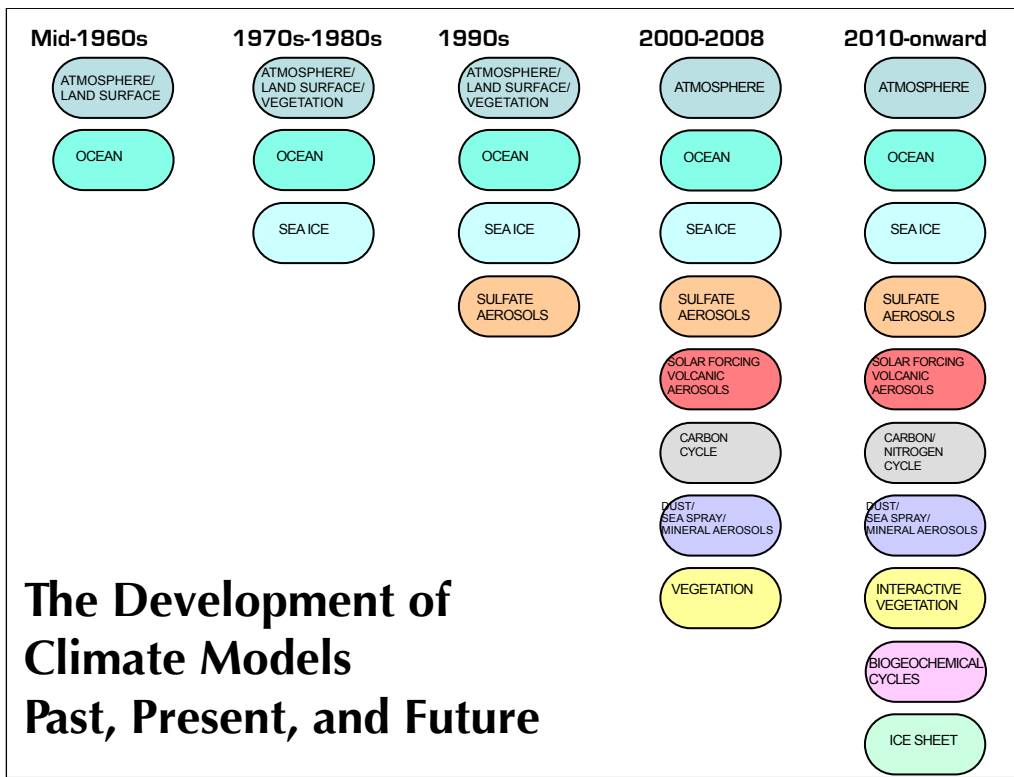


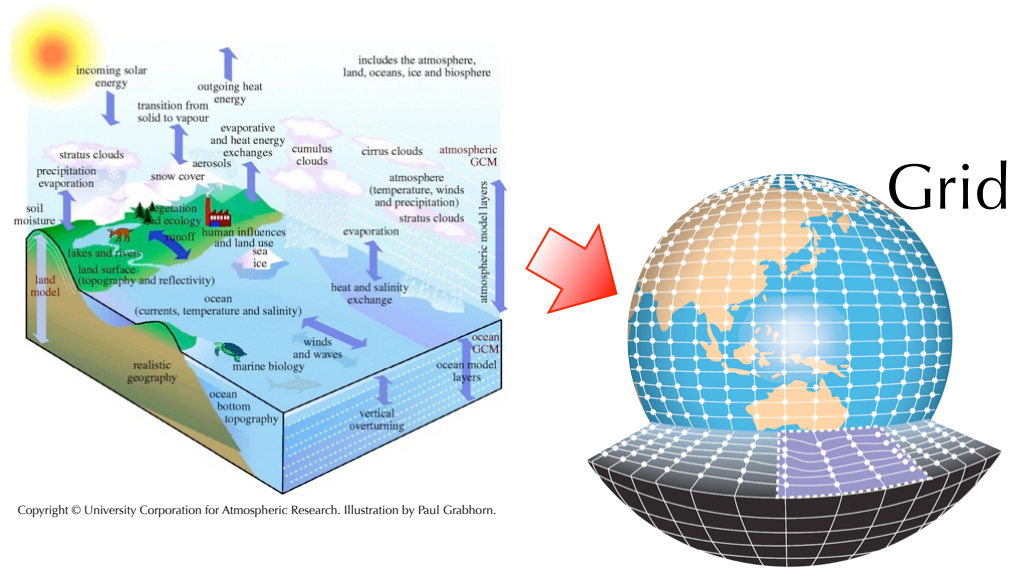
Applications of netCDF: The NCAR CESM, and CMIP5

2012 Unidata netCDF workshop
Gary Strand
NCAR/NESL/CGD



**The Development of
Climate Models
Past, Present, and Future**

Schematically Processes



Copyright © University Corporation for Atmospheric Research. Illustration by Paul Grabhorn.

