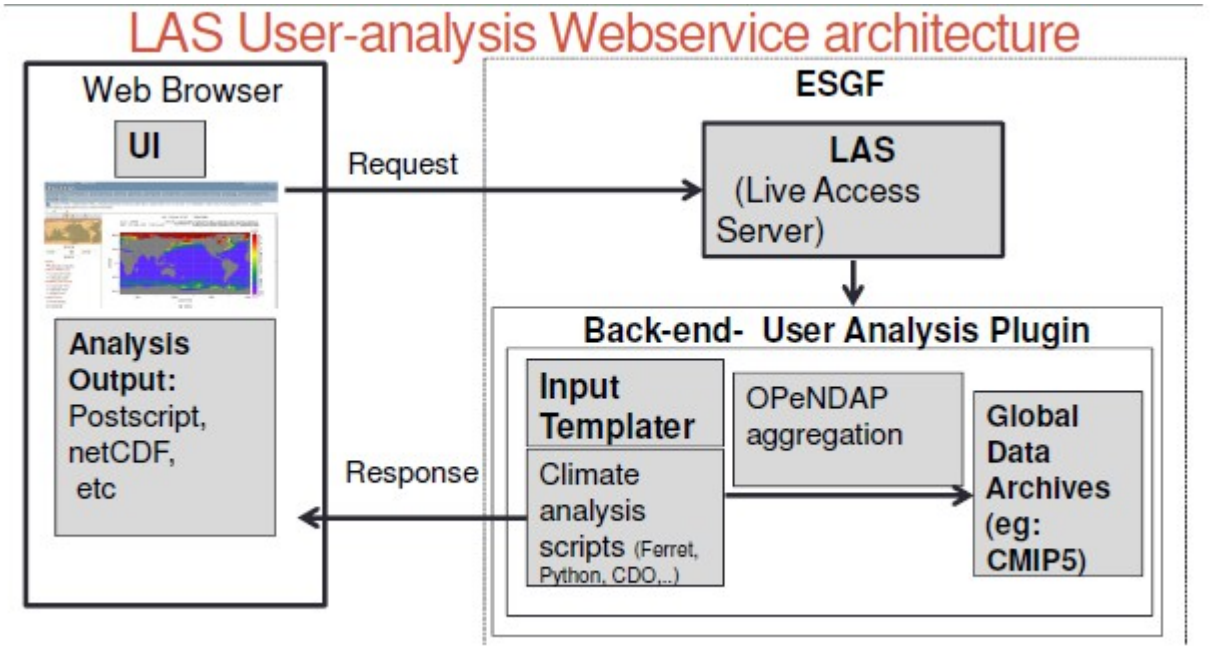




- Standards based to promote interoperability – especially use by client software

Taking the processing to the archive – GFDL

Exploiting the power of the NOAA – PMEL "Live Access Server"



- User specifies dataset and variables;
- Back-end scans catalogues and constructs a LAS request;
- Output (images or data) are returned to user;

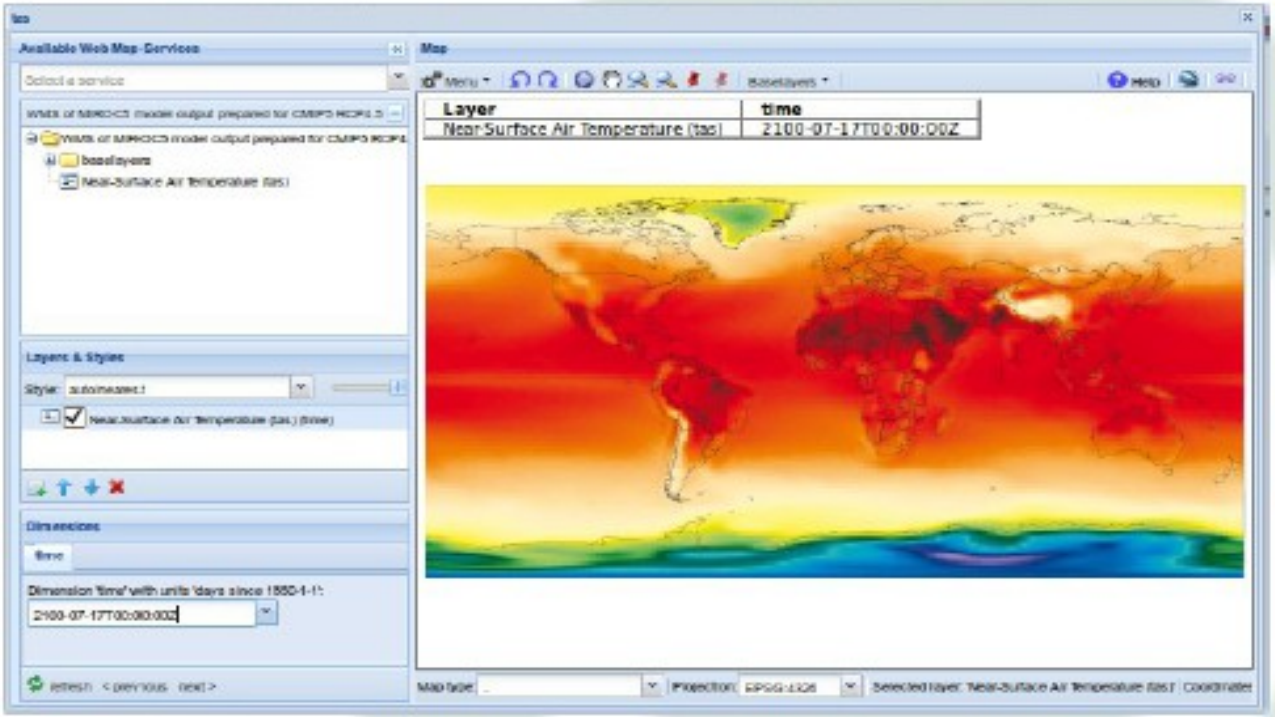
Taking the processing to the portal – KNMI

http://climate4impact.eu/

is-enes
INFRASTRUCTURE FOR THE EUROPEAN NETWORK FOR EARTH SYSTEM MODELLING

A portal to support the climate impacts community

Taking the processing to the portal – KNMI



- Data provider: MIROC
- Distribution: DIAS (JAPAN)
- Identity provider: BADC
- Authorisation: PCMDI
- Quality control: DKRZ
- Visualisation: KNMI

A federated system optimises the use of the limiting resource: ***people.***

No institution can go it alone: data at scale is a global activity based around large national facilities....

