Planning, Coordination, and Infrastructure Requirements for CMIP

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Presented to the USGCRP Interagency Group on Integrative Modeling (IGIM)

College Park, MD
3 October 2012

CMIP5 timeline retrospective:

- 2006: Planning began in earnest.
- Fall 2008: Experiment design approved by WGCM
- December 2009: Nearly all experiment details in place
- March 2011: Output requirements and list of requested output finalized
- April 2011: First model output available

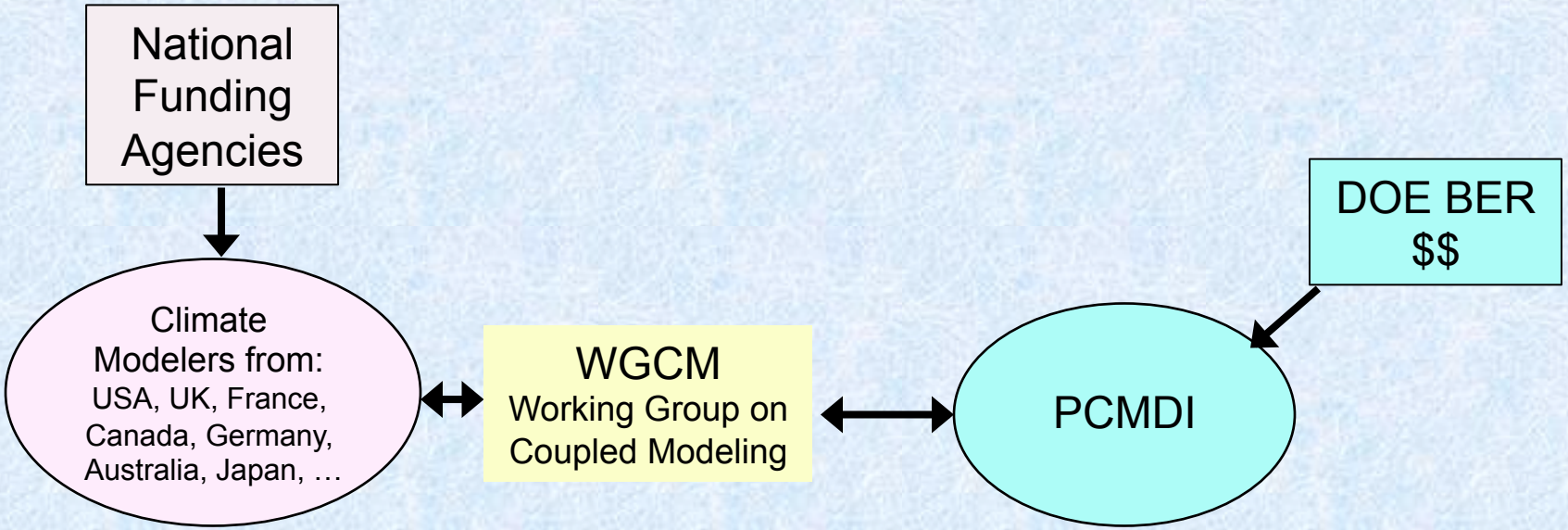
15 months

- August 2011: RCP forcing datasets finalized
- March 2012: A petabyte of data stored in 2,000,000 files
- July 2012: More than 200 journal articles based on CMIP5 output in some stage of publication
- Now: 59 models available from 24 modeling centers; 1.7 PB in 4×10^6 files
- CMIP5 research just beginning

Preview

- In the "trenches" view of how CMIP actually gets done
- CMIP3 vs. CMIP5
- Ongoing priorities
- What about the future of CMIP?

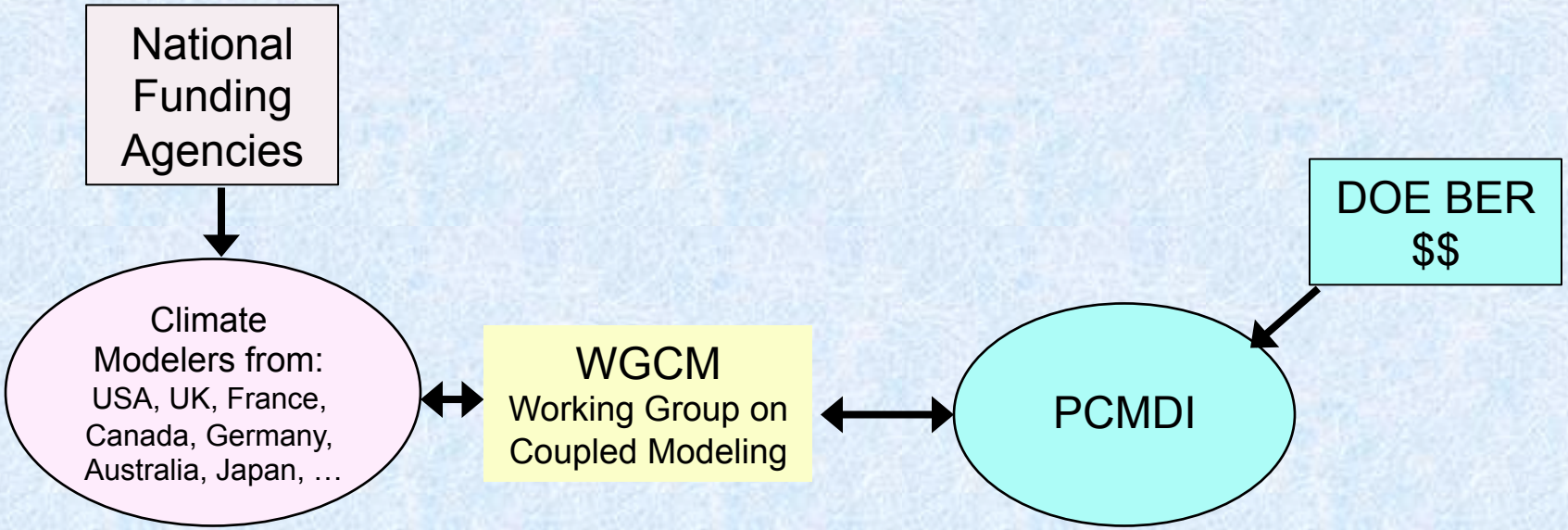
CMIP: A grass-roots collaborative effort