<http://www.bom.gov.au/info/GreenhouseEffectAndClimateChange.pdf>

What is “CESM”?

Community

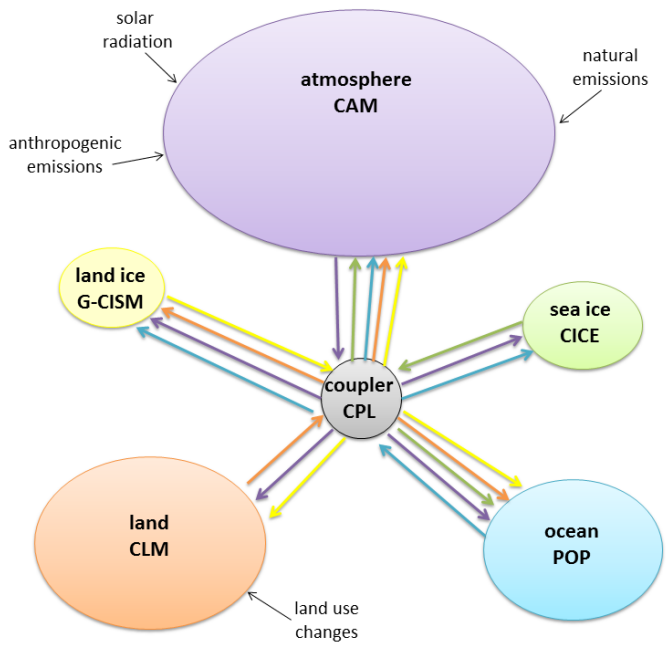
Earth

System

Model

CESM belongs to an elite category of computer-based simulations known as **earth system models**. Such models use mathematical formulas to recreate the chemical and physical processes that drive Earth’s climate. Extraordinarily sophisticated, they incorporate phenomena ranging from the effect that volcanic eruptions have on temperature patterns to the impact of shifting sea ice on sunlight in the atmosphere. What emerges from trillions of computer calculations is a picture of the world’s climate in all its complexity.

A CESM schematic



Courtesy Caitlin Alexander, ClimateSight

A brief history of the IPCC & data

1990 - First Assessment (FAR)

5 modeling groups, 8 models, 7 simulations

1995 - Second Assessment (SAR)

8 modeling groups, 10 models, 6 "IS92a" simulations

2001 - Third Assessment (TAR)

7 modeling groups, 8 models, 6 "SRES" simulations

2007 - Fourth Assessment (AR4)

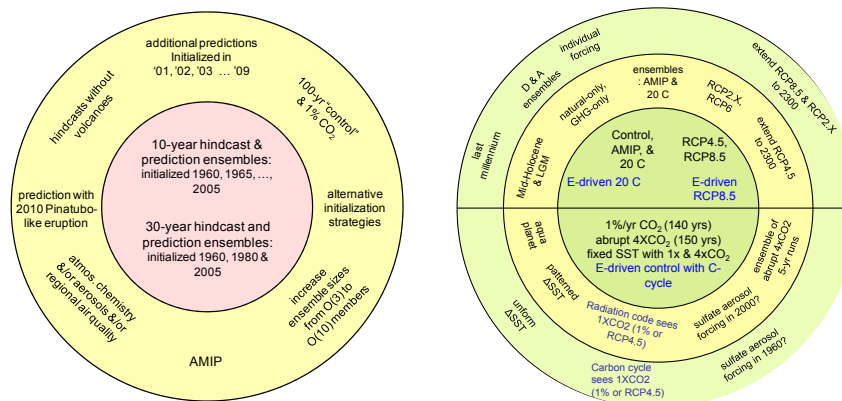
16 modeling groups, 24 models, 12 simulation types

2013 - Fifth Assessment (AR5)

26 modeling groups, 59 models, 96 simulation types
(decadal prediction and long-term)

CMIP5 experimental design

The second large-scale coordination of climate modeling efforts, data analysis, data management and data dissemination by the global climate modeling community: 20+ global coupled climate models from many modeling centers located around the world.

