Exploiting (high volume) Climate Simulations and Observations

Bryan Lawrence

National Centre for Atmospheric Science
on behalf of the
European Network for Earth System Modelling

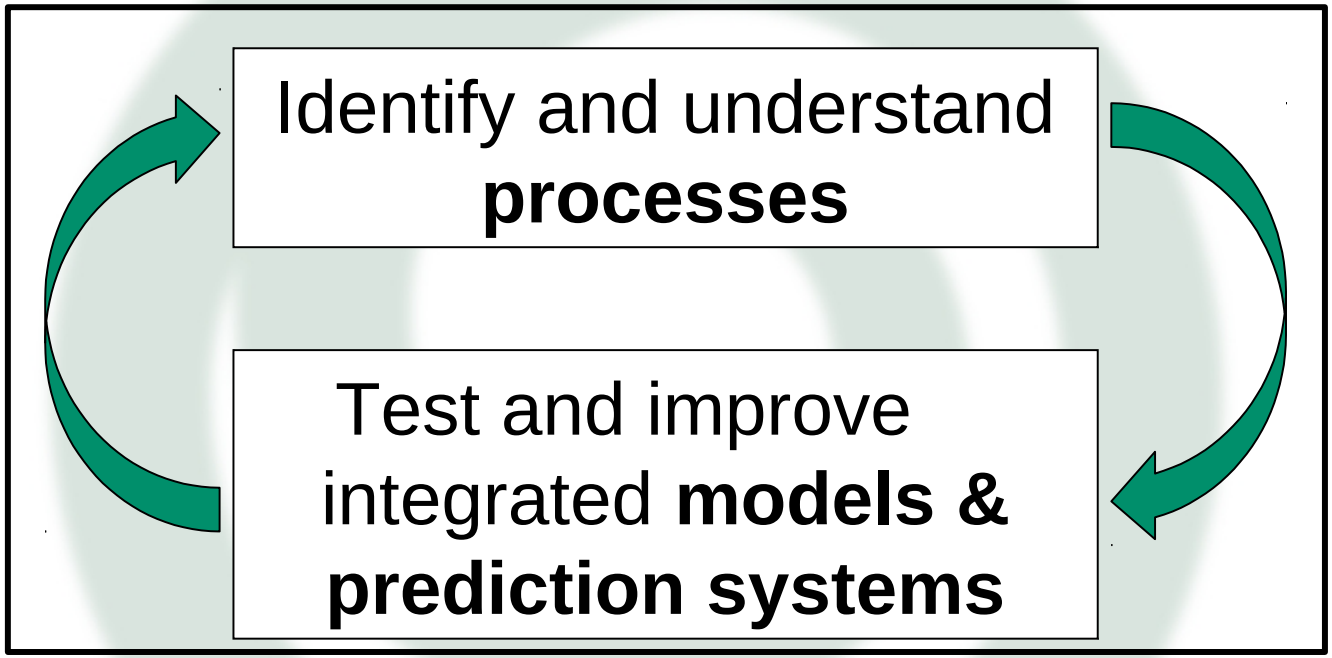
With contributions from
Sylvie Joussaume, Stephen Pascoe
and others

Exploiting climate simulations and observations

Outline:

1) Science Drivers
    - Understanding, Initialising, Evaluating, Predicting ...
2) ENES
3) European and U.S. Strategies
    - IS-ENES Foresight Strategy
    - (US) National Academy Strategy
4) Distributed Data Infrastructure
    - GO-ESSP and ESGF
    - OBS4MIP
    - A walk through ESGF
    - Final thoughts for the future: CHARM. CEMS
5) Summary

How do we advance climate science?



Adapted from R.Sutton, June 2012

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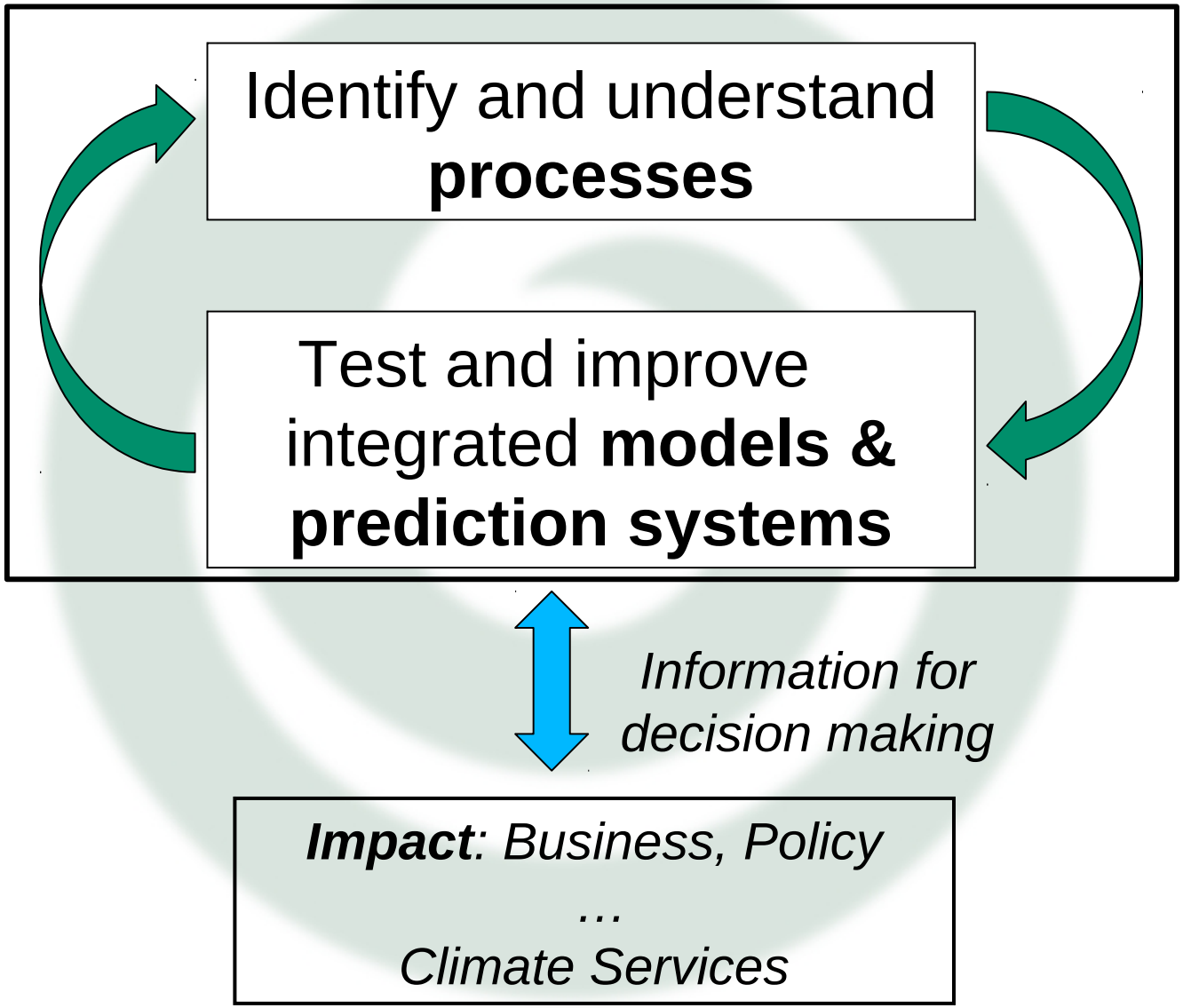

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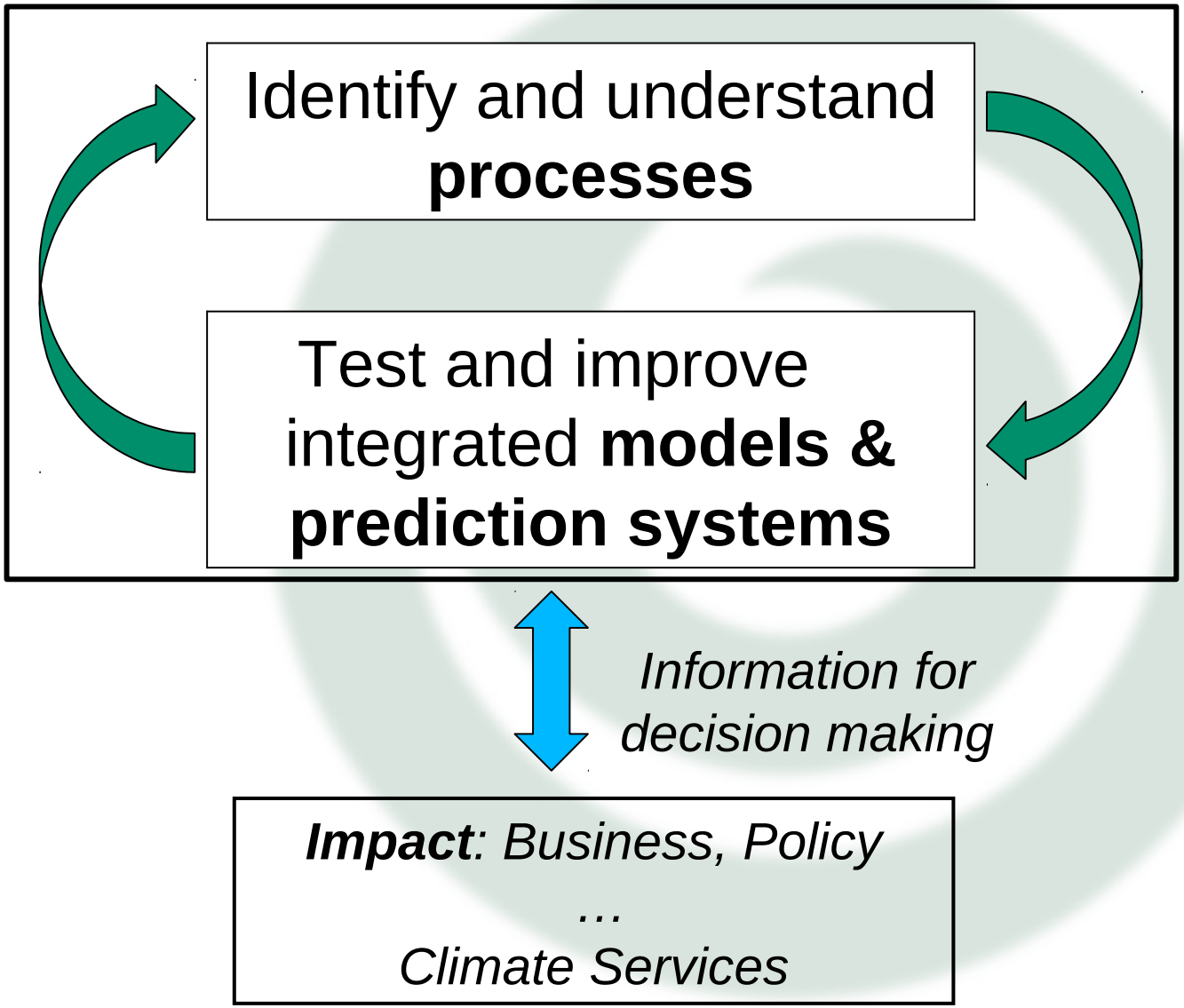