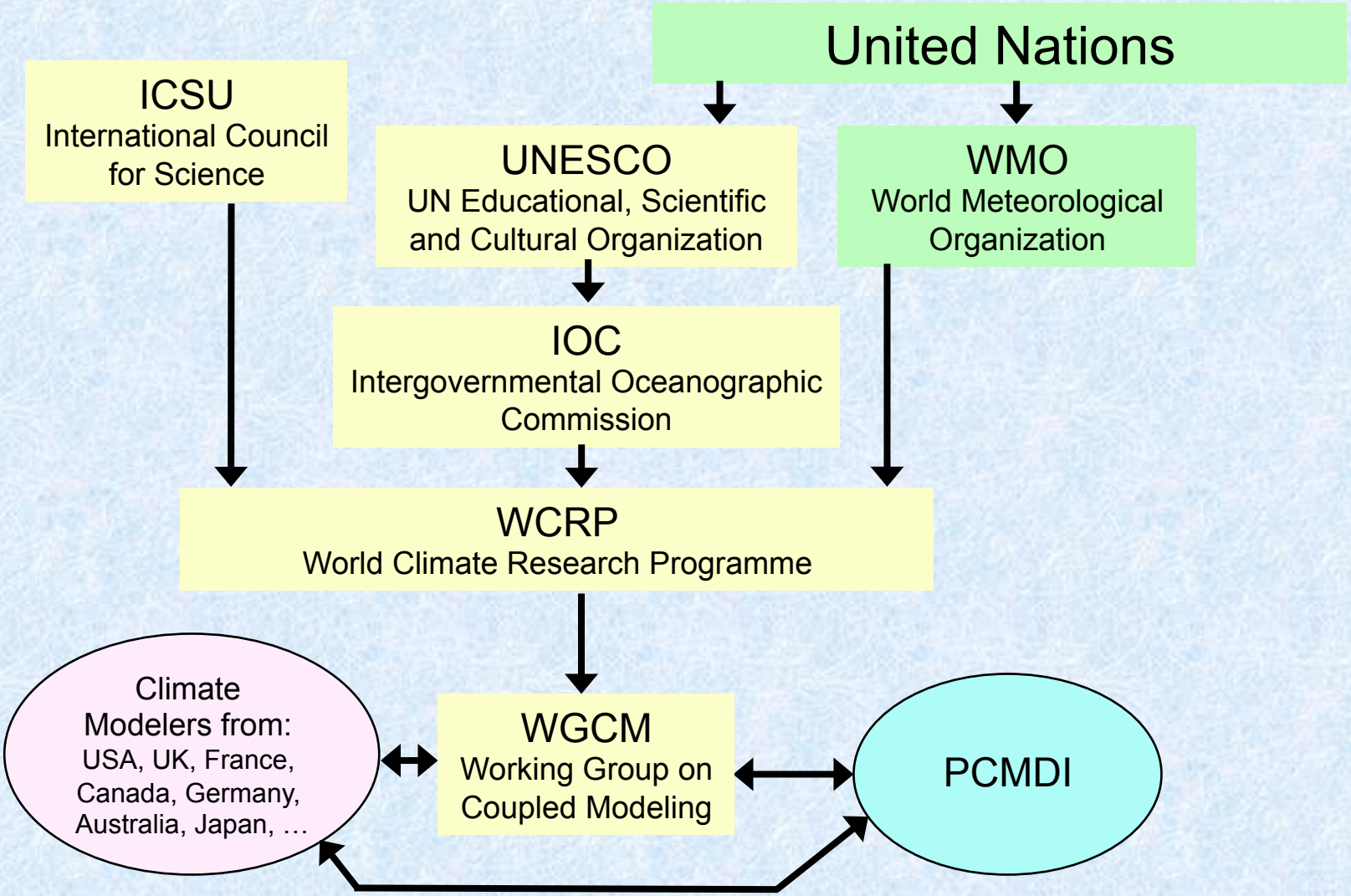
CMIP5 participating groups 22 Sept. 2012:
59 models available from 24 groups

Primary Group	Country	Model
CSIRO-BOM	Australia	ACCESS 1.0, 1.3
BCC	China	BCC-CSM1.1, 1.1(m)
GCESS	China	BNU-ESM
CCCMA	Canada	CanESM2, CanCM4, CanAM4
DOE-NSF-NCAR	USA	CCSM4, CESM1 (BGC), (CAM5), (CAM5.1,FV2), (FASTCHEM), (WACCM)
RSMAS	USA	CCSM4(RSMAS)
CMCC	Italy	CMCC- CESM, CM, & CMS
CNRM/CERFACS	France	CNRM-CM5
CSIRO/QCCCE	Australia	CSIRO-Mk3.6.0
EC-EARTH	Europe	EC-EARTH
LASG-IAP & LASG-CESS	China	FGOALS- g2, s2, & gl
FIO	China	FIO-ESM
NASA/GMAO	USA	GEOS-5
NOAA GFDL	USA	GFDL- HIRAM-C360, HIRAM-C180, CM2.1, CM3, ESM2G, ESM2M
NASA/GISS	USA	GISS- E2-H, E2-H-CC, E2-R, E2-R-CC, E2CS-H, E2CS-R
MOHC	UK	Had CM3, CM3Q, GEM2-ES, GEM2-A, GEM2-CC
NMR/KMA	Korea / UK	HadGEM2-AO
INM	Russia	INM-CM4
IPSL	France	IPSL- CM5A-LR, CM5A-MR, CM5B-LR
MIROC	Japan	MIROC 5, 4m, 4h, ESM, ESM-CHEM
MPI-M	Germany	MPI-ESM- HR, LR, P, ESM-P
MRI	Japan	MRI- AGCM3.2H, AGCM3.2S, CGCM3, ESM1
NCC	Norway	NorESM1-M, NorESM-ME
NCEP	USA	CFSv2-2011
NICAM	Japan	NICAM-09
INPE	Brazil	BESM OA2.3

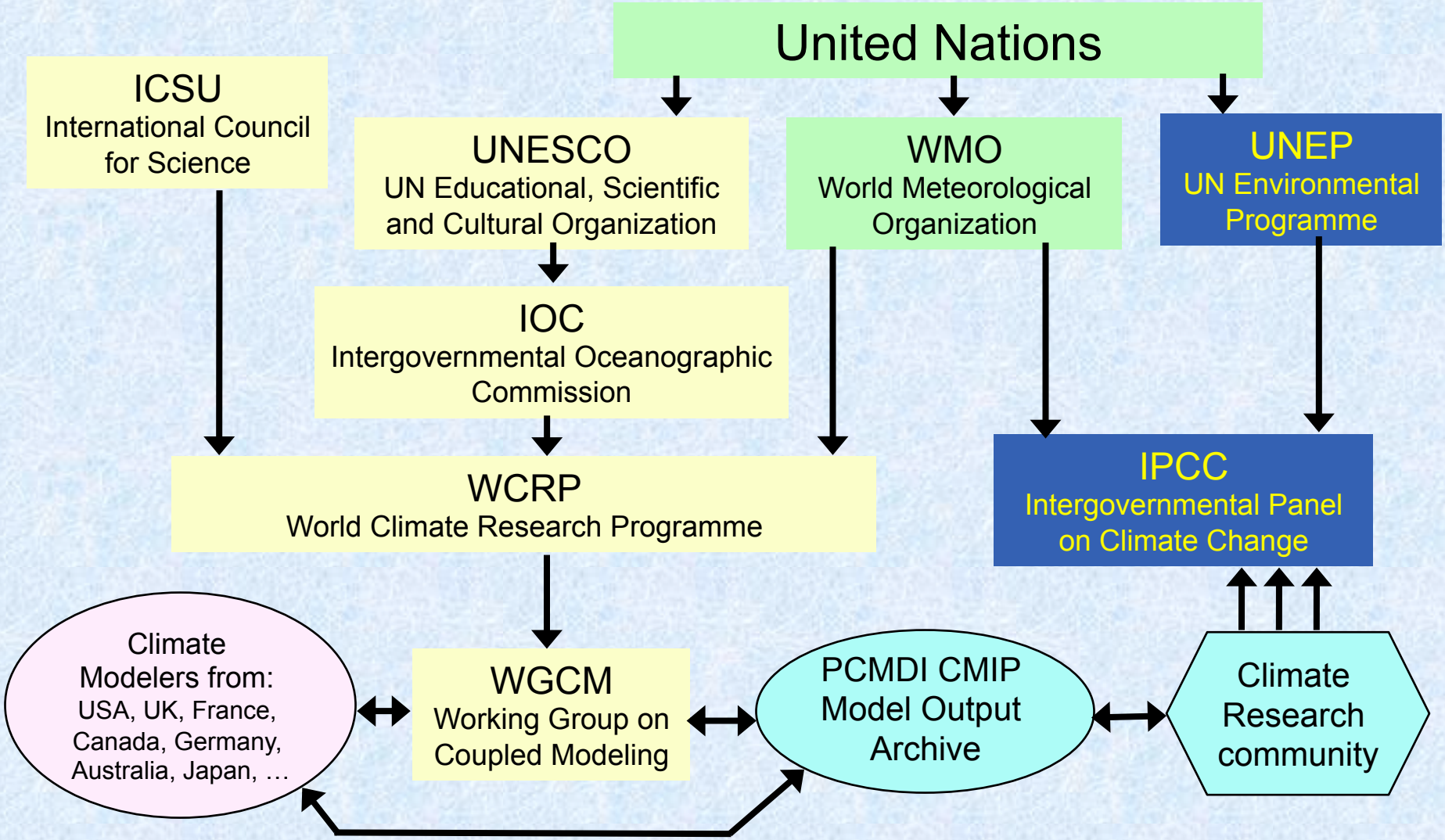
CMIP: A grass-roots collaborative effort



CMIP: Under the umbrella of an internationally-coordinated research program



IPCC assessments are separate from the international climate research programs



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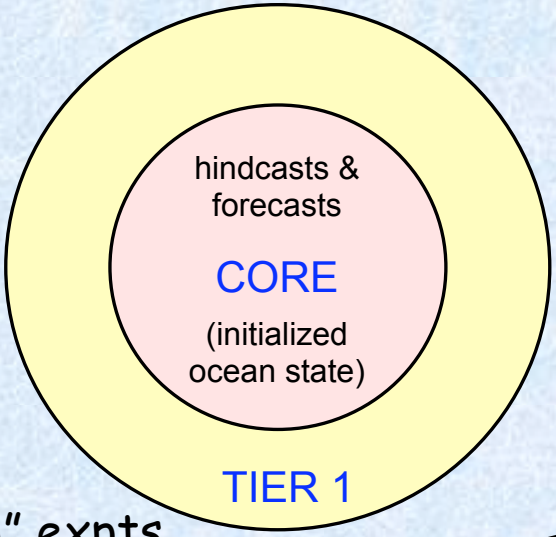
Executing CMIP: A collaboration between climate scientists and IT experts.

