



**British Atmospheric  
Data Centre**

NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE  
NATURAL ENVIRONMENT RESEARCH COUNCIL



# ExArch: Climate analytics on distributed exascale data archives

**Martin Jukes**, V. Balaji, B.N. Lawrence,  
M. Lautenschlager, S. Denvil, G. Aloisio, P. Kushner, D. Waliser,  
S. Pascoe, A. Stephens, P. Kershaw, F. Laliberte, J. Kim, S. Fiore

**UCLA**



Institut  
Pierre  
Simon  
Laplace



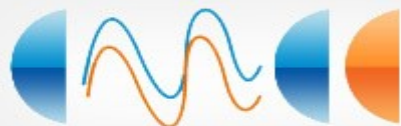
**DKRZ**



UNIVERSITY OF  
**TORONTO**



**Princeton  
University**



Centro Euro-Mediterraneo  
per i Cambiamenti Climatici



ExArch, Toulouse, Feb., 2013

**RAL Space**

Harwell International Space Innovation Centre

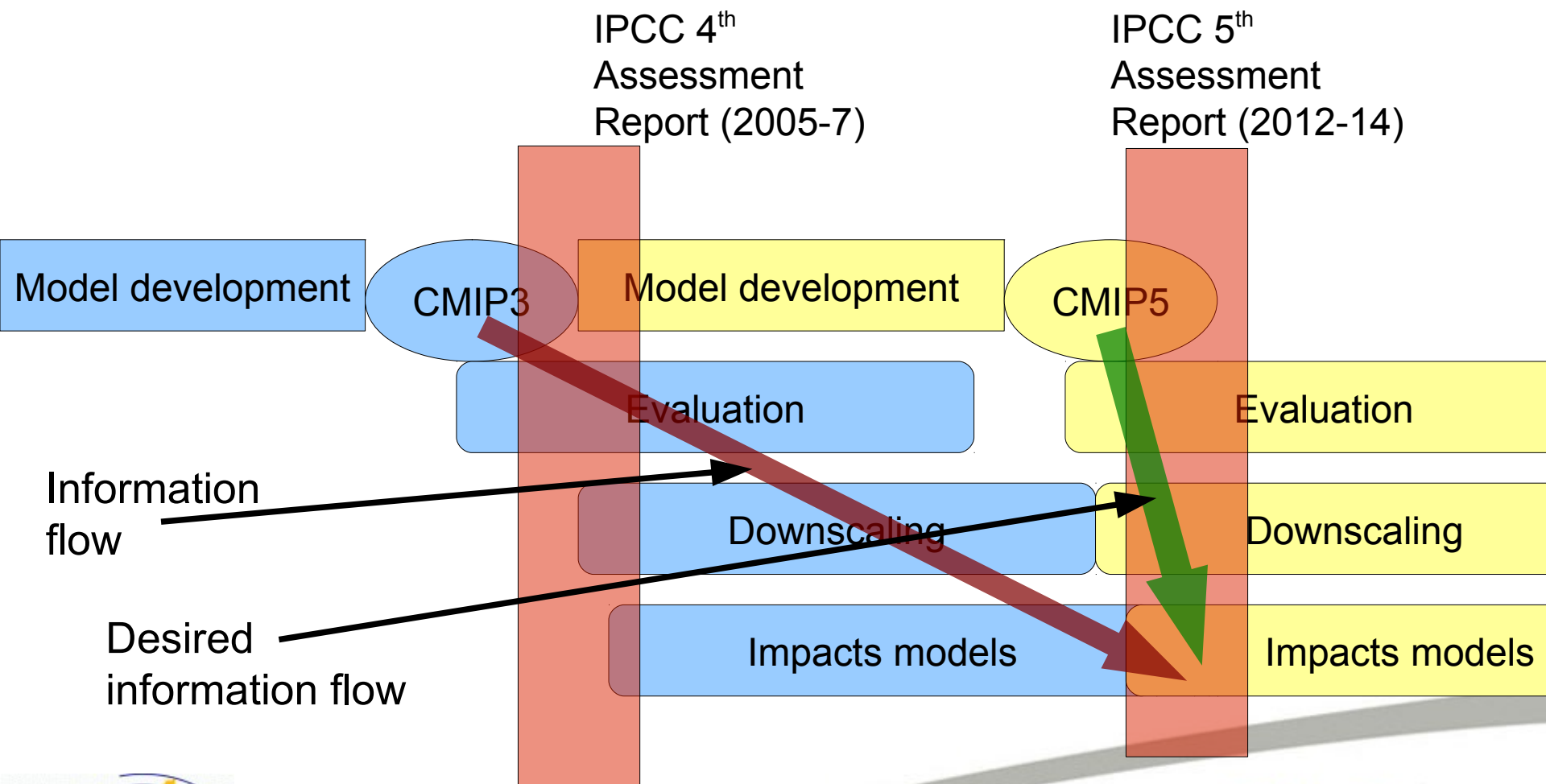


# ExArch

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

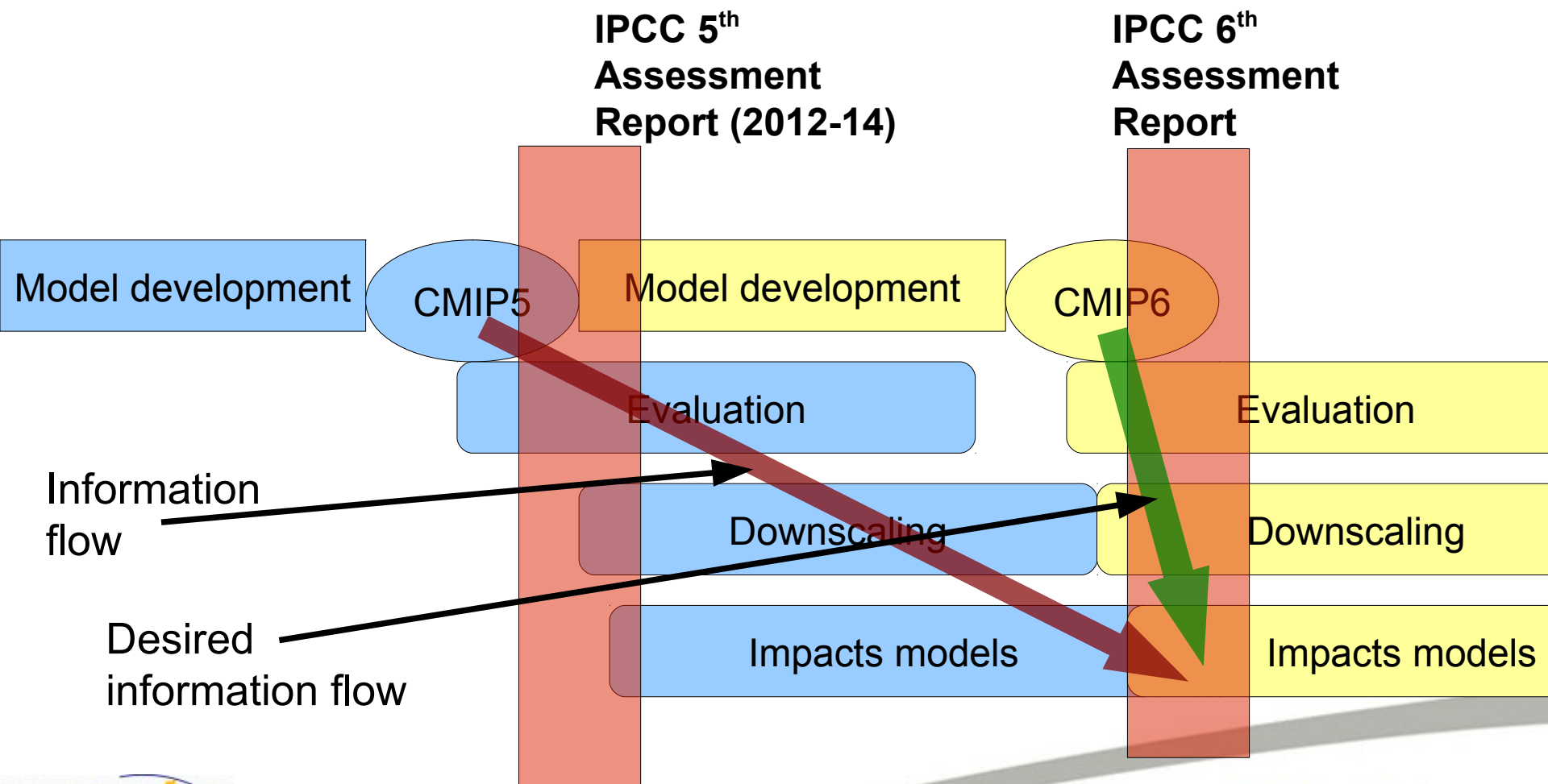


# The climate assessment process





# The climate assessment process





## *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.*



## *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.**





## 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**



## *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

# 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	2012/3	2020
Purchase cost/Tb	200 USD	60 USD	3 USD
Operating power	10 W/Tb	<b>2W/Tb</b>	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