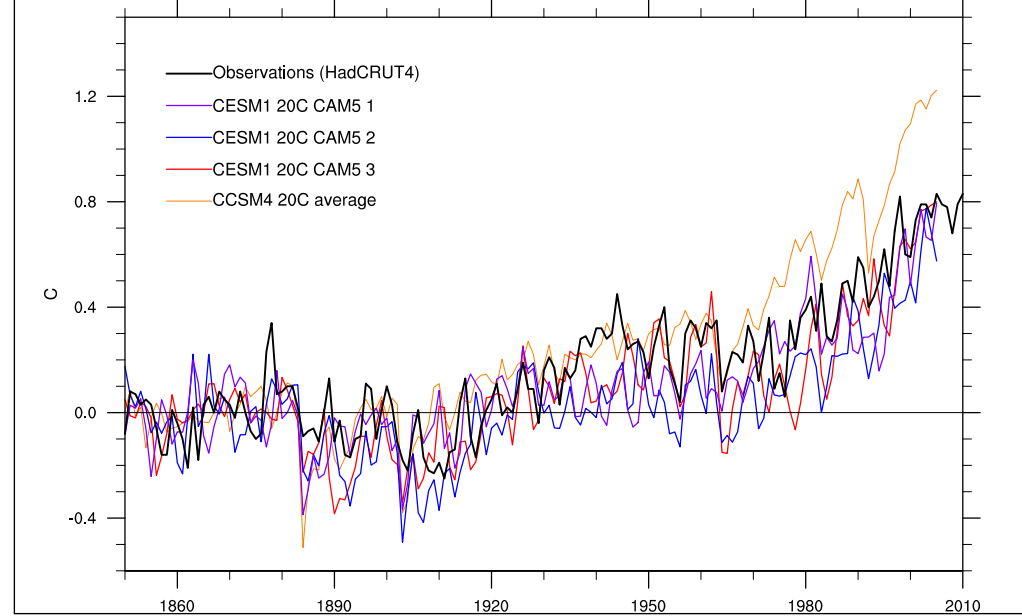


A visualization

Surface temperature

anomaly from 1850-1879, annual and global mean

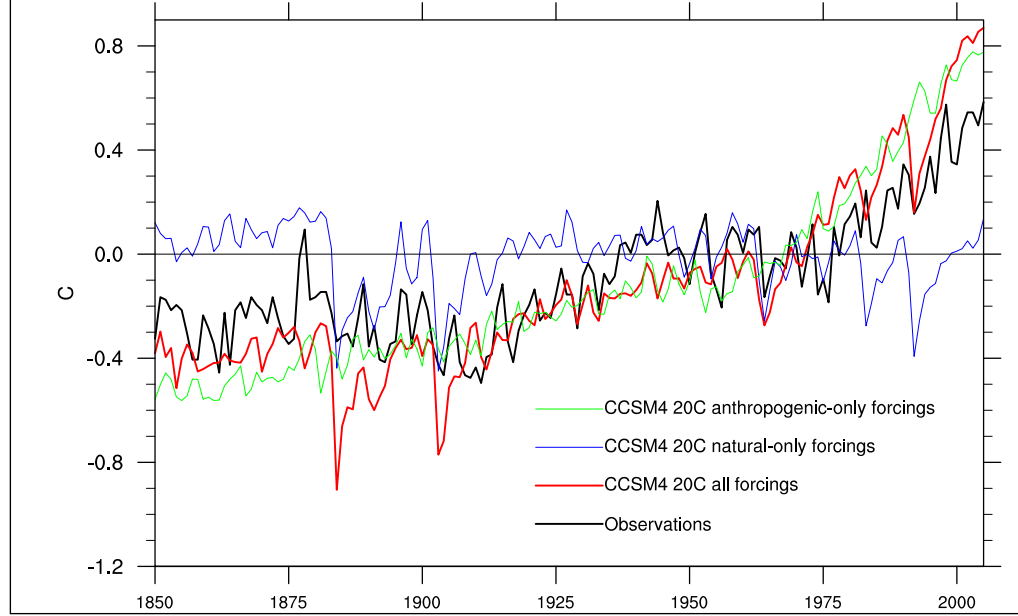
Fri Jul 27 18:32:13 MDT 2012



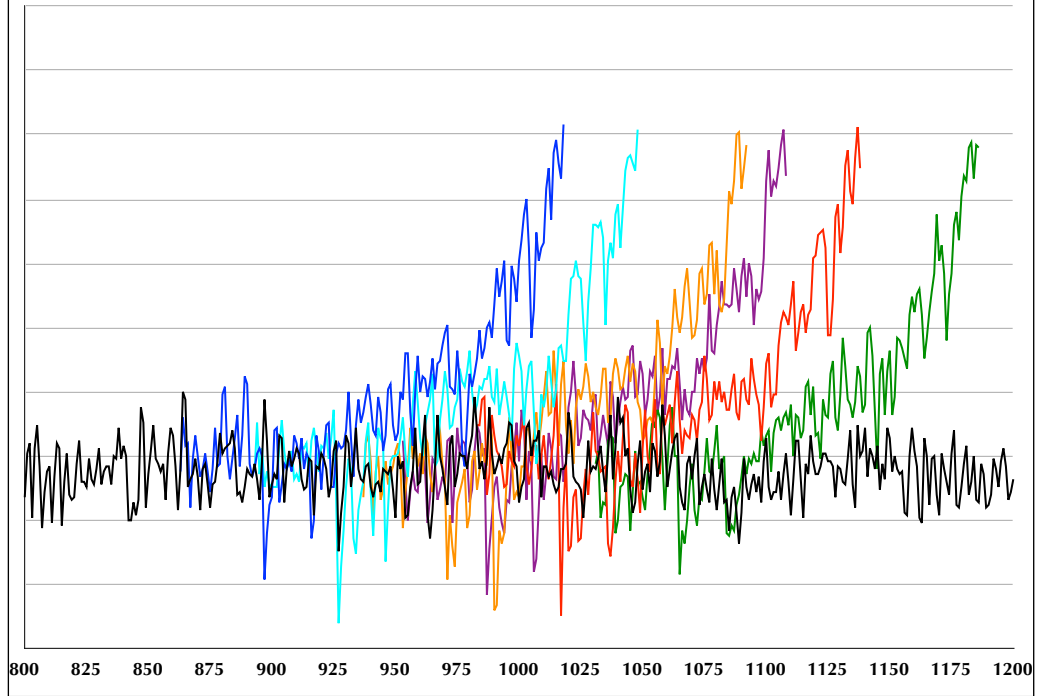
A visualization II