- Establish suite of experiments
- Define list of requested output variables (and frequencies and domains)
- Impose output requirements
- Do experiments and write output consistent with specifications
- Implement services to make output accessible to users
- Provide user support

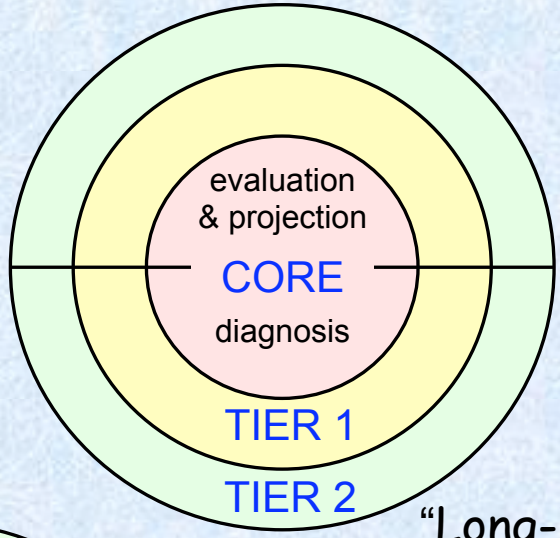
CMIP5 planning: CMIP5 experiment design

- Obtain community input:
  - Workshops (e.g., Aspen Global Change Inst.)
  - Sister MIPs (e.g., C4MIP, PMIP, CFMIP)
  - WCRP
- Reach consensus through the WGCM
- Work out details of experiments
  - e.g., specify length of runs, boundary conditions, … (see http://cmip-pcmdi.llnl.gov/cmip5/docs/Taylor_CMIP5_design.pdf)
  - Prioritize experiments
  - Coordinate with integrated assessment community to develop new scenarios
  - PCMDI and WGCM CMIP Panel shared responsibility
- Gain WGCM approval

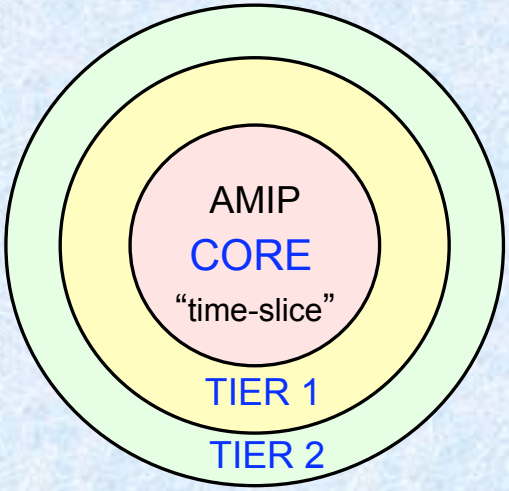
CMIP5 is organized around three types of simulations



"Near-Term" expts.
(decadal prediction)



"Long-Term"
traditional expts.
(century & longer)

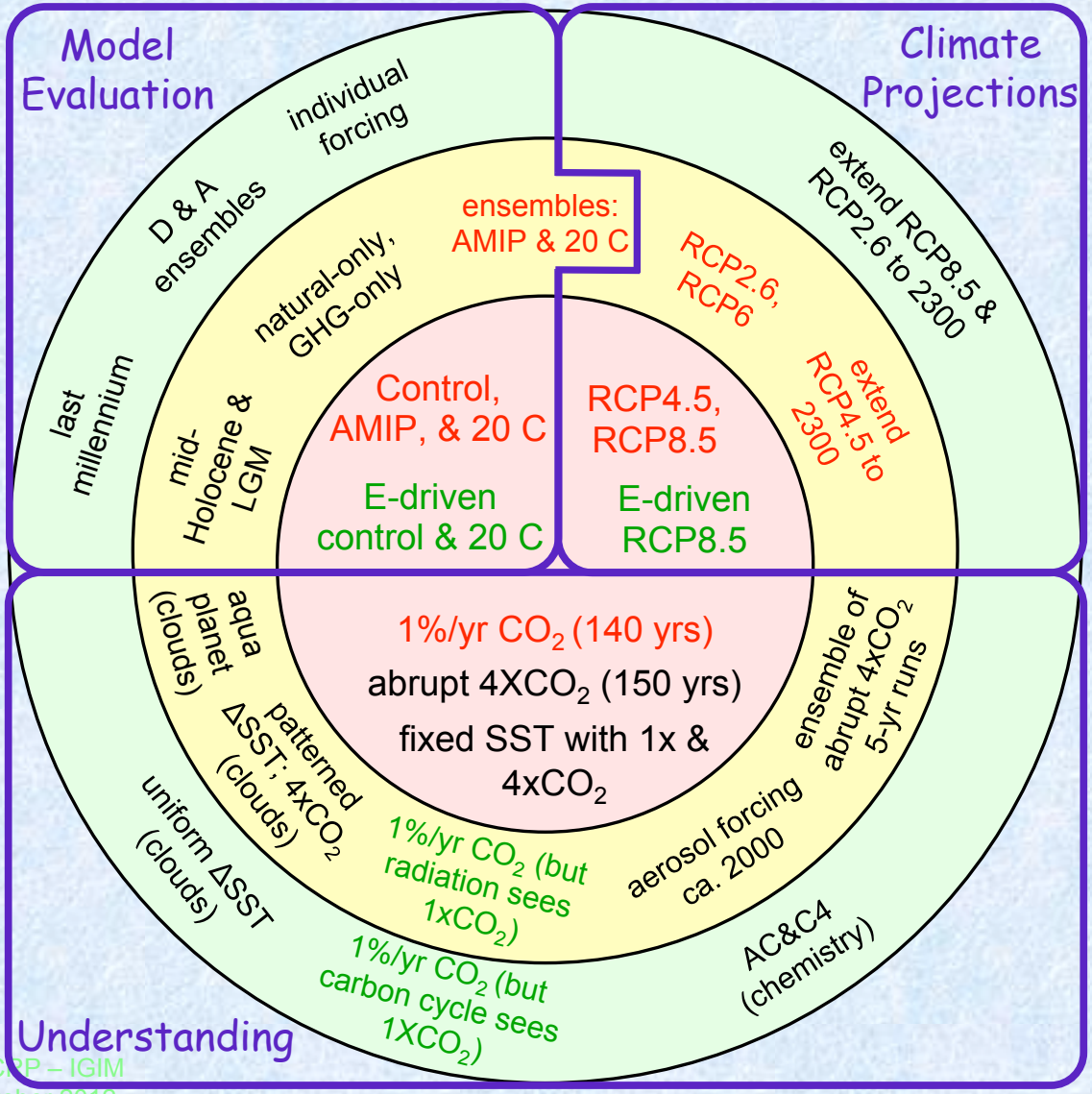


Atmosphere-Only Simulations

(for computationally demanding and NWP models)

See Taylor, Stouffer, & Meehl, *Bull. Amer. Meterol. Soc.*, 2012

A rich set of "long-term" experiments, drawn from several predecessor MIPs, focuses on model evaluation, projections, and understanding



Red subset matches the entire CMIP3 experimental suite

Green subset is for coupled carbon-cycle climate models only

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Planning CMIP5: Define list of requested output

- Build on variable lists from earlier MIPs, and gather community input to expand requested output list