## *Take the compute to the data – but how?*

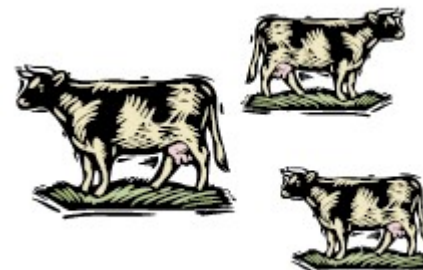
- 1: a library of operations which can be executed at the archive**
- 2: a portal with domain specific derived products**
- 3: use OGC\* standards to ensure maximum interoperability**
- 4: use intuitive syntax to promote ease of use**
- 5: link to existing archives, or create a local collection to support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



## Taking the processing to the archive – BADC

CEDA OGC Web Services



- Employ the Climate Data Operators ([code.zmaw.de/projects/cdo](http://code.zmaw.de/projects/cdo)) to ensure that users can repeat calculations on other machines
- User dashboard to show progress of asynchronous requests
- ♦ Process resource estimation to avoid system overload

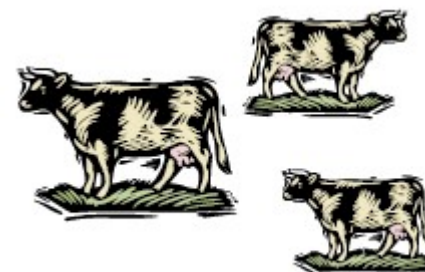


## Taking the processing to the archive – BADC

### CEDA OGC Web Services

Based on a XACML-based policy that checks the URL against a set of rules that permit/refuse access (per process, including arguments and their value). E.g.:

```
http://ceda-wps2.badc.rl.ac.uk/wps?  
Request=Execute&Format=text/xml&  
Inform=true&  
Identifier=HadISSTSubsetter&  
Store=false&Status=false&Costonly=true&  
DataInputs=Variable=sea_ice_area_fraction;  
EndDateTime=2012-09-11T15%3A44%3A15;  
StartDateTime=1870-01-01T00%3A00%3A00
```