observations and models are centrally involved in both activities

observations *alone are not Enough!*

models *alone are not Enough!*

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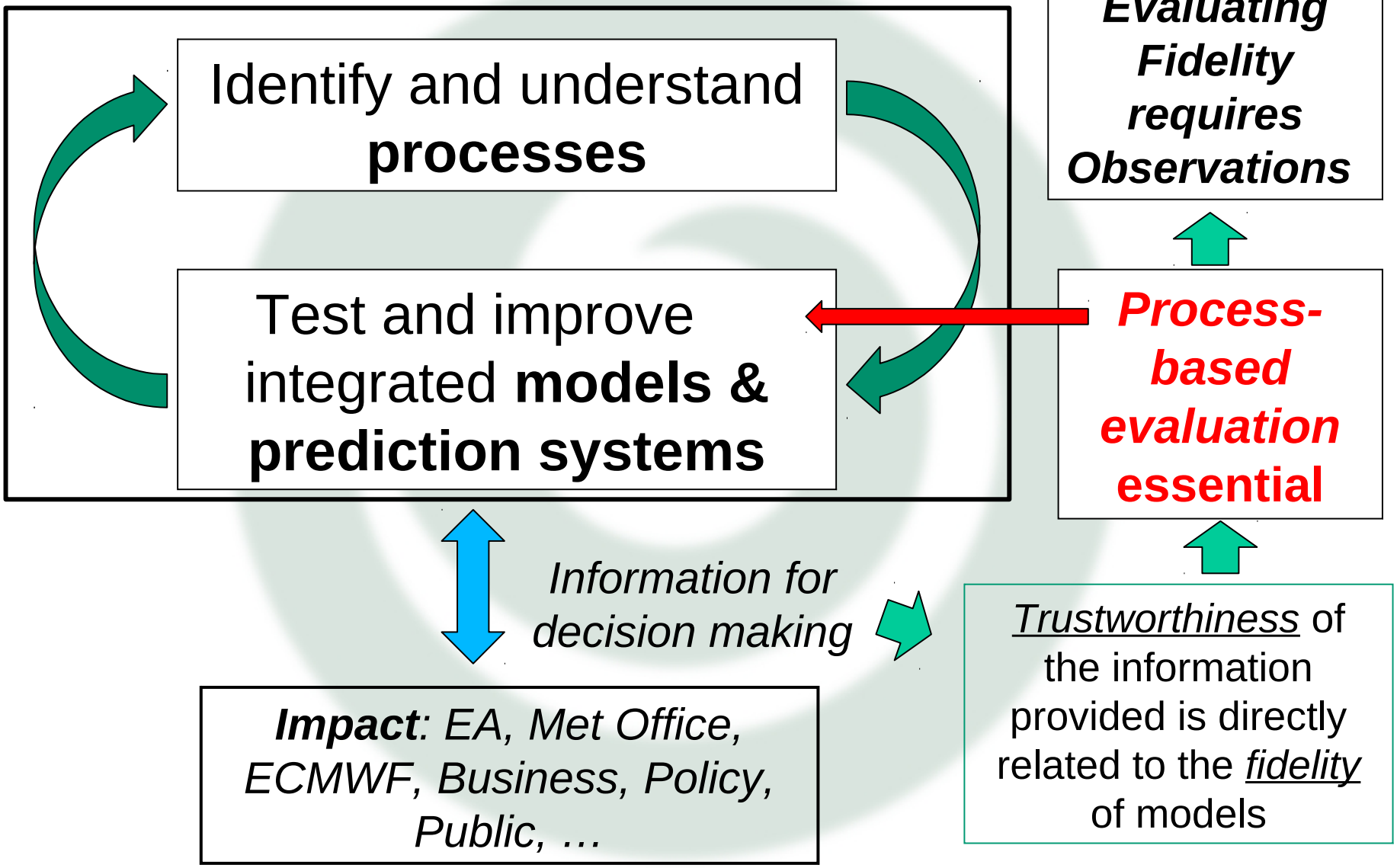
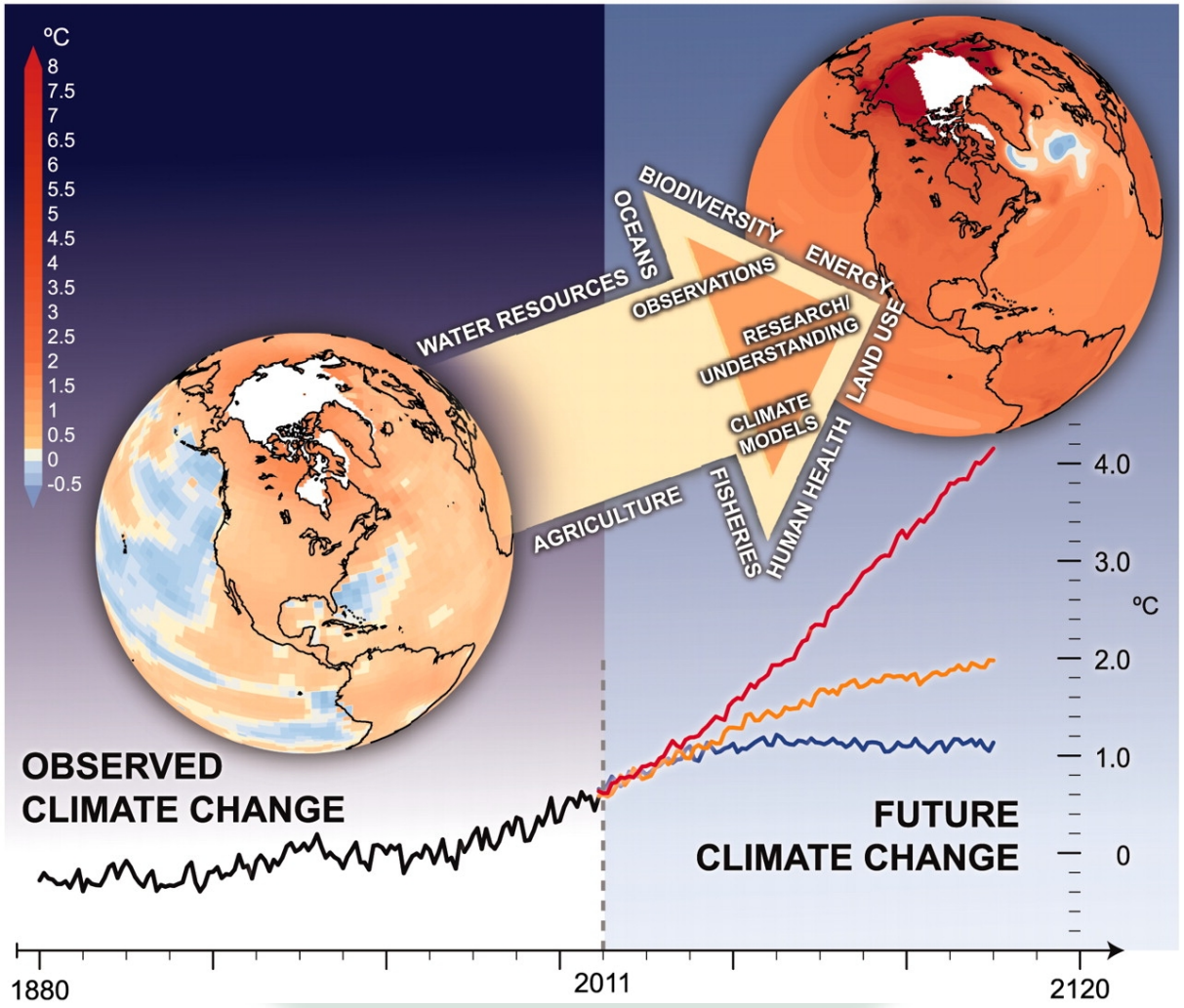
How do we advance climate science?



Adapted from R.Sutton, June 2012

Observations crucial to evaluation AND prediction!



J T Overpeck et al. Science 2011;331:700-702

Science
AAAS

A Modest Proposal (from Rowan Sutton)

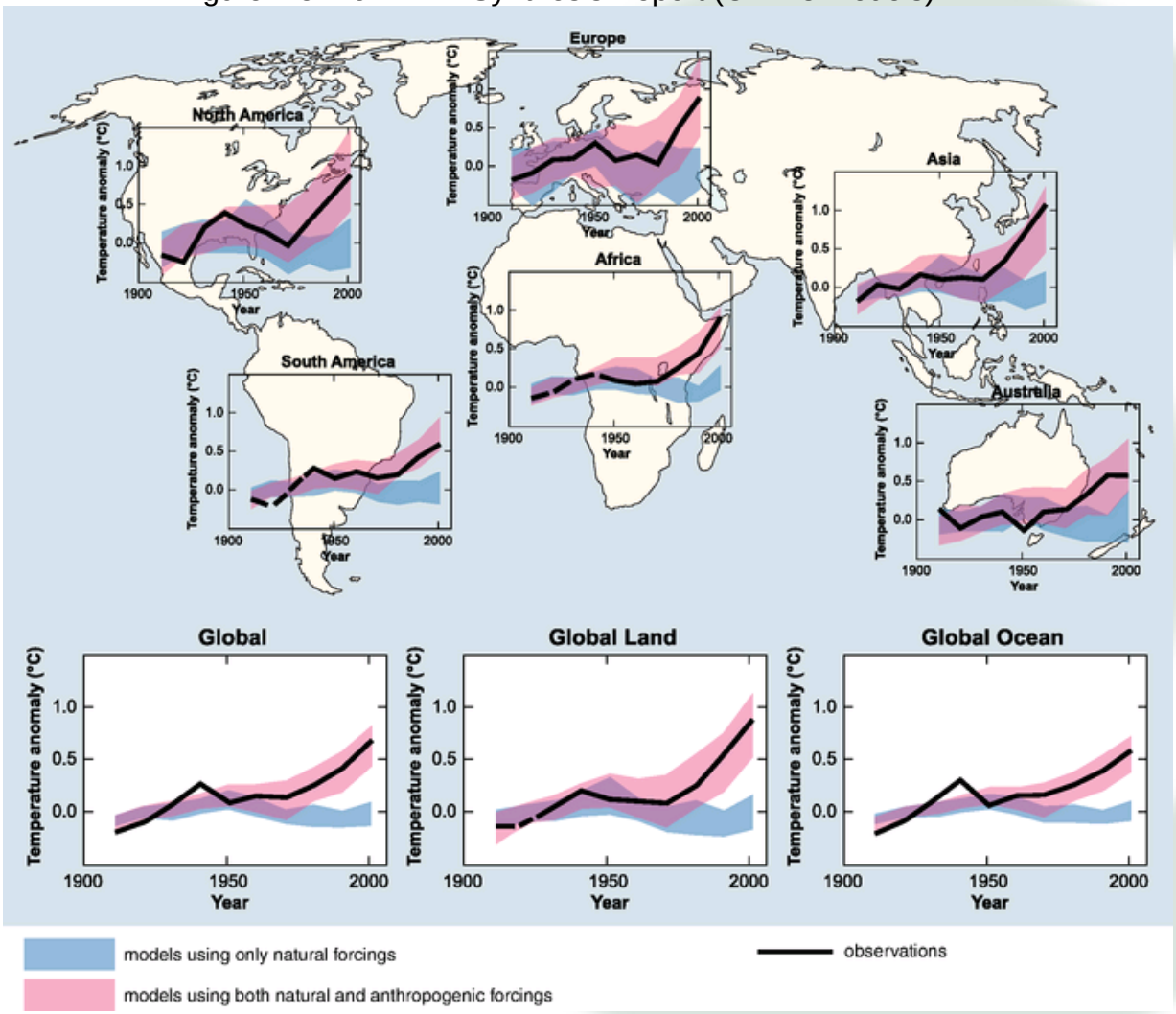
An (earth system) model cannot be judged fit for the purpose of **projection** until it has been shown to be capable of **simulating past** observed changes on **relevant timescales**, within **known uncertainties**, **for all variables for which sufficient observations are available.**

A necessary, though not sufficient, condition for confidence in (near term) climate projections.

A measurable, relevant, and useful target for model evaluation.

Implementation

Figure 2.5 from AR4 Synthesis Report (CMIP3 Models)



Require consistency for **all** variables of interest, within uncertainties due to:

- Forcings
- Internal variability
- Observations

May need more attention to fully sampling the uncertainties in past emissions, especially aerosol

All CMIP5 models would fail this test => A useful driver of progress

Why haven't we done that?