Surface temperature

anomaly from 1951-1980, annual and global mean



Ensembles



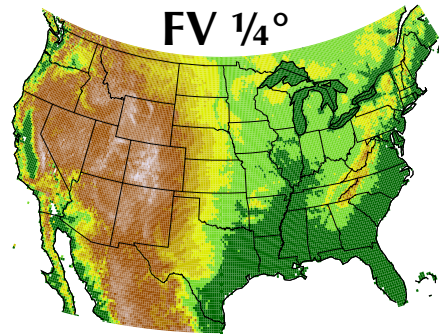
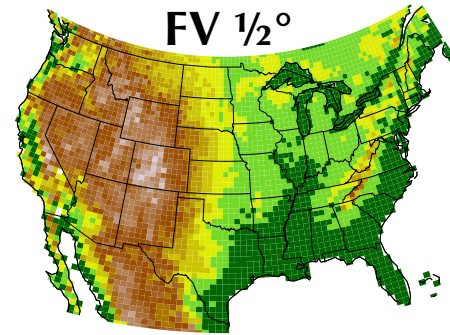
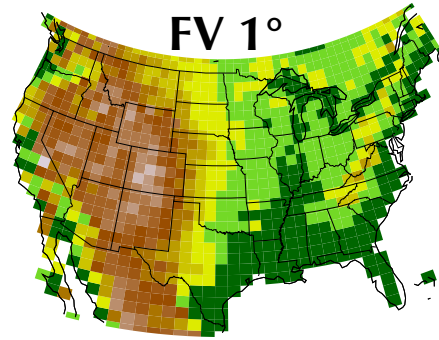
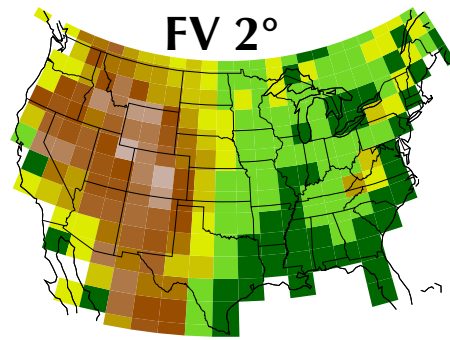
The NCAR CMIP5 model