- Prioritize variables and create tables of variables and their attributes (standard names, dimensions, units, etc.)
  http://cmip-pcmdi.llnl.gov/cmip5/docs/standard_output.pdf

CMIP5 output fields requested (goes well beyond what was available from CMIP3)

- Domains (number of monthly variables*):
  - Atmosphere (60)
  - Aerosols (77)
  - Ocean (69)
  - Ocean biogechemistry (74)
  - Land surface & carbon cycle (58)
  - Sea ice (38)
  - Land ice (14)
  - CFMIP output (~100)
- Temporal sampling (number of variables*)
  - Climatology (22)
  - Annual (57)
  - Monthly (390)
  - Daily (53)
  - 6-hourly (6)
  - 3-hourly (23)

*Not all variables will be saved for all experiments and time-periods

http://cmip-pcmdi.llnl.gov/cmip5/output_req.html

Planning CMIP5: Define model output specifications

- Agree to write netCDF files conforming to CF conventions
  - The CF-conventions allows for creation of self-describing files with information typically needed to perform analysis
    See http://cf-pcmdi.llnl.gov/
- Define metadata requirements to ensure all essential information needed for analysis is included (consistent with, but more prescriptive than CF)
  http://cmip-pcmdi.llnl.gov/cmip5/docs/CMIP5_output_metadata_requirements.pdf
- Construct filename templates and directory structures to be adopted by all models
- Define and impose "controlled vocabularies" for experiment names, model names, sampling frequencies, realms, etc.
  cmip5_data_reference_syntax.pdf

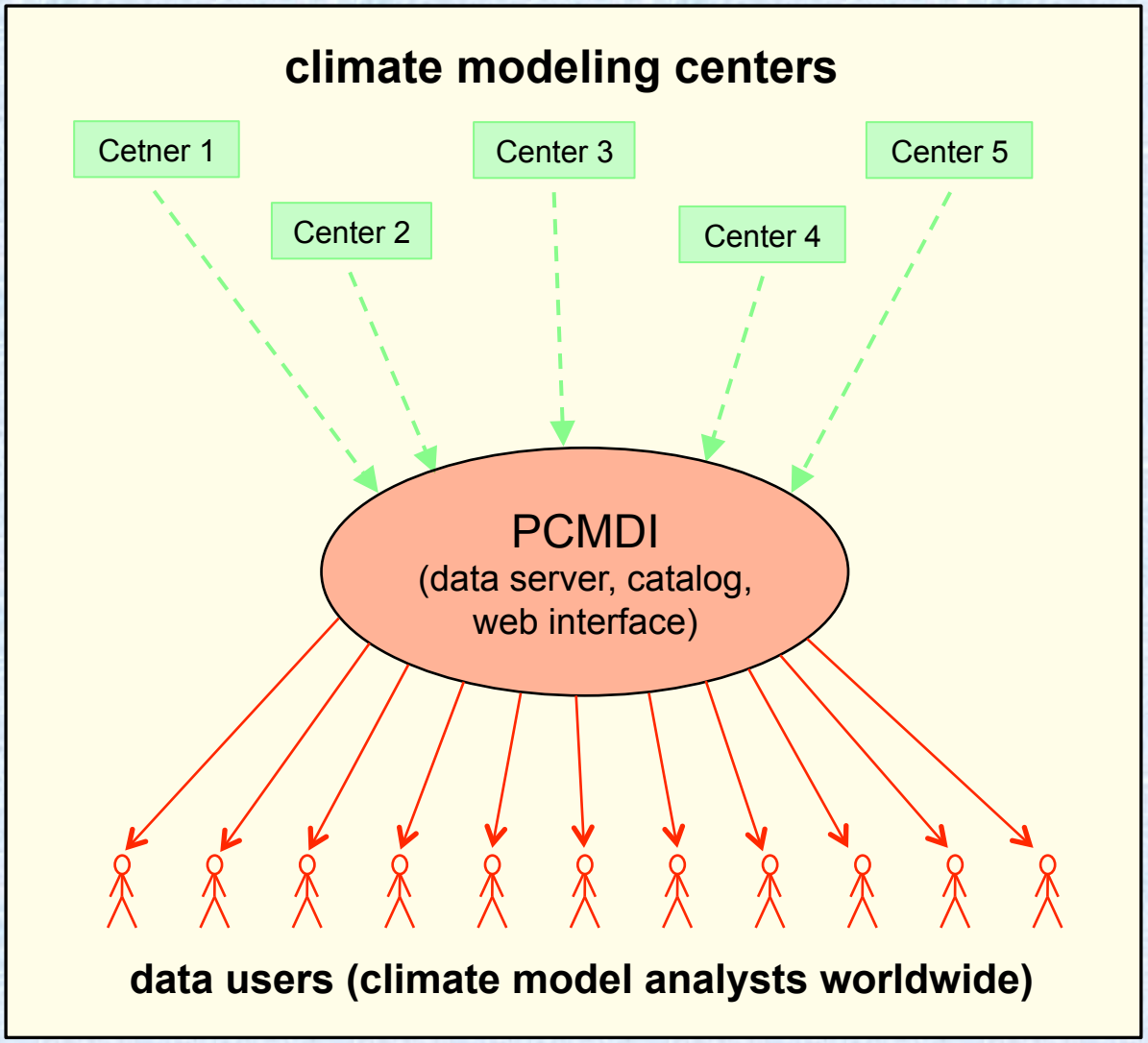
Modeling groups accepted huge task.

- Install COSP (CFMIP Observational Simulator Package)
- Run experiments consistent with CMIP5 requirements
- Prepare output for CMIP5 archive
  - Rewrite model output ("CMORize" data)
    http://www2-pcmdi.llnl.gov/cmor
- Install ESGF data node software (or transfer data to a data center)
- "Publish" model output on ESGF and maintain system.
- Record detailed documentation of models and simulations through the METAFOR questionnaire.

Serving CMIP5 output to users:

- Develop and deploy ESGF "node" software to modeling groups and data centers:
  - "Publish" data
  - Establish protocols allowing external users to download data (http, gridftp, opendap??)
  - Enable replication
- Develop and establish ESGF "portals" where users can
  - Search distributed archive
  - Download CMIP output (either point-and-click, or with wget scripts)

Evolution of operational ESG: CMIP3



- Data shipped to PCMDI on hard disks
- Delayed availability
- Hindered corrections

- Search through web gateway
- Download from single location (ftp, http)

Evolution of operational ESG: CMIP5 (until recently)

- ESG software architecture similar to CMIP3, but
  - Data distributed worldwide at "data nodes"
  - Catalogs of data were hosted at gateways
  - Gateways shared catalog information
  - Users accessed data through gateways
- ESG limitations
  - Search engine hopelessly slow
  - Gateways often inaccurate in reporting data holdings
  - Overly monolithic structure of gateway software impaired timely
    - Modification to correct performance issues and bugs
    - Implementation of enhancements needed for CMIP5 (e.g., model documentation)
- ESG Federation formed (spring of 2010) to develop alternative

Evolution of operational ESG: CMIP5 peer-to-peer ESGF

- P2P timeline
  - Spring 2010: conception
  - Spring 2011: unanimous decision to transition to p2p system for CMIP5 (when ready)
  - Fall 2011: Prototype system ready for testing
  - August 2012: user comment -- “The new portal is wonderful! In one afternoon work achieved more than several weeks work with the old system.”
  - September 2012: *Old gateways deprecated; P2P now operational*
- Peer-to-peer (p2p) architecture is designed to be
  - Scalable to data needs of future
  - Simplified and modularized to enable nimble modification
  - Open-source to attract contributions and resources across the community
  - Easy to interface to (by API’s)
  - Multiple, fast search options (including simple http inquiry outside user interface)

See pcmdi9.llnl.gov

Provide user support and information for basic understanding of CMIP:

- Partner with the IPCC's Data Distribution Center (DDC) – BADC and DKRZ
- Maintain a "help desk"
- Dataset errata
- Collect and make accessible model and experiment documentation (METAFOR, CURATOR, and ES-docs)
- Develop and update a comprehensive CMIP5 website
  - Guide to data providers
  - Guide to users
  - Resources (e.g., forcing data sets, lists of modeling group official names, etc.)
- Provide searchable record of CMIP5-based journal articles (http://cmip.llnl.gov/cmip5/publications/allpublications)