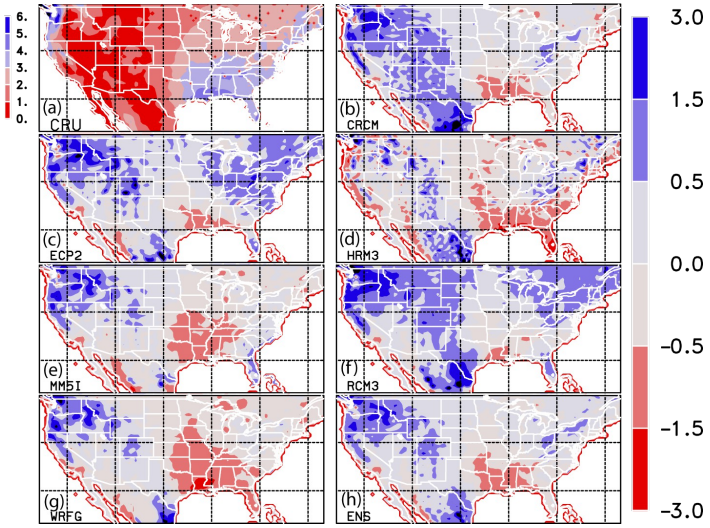
is-enes

Enhancing user efficiency: RCMES

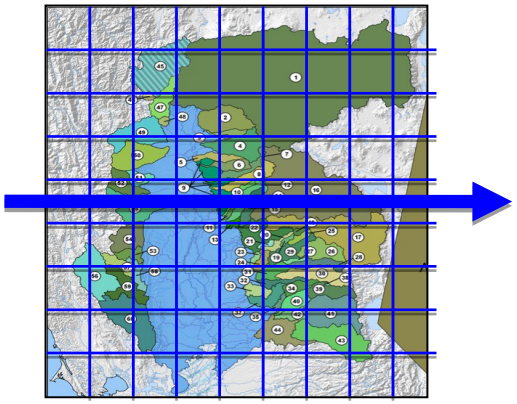
Regional Climate Model Evaluation System (RCMES)

UCLA

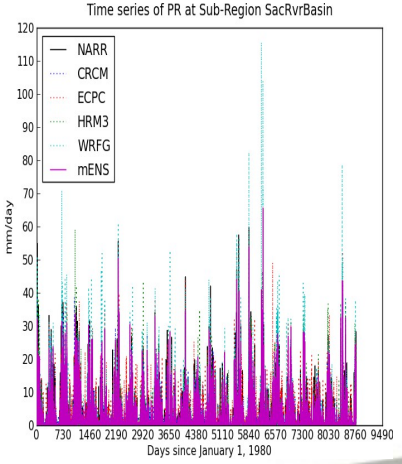
NASA Jet Propulsion Laboratory
California Institute of Technology



Observation/Model rainfall



Map over a basin using an area-matching method



Get basin-mean time series

Figure. Calculation of area-mean data for an irregularly-shaped watershed from gridded climate model data.

Enhancing user efficiency: CDB

Climate diagnostics benchmarks

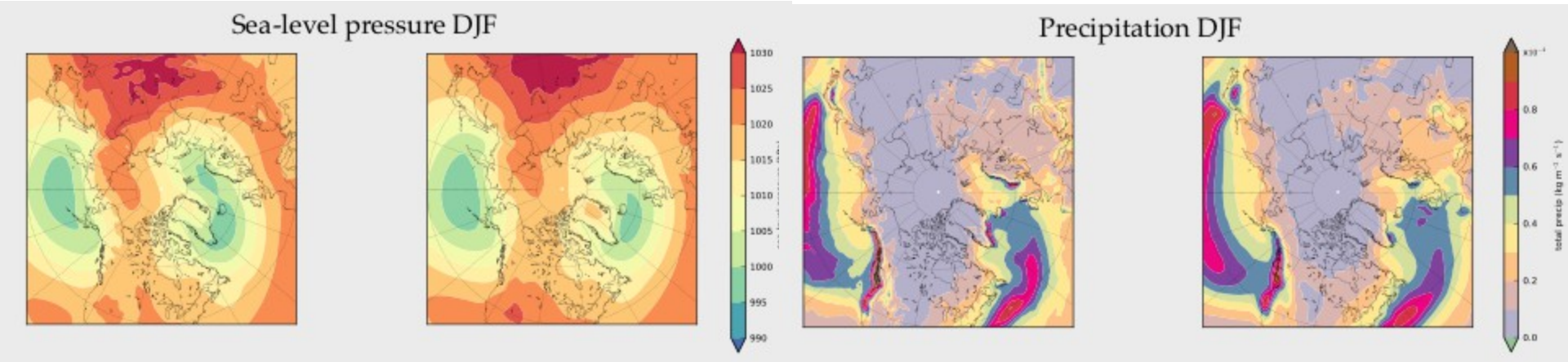
- *Benchmarking data processing workflows*

– Should we move the calculation to a machine with fast archive access, or move the data to a machine with fast processing?

– What is the data reduction achieved by the processing?

– What is the probability of needing to do the calculation again, or how many times do you expect to do the calculation?

– E.g. calculating daily cyclone distributions → reduce data by a factor 3; monthly mean cyclone distribution → reduce data by a factor 100.



Other issues

- Pre-computed products – automated updating;
- Documentation – machine readable;
- Quality control – with machine readable results;

Who will ExArch help?

Users --- needs

85% Pre-computed products: e.g. global means; climatologies; multi-model ensemble

9% Simple calculations: e.g. Ad-hoc ensembles; comparisons;

0.9% Simple work-flows: composite years with high cyclone activity

0.1% Complex work-flows.

5% Indirect access through client software

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0.1% Complex work-flows.