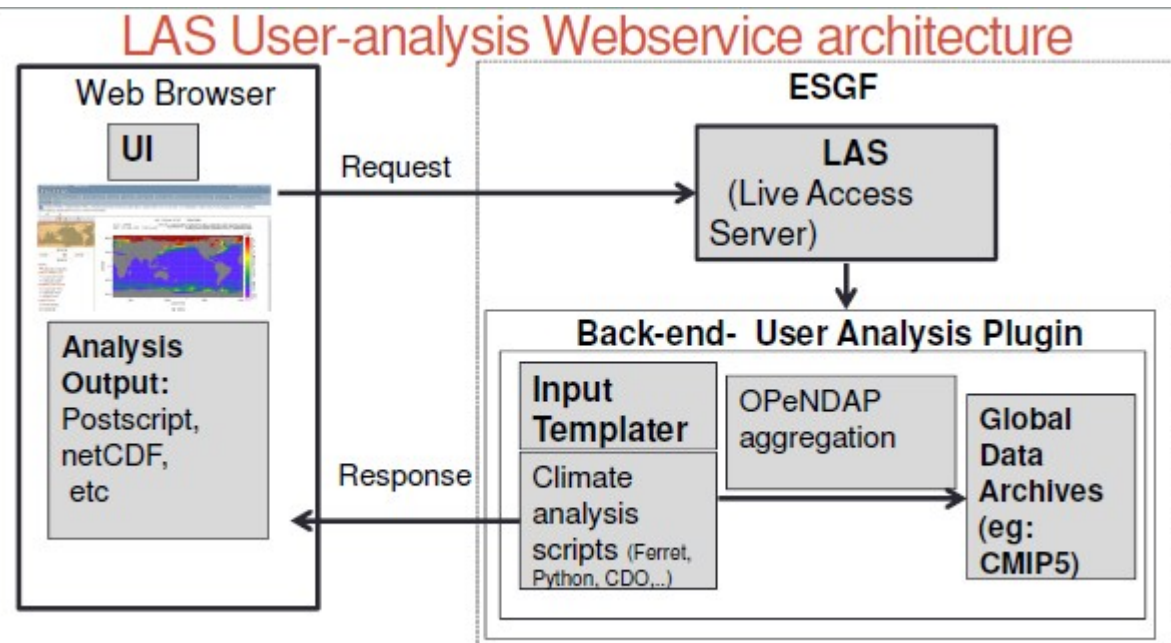


- Standards based to promote interoperability – especially use by client software



## *Taking the processing to the archive – GFDL*

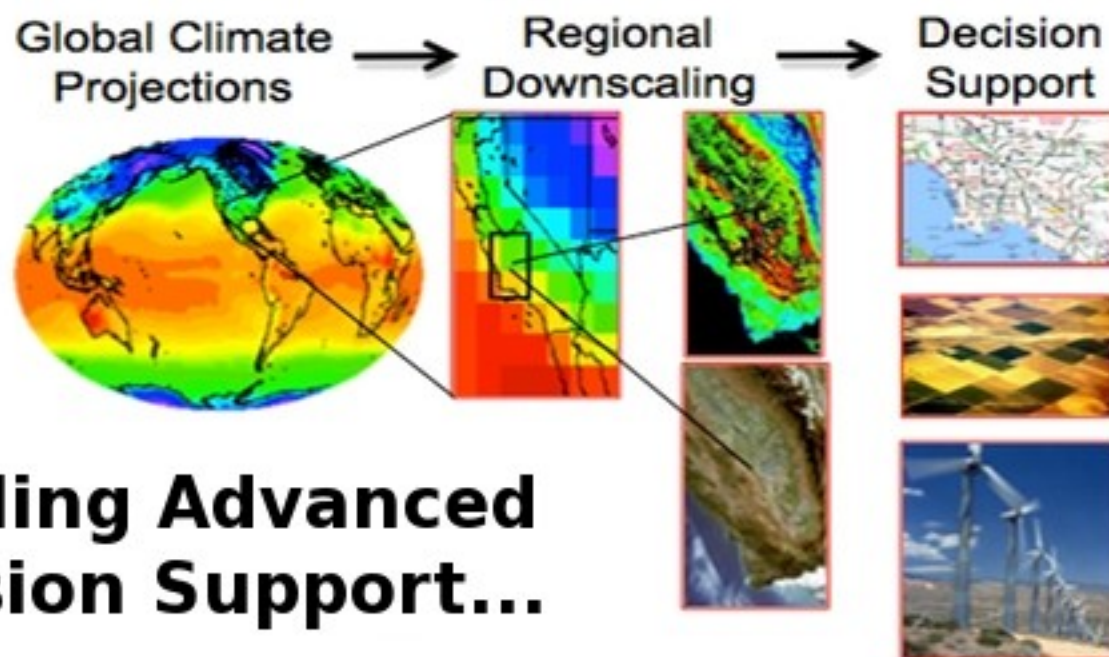
Exploiting the power of the NOAA – PMEL “Live Access Server”



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



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



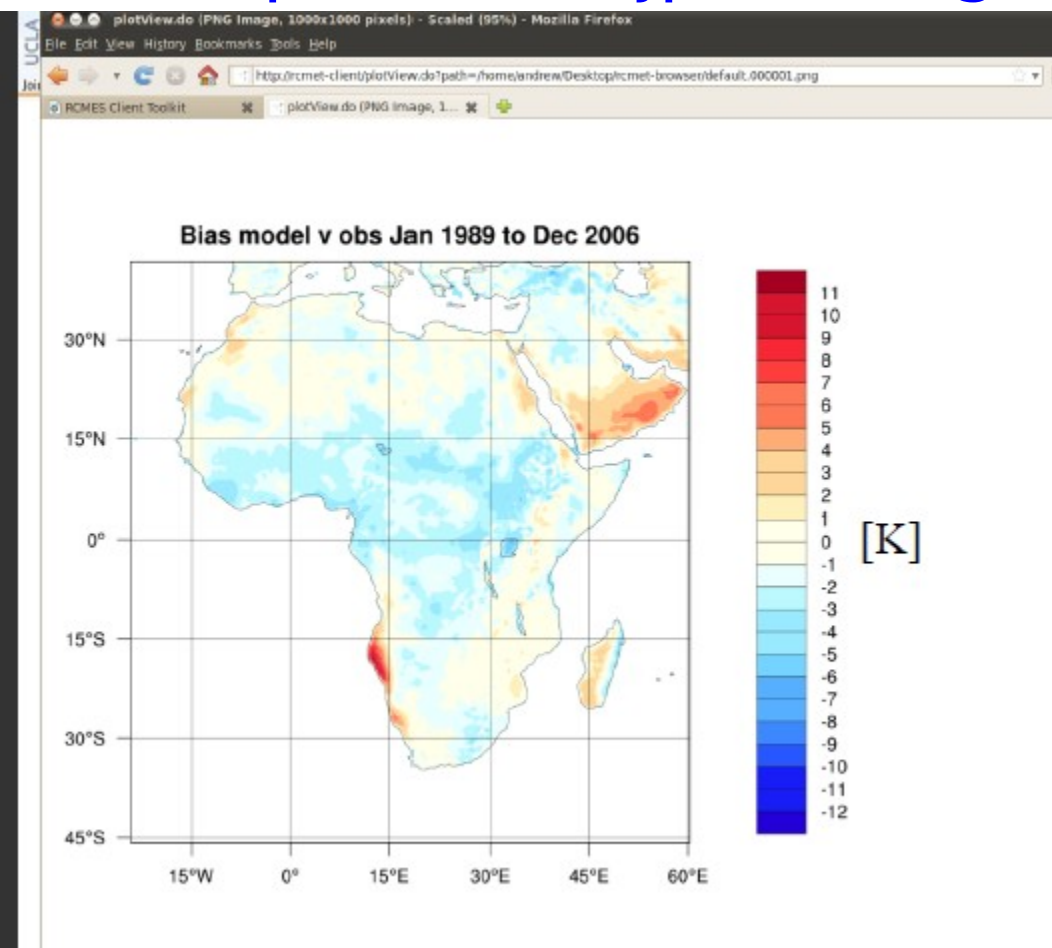
## Enabling Advanced Decision Support...