Record of CMIP5 publications

CMIP Coupled Model Intercomparison Project

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Total Publications Count: 248

All Publications

Author	Article Title	Journal
?eparovi? L. , A. Alexandru, R. Laprise, A. Martynov, L. Sushama, ...	Present climate and climate change over North America as simulated by the fifth-generation Canadian Regional Climate Model (CRCM5); (Citation) (More Information)	Climate Dynamics
Ahlström A. , G. Schurgers, B. Smith	Robustness and uncertainty in terrestrial ecosystem carbon response to CMIP5 climate change projections; (Citation) (More Information)	Environmental Research Letters
Ahmed C. B. , S. Sensoy	Assessment of climate change effects on agriculture in the Mediterranean countries; (Citation) (More Information)	
Alan I. , M. Demircan, S. Sensoy	Trends in Turkey climate extreme indices from 1971 to 2004; (Citation) (More Information)	
Anav A. , P. Friedlingstein, M. Kidston, L. Bopp, P. Ciais, ...	EVALUATING THE LAND AND OCEAN COMPONENTS OF THE GLOBAL CARBON CYCLE IN THE CMIP5 EARTH SYSTEM MODELS; (Citation) (More Information)	Journal of Climate
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Publication Views

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Click on "citation" and "more information" to expand to:

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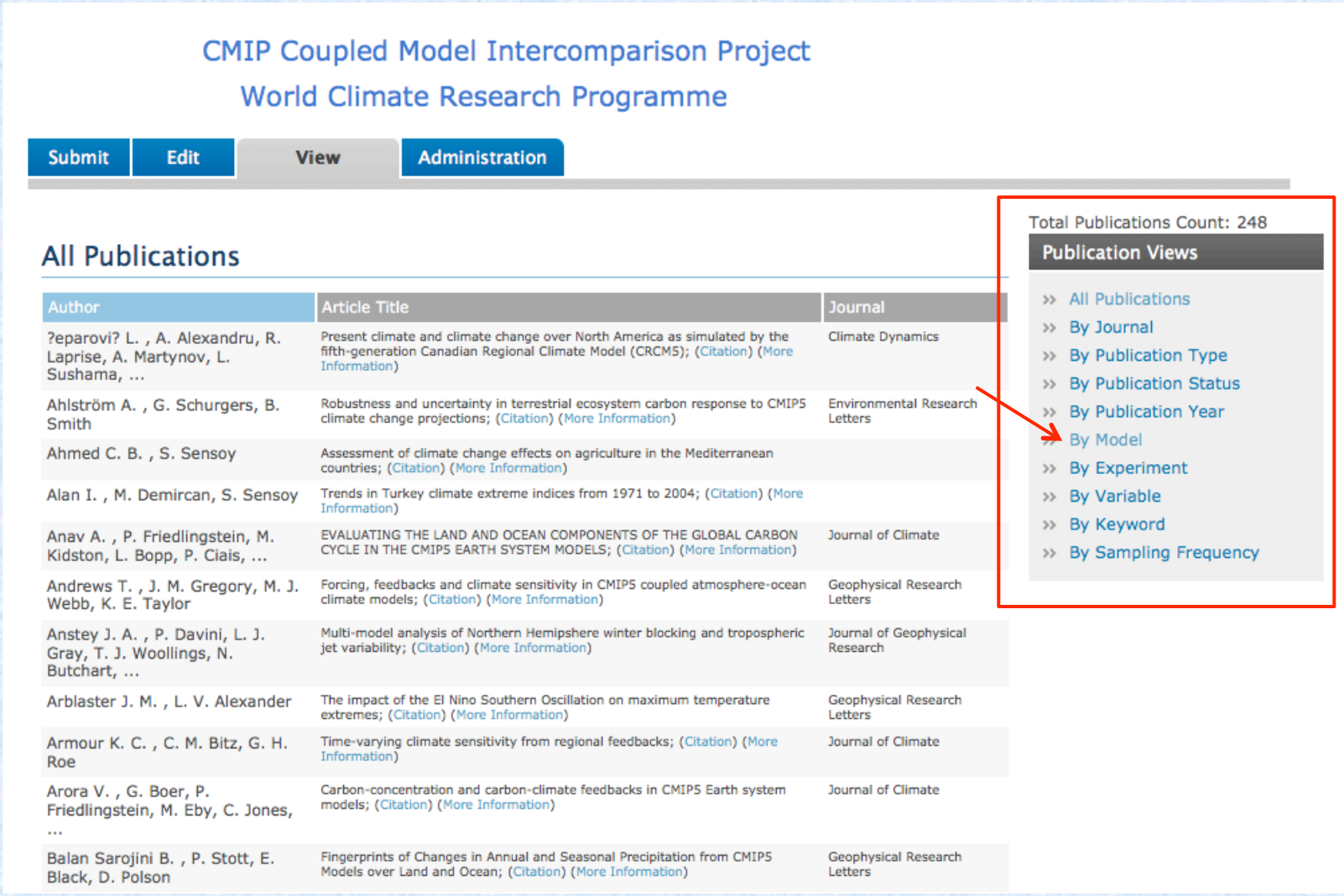
(More Information)

Experiments	Models	Variables	Keywords
abrupt4xCO2	CanESM2	land area fraction	WG1 (physical climate system)
piControl	CNRM-CM5	surface temperature	Abrupt change
sstClim	CSIRO-Mk3.6.0	toa incoming shortwave flux	Globe
sstClim4xCO2	GFDL-CM3	toa outgoing longwave flux	Energy budget
	GFDL-ESM2G	toa outgoing longwave flux assuming clear sky	Radiatiave forcing
	GFDL-ESM2M	toa outgoing shortwave flux	Clouds
	HadGEM2-ES	toa outgoing shortwave flux assuming clear sky	Radiation
	INM-CM4		Feedbacks
	IPSL-CM5A-LR		Climate sensitivity
	MIROC-ESM		
	MIROC5		
	MPI-ESM-LR		
	MPI-ESM-P		
	MRI-CGCM3		
	NorESM1-M		

Different subsets of information can be displayed.



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Publications analyzing model: ACCESS1.0

Author	Article Title	Journal
Bathols J. , C. Heady, I. G. Watterson	Are climate models more skillful in their home continent?; (Citation) (More Information)	Bulletin of the American Meteorological Society
Bracegirdle T. J. , D. B. Stephenson	On the robustness of emergent constraints used in multi-model climate change projections of Arctic warming; (Citation) (More Information)	Journal of Climate
Brown J. R. , A. F. Moise, R. A. Colman	The South Pacific Convergence Zone in CMIP5 simulations of historical and future climate; (Citation) (More Information)	Climate Dynamics
Brutel-Vuilmet C. , M. Menegoz, G. Krinner	An analysis of present and future seasonal Northern Hemisphere land snow cover simulated by CMIP5 coupled climate models; (Citation) (More Information)	The Cryosphere
Ceppi P. , Y. Hwang, D. M. Frierson, D. L. Hartmann	Southern Hemisphere jet latitude biases in CMIP5 models linked to shortwave cloud forcing; (Citation) (More Information)	Geophysical Research Letters
Collier M. A. , L. D. Rotstayn, J. Kim, K. Kim	An assessment of central and eastern Pacific El Nino's in the CSIRO-Mk3.6, ACCESS1.0 and ACCESS1.3 CMIP5 coupled climate models and their impact on Australian Rainfall; (Citation) (More Information)	Journal of Climate
Dirmeyer P. A. , Y. Jin, B. Singh, X. Yan	Trends in land-atmosphere interactions from CMIP5 simulations; (Citation) (More Information)	Journal of Hydrometeorology
Dirmeyer P. A. , Y. Jin, B. Singh, X. Yan	Evolving land-atmosphere interactions over North America from CMIP5 simulations; (Citation) (More Information)	Journal of Climate
Du Y. , X. Shang-Ping, Y. Ya-Li, X. Zheng, L. Liu, ...	Indian Ocean variability in the CMIP5 multi-model ensemble: The basin mode; (Citation) (More Information)	Journal of Climate
DU Z. , R. HUANG, G. Huang	How Well can CMIP5 CGCMs Simulate the EAP/PJ Teleconnection Pattern and its Corresponding Summer Climate in the East Asian Monsoon Region; (Citation) (More Information)	Other
DU Z. , R. HUANG, G. Huang	How well can CMIP5 CGCMs simulate the Asian summer monsoon rainfall and its interannual variability and their future projections; (Citation) (More Information)	Advances in Atmospheric Sciences
Fettweis X. , B. Franco, M.	Estimating Greenland ice sheet surface mass balance contribution to future sea level rise using the regional atmospheric climate model MAR; (Citation)	The Cryosphere Discuss