5% Indirect access through client software

Data standards

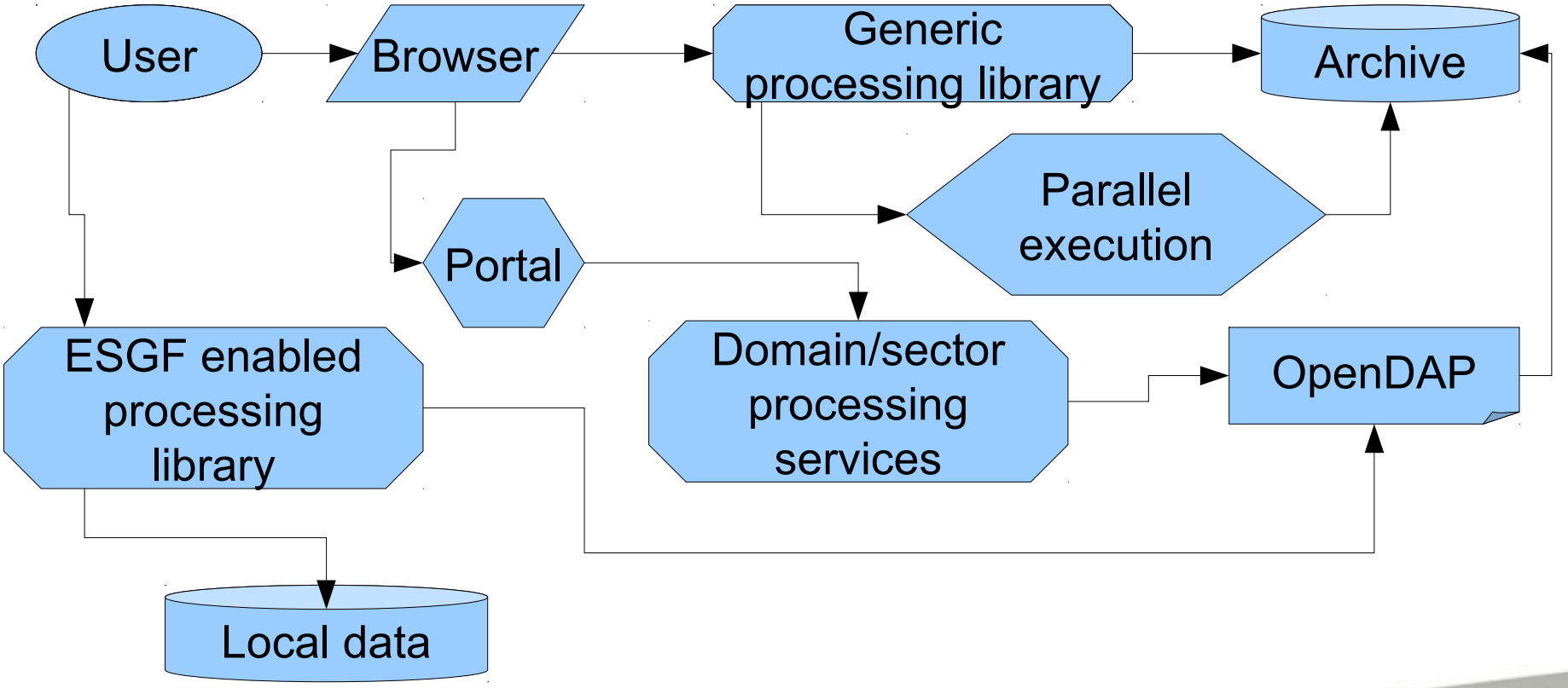
CMIP5:

- NetCDF file format;
- CF convention;
- CMOR compliant:
  - MIP tables;
- Data Reference Syntax;
- THREDDS profile;
- OpenDAP;
- ESGF Security;
- Open Geospatial Consortium:
  - Web Map Services
- METAFOR Common Information Model (CIM): detailed model documentation

ExArch will:

- Enhance implementation of the METAFOR CIM;
- Explore development of a standard for processing requests;
- Prototype compliance testing for protocols which inherit elements of standards;

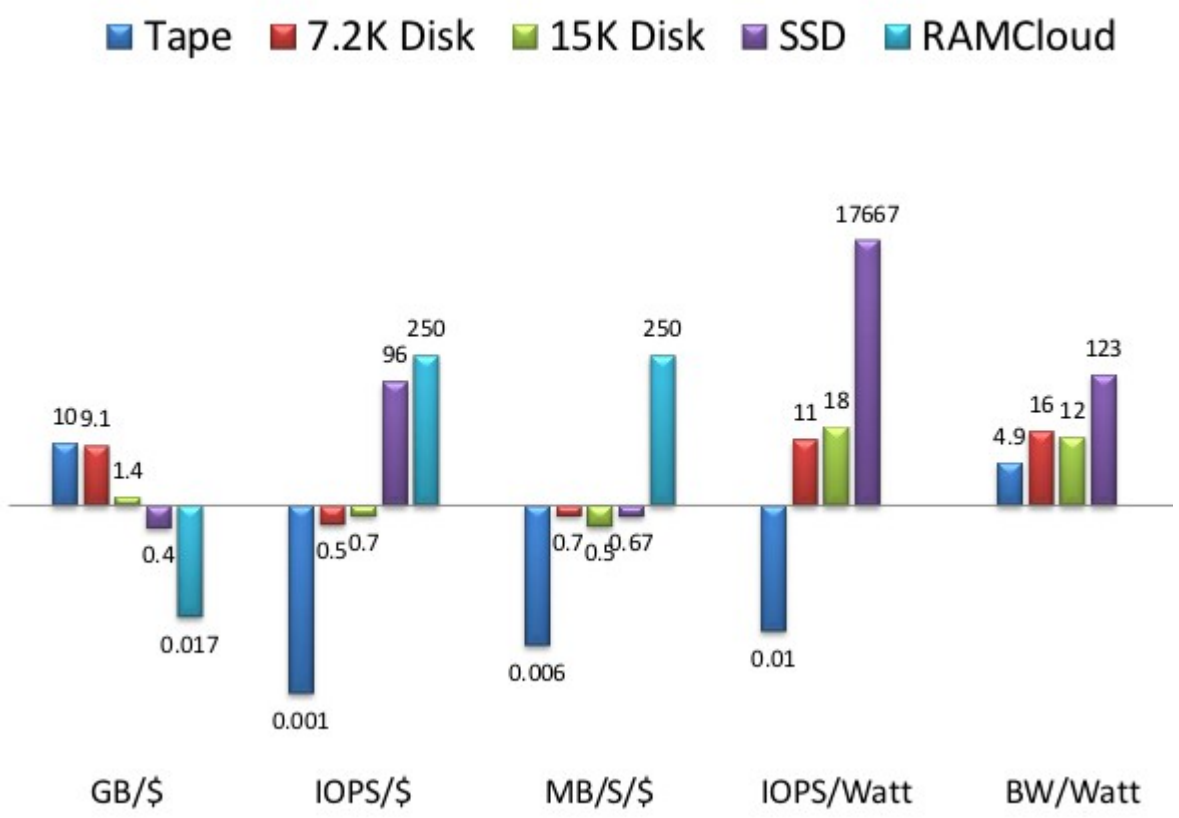
Climate Analytics System Of Systems



Summary

- There are many approaches to “taking the processing to the data”;
- The exascale analytics system must support a huge diversity of user requirements;
- Different approaches need to be coordinated.