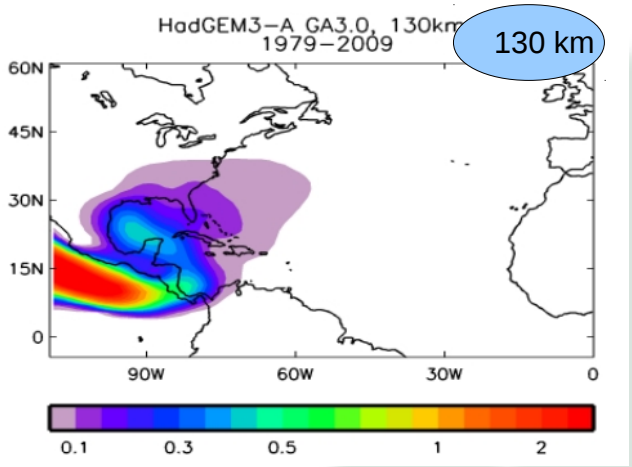
Some (but not all of) the answers:

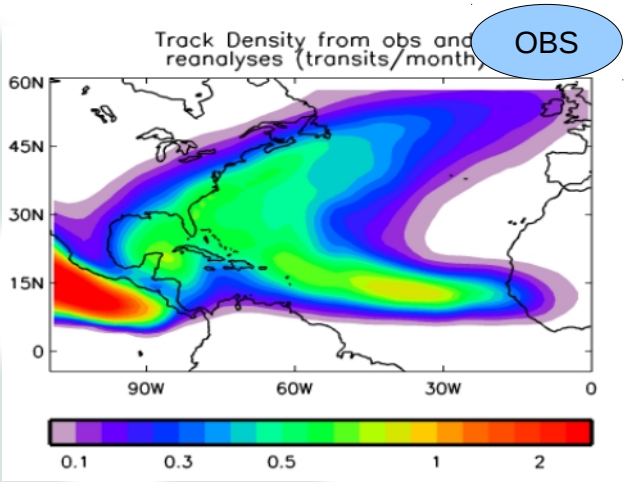
- Model resolution is not yet good enough (but getting there).
- Process understanding (and hence model complexity) is not yet good enough (but getting there)
- We can't initialise our models and keep them on the same trajectory as the real climate.

(but assimilating initial conditions help)

- We don't have enough data, and much of what data we have is not accessible enough to use! (but getting there)
  - Constraints include: delivery systems, formats, metadata, …, and eventually, … we get to words like quality and accuracy!

But we're getting there: inexorable progress ...

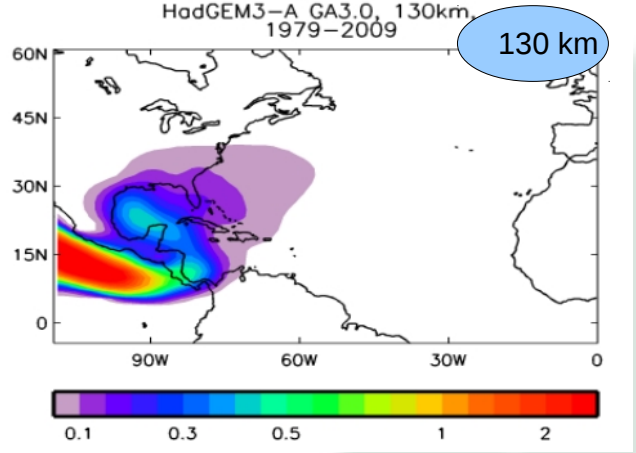


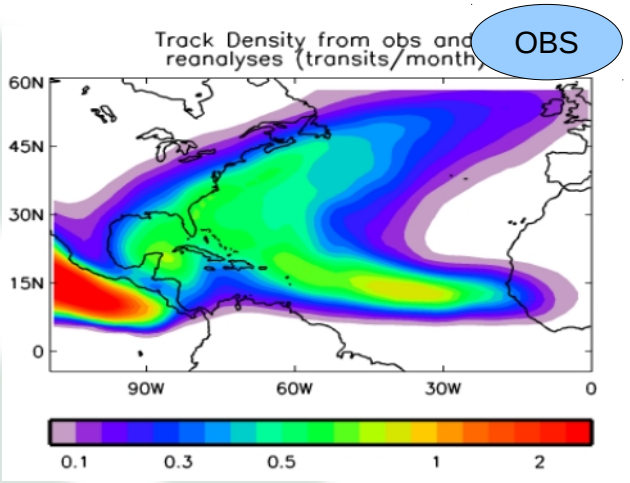


Tropical cyclone tracks: transits per month.

Slide adapted from material from Roberts and Vidale

But we're getting there: inexorable progress ...





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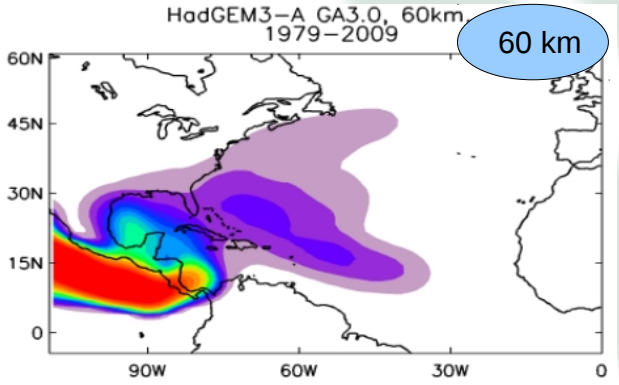
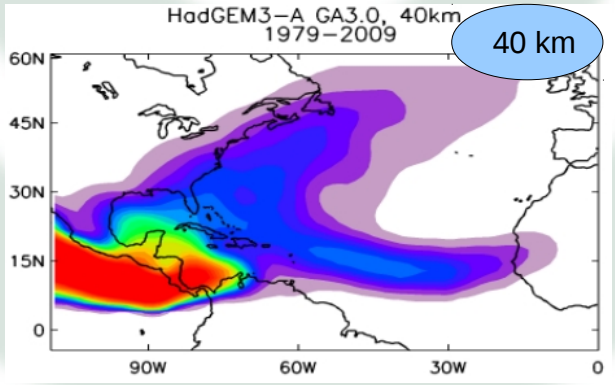
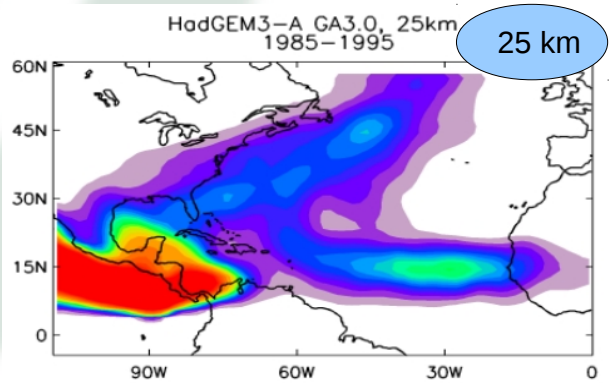






Slide adapted from material from Roberts and Vidale
UPSCALE Project (PI P-L Vidale, NCAS, University of Reading.)

European Network for Earth Simulation

Sylvie JOUSSAUME, CNRS-IPSL, Coordinator

Scientific Board : S. Joussaume, J.C. André, J. Mitchell, T. Palmer, J. Marotzke, R. Budich, A. Navarra, P. Kabat, B.N. Lawrence

+

ENES (http://enes.org)

EUROCLIVAR foresight in 1998, recommended:

(http://www.knmi.nl/euroclivar/frsum.html)

"a better integration of the European modelling effort with respect to human potential, hardware and software"

A network of European groups in climate/Earth system modeling

Launched in 2001 by Guy Brasseur

More than 40 groups from academic, public and industrial world

Main focus : accelerate European progress in climate/Earth system modelling and understanding

Several EU projects

FP5: PRISM, FP6: ENSEMBLES,
FP7: METAFOR, COMBINE, **IS-ENES**, EUCLIPSE, EMBRACE
IS-ENES2, SPECS
Collaboration with PRACE

European Research Area

National funding **:**

Examples: UK (NERC); France (INSU); Germany (BMBF) ....

European Commission funding :

(over the last 30 years, 3-4 year projects)

Environment projects: ENSEMBLES; COMBINE ....

Infrastructure projects: IS-ENES ; METAFOR ...

NEW: Joint Programming Initiative

Long-term coordination and programming between countries for societal challenges

JPI Climate :
Integrate knowledge on climate change for society

Moving towards decadal prediction
Developing climate services
Understanding societal transformation
Tools for decision-making (impact/vulnerability/adaptation)

IS-ENES : Infrastructure for ENES

FP7 project « Integrating Activities »

InfraStructure for the European Network for Earth System Modelling

is-enes

1st phase: 2009-2012 (7.6 M€), 18 partners
2nd phase: 2013-2016 (8 M€), 23 partners

Infrastructure
Models and their environment
Model data
Interface with HPC ecosystem

Users
The ENES community
Regional Climate Models
Impacts Studies

http://is.enes.org/

Europe : 7 global climate models
CMCC, MPI-ESM, EC-Earth, Hadley, IPSL, Meteo-France , NorESM

Support to international databases :
CMIP5 & CORDEX
EuroCordex, Africa, Medcordex

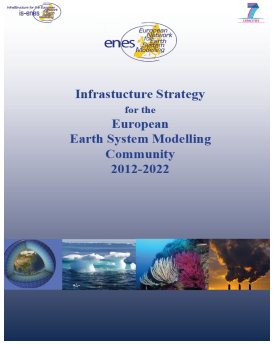
WCRP World Climate Research Programme

ENES Strategy Drivers : Science & Society

From understanding to the development of “Climate Services”

Key science questions

- What is needed to provide reliable predictions of regional changes in climate?
- How predictable is climate ?
- What is the sensitivity of climate (feedbacks, nonlinear behaviours) ?
- Can we model and understand glacial-interglacial cycles ?
- Can we attribute observed signals and understand processes ?



Foresight Meetings
Montvillargennes, Mar 2010, Hamburg, Feb 2011
52 contributors from BE, CZ, DE, DK, FI, FR, IT, NO, SE, SP, UK

Infrastructure Strategy for the European Earth System Modelling Community, 2012-2022

A European Infrastructure

Many Recommendations, including:

4. **Build a physical network** connecting national archives with transfer capacities exceeding Tbits/sec.

But in the context of the CCI, detail includes:

DATA

Integrate distributed databases

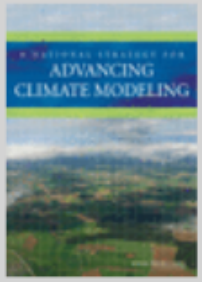
exploit CMIP5 & CORDEX, metadata & common standards

Large data storage commensurate with HPC

Develop interoperability with observations

Develop interface with the impact communities

U.S. Strategy (published September, 2012)



A National Strategy for Advancing Climate Modeling

ISBN
978-0-309-25977-4

300 pages
7 x 10
PAPERBACK (2012)

Committee on a National Strategy for Advancing Climate Modeling; Board on Atmospheric Studies and Climate; Division on Earth and Life Studies

The nation should (9 bullet points, precise for this meeting):

1. Evolve to a common national software infrastructure that supports a diverse hierarchy of different models for different purposes …
2. Convene … forum … promotes tighter coordination and more consistent evaluation …
3. Nurture a unified weather-climate modeling effort …
5. Sustain the availability of state-of-the-art computing systems for climate modeling
8. Enhance the national and international IT infrastructure that supports climate modeling data sharing and distribution

Recommendation 8:

Growth rate of climate model data archives is exponential, and maintaining access to this data is a growing challenge!