## Taking the processing to the archive – UCLA

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



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



*Taking the processing to the archive – KNMI*  
*(funded by IS-ENES)*

<http://climate4impact.eu/>

A portal to support the climate impacts community





*Taking the processing to the archive – KNMI  
(funded by IS-ENES)*

<http://climate4impact.eu/>

Home Data discovery Map & Plot Documentation Help About us Log in


**Login with your OpenID account**

OpenID account:

- Login
- ☒ Keep identifier on this computer

Don't have an account yet?

- Detailed instructions on how to create an account can be found here: [HowTo: Create an ESGF account.](#)

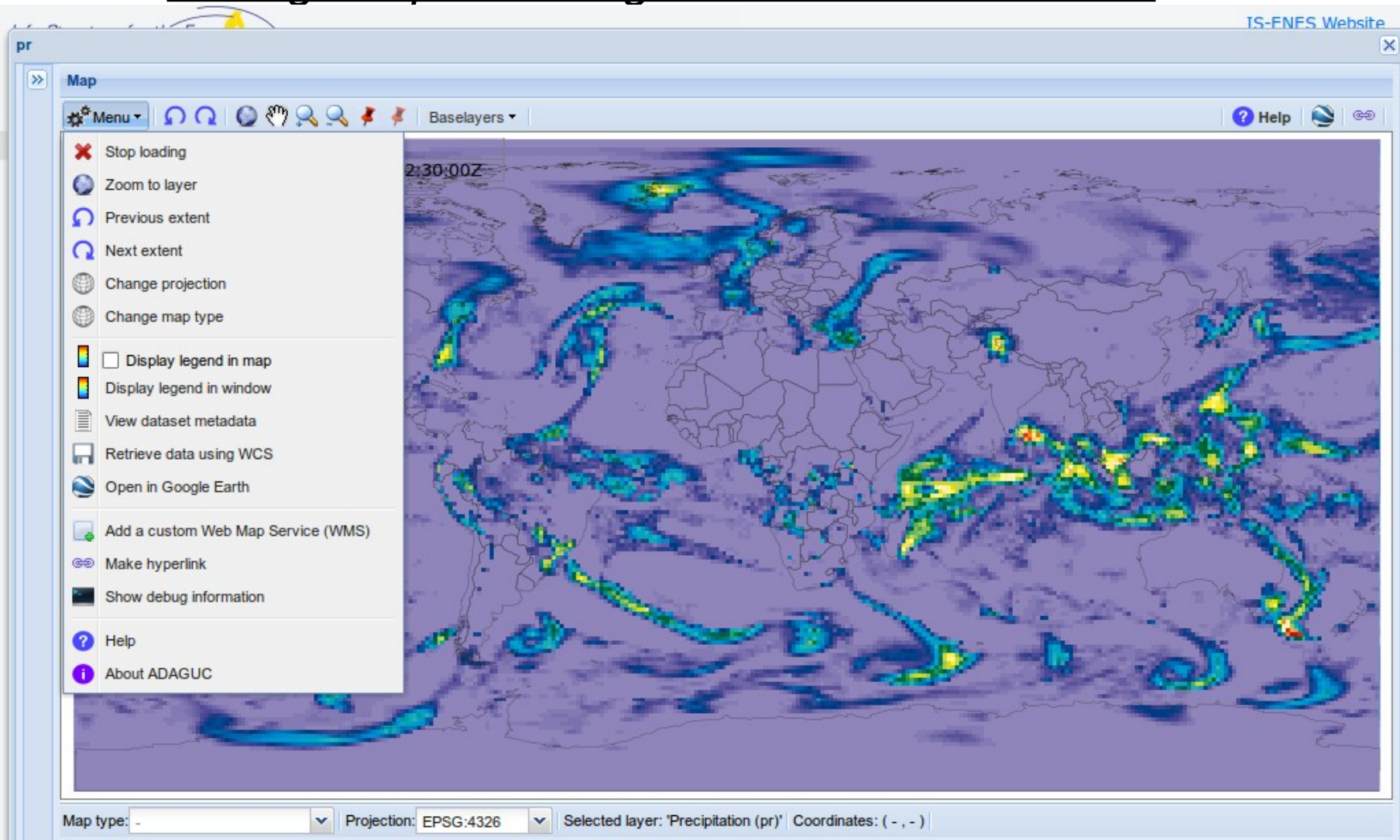


An extension to the ESGF security infrastructure provided by ExArch allows the climate4impact portal (and other clients) to access to secured CMIP5 data on behalf of accredited users.





## Taking the processing to the archive – KNMI





## Structured meta-data

Model categories, based on CIM metadata

<b>Atmosphere-Ocean Models:</b>	
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
<b>Coupled-chemistry models:</b>	
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
<b>Earth System Models:</b>	
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



InfraStructure for the European Network for Earth System Modelling



HomeSearchToolsLoginHelp

Current Selections

[remove all](#)  
[\(x\) project:CMIP5](#)  
[\(x\) experiment:historical](#)  
[\(x\) model:GFDL-ESM2M](#)

Search Categories

Project

Institute

Model

Instrument

Experiment Family

Experiment

Time Frequency

Product

Realm

Variable

Variable Long Name

CMIP Table

Search

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

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*.