The end



Ted Wobber, MSR (presentation at LLNL, 2011)

Dealing with the energy bottleneck

- We need a better understanding of data usage patterns;
- A single media archive won't to satisfy user needs and budget constraints;
- More efficient use of storage (don't store data on disk at more locations than needed);
- Multi-media archives will require sophisticated caching;
  - Frequently read data → fast disk or solid state;
  - Rarely read data → slow disk or tape;

Caching infrastructure needs to support checksumming and access controls;

ExArch components

British Atmospheric Data Centre
NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE
NATURAL ENVIRONMENT RESEARCH COUNCIL

Princeton University

Institut Pierre Simon Laplace

DKRZ

UNIVERSITY OF TORONTO

UCLA

Centro Euro-Mediterraneo per i Cambiamenti Climatici

- Web processing services
- Query syntax
- Common information model
- Processing operators and quality control
- Scientific diagnostics
- EO data for model evaluation
- Grid computing

Web processing services

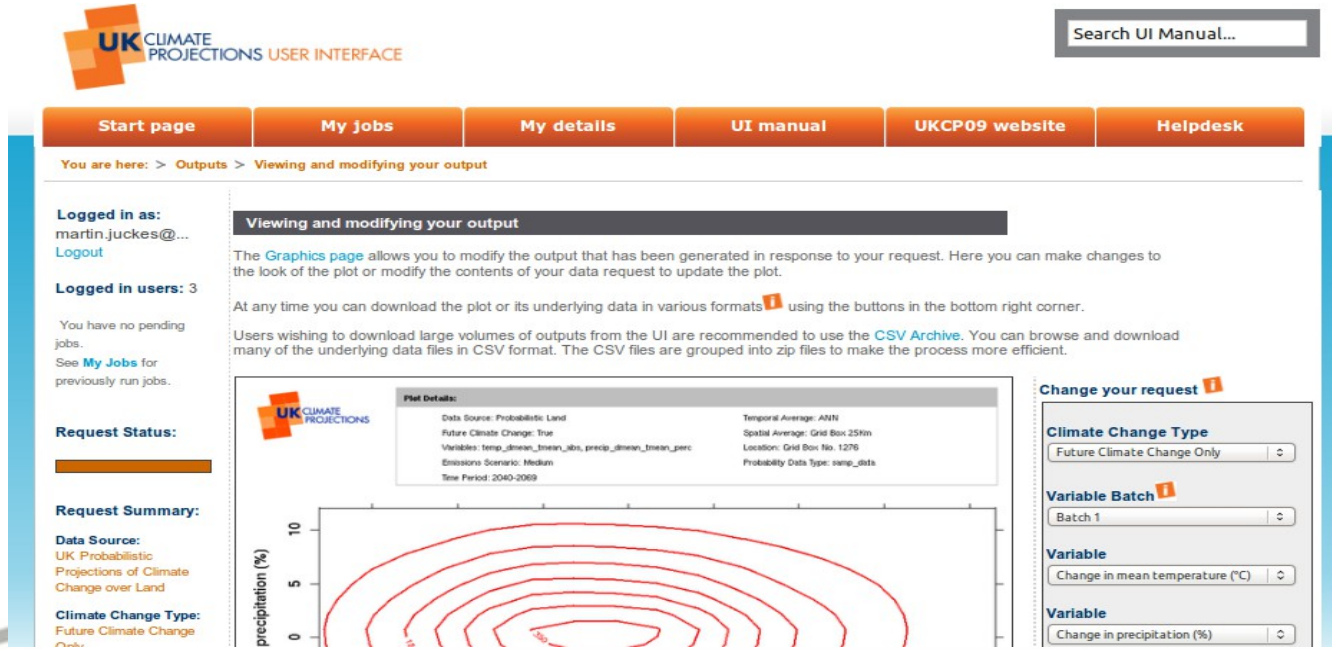
- *Build on experience with UK climate projections portal:*

- *OGC services: flexibility through standards;*
- *Load balancing, synchronous and asynchronous execution;*
- *Exploit CDO operators to ensure reproducibility;*

NEEDED:

Standard request syntax; e.g.:

List/specification of data files + specification of spatio-temporal domain + operator (e.g. MathML);



Quality control

- *CMIP5: core components*
  - *QC tool: software to carry out multiple tests with high computational and IO efficiency;*
  - *QC wrapper: software to manage results for thousands of files;*
  - *QC repository: somewhere to store the results;*
  - *QC terminology: well defined success and failure codes;*
- *CMIP5 lessons:*
  - *Lack of community standards in test definitions leads to confusion;*
  - *Need to be able to annotate automated QC results;*
  - *Data providers should be able to run the tests themselves – before publishing data;*

Structured meta-data

The CMIP5 archive is:

- Pioneering the use of structured meta-data data, with information entered through an on-line questionnaire, over 800 questions;
- Introducing a three level quality control process.