...

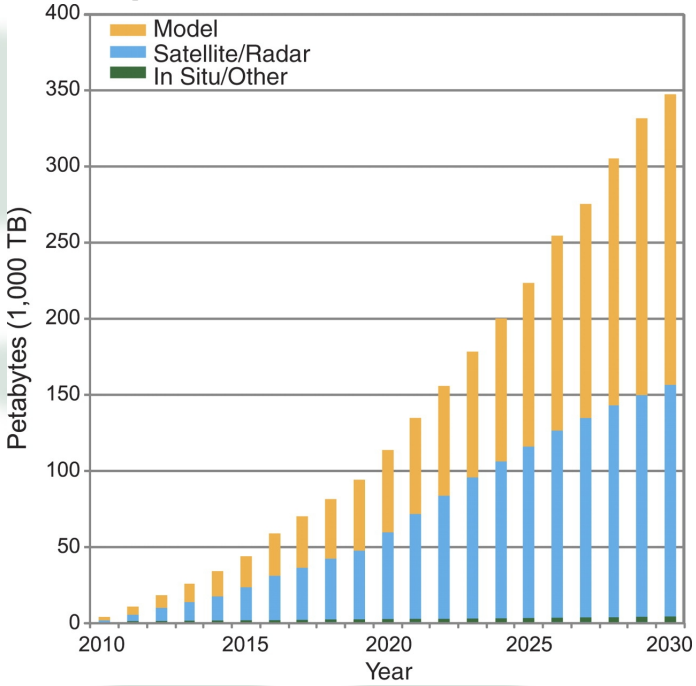
the climate research community and decision makers and other user communities desire to analyse and use (simulation and observational) data in increasingly sophisticated ways.

…

These two trends imply growth in resource demands that cannot be managed in ad-hoc way. Instead

Data-sharing infrastructure … should be systematically supported as an operational backbone for climate research and serving the use community.

J T Overpeck et al. Science 2011;331:700-702



Without substantial research effort into new methods of storage, data dissemination, data semantics and visualization, ***all aimed at bringing analysis and computation to the data, rather than trying to download the data and perform analysis locally***, it is likely that data might become frustratingly inaccessible to users!

Some pithy quotes from the NA report

Finding 5.3: To be useful for evaluating climate and Earth system models, observations need to be regionally comprehensive, global in scope and **internationally coordinated** in a way that **ensures consistency** and transparency across measurement standards, spatial and temporal sampling strategies, and **data management protocols** (metadata standards, quality control, uncertainty estimates, processing techniques, etc.).

Another issue with climate data from all sources is that there are **significant differences in the metadata, availability,** and provision of error/uncertainty estimates for different climate datasets. While it is difficult to make this globally conformable, climate model validation and inter-comparison exercises require a thorough understanding of the available data and its limitations. **The climate observing and modeling communities are not optimally integrated, so observations are not always used appropriately.**

(An) effort in its early stages is “Obs4MIPs,” which is an attempt to provide modeling groups with a limited collection of well established and documented data sets that have been organized according to the CMIP5 model output requirements. **More activities along these lines should be supported**, as they are **vital** to the integrity of observational, modeling and prediction studies of climate variability and change.

The formatting and gridding of the various datasets should not be an issue to the user …

Ideally, the development of such an infrastructure would be primarily community-organized and well-coordinated with model intercomparison efforts (which require exactly this kind of product, but then also generate model outputs on the same grid).

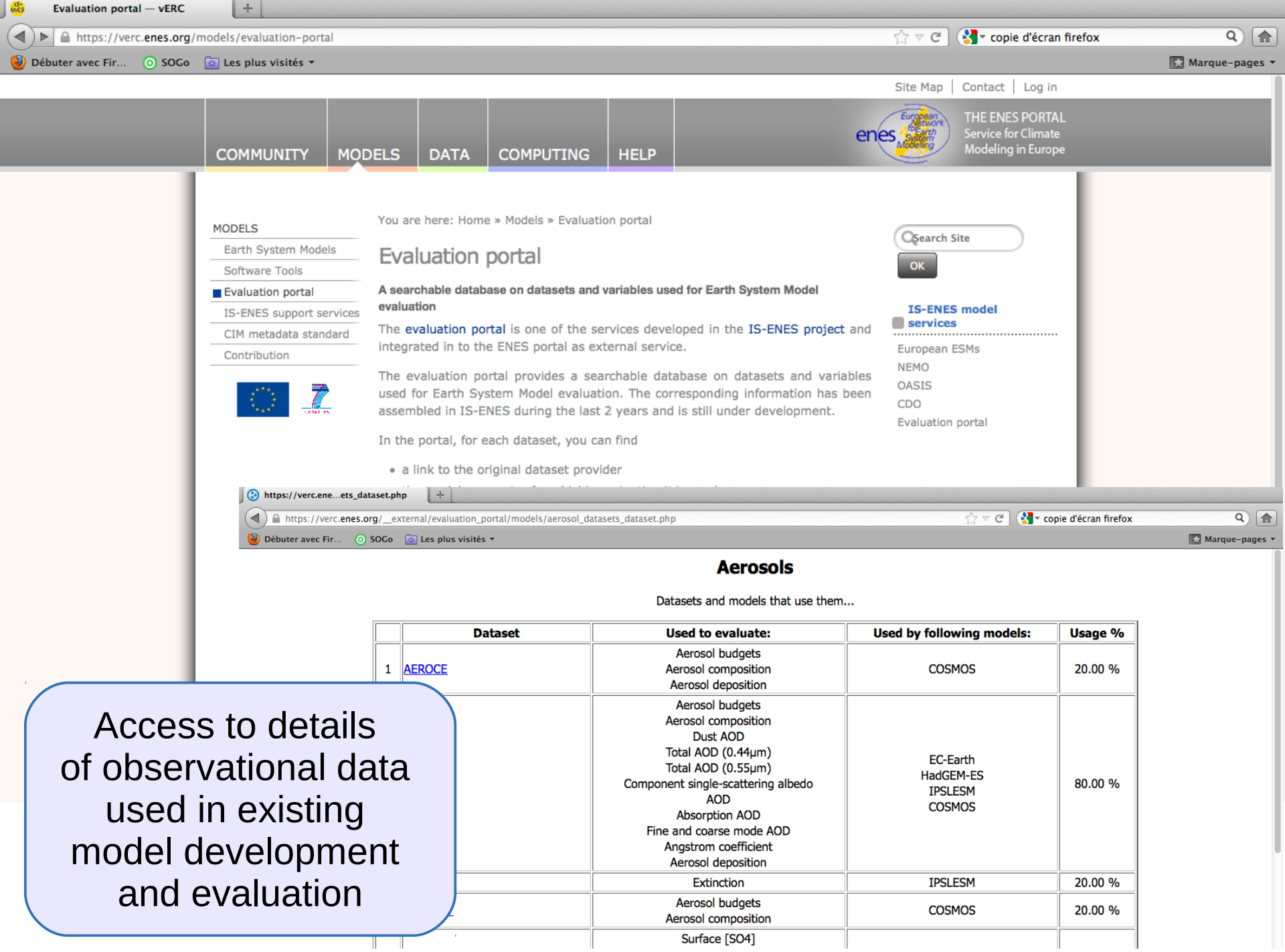
Key Pieces of European and Global Infrastructure

Earth System Grid Federation:

- evolved from the US Earth System Grid to become a global federation
- (currently) governed by the Global Organisation for Earth System Science Portals
- consists of data nodes and index nodes
- some nodes act as replicant archives (have copies of large parts of the global distibuted archive).

European Networks:

- have evolved from a range of activities.
- mostly under defacto goverance of ENES since IS-ENES1 and 2 provide bulk funding.
- Key components include the Virtual Earth System Resource Centre (VERC) and the European components of ESGF:
  - DKRZ and BADC replicant archives
  - A range of data and index nodes



Access to details of observational data used in existing model development and evaluation

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

ENES Portal Interface for the Climate Impact Communities (Prototype)

IS-ENES Website

ENES Portal Interface for the Climate Impact Communities

Welcome to the ENES **Portal Interface for the Climate Impact Communities (EPICIC)**, oriented towards climate change impact modellers, impact and adaptation consultancy offices, as well as scientists using climate change data.

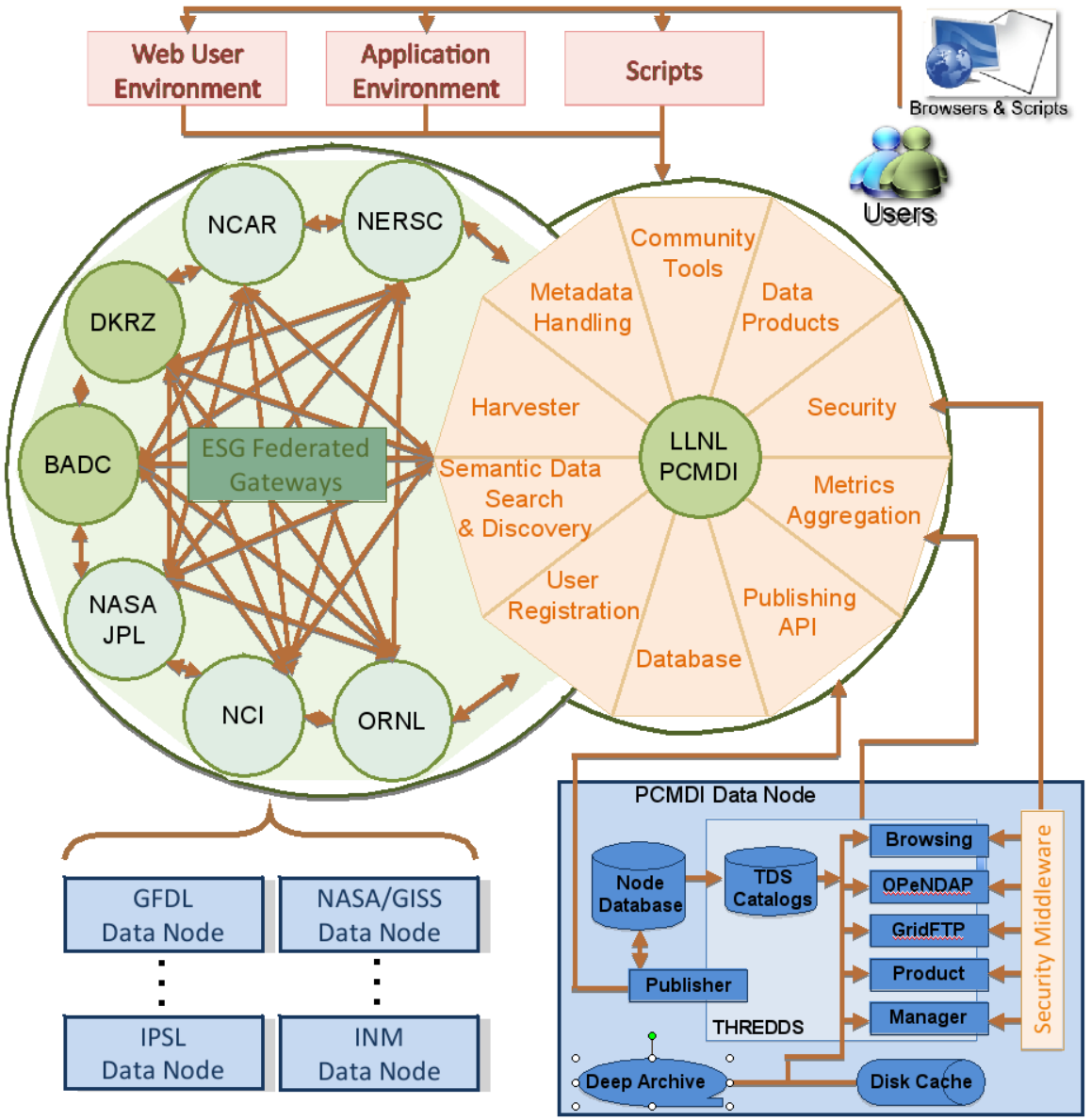
Here you will find **access to data** and *quick looks* of global climate models (GCM) scenarios, as well as some regional climate model (RCM) and downscaled higher resolution climate data. The portal provides data transformation tooling for **tailoring data** to your needs and **mapping & plotting** capabilities. All using standardised interfaces and common data processing tools to access and process data, properly described with standardised metadata.