Total Publications Count: 248

Model	Count
ACCESS1.0	45
ACCESS1.3	28
BCC-CSM1.1	94
BCC-CSM1.1-m	17
BESM-OA2.3	6
BNU-ESM	23
CanAM4	23
CanCM4	34
CanESM2	126
CCSM4	104
CCSM4-RSMAS	13
CESM-BGC	20
CESM1-CAM5	24
CESM1-CAM5.1.FV2	15
CESM1-FASTCHEM	17
CESM1-WACCM	18
CFSv2-2011	12
CMCC-CESM	15
CMCC-CM	25
CMCC-CMS	17
CNRM-CM5	120

Ongoing priorities to enhance CMIP5 data services?

Well along:

- Improved access to model and experiment documentation through p2p ESG interface
- Replication of subset of data (redundancy, improved performance, server-side calculations)
- Additional methods to download (gridFTP, ftp of a subset)
- Service to notify users of availability of new datasets of interest

Ongoing priorities to enhance CMIP5 data services?

In development:

- Sub-setting and server-side computation
- Service to tell users whether their files have been withdrawn/replaced
- Method of recording provenance of data used in CMIP5 publications (e.g., doi assignment and other options)
- Scalable method of reporting/notifying users of errors in data, but at present: http://cmip-pcmdi.llnl.gov/cmip5/errata/cmip5errata.html
- Improved automated QC

Differences between CMIP3 and CMIP5

- A wider variety of models – ESMs, EMICs, atmosphere-only
- A more ambitious suite of experiments designed to
  - Address a wider variety of questions (e.g., decadal predictability)
  - Meet the needs of a broader community of users
  - Encompass originally independent MIPs into a single MIP that through coordination provides synergistic opportunities for greater scientific understanding
- A more comprehensive set of model output
  - Enabling more complete diagnostic process studies (e.g., clouds)
  - Providing information requested by a wider variety of users (e.g., impact studies)
  - For use in dynamical and empirical downscaling
  - Data volume increase from ~35 TB to ~3000 TB

Differences between CMIP3 and CMIP5

- More complete documentation of models/experiments
  - But just now becoming available
- New strategies for making output accessible to users
- Increased standardization of model output

Remarks on CMIP's future

- Value of multi-model ensemble has been established
- CMIP has subjected models to wider scrutiny
- Resources devoted to CMIP tax modeling groups heavily

Suggestion:

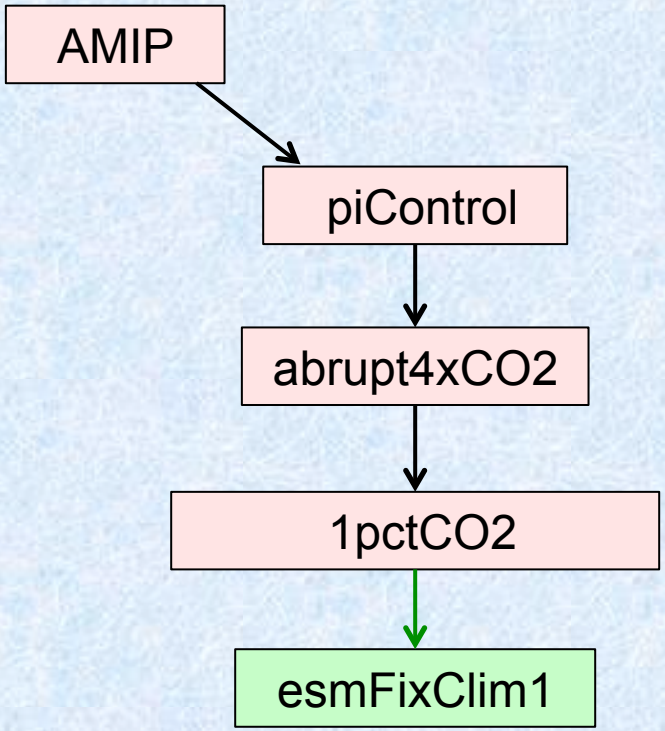
- Establish a set of benchmark (core CMIP) experiments that would
  - Be done anyway by most groups as part of the development cycle.
  - Evolve only slowly
  - Be revisited whenever a new model was developed
- Around these build additional, specialized intercomparisons that would make use of the same standards and infrastructure.

Start with essential CMIP benchmark experiments (omitting decadal prediction for now)