☒ 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](#)

ResultsData 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](#)

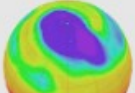
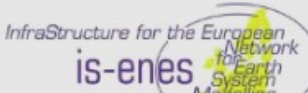

project=CMIP5,model=GFDL-ESM2M,Geophysical Fluid Dynamics Laboratory,experiment=historical,time\_frequency=6hr,modeling\_realm=atmos,ensemble=r1i1p1,version=20120328

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



Earth System Documentation - Viewer | CMIP5 Model - GFDL-ESM2M (v4)

CMIP5 Model - GFDL-ESM2M

Model Experiment

Overview

Citations

Contacts

Properties

Components

Project

Short Name

Long Name

Institute

Funder

Principal Investigator

Release Date

Language

Description

CMIP5

GFDL-ESM2M

GFDL-CM2.1, Geophysical Fluid Dynamics Laboratory

NOAA Geophysical Fluid Dynamics Laboratory

NOAA Geophysical Fluid Dynamics Laboratory

NOAA Geophysical Fluid Dynamics Laboratory

2011-11-26 00:00:00

--

--

Earth System Documentation - Viewer (v0.8.6.2)CMIP5 Model - GFDL-ESM2M (v4)

Project

Institute

Model

Instrument

Experiment Family

Experiment

Time Frequency

Product

Realm

Variable

Variable Long Name

Add All Displayed to Datacart

Remove All Displayed from Datacart

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](#)


project=CMIP5, model=GFDL-ESM2M, Geophysical Fluid Dynamics Laboratory, experiment=historical, time\_frequency=6hr, modeling\_realm=atmos, ensemble=r1i1p1, version=20120328

Data Node: esgdata.gfdl.noaa.gov

Version: 20120328

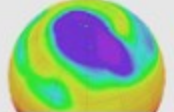
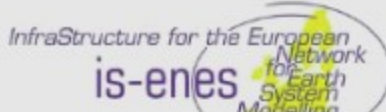

Description: NOAA GFDL GFDL-ESM2M, historical (run 1) experiment output for CMIP5 AR5

Further options: [Add To Cart](#) [Visualize and Analyze](#) [Model Metadata](#)





## Structured meta-data



Earth System Documentation - Viewer | CMIP5 Model - GFDL-ESM2M (v4)

CMIP5 Model - GFDL-ESM2M

ModelExperiment

OverviewCitationsContactsPropertiesComponents

Atmosphere

- Convection Cloud Turbulence
  - Cloud Scheme
- Dynamical Core
  - Advection
- Orography & Waves
- Radiation

Land Surface

- Albedo
- Carbon Cycle
- Vegetation

**Energy Balance**

Lakes

River Routing

Snow

Soil

- Heat Treatment
- Hydrology

Vegetation

Ocean

- Advection
- Boundary Forcing

Land Surface > Energy Balance

Properties

- Number Of Surface Temperatures : 1 Per Tile
- Scheme Method > Processes : Other
- Scheme Method > Processes : Transpiration
- Scheme Method > Type Of Evaporation Formulation : Other
- Scheme Method > Type Of Evaporation Formulation : Linked To Photosynthesis
- Specific Tiling : Yes
- Subsurface Tiling : Yes

Contacts

Role	PI
Person	—
Organisation	NOAA Geophysical Fluid Dynamics Laboratory
Address	—
Email	—
URL	—

Role	CONTACT
Person	—
Organisation	NOAA Geophysical Fluid Dynamics Laboratory
Address	—
Email	—
URL	—



## Detailed Quality Control

Scientists like to get the data on their own machine so that they can check every step of the analysis.

If analytics are done in the archive, we need to be very careful to ensure that small irregularities in the data do not contaminate the final results.

ExArch will tackle the standardisation of quality control tests, so that processing software can exploit QC results.

Test classes (e.g. range test)

Specific tests (e.g. Horizontal wind speed in range -200 to +200 m/s)

Test results (e.g. True {max=95; min=-64})

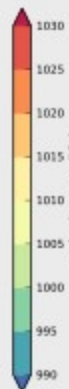
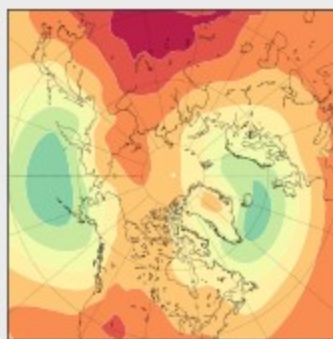
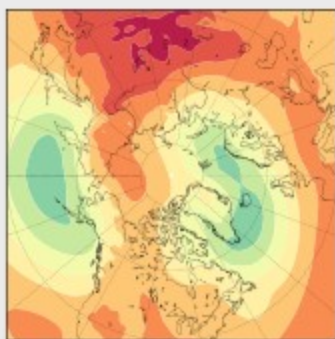


# Climate diagnostics benchmarks

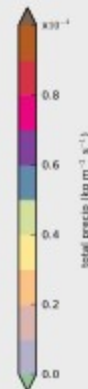
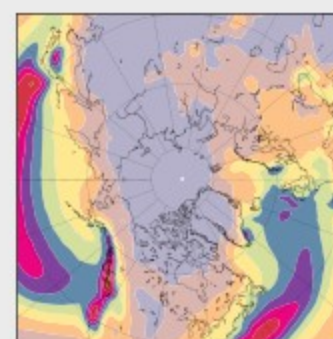
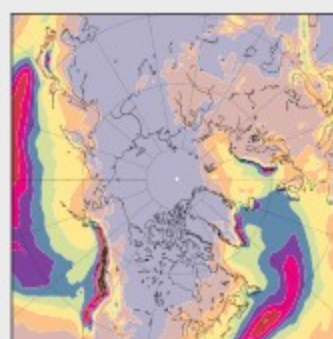
## • Benchmarking data processing workflows

- 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.