Guidance on how to use climate scenarios, **documentation** on the climate system, frequently asked questions (FAQ) and **examples** in several impact and adaptation themes (Use Cases) are presented and described, along with the steps required to go from the GCM data to the impact model input data (workflow).

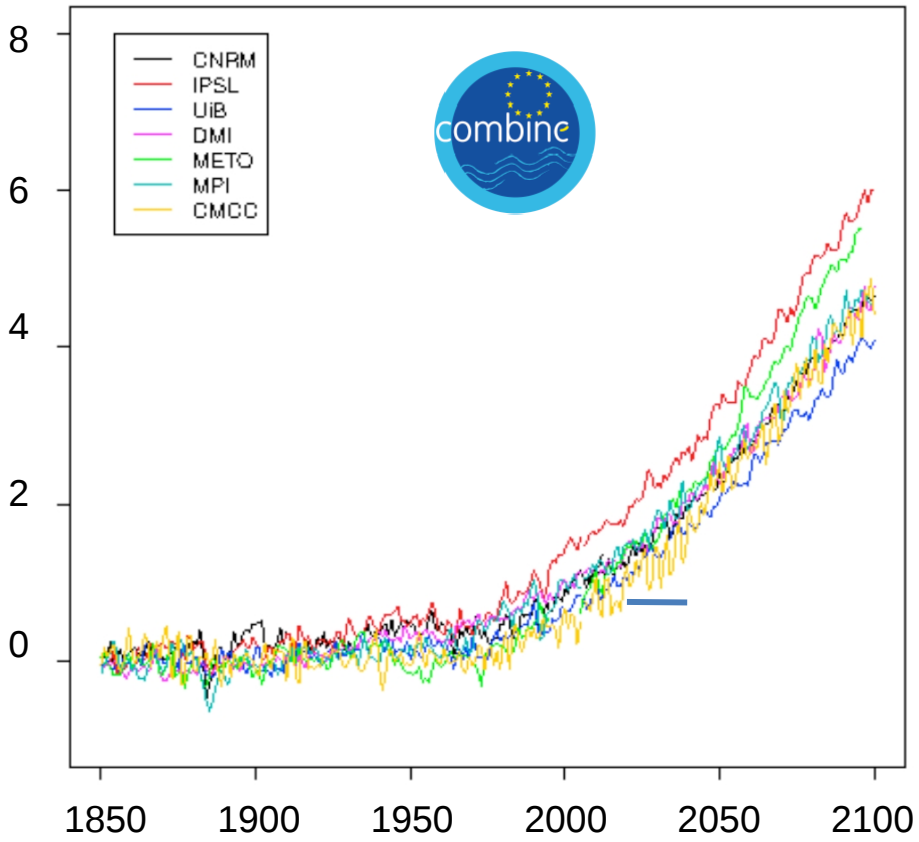
The Earth System Grid Federation

Data Nodes,
providing data services and publishing to
Data Indexes/Gateways linked in a
Global Federation

At least three nodes committed to ***persisting*** the data!



Temperature change (°C)
Historical and RCP8.5 – European models



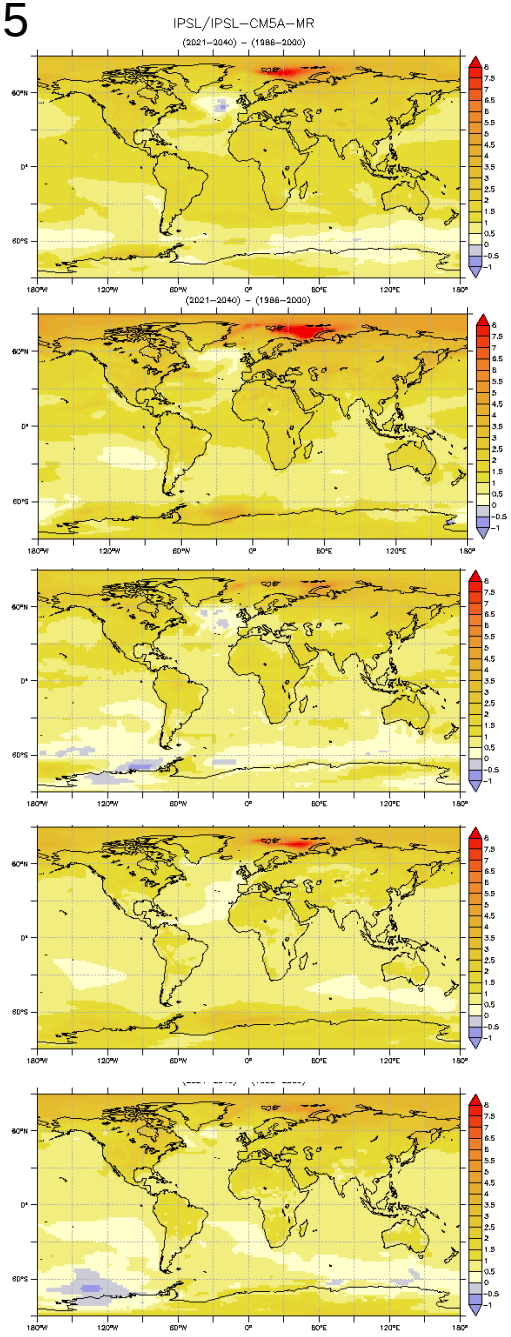
Climate change projections

CMIP5: Fifth Coupled Model Intercomparison Project : Strong international effort

RCP8.5

(2021-2040) minus (1986-2000)

CMIP5



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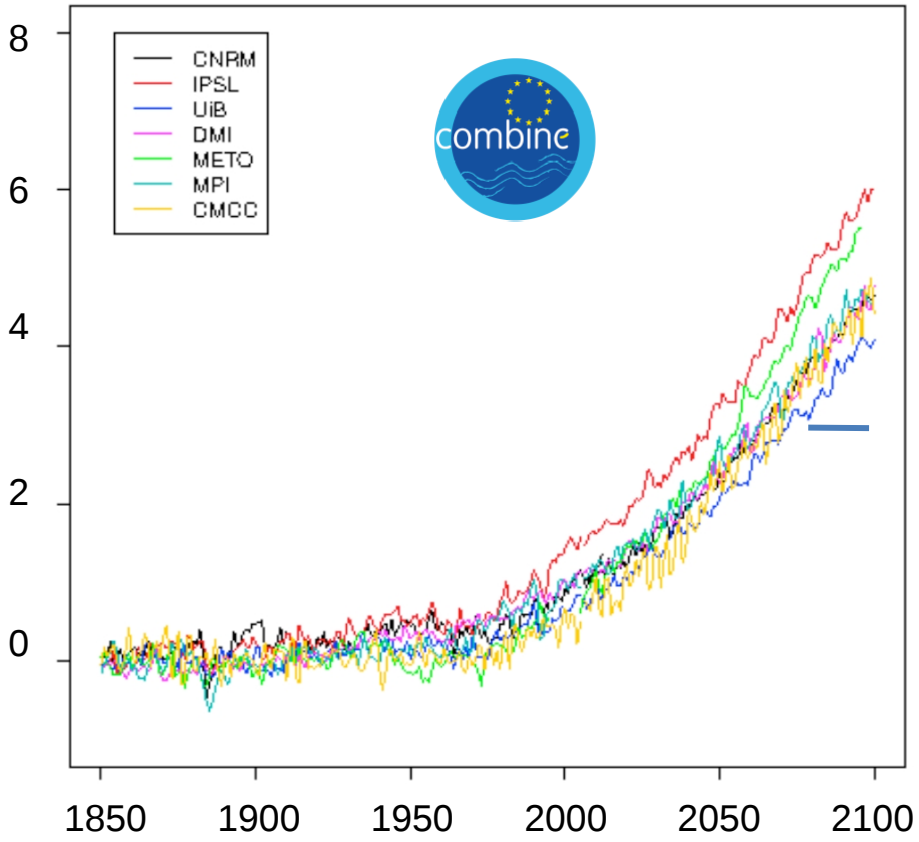
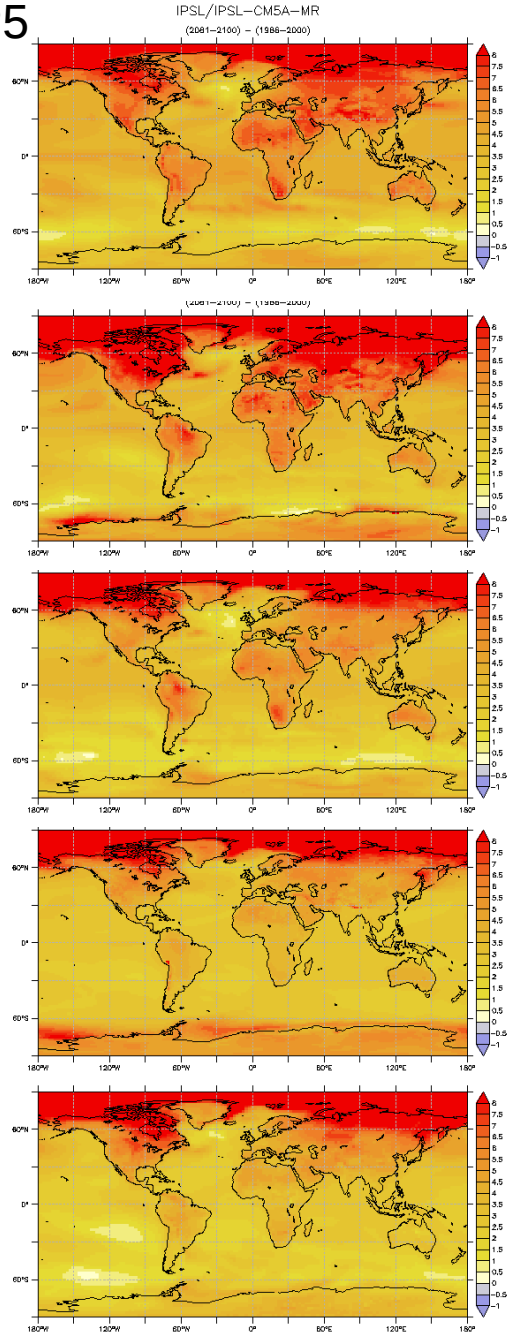


Climate change projections

CMIP5: Strong international effort

RCP8.5
(2081-2100) minus (1986-2000)

CMIP5



CMIP5 Archive Status

Last Update: *Sunday, 23. September 2012 12:11AM* (UTC)

CMIP5 Federated Archive

Summary	
Modeling centers	27
Models	59
Experiments	96
Data nodes	23
P2P Index	10
Datasets	55735
Size	1,762.37 TB
Files	4,005,595

Latest version only; no replicas.