“Community Earth System Model”, version 1

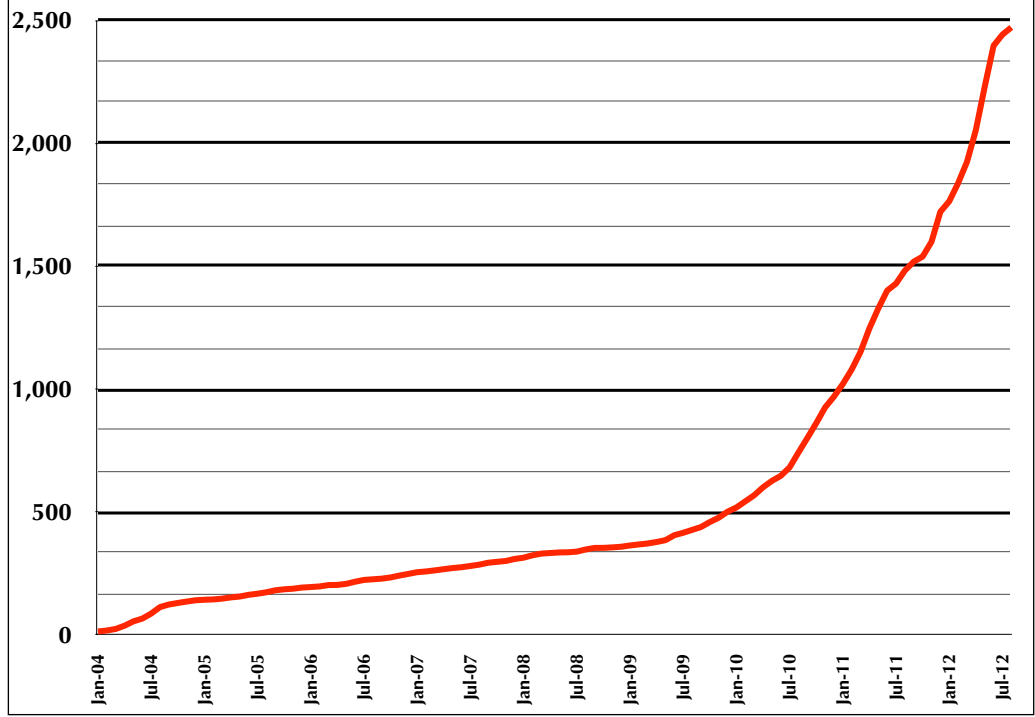
- Fully-coupled global climate model
- Different resolutions and components, depending on experiment

	used for CMIP5		under development	
	2x1	1x1	0.5x1	0.25x0.1
atmosphere	144x96x26	288x192x26	576x384x32	1152x768x32
	(280 km x 200 km)	(140 km x 100 km)	(70 km x 50 km)	(35 km x 25 km)
land surface	144x96x15	288x192x15	576x384x15	1152x768x15
ocean	384x320x60	384x320x60	384x320x60	3600x2400x60
sea ice	384x320	384x320	384x320	3600x2400

The NCAR CMIP5 models



Archived CESM model data volume (TB)



NCAR's climate model data

A bit of history...