Sea-level pressure DJF



Precipitation DJF



## Governance issues

Climate science relies on global standardisation of file formats  
and will rely on global standardisation of data services;  
The range and complexity of the standards grows with the  
complexity of the data products;



## 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





## Summary

- ExArch covers a wide range of topics, with a focus on leverage existing work;
- The CMIP5 archive has created a global federation of linked data stores;
- ExArch will provide software to enable the global federation to meet exa-scale demands;



**British Atmospheric  
Data Centre**

NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE  
NATURAL ENVIRONMENT RESEARCH COUNCIL



# The end



ExArch, Toulouse, Feb., 2013

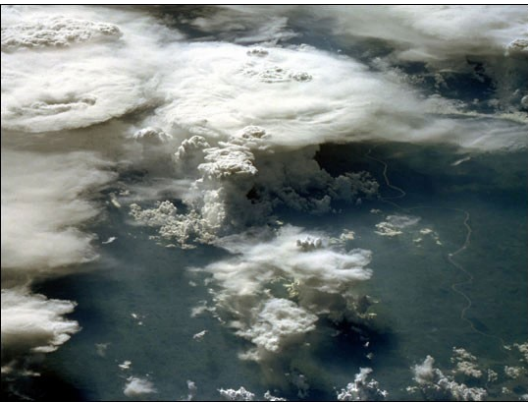
**RAL Space**

Harwell International Space Innovation Centre

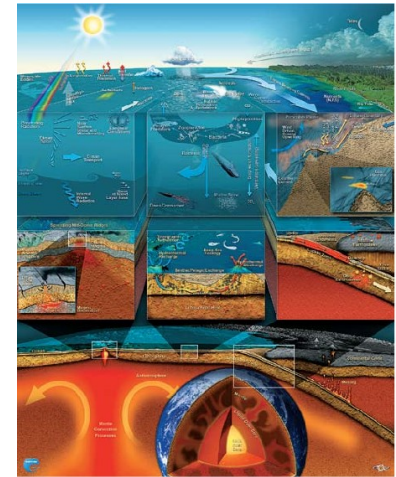




# Climate Science drivers



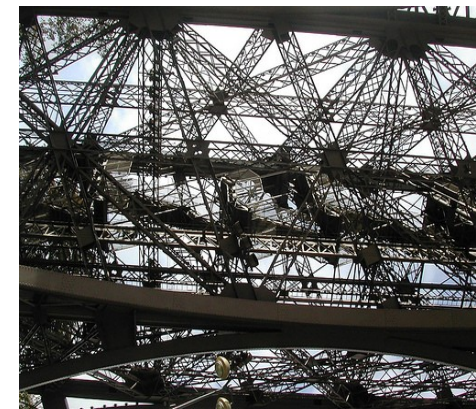
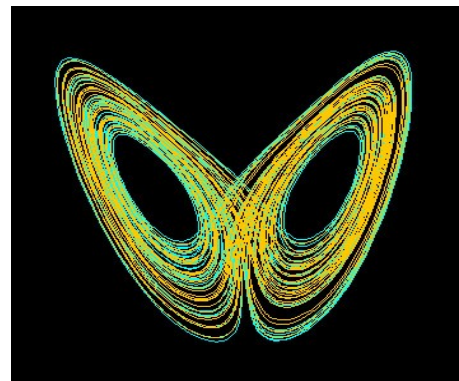
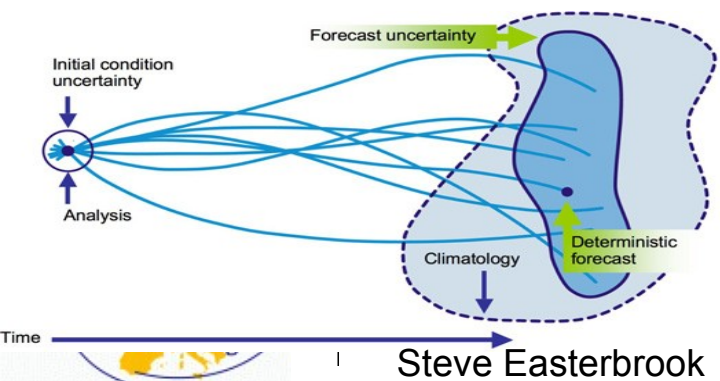
*Greater precision;  
Increased complexity;  
Improved quantification of  
uncertainty:*