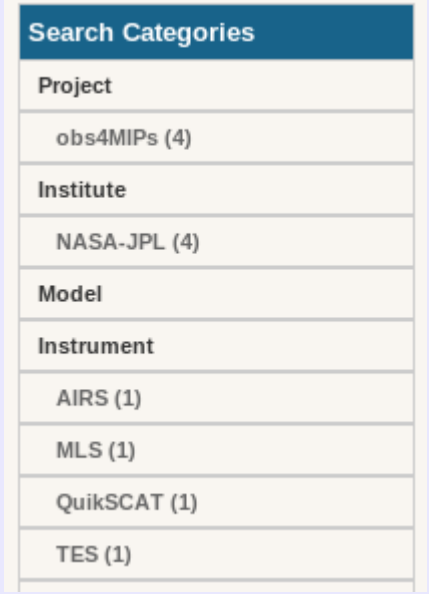
Search Categories
Project
CMIP5 (53203)
CORDEX (7)
COUND (4)
CSSEF (102)
GeoMIP (327)
LUCID (143)
PMIP3 (137)
TAMIP (1344)
TEST (11)
ana4MIPs (1)
cloud-cryo (10)
euclipse (1)
geomip (62)
obs4MIPs (16)

BADC alone has had 96 Tb of (mostly UKMO) data downloaded in last calendar year.

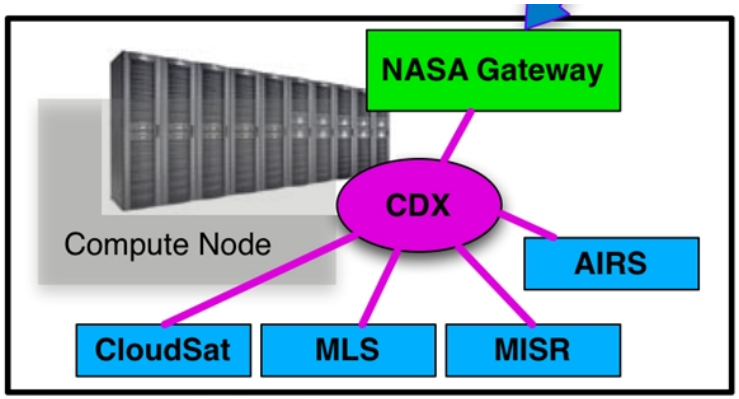
… beyond CMIP5!

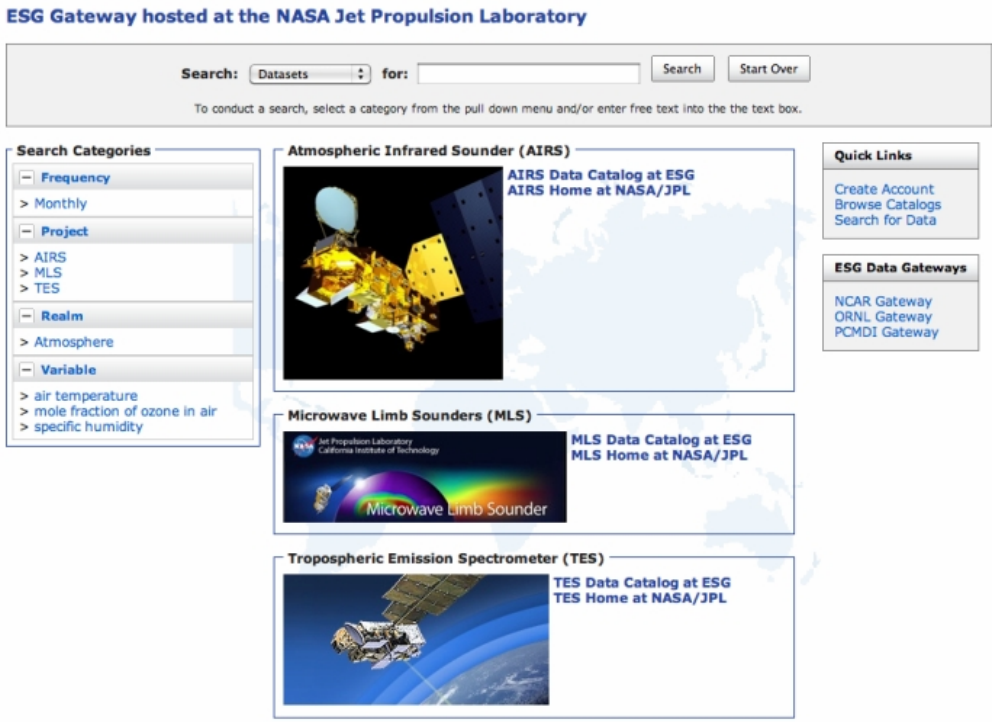
NASA JPL & CMIP5

JPL and PCMDI have established a collaboration through the ESG to share observations to support *model-to-data comparison*

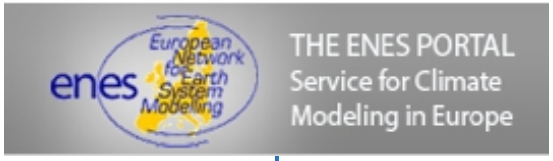


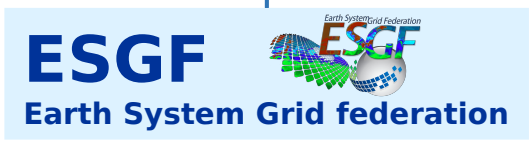
Earth System Grid





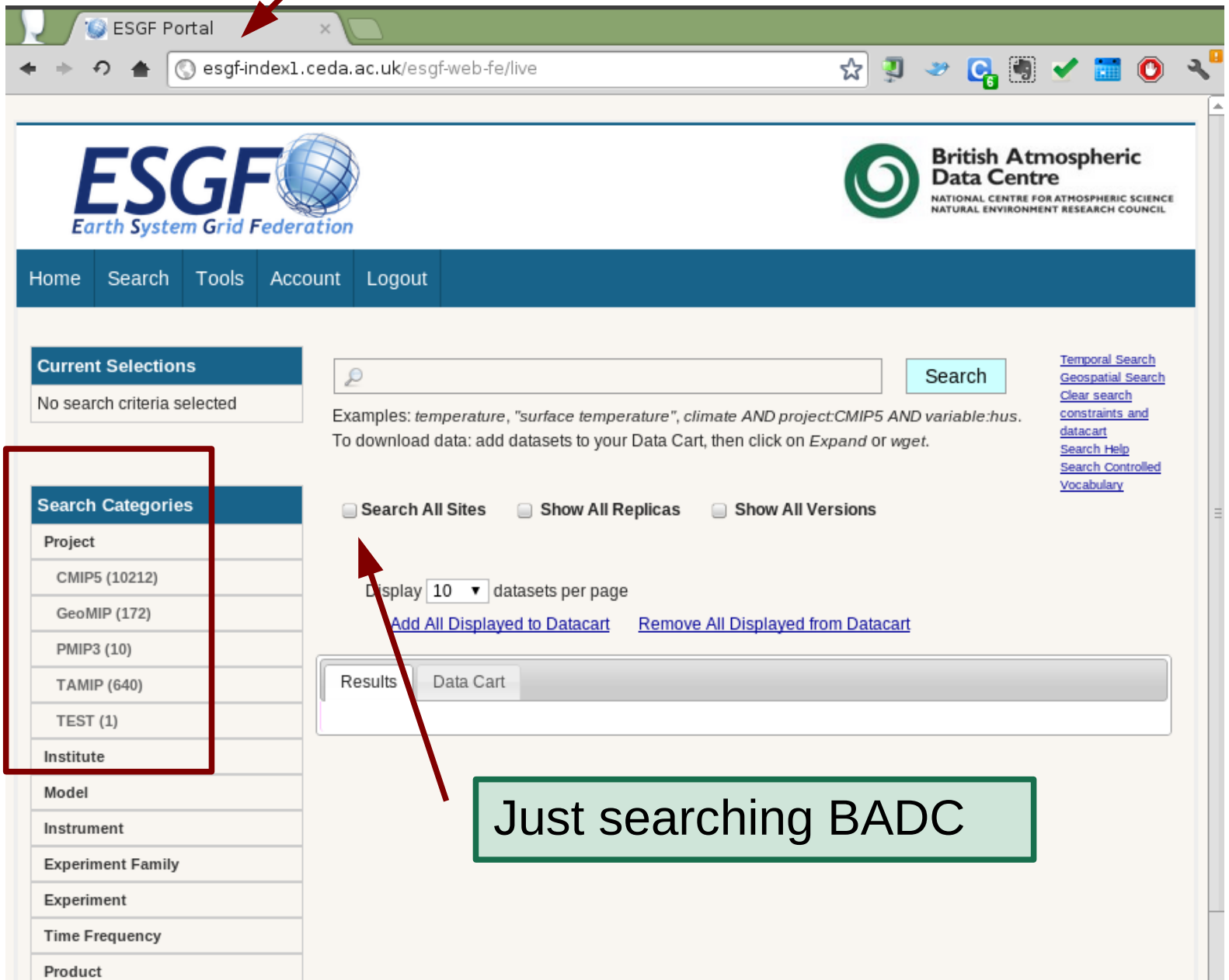
Information courtesy of Dean Williams, Luca Cinquini and Dan Crichton