ExArch will explore:

- Direct generation of meta-data from climate models;
- Transformation from meta-data to model configuration files and back;
- Extensions and interoperability with Earth Observation meta-data;
- Structured description of multi-level quality control;
- Designing quality control to meet user and software client requirements;

es-doc.org :: interface to the metadata repository

Climate Science Metadata Standards

metafor Common Information Model

Home | Ontology | Repository | Tools

REPOSITORY - SEARCH

Project: CMIP5 | Document Type: All | Document Version: Latest | Document Language: English | Search

Experiments (40) | Models (29) | Simulations (323) | Ensembles (189) | Grids (32) | Platforms (13) | Data (159)

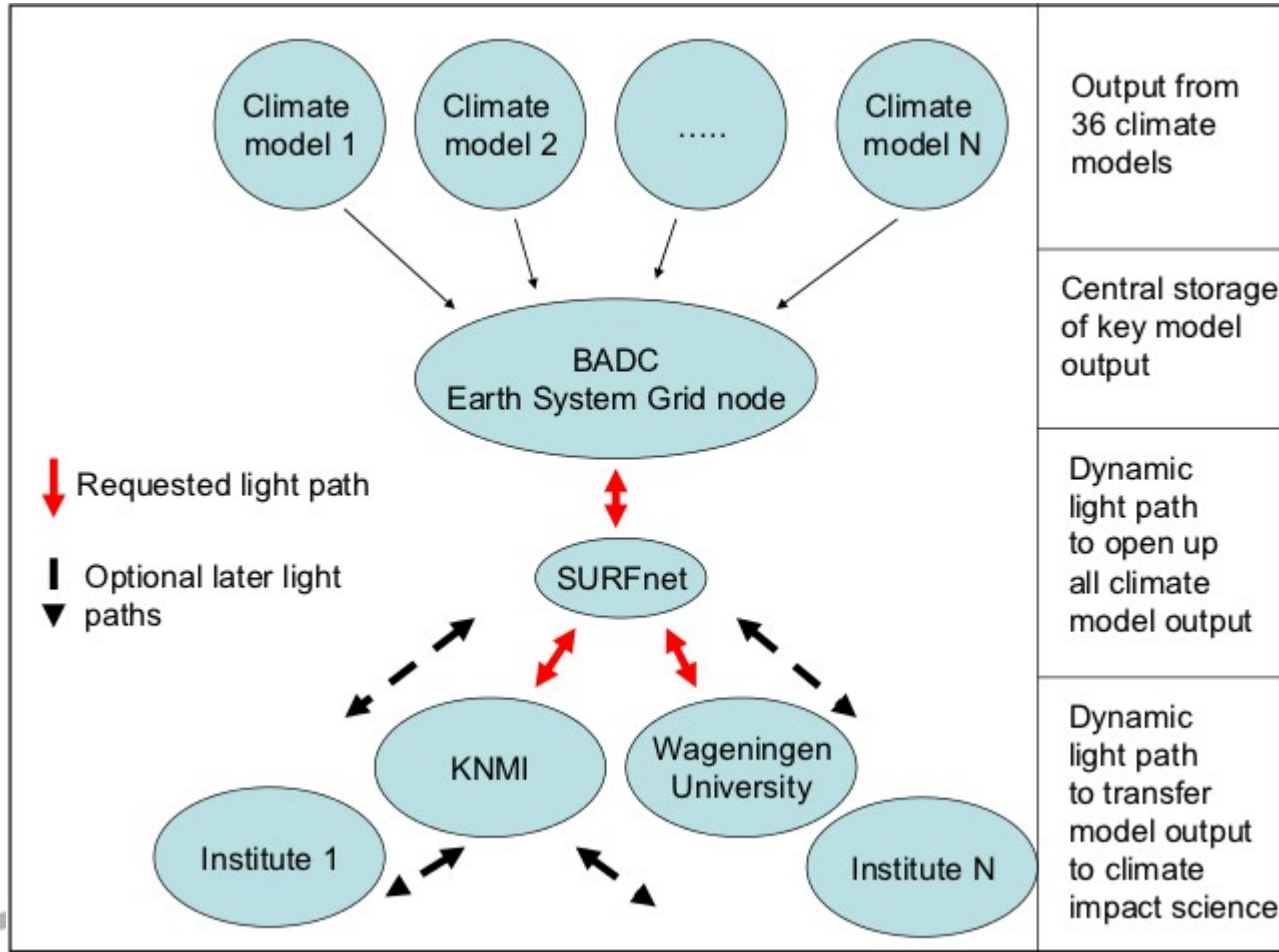
1 to 25 of 29 entries | Filter:

Project	Short Name	Long Name	Released	Vers.		
CMIP5	BCC_CSM1.1	Beijing Climate Center Climate System Model version 1.1	2011	3	xml	json
CMIP5	CCSM4	Community Climate System Model 4 with 1° atmosphere, land, ocean, and sea ice	2010	1	xml	json
CMIP5	CMCC-CESM	CMCC Carbon Earth System Model	2009	1	xml	json
CMIP5	CMCC-CM	CMCC Climate Model	--	1	xml	json
CMIP5	CMCC-CMS	CMCC Climate Model with a resolved Stratosphere	--	1	xml	json
CMIP5	CNRM-CM5	CNRM-CM5	2010	3	xml	json
CMIP5	EC-EARTH	EC-EARTH	2010	4	xml	json
CMIP5	GISS-E2-H	GISS ModelE version 2, HYCOM ocean model	--	3	xml	json
CMIP5	GISS-E2-R	GISS ModelE version 2, Russell ocean model	2011	2	xml	json
CMIP5	GISS-E2CS-H	GISS ModelE version 2, Cubed-sphere, HYCOM ocean	2011	1	xml	json
CMIP5	GISS-E2CS-R	GISS ModelE version 2, Russell ocean model, Cubed Sphere grid	2011	1	xml	json
CMIP5	HadCM3	HadCM3 (2000) atmosphere: HadAM3 (N48L19); ocean: HadOM (lat: 1.25 lon: 1.25 L20); land-surface/vegetation: MOSES1;	1998	1	xml	json
CMIP5	HadGEM2-A	Hadley Global Environment Model 2 - Atmosphere	2009	1	xml	json
CMIP5	HadGEM2-CC	Hadley Global Environment Model 2 - Carbon Cycle	2010	1	xml	json

Networks

- The climate research community currently relies on the open academic network – no direct cost, but limited bandwidth;
- Dedicated links can provide much faster connections for a moderate cost;

Efficient use of dedicated links requires greater co-ordination between archives.