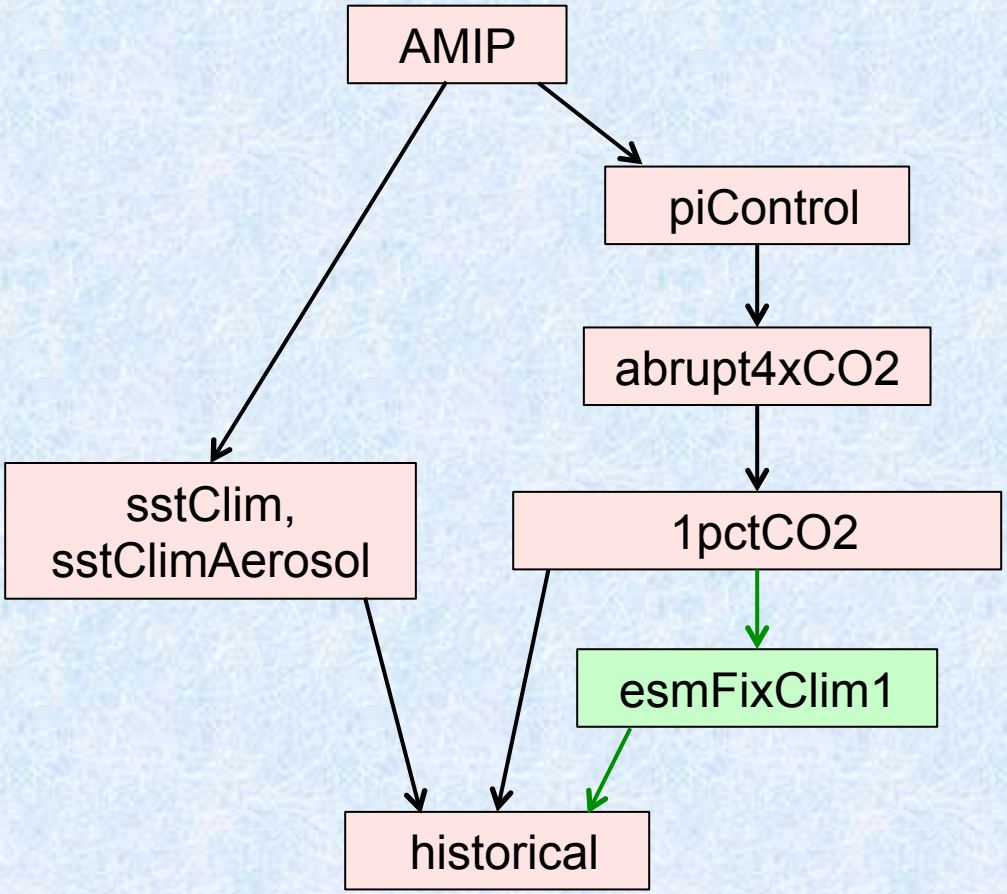
Atmosphere only

All coupled models

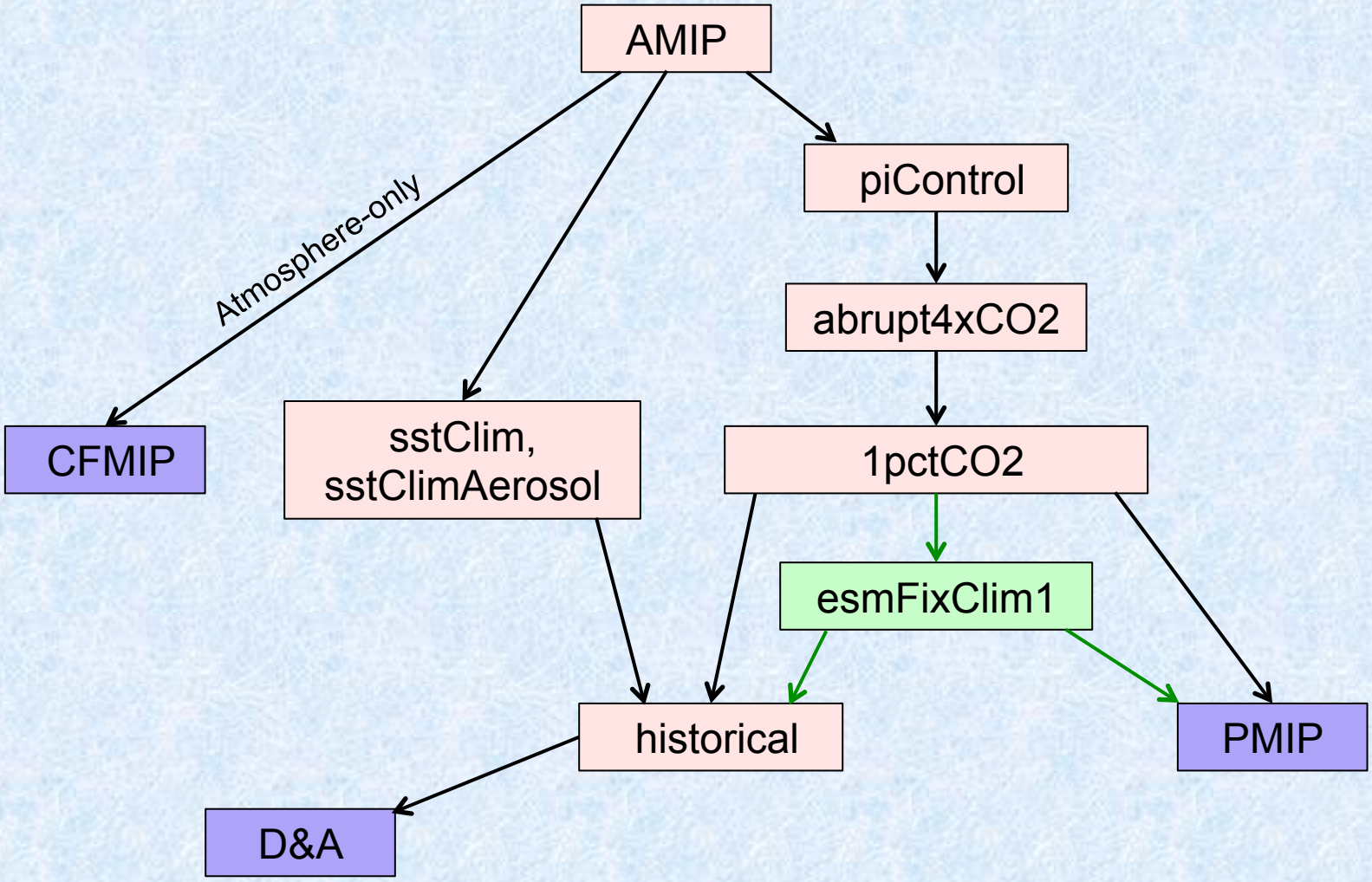
coupled carbon-climate models only



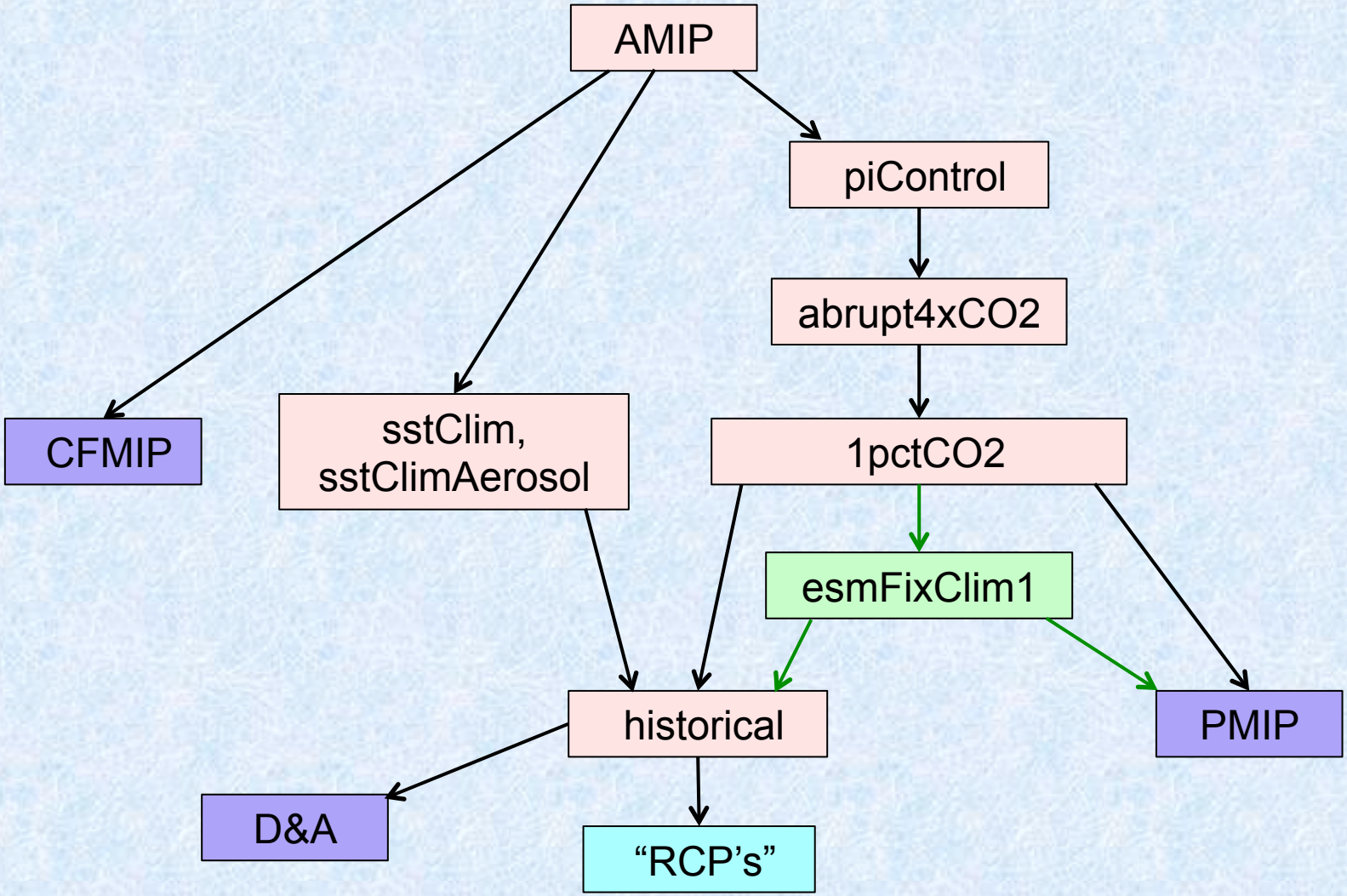
Include historical run for baseline detection & attribution experiments



Special interest MIP's would fit in but might not be revisited with every model version.