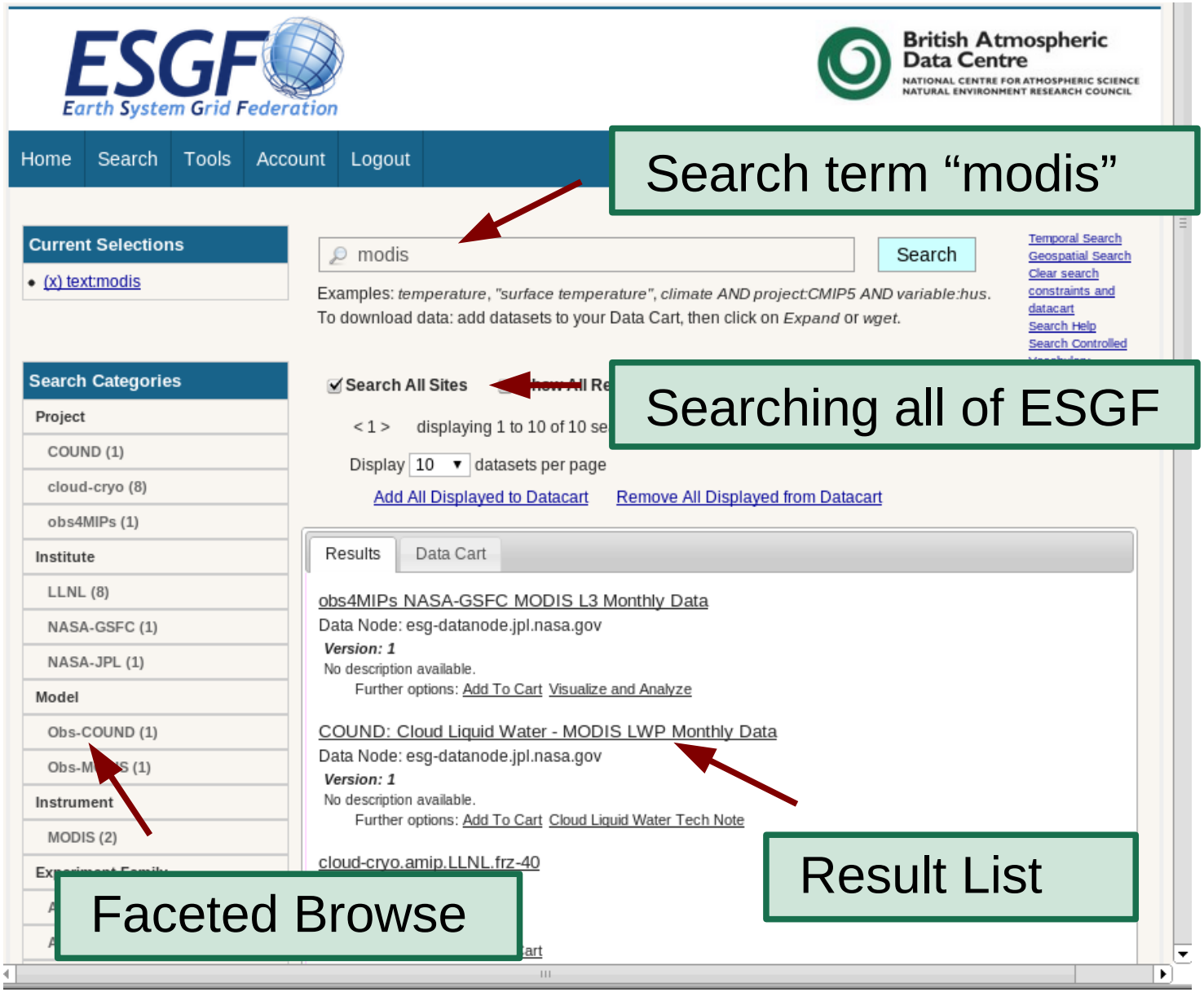


ENES collaboration with PCMDI, ESGF and GO-ESSP

BADC ESGF INDEX node



Just searching BADC


ESGF
Earth System Grid Federation
British Atmospheric Data Centre
NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE
NATURAL ENVIRONMENT RESEARCH COUNCIL
Home
Search
Tools
Account
Logout
Search term “modis”
Current Selections
(x) text:modis
modis
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
Search Categories
Search All Sites
Searching all of ESGF
< 1 > displaying 1 to 10 of 10 se
Display 10 datasets per page
Add All Displayed to Datacart
Remove All Displayed from Datacart
Project
COUND (1)
cloud-cryo (8)
obs4MIPs (1)
Institute
LLNL (8)
NASA-GSFC (1)
NASA-JPL (1)
Model
Obs-COUND (1)
Instrument
MODIS (2)
Results
Data Cart
obs4MIPs NASA-GSFC MODIS L3 Monthly Data
Data Node: esg-datanode.jpl.nasa.gov
Version: 1
No description available.
Further options: Add To Cart Visualize and Analyze
COUND: Cloud Liquid Water - MODIS LWP Monthly Data
Data Node: esg-datanode.jpl.nasa.gov
Version: 1
No description available.
Further options: Add To Cart Cloud Liquid Water Tech Note
cloud-cryo.amip.LLNL.frz-40
Faceted Browse
Result List

ESGF Earth System Grid Federation

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

Home | Search | Tools | Login

Current Selections

- remove all
- (x) text:modis
- (x) project:obs4MIPs

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

Search Categories

- Project
- Institute
- Model
- Instrument
- Experiment Family
- Experiment
- Time Frequency
- Product
- Realm
- Variable
- Variable Long Name
  - Total Cloud Fraction (1)
  - Total Cloud Fraction Number of Observations (1)
  - Total Cloud Fraction Standard Deviation (1)

< 1 > displaying 1 to 1 of 1 search results

Display 10 ▾ datasets per page

Add All Displayed to Datacart Remove All Displayed from Datacart

Results | Data Cart

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

☑ **obs4MIPs.NASA-GSFC.MODIS.mon.v1|esg-datanode.jpl.nasa.gov**
(Total Number of Files: 3) Expand | WGET | Remove

Downloading Data

Downloading across federation: each node is part of their own local environment.

Users don't want multiple passwords:

ESGF solution:

- Access control using OpenID for web based authentication and X509 certificates for scripts.

Web site provides “wget scripts”, which are editable scripts which provide bulk download capabilty!

Also provide support for:

- native http download (click and download)
- OpeNDAP, and
- … and whatever the datanode provide as endpoints (as listed in the THREDDS catalogue), e.g. WMS etc.

ESGF Earth System Grid Federation

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

Home | Search | Tools | Login

Current Selections

- remove all
- (x) text:modis
- (x) project:obs4MIPs

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

Search Categories

- Project
- Institute
- Model
- Instrument
- Experiment Family
- Experiment
- Time Frequency
- Product
- Realm
- Variable
- Variable Long Name
  - Total Cloud Fraction (1)
  - Total Cloud Fraction Number of Observations (1)
  - Total Cloud Fraction Standard Deviation (1)

< 1 > displaying 1 to 1 of 1 search results

Display 10 ▾ datasets per page

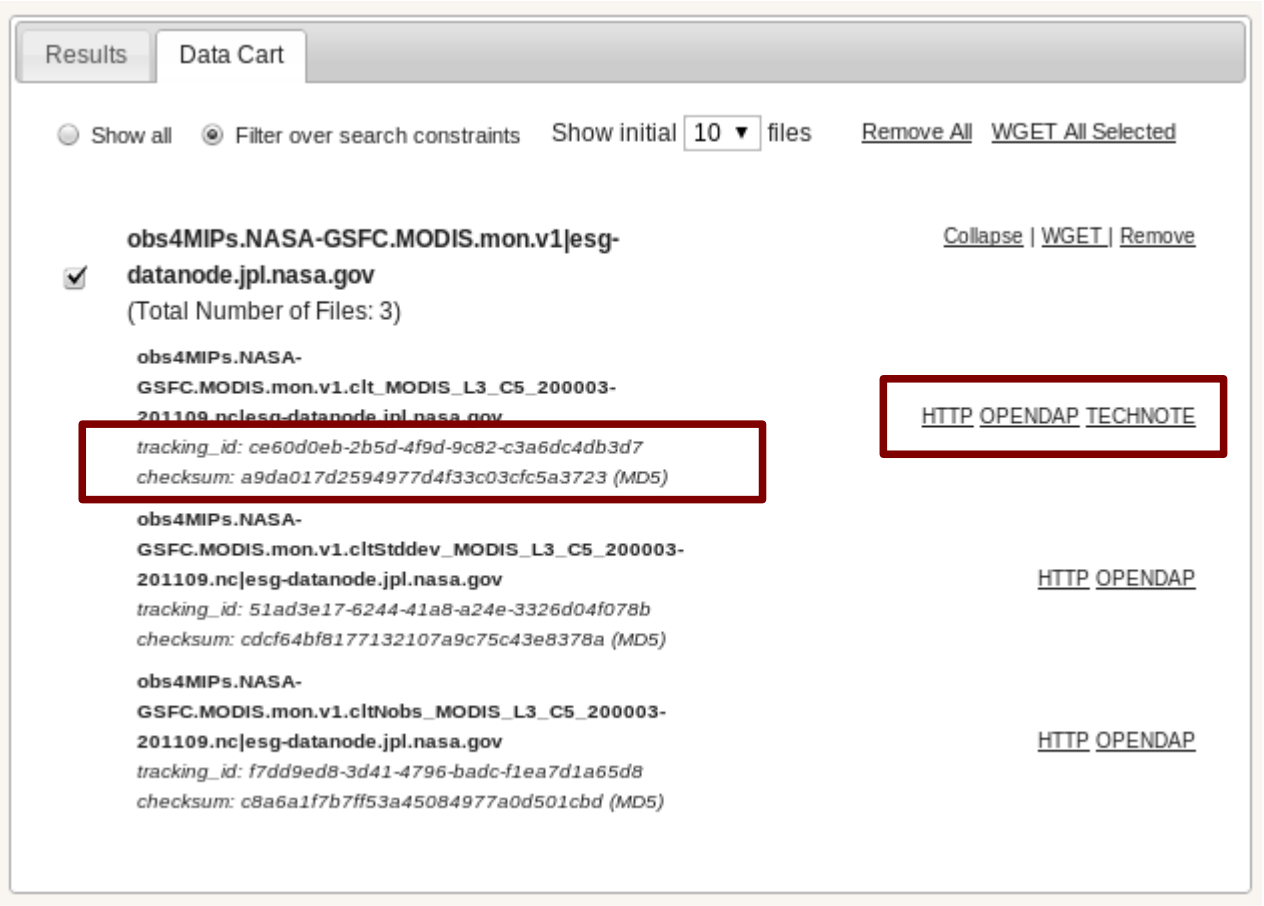
Add All Displayed to Datacart | Remove All Displayed from Datacart

Results | Data Cart

◯ Show all ◉ Filter over search constraints Show initial 10 ▾ files Remove All | WGET All Selected

☑ **obs4MIPs.NASA-GSFC.MODIS.mon.v1|esg-datanode.jpl.nasa.gov**
(Total Number of Files: 3)

Expand | WGET | Remove


Results
Data Cart
Show all
Filter over search constraints
Show initial 10 files
Remove All
WGET All Selected
obs4MIPs.NASA-GSFC.MODIS.mon.v1|esg-datanode.jpl.nasa.gov
(Total Number of Files: 3)
Collapse | WGET | Remove
obs4MIPs.NASA-GSFC.MODIS.mon.v1.clt_MODIS_L3_C5_200003-201109.nc|esg-datanode.jpl.nasa.gov
tracking_id: ce60d0eb-2b5d-4f9d-9c82-c3a6dc4db3d7
checksum: a9da017d2594977d4f33c03cfc5a3723 (MD5)
HTTP OPENDAP TECHNOTE
obs4MIPs.NASA-GSFC.MODIS.mon.v1.cltStddev_MODIS_L3_C5_200003-201109.nc|esg-datanode.jpl.nasa.gov
tracking_id: 51ad3e17-6244-41a8-a24e-3326d04f078b
checksum: cdcf64bf8177132107a9c75c43e8378a (MD5)
HTTP OPENDAP
obs4MIPs.NASA-GSFC.MODIS.mon.v1.cltNobs_MODIS_L3_C5_200003-201109.nc|esg-datanode.jpl.nasa.gov
tracking_id: f7dd9ed8-3d41-4796-badc-f1ea7d1a65d8
checksum: c8a6a1f7b7ff53a45084977a0d501cbd (MD5)
HTTP OPENDAP

Data Access Login

The following URL requires authentication:
http://esg-datanode.jpl.nasa.gov/thredds/fileServer/esg_dataroot/obs4MIPs/observations/atmos/clt/mon/grid/NASA-GSFC/MODIS/v20111130/clt_MODIS_L3_C5_200003-201109.nc

Please enter your OpenID and you will be redirected to the login page at that site

Status: not logged-in

OpenID https://ceda.ac.uk/openid/Bryan.Lawrence GO

Remember my OpenID on this computer

After logging in, you will be redirected to:
http://esg-datanode.jpl.nasa.gov/thredds/fileServer/esg_dataroot/obs4MIPs/observations/atmos/clt/mon/grid/NASA-GSFC/MODIS/v20111130/clt_MODIS_L3_C5_200003-201109.nc

Approve OpenID Request?

The website **https://esg-datanode.jpl.nasa.gov/** has requested your OpenID for sign in:

https://ceda.ac.uk/openid/Bryan.Lawrence

This site has also requested some additional information:

Item	Value	Return Item to Requesting Site?
firstname	Bryan	✓
lastname	Lawrence	✓
email	bryan.lawrence@stfc.ac.uk	✓

Would you like to pass your OpenID credential information back to https://esg-datanode.jpl.nasa.gov/ and return to this site?