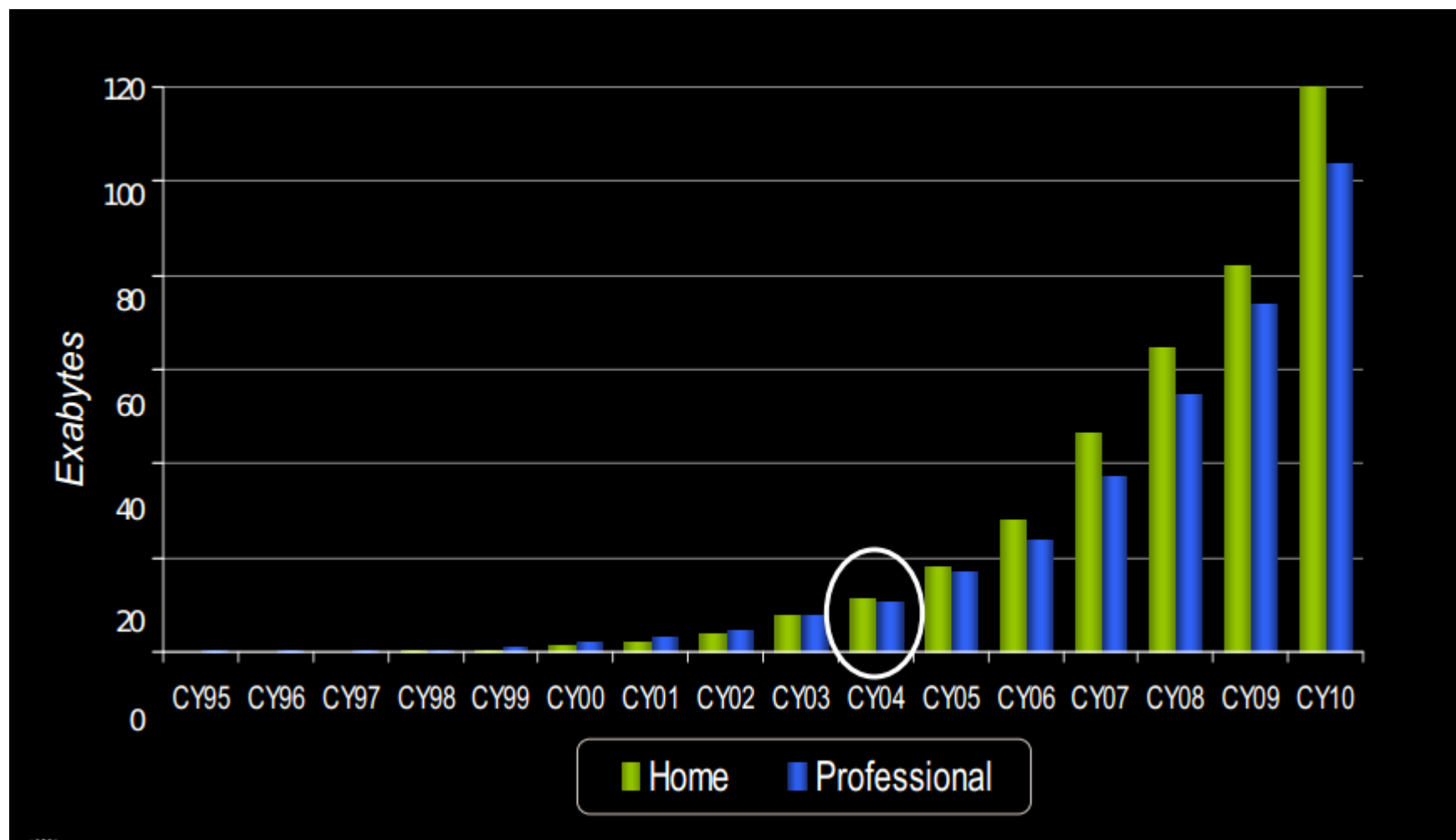


Delaney and  
Barga (2010)

*All in the context of increasing societal  
relevance.*

Earth Science Image Analysis Lab.





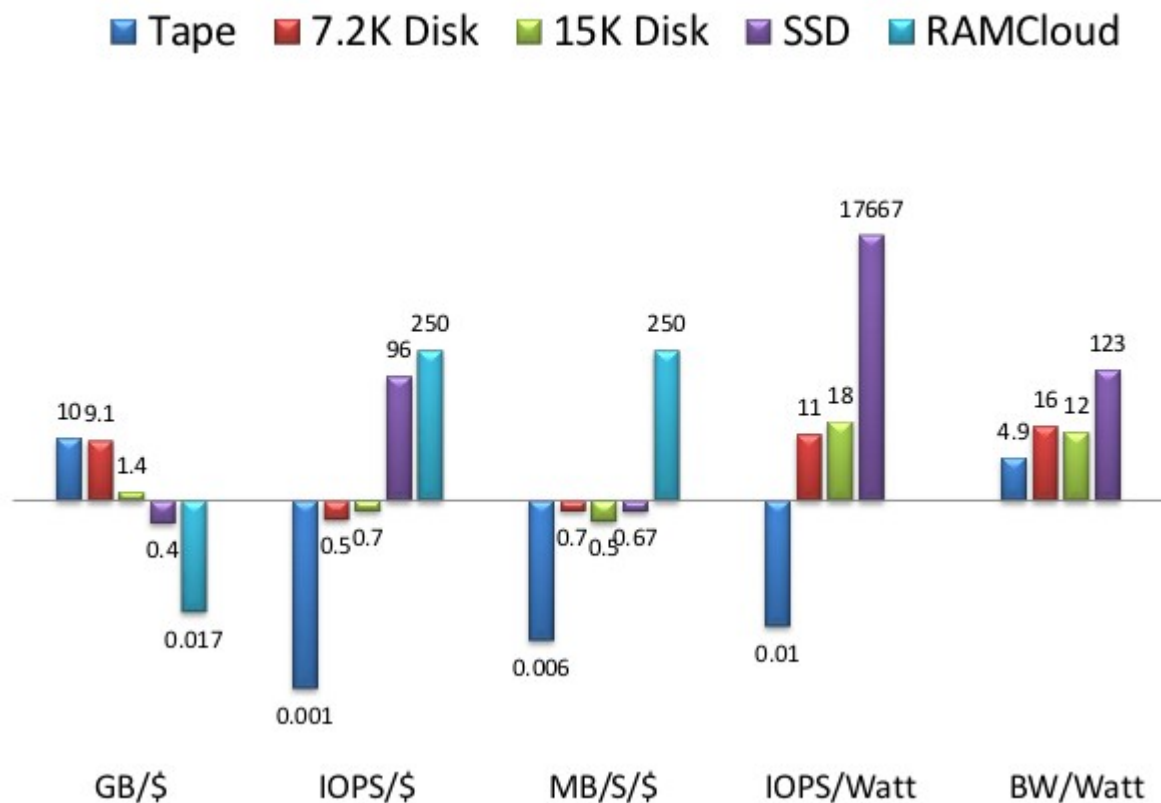
Dave Aune, Seagate (presentation at LLNL, August 2008)



ExArch, Toulouse, Feb., 2013

RAL Space

Harwell International Space Innovation Centre



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 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;





**British Atmospheric  
Data Centre**

NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE  
NATURAL ENVIRONMENT RESEARCH COUNCIL



## ExArch components



**Princeton  
University**



DKRZ



UNIVERSITY OF  
**TORONTO**  
**UCLA**



Centro Euro-Mediterraneo  
per i Cambiamenti Climatici



ExArch, Toulouse, Feb., 2013

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

**RAL Space**

Harwell International Space Innovation Centre



# 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);



ExArch, Toulouse

**UK CLIMATE PROJECTIONS USER INTERFACE**

Search UI Manual...

**Start page** **My jobs** **My details** **UI manual** **UKCP09 website** **Helpdesk**

You are here: > Outputs > Viewing and modifying your output

**Logged in as:**  
martin.jukes@...  
[Logout](#)

**Logged in users:** 3

You have no pending jobs.  
See [My Jobs](#) for previously run jobs.