1960s - 1990s

Self-designed self-implemented binary formats

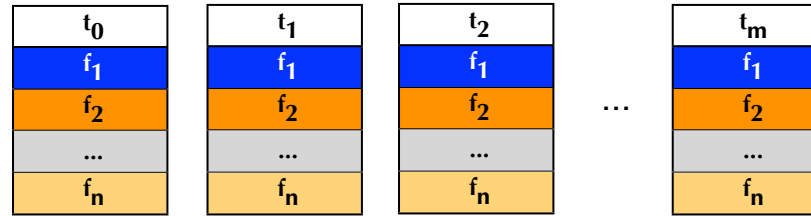
1990s-2000s

netCDF-3 for model output, some input

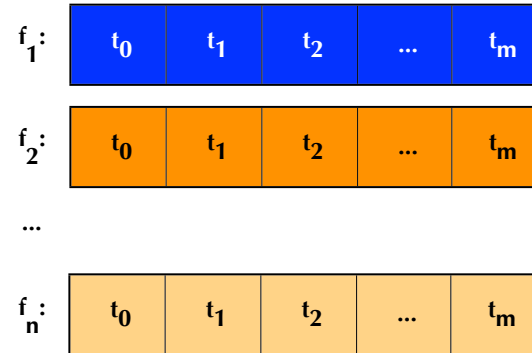
today

all netCDF, all the time

CESM output data arrangement



CMIP5 arrangement



NCAR CMIP5 simulations

CMIP5 type	Description	#
piControl	pre-industrial control	8
1% CO2 increase	1 percent per year CO2	5
historical	Simulate 20th century climate and variations	18
historical variations	Single forcing runs, etc.	38
paleoclimate	Past climate (LGM, mid-Holocene, past 1000 years)	5
RCPs	RCPs 2.6, 4.5, 6.0, 8.5	50
Decadal predictions	Predictions (hindcast and forecast)	400
ESM	Earth System Model (BGC, carbon cycle, &c)	16
Other	Sensitivity and "idealized" Earths	17
Totals		557

IPCC AR5 variable counts

	1 hour	3 hour	6 hour	daily	month	annual	totals
aerosol	0	0	0	0	81	0	81
atmosphere	75	101	9	86	184	0	455
land	0	3	0	2	59	0	64
land ice	0	0	0	2	13	0	15
ocean	0	1	0	3	116	0	120
biogeochemistry	0	0	0	0	88	71	159
sea ice	0	0	0	4	47	0	51
totals	75	105	9	97	588	71	945

Data requirements

Rather detailed (167 page PDF), including:

- Specific model fields, unchanged as well as derived
- From atmosphere, land surface, ocean and sea ice, aerosols, cloud feedbacks, and more
- Monthly averages, daily and sub-daily, annual averages, climatologies
- Single model field per netCDF-3 file, all time samples
- File sizes must be < 4 GB
- Considerable amount of metadata required
- Defined horizontal and vertical resolutions
- Stringent data and metadata conventions, CF-compliant

Metadata requirements

Standard model output for specific variable

```
float TS(time, lat, lon) ;
  TS:units = "K" ;
  TS:long_name = "Surface temperature (radiative)" ;
  TS:cell_method = "time: mean" ;
```

As required by CMIP5

```
float ts(time, lat, lon) ;
  ts:standard_name = "surface_temperature" ;
  ts:long_name = "Surface Temperature" ;
  ts:comment = "\"skin\" temperature (i.e., SST for open ocean)" ;
  ts:units = "K" ;
  ts:original_name = "TS" ;
  ts:cell_methods = "time: mean (interval: 30 days)" ;
  ts:cell_measures = "area: areacella" ;
  ts:history = "2011-07-22T00:05:32Z altered by CMOR: replaced missing value
flag (-1e+32) with standard missing value (1e+20)." ;
  ts:missing_value = 1.e+20f ;
  ts:_FillValue = 1.e+20f ;
  ts:associated_files = "baseUrl: http://cmip-pcmdi.llnl.gov/CMIP5/dataLocation
gridspecFile: gridspec_atmos_fx_CCSM4_historical_r0i0p0.nc areacella:
areacella_fx_CCSM4_historical_r0i0p0.nc" ;
```