The end

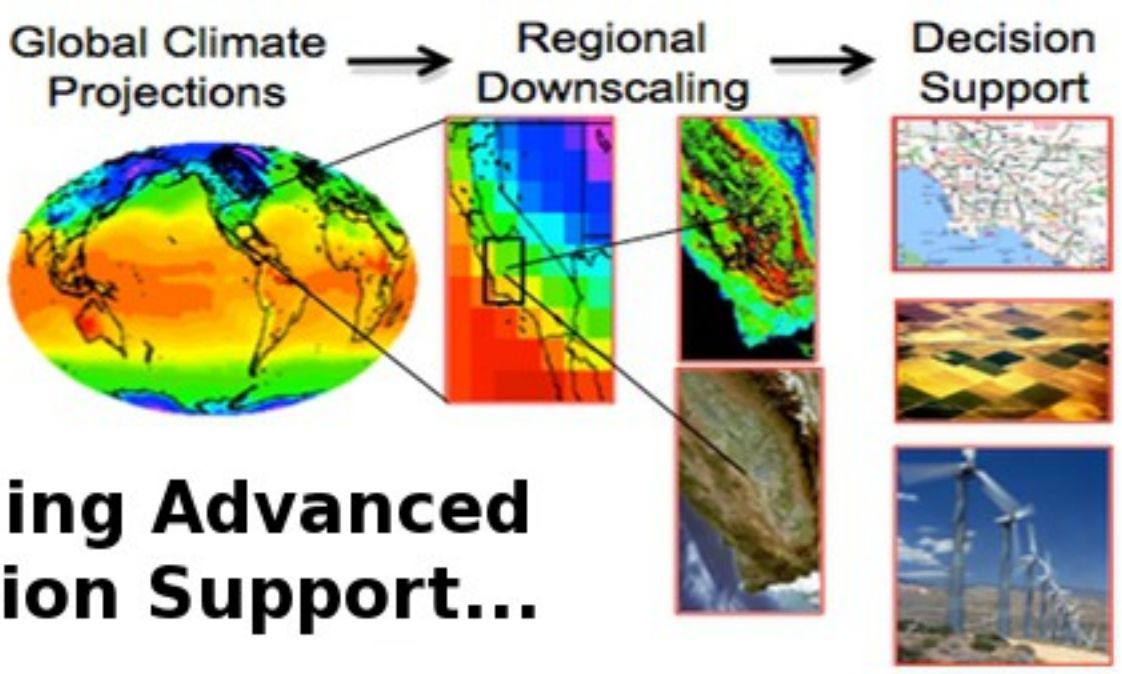
Take the compute to the data – but how?

ExArch is supporting 3+1 approaches, as no single approach will meet user needs.

(1) Providing an interface to an extensive (pre-existing) library of operations (the Climate Data Operator [CDO] library);
(2) Supporting integration of the NOAA LAS into the ESGF peta-scale CMIP5 archive;
(3) Supporting the development of an evaluation suite for the CORDEX archive of regional climate projections;
(4) and collaborates with the IS-ENES development of a specialist portal for climate impacts analysis;

Taking the processing to the archive – UCLA

http://rcmes.jpl.nasa.gov/



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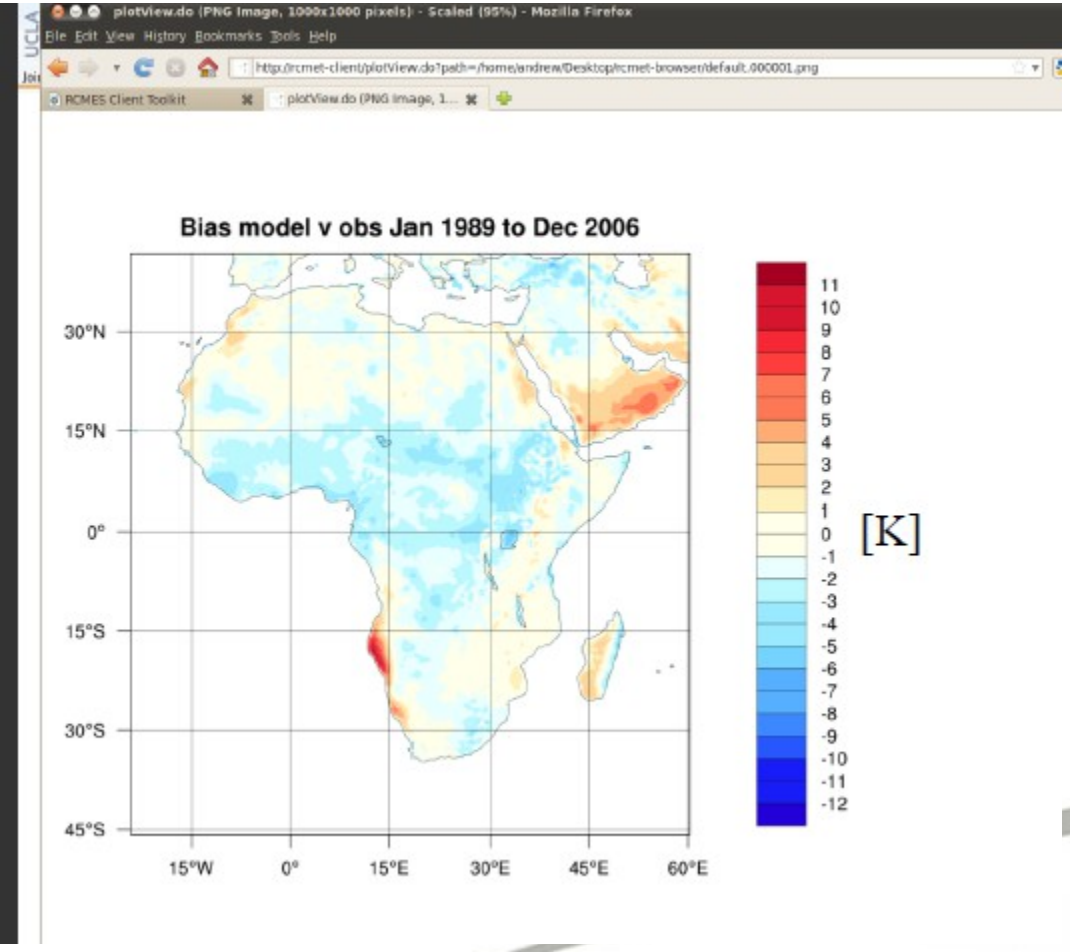
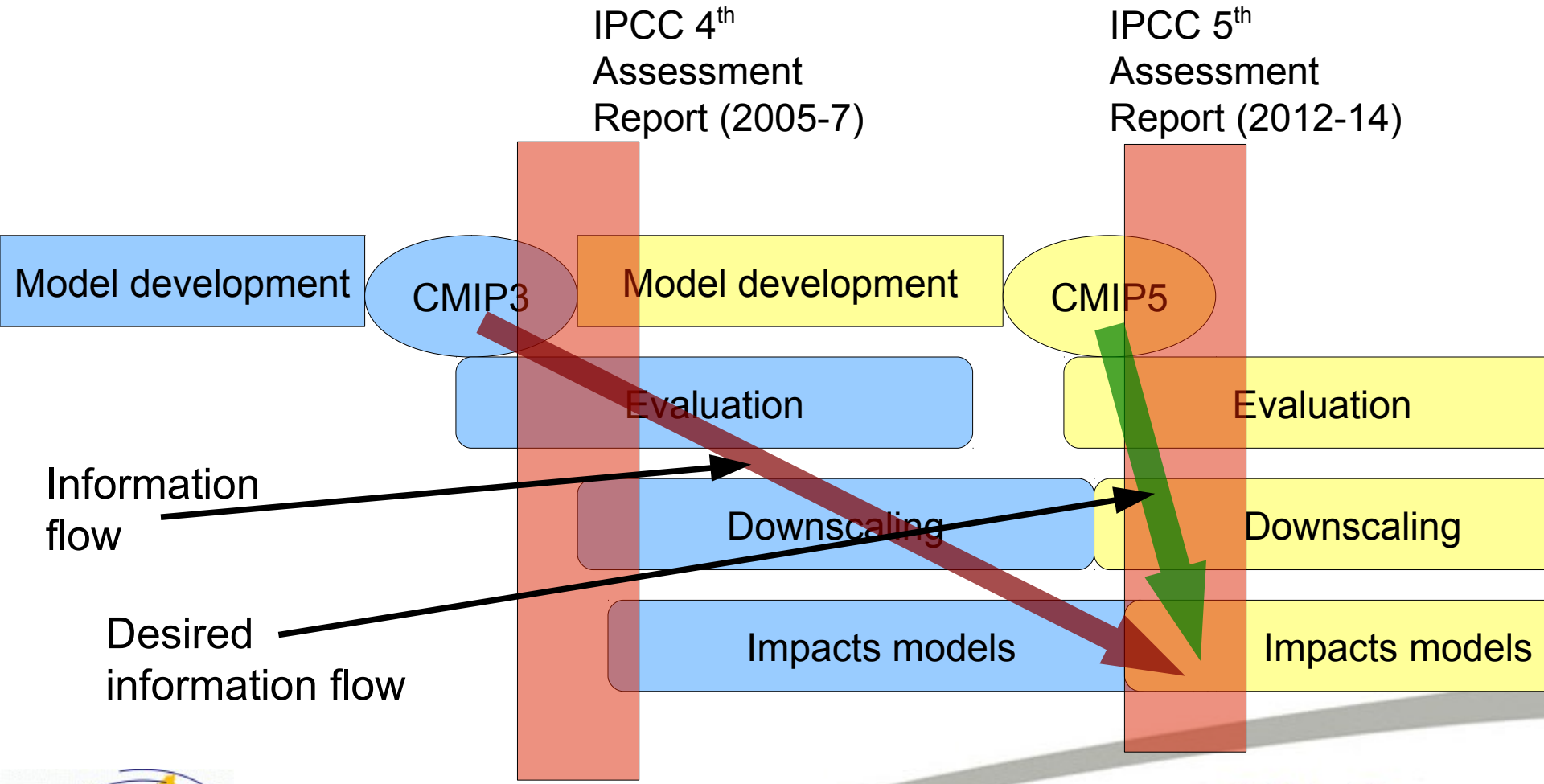