**Request Status:**

**Request Summary:**

**Data Source:**  
UK Probabilistic Projections of Climate Change over Land

**Climate Change Type:**  
Future Climate Change

**Plot Details:**

Data Source: Probabilistic Land  
Future Climate Change: True  
Variables: temp\_1mean\_1mean\_10s, precip\_1mean\_1mean\_perc  
Emissions Scenario: Medium  
Time Period: 2040-2069

Temporal Average: ANN  
Spatial Average: Grid Box 25km  
Location: Grid Box No. 1276  
Probability Data Type: samp\_data

**Viewing and modifying your output**

The [Graphics page](#) allows you to modify the output that has been generated in response to your request. Here you can make changes to the look of the plot or modify the contents of your data request to update the plot.

At any time you can download the plot or its underlying data in various formats using the buttons in the bottom right corner.

Users wishing to download large volumes of outputs from the UI are recommended to use the [CSV Archive](#). You can browse and download many of the underlying data files in CSV format. The CSV files are grouped into zip files to make the process more efficient.

**Change your request**

**Climate Change Type**  
Future Climate Change Only

**Variable Batch**   
Batch 1

**Variable**  
Change in mean temperature (°C)

**Variable**  
Change in precipitation (%)



# 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

## Common Information Model

[Home](#)
[Ontology](#)
[Repository](#)
[Tools](#)



# REPOSITORY - SEARCH

Project

Document Type

Document Version

Document Language

Search

CMIP5

All

Latest

English

Experiments (40)

Models (29)

Simulations (323)

Ensembles (189)

Grids (32)

Platforms (13)

Data (159)

1 to 25 of 29 entries

Filter:

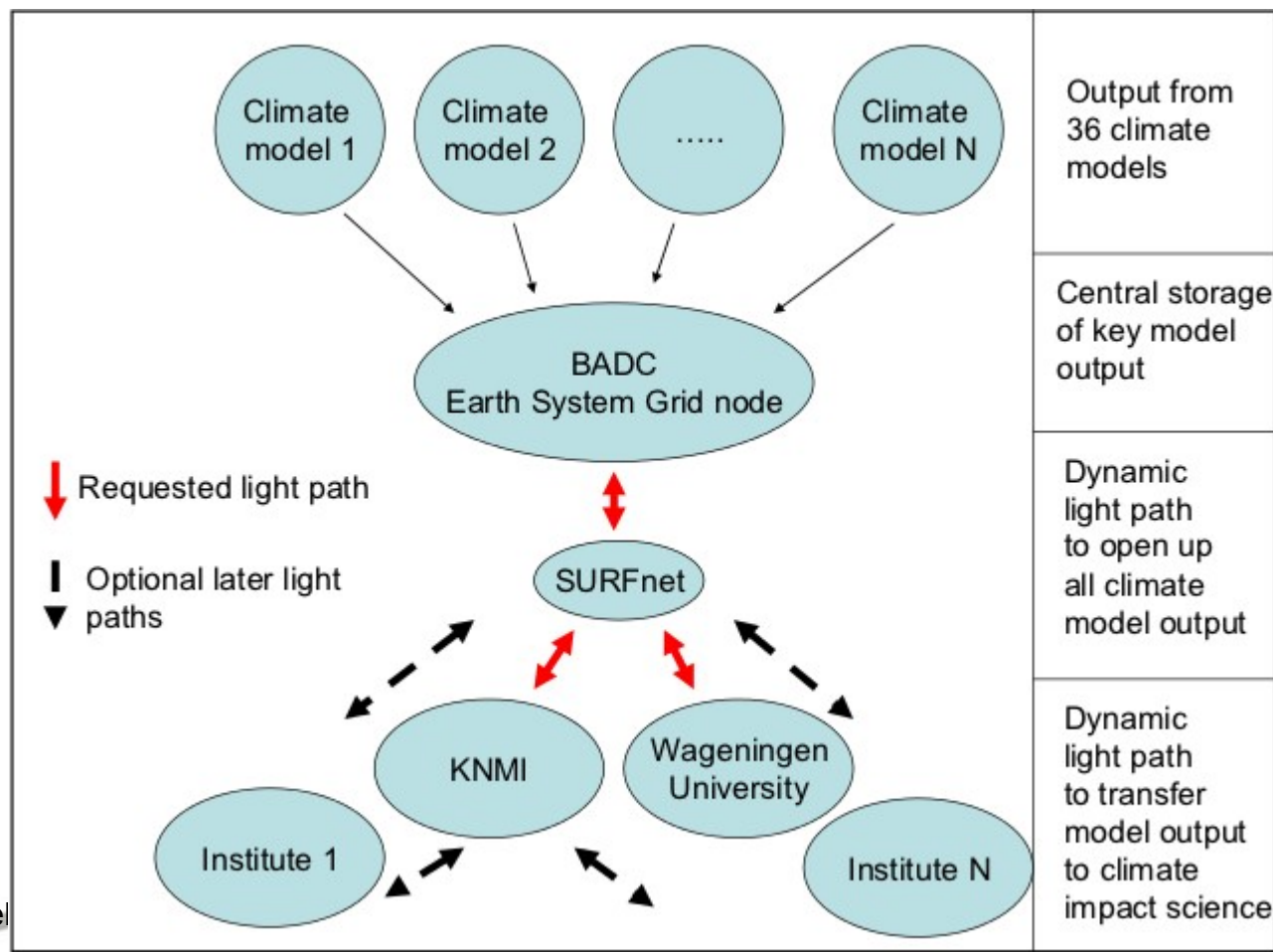
Project	Short Name	Long Name	Released	Vers.		
CMIP5	BCC_CSM1.1	Beijing Climate Center Climate System Model version 1.1	2011	3	<a href="#">xml</a>	<a href="#">json</a>
CMIP5	CCSM4	Community Climate System Model 4 with 1° atmosphere, land, ocean, and sea ice	2010	1	<a href="#">xml</a>	<a href="#">json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



## 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.





**British Atmospheric  
Data Centre**

NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE  
NATURAL ENVIRONMENT RESEARCH COUNCIL



# The end



ExArch, Toulouse, Feb., 2013

**RAL Space**

Harwell International Space Innovation Centre



## *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;