Metadata requirements

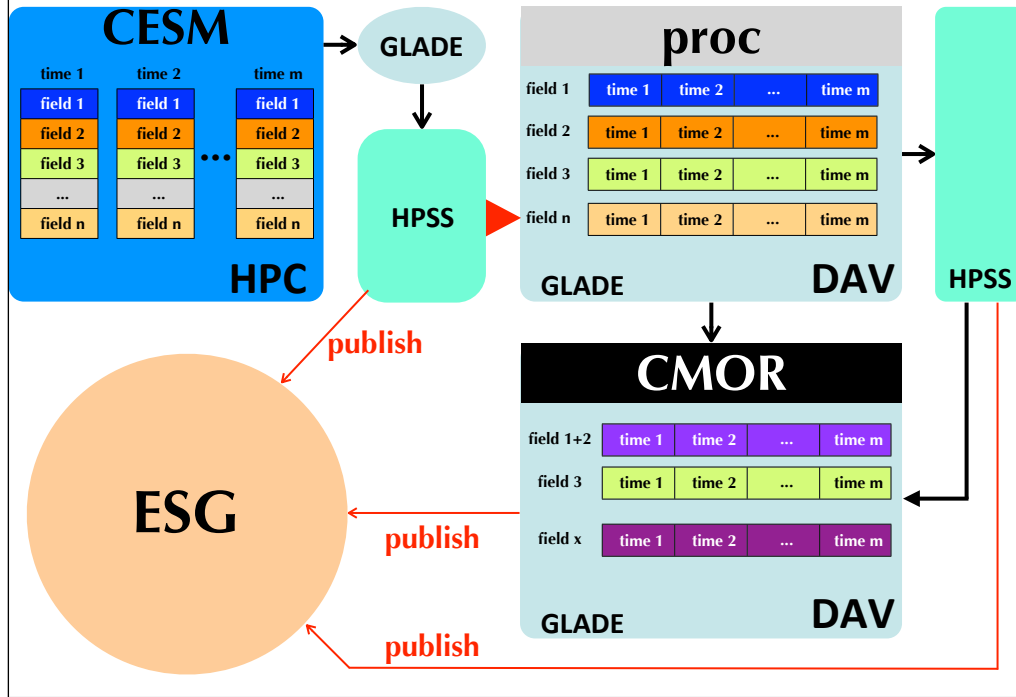
Standard model global attributes

```
:Conventions = "CF-1.0" ;
:source = "CAM" ;
:case = "b40.20th.track1.ldeg.006" ;
:title = "UNSET" ;
:logname = "mal" ;
:host = "be0609en.ucar.ed" ;
:Version = "$Name$" ;
:revision_id = "$Id$" ;
:initial_file = "b40.1890.track1.ldeg.006.cam2.i.0893-01-01-0000.nc" ;
:topography_file = "/fs1/cg4/cseg/cam/inputdata/atm/cam/topo/USGS-gtopo30_0.9x1.25_remapp_c051027.nc" ;
:nco_openmp_thread_number = 1 ;
```