- Users can choose from a set of pre-imported observational datasets;
- Select regional model data;
- Create standard plots differences;

The climate assessment process



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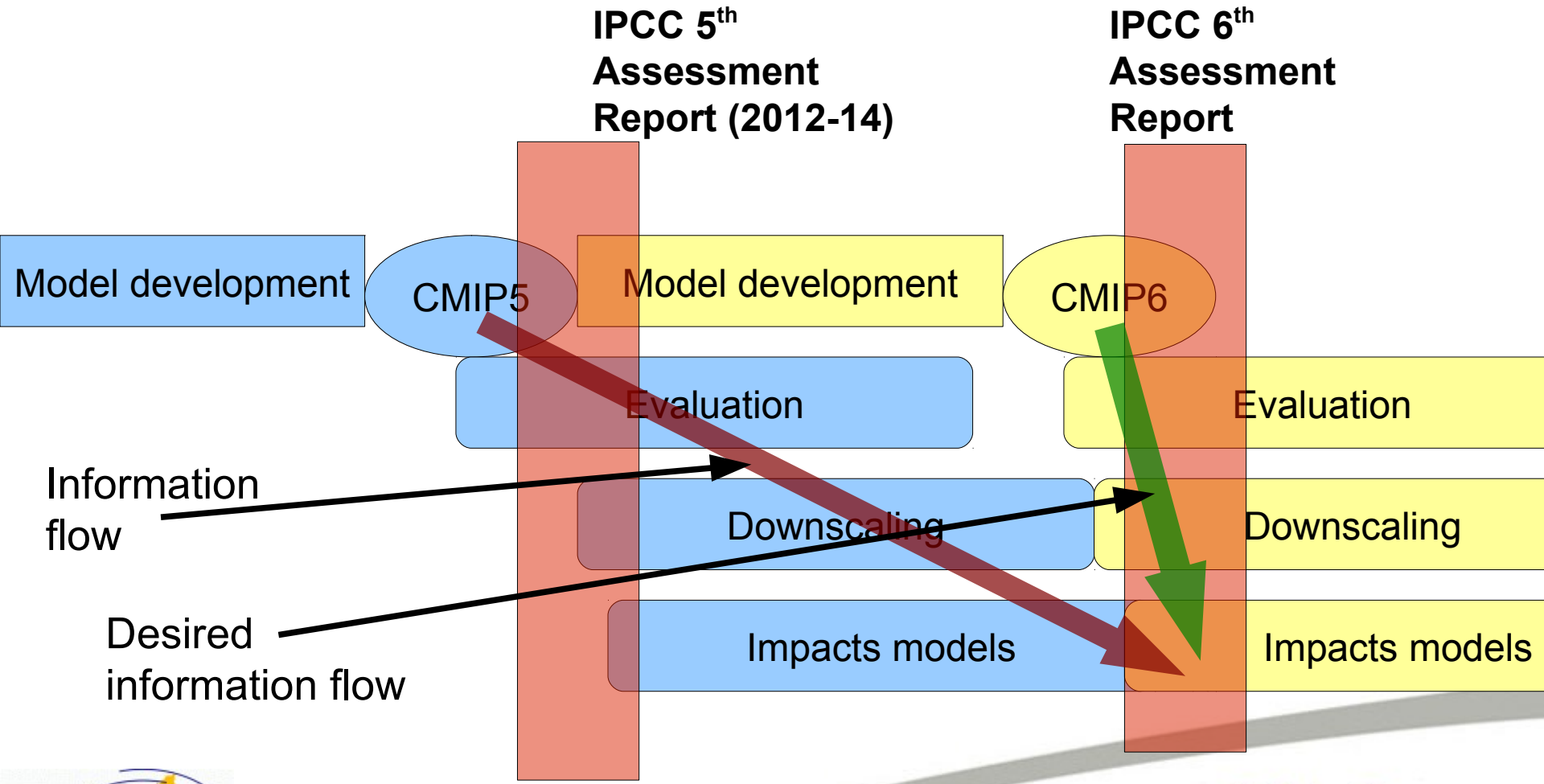