RCP runs (or their successors) would only be performed when needed for IPCC assessments



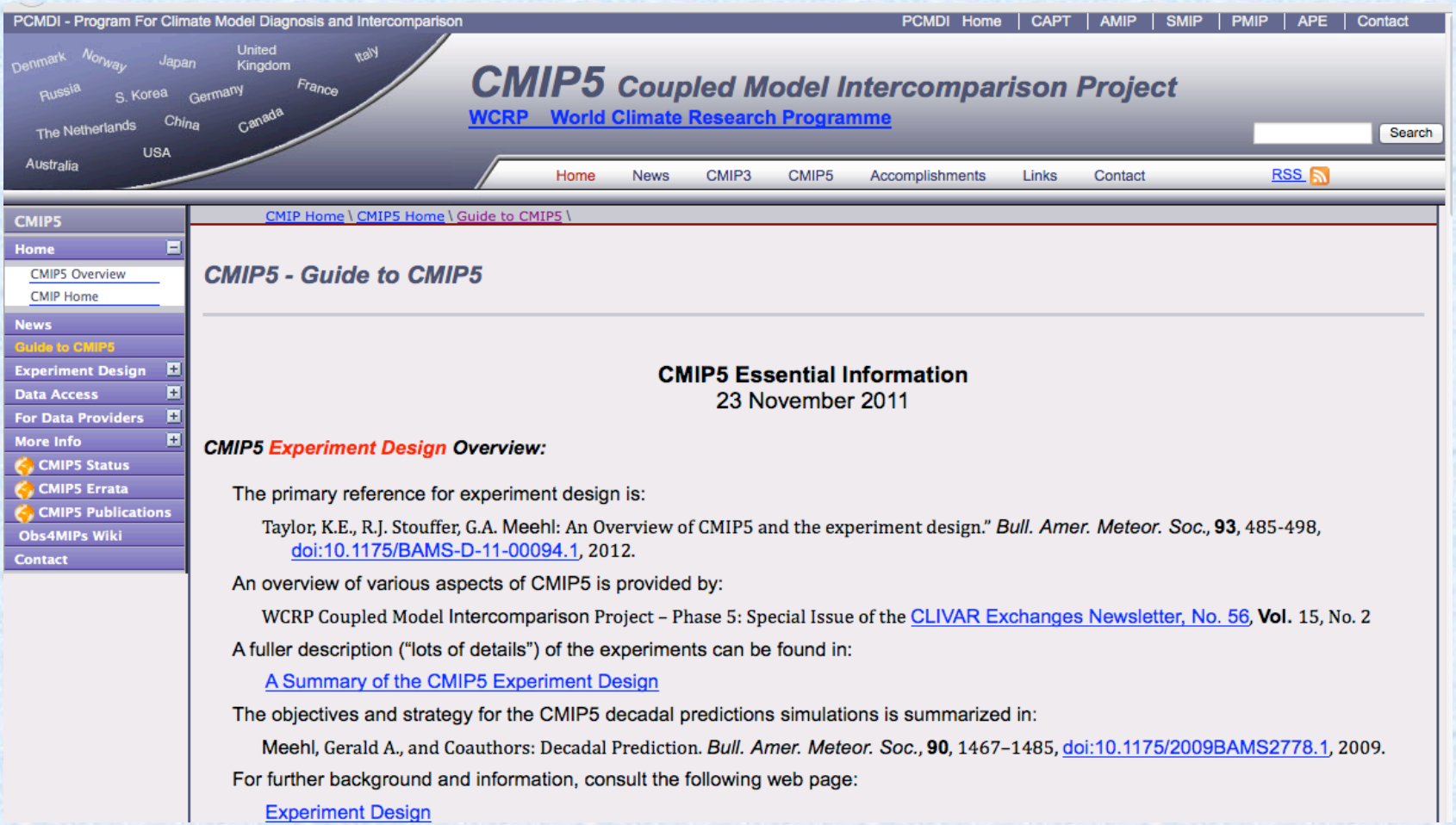
Concluding remarks

- CMIP requires planning, coordination, and a complex and multifaceted infrastructure.
- Some of the work is unfunded and gets done by community volunteers (e.g. CF conventions).
- Much of the work is underfunded, which makes deadlines difficult to meet.
- Perceived agency pressure to be seen as a "leader" rather than a "contributor" threatens to undermine the remarkably cooperative team-work established at the grass-roots level.

CMIP website:

http://cmip-pcmdi.llnl.gov

(or search on “CMIP5”)



"Long-term" experiments: output available, as of (March 3 and) Sept. 22, 2012

Experiment(s)	# of models
* Control & historical	(29) 48
* AMIP	(18) 28
* RCP4.5 & 8.5	(24) 40
RCP2.6	(21) 29
RCP6	(15) 22
RCP's to year 2300	?
* 1% CO2 increase	(21) 32
* Fixed SST CO2 forcing diagnosis	(10) 12
* Abrupt 4XCO2 diagnostic	(20) 30

Experiment(s)	# of models
Fast adjustment diagnostic	?
Aerosol forcing	(6) 9
*ESM cntrl, hist. & RCP8.5	(8) 13
Carbon cycle feedback isolation	(7) 10
Mid-Holocene	(11) 13
LGM	(4) 7
Millenium	(6) 7
CFMIP runs	(6) 10
D & A runs	(16) 17

** Core simulations*

"Decadal" experiments: Output available, as of (March 3 and) Sept. 22, 2012

** Core simulations simulations*

Experiment(s)	Number of models
*Hindcasts and predictions	(14) 18
AMIP	(7) ?
Volcano-free hindcasts	(1) 2
2010 "Pinatubo-like" eruption	(1) 3
Initialization alternatives	?
Pre-industrial control	(12) ?
1% CO2 increase	(7) ?

What were some of the challenges?
Experiment design

- Design a coordinated set of experiments serving several purposes:
  - Enable systematic model evaluation
  - Make projections useful to a broad community of users studying climate, impacts, policy, etc.
  - Provide a basis for "downscaling" to subregional scales
  - Include idealized experiments focusing on understanding of differences in model projections.
- Include initialized decadal climate predictions, PMIP, CFMIP, C4MIP simulations
- Provide a rational basis for considering both ESMs and models without interactive carbon cycles

Through active contributions from many, we came up with a rational set of experiments. (perhaps overly ambitious though)

[summarized by Taylor, Stouffer, & Meehl, BAMS, 2012]

What were some of the challenges?
Model output volume

- Compared with CMIP3, much more model output requested (~100 x)
  - Reported from a larger number of experiments
  - Generated at higher resolution
  - Reported on more complex grids (not just lon-lat grids)
  - Includes many more variables, e.g., aerosols, biogeochemistry, output from satellite simulators
  - Includes fields needed to drive regional models

We provided tables defining all the variables and we provided an enhanced version of CMOR to accommodate the new data requirements.

We agreed upon "controlled" vocabularies for unambiguously defining the output fields (expt., variable, and model names, sampling frequency, ensemble numbering, etc.)

What were some of the challenges?
Delivering data to users

- For CMIP3, data was shipped to PCMDI via disk, then made available to users
  - Several weeks delay between generation of files and availability to users
  - Correcting errors in data was difficult
  - PCMDI became a single point of failure (a catastrophic crash of our RAID system meant data was inaccessible for several weeks)
- For CMIP5, a new (and more complicated approach) was followed
  - Distributed data archive (currently 1.7 Pbyte, 4,000,000 files)
  - Coordination with the IPCC's Data Distribution Centre (BADC & DKRZ)

What's gone well?

- Experiment design was largely in place by January 2009
- The CMIP5 website provides extensive information about all aspects of the project, including the requirements and all the details (http://cmip-pcmdi.llnl.gov/cmip5)
- The data centers have generally worked together well
  - with limited resources
  - to design and develop a distributed data archive
  - which has minimized the delay in getting data to users

What's *not* gone so well?

- Forcing datasets for the RCP's were delayed
- Modeling groups struggled to meet the ambitious and detailed requirements of CMIP5
- Inevitably a few details of the expt. design and model output request had to be clarified after CMIP5 was well underway
- The search engine was until recently unacceptably slow
- The complexity of the distributed data archive caused extreme frustration for those downloading the data and delayed analysis, but this has been now remedied

What further plans are there?

- Data error reports/notification (rudimentary pages now in place)
  http://cmip-pcmdi.llnl.gov/cmip5/errata/cmip5errata.html

- Service to notify users when new datasets of interest become available.

- Citable record of CMIP5 provenance (doi assignment and other options)

- Sub-setting of files before download (and other server-side calculations) – will be implemented after moving to P2P