Yes No

Remember this decision for session duration

CEDA OpenID Provider Site. Logged in as lawrence. [Log out]

Centre for Environmental Data Archival
SCIENCE AND TECHNOLOGY FACILITIES COUNCIL
NATURAL ENVIRONMENT RESEARCH COUNCIL

ESGF Earth System Grid Federation

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

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modis Search

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Project
- COUND (1)
- cloud-cryo (8)
- obs4MIPs (1)

Institute
- LLNL (8)
- NASA-GSFC (1)
- NASA-JPL (1)

Model
- Obs-COUND (1)
- Obs-MODIS (1)

Instrument
- MODIS (2)

Experiment Family
- All (9)
- Atmos-only (8)

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

< 1 > displaying 1 to 10 of 10 search results

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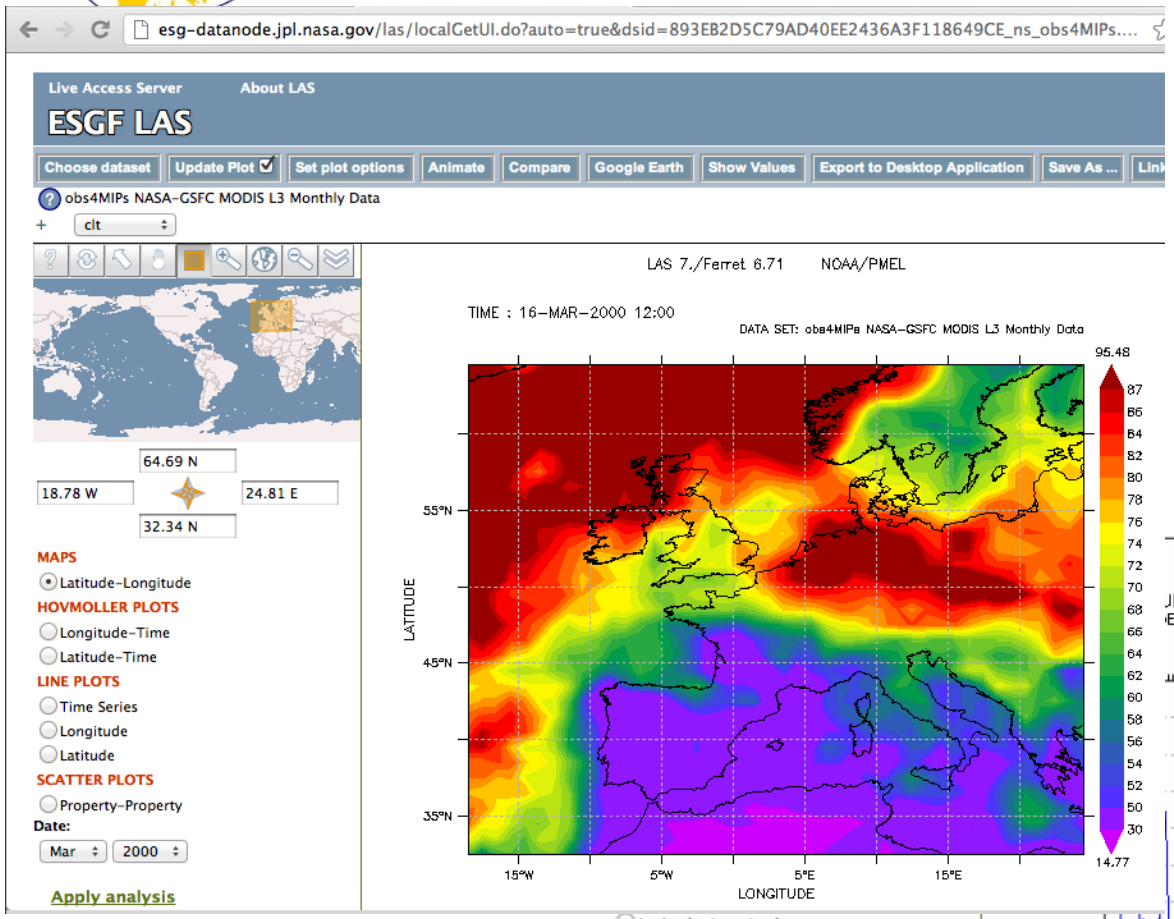
Results | Data Cart

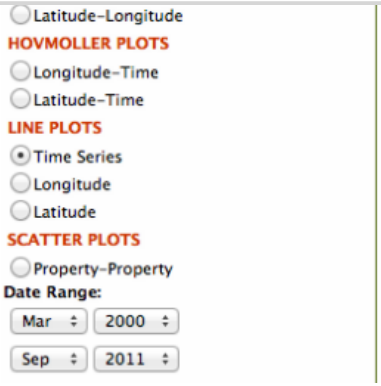
obs4MIPs NASA-GSFC MODIS L3 Monthly Data
Data Node: esg-datanode.jpl.nasa.gov
Version: 1
No description available.
Further options: Add To Cart Visualize and Analyze

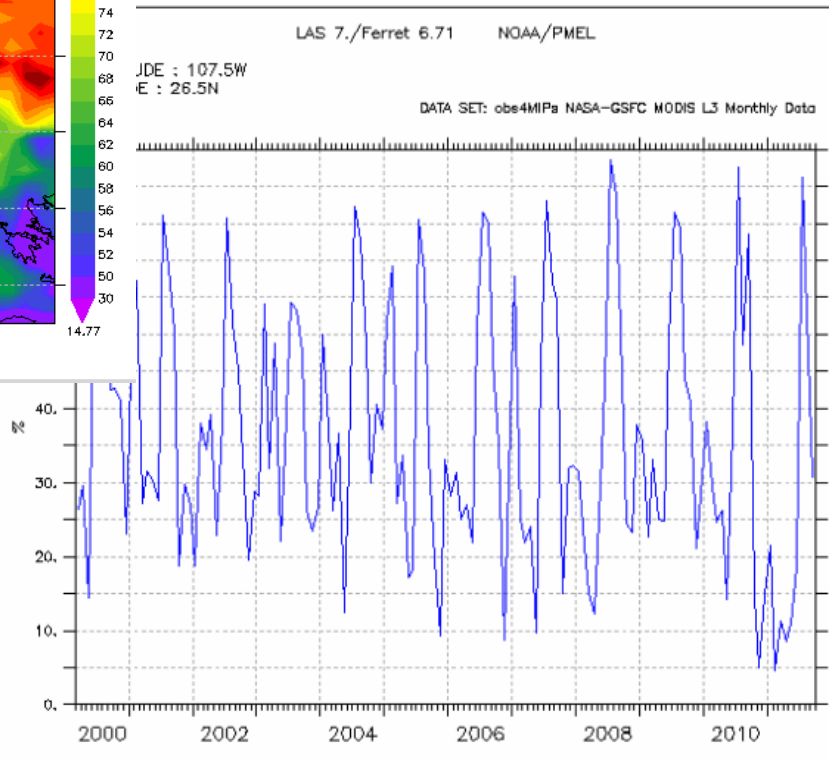
COUND: Cloud Liquid Water - MODIS LWP Monthly Data
Data Node: esg-datanode.jpl.nasa.gov
Version: 1
No description available.
Further options: Add To Cart Cloud Liquid Water Tech Note

cloud-cryo.amip.LLNL.frz-40
Data Node: pcmdi9.llnl.gov
Version: 1
No description available.
Further options: Add To Cart

Live Access Server exploiting OPeNDAP data interface







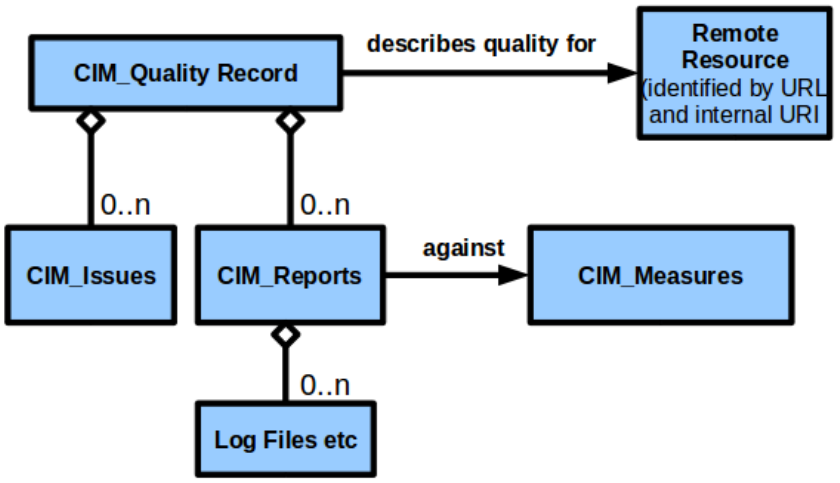
ESGF Dependencies

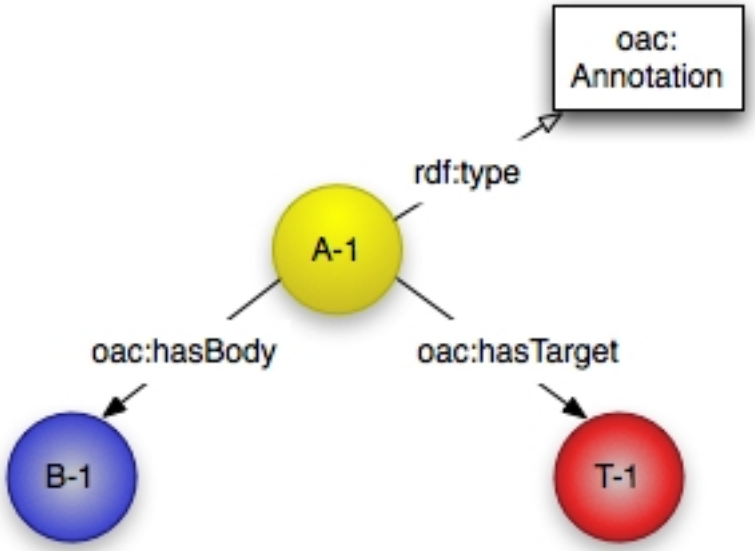
ESGF depends on

- Constraining data provision to specific formats (NetCDF), and specific conventions (CF+CMIP5 specific constraints).
- Metadata conventions.
- Constraining the data layout on disk. A filename convention.
- Agreements on how to do, and use, authentication and authorisation (openID+X509).
- A lot of opensource software!

Building-on/Contributing-to the ESGF

- Metafor Common Information Model (CIM): provides rich paradigm for describing models, simulations and experiments.
- Used for CMIP5, currently includes detailed descriptions of 42 models, 600 simulations, and the CMIP5 experiments themselves.
- Also provided paradigm for annotating remote resources





CHARM: New FW7 Project

How to judge data's fitness for purpose? Need "Commentary metadata"

- Consistent mechanism to collate and link to data
- Information may come from other parties, not the original data provider

CHARM will create:

- Connected repositories of Commentary metadata
- Web service interfaces to query the information
- Example applications including climate observations and model datasets

Defined for CHARM, to include:

- Post-fact annotations, e.g. citations, ad-hoc comments and notes
- Results of assessments, e.g. validation campaigns, intercomparisons with models or observations, reanalysis
- Provenance, e.g. dependencies on other datasets, processing algorithms and chain, data source
- Properties of data distribution, e.g. data policy and licensing, reliability
- External events that may affect the data, e.g. volcanic eruptions, satellite or instrument failure, etc

Slide courtesy of Bennett, Clifford and Kershaw

Downloading or Centralisation: CEMS?

Electron Building, ISIC

Panasas storage, R89 Building, RAL STFC

A joint academic-industrial facility for climate and environmental data services

Centred at ISIC, the International Space Innovation Centre, Harwell, UK

Will provide:

- Access to large-volume climate and EO datasets, **alongside** processing capability;
- Commercial and scientific applications and services, hosted **alongside** key datasets;
- Data quality, integrity and visualisation tools **alongside** advice and consultancy;

CEMS isn't attempting to replace in-house computing facilities or other capabilities, it's a complementary resource.

Initial partners:

RAL Space

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

logica
be brilliant together

ASTRIUM
AN EADS COMPANY

Slide courtesy of Bennett and Kershaw

Summary

Scientific drivers inextricably link dependence of models on observations (and vice versa)!

Observations are still difficult to use, issues of formating, metadata conventions, limit widespread use of some data.

ESGF + CMIP5 conventions mitigate against formating differences (common toolkits, common documentation conventions etc).

ENES consortium of the major modelling groups in Europe:

- provides significant European infrastructure to support a range of projects, European and Global.

ESGF provides vast globally distributed archive, with increasing quantities of observational data – 1.7 PB of unique model data.

Many new projects (CHARM, CEMS etc) will exploit ESGF.