Big Data: RDA view

Big Data *refers to digital data volume, velocity and/or variety [,veracity] that:*

enable novel approaches to frontier questions previously inaccessible or impractical using current or conventional methods; and/or

exceed the capacity or capability of current or conventional methods and systems.

Voting: standards need broad consensus or institutions with a clear mandate – becomes harder as the target user groups become larger.

Take the compute to the data – but how?

1: a library of operations which can be executed at the archive
2: a portal with domain specific derived products
3: use OGC* standards to ensure maximum interoperability
4: use intuitive syntax to promote ease of use
5: link to existing archives, or create a local collection to support specific operations?

*Aviation, Built Environment & 3D, Business Intelligence, Defense & Intelligence, Emergency Response & Disaster Management, Geosciences & Environment, Government & Spatial Data Infrastructure, Mobile Internet & Location Services, Sensor Webs, University & Research

Thematic areas

Computation close to the archive – reducing data movement

Exploiting complex documentation

Support for detailed quality control

Benchmarking of analysis work-flows

Governance

Strategic outlook: some trends

Analysis by Kryder and Soo Kim (2009) suggests hard drives will not be replaced by solid state or other new media before 2020.

	Change per year	Change per decade
Data centre storage	+60%	~100-fold increase
Energy use/unit capacity	-22%	~10-fold decrease
Data centre energy use	+25%	~10-fold increase

	2010	2020
Purchase cost/Tb	200 USD	3 USD
Operating power	10 W/Tb	1W/Tb
Electricity cost (UK)	90 GBP/MWh	120 GBP/MWh
Cost of 1Tb* 3 years	200 + 37	3 + 5
Size at constant funding	1Pb	30Pb

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	2010	2012/3	*2020*
Purchase cost/Tb	200 USD	60 USD	*3 USD*
Operating power	10 W/Tb	**2W/Tb**	*1W/Tb*
Electricity cost (UK)	90 GBP/MWh	95 GBP/MWh	*120 GBP/MWh*
Cost of 1Tb* 3 years	200 + 37	60 + 8	*3 + 5*
Size at constant funding	1Pb	3.5Pb	*30Pb*

Structured meta-data

Model categories, based on CIM metadata

Atmosphere-Ocean Models:	
Atmosphere, Land, Ocean, Sea ice, Aerosol;	CCSM4, HadCM3, GFDL-CM2p1
Atmosphere, Land, Ocean, Sea ice;	CMCC-CM, EC-Earth
Atmosphere, Ocean, Sea ice;	CMCC-CMS
Coupled-chemistry models:	
Atmosphere, Land, Ocean, Land ice, Sea ice, Aerosol, Atmospheric Chemistry;	GISS-E2-H/E2-R
Atmosphere, Land, Ocean, Sea ice, Aerosol, Atmospheric Chemistry;	GFDL-CM3
Earth System Models:	
Atmosphere, Land, Ocean, Sea ice, Ocean Bio-geochemistry;	IPSL-CM5A-LR/MR, MPI-ESM-LR/MR/P, GFDL-ESM2G/M
Atmosphere, Land, Ocean, Sea ice, Aerosol, Atmospheric Chemistry, Ocean Bio-geochemistry;	HadGEM2-ES/CC

Structured meta-data

ESGF Earth System Grid Federation

InfraStructure for the European Network for Earth System Modelling is-enes

Home | Search | Tools | Login | Help

Current Selections

remove all
(x) project:CMIP5
(x) experiment:historical
(x) model:GFDL-ESM2M

Search

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

Temporal Search
Geospatial Search
Clear search constraints and datacart
Search Help
Search Controlled Vocabulary

☑ Search All Sites ☐ Show All Replicas ☐ Show All Versions

< 1 2 3 > displaying 1 to 10 of 24 search results

Display 10 datasets per page

Add All Displayed to Datacart Remove All Displayed from Datacart

Search Categories

- Project
- Institute
- Model
- Instrument
- Experiment Family
- Experiment
- Time Frequency
- Product
- Realm
- Variable
- Variable Long Name
- CMIP Table

Results | Data Cart

project=CMIP5, model=GFDL-ESM2M, Geophysical Fluid Dynamics Laboratory, experiment=historical, time_frequency=3hr, modeling realm=atmos, ensemble=r1i1p1, version=20120227
Data Node: esgdata.gfdl.noaa.gov
Version: 20120227
Description: NOAA GFDL GFDL-ESM2M, historical (run 1) experiment output for CMIP5 AR5
Further options: Add To Cart Visualize and Analyze Model Metadata

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Data Node: esgdata.gfdl.noaa.gov
Version: 20120328
Description: NOAA GFDL GFDL-ESM2M, historical (run 1) experiment output for CMIP5 AR5
Further options: Add To Cart Visualize and Analyze Model Metadata

Structured meta-data

- Data centres accounted for around 1% of global electricity use in 2010 (Koomey et al., 2011);
- Google accounts for around 1% of global data centre electricity use [.22Gw];
- CEDA has about 0.1% of the electricity bill of Google.

Google data center, 1998 – from a tech. blog.

Summary

- ExArch covers a wide range of topics, with a focus on leverage existing work;
- There are many approaches to data analysis, reflecting a vast diversity of user applications;
- ExArch has brought together groups working on a wide range of data analysis frameworks;
- At Exa-scale all these approaches will have to be supported.