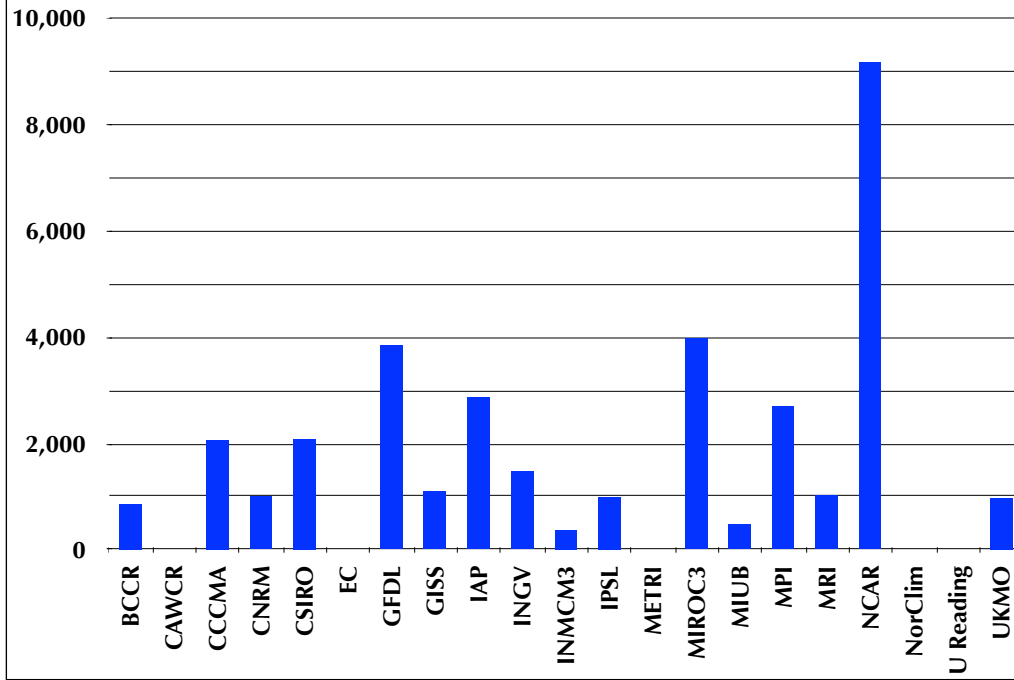
As required by CMIP5

```
:institution = "NCAR (National Center for Atmospheric Research) Boulder, CO, USA" ;
:institute_id = "NCAR" ;
:experiment_id = "historical" ;
:source = "CCSM4 (repository tag: ccsm4_0_beta43 compset: B20TRCN)" ;
:model_id = "CCSM4" ;
:forcing = "s1 GHG VI SS DS SD BC MD OC Oz AA LU" ;
:parent_experiment_id = "piControl" ;
:parent_experiment_rip = "r1i1p1" ;
:branch_time = 937. ;
:contact = "cesm_data@ucar.edu" ;
:references = "Gent P. R., et.al. 2011: The Community Climate System Model version 4. J. Climate, doi: 10.1175/2011JCLI4083.1" ;
:initialization_method = 1 ;
:physics_version = 1 ;
:tracking_id = "d33ccf77-a73c-4f55-8f02-3a0734d51151" ;
:acknowledgements = "The CESM project is supported by the National Science Foundation and the Office of Science (BER) of the U.S. Department of Energy." ;
n",
    "NCAR is sponsored by the National Science Foundation.\n",
    "Computing resources were provided by the Climate Simulation Laboratory at the NCAR Computational and Information Systems Laboratory (CISL),\n",
    "sponsored by the National Science Foundation and other agencies." ;
:resolution = "f09_g16 (0.9x1.25_gx1v6)" ;
:forcing_note = "Additional information on the external forcings used in this experiment can be found at\n",
    "http://www.cesm.ucar.edu/CMIP5/forcing\_information" ;
:product = "output" ;
:experiment = "historical" ;
:frequency = "mon" ;
:creation_date = "2011-07-22T00:05:32Z" ;
:history = "2011-07-22T00:05:32Z CMOR rewrote data to comply with CF standards and CMIP5 requirements." ;
:Conventions = "CF-1.4" ;
:project_id = "CMIP5" ;
:table_id = "Table Amon (27 April 2011) a5alc518f52ae340313ba0aada03f862" ;
:title = "CCSM4 model output prepared for CMIP5 historical" ;
:parent_experiment = "pre-industrial control" ;
:modeling_realm = "atmos" ;
:realization = 1 ;
:cmor_version = "2.7.1" ;
```

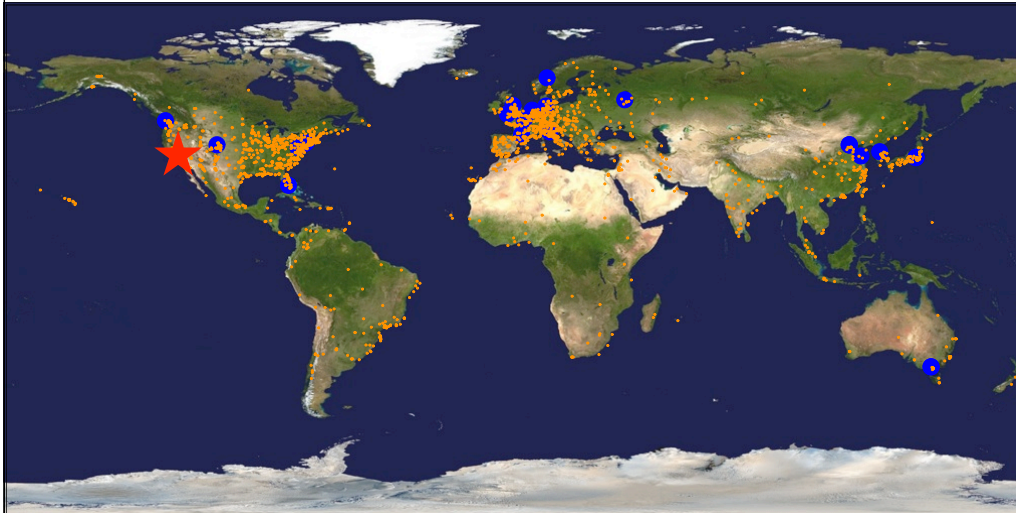
CESM to CMIP5 workflow



CMIP3 data volumes by group (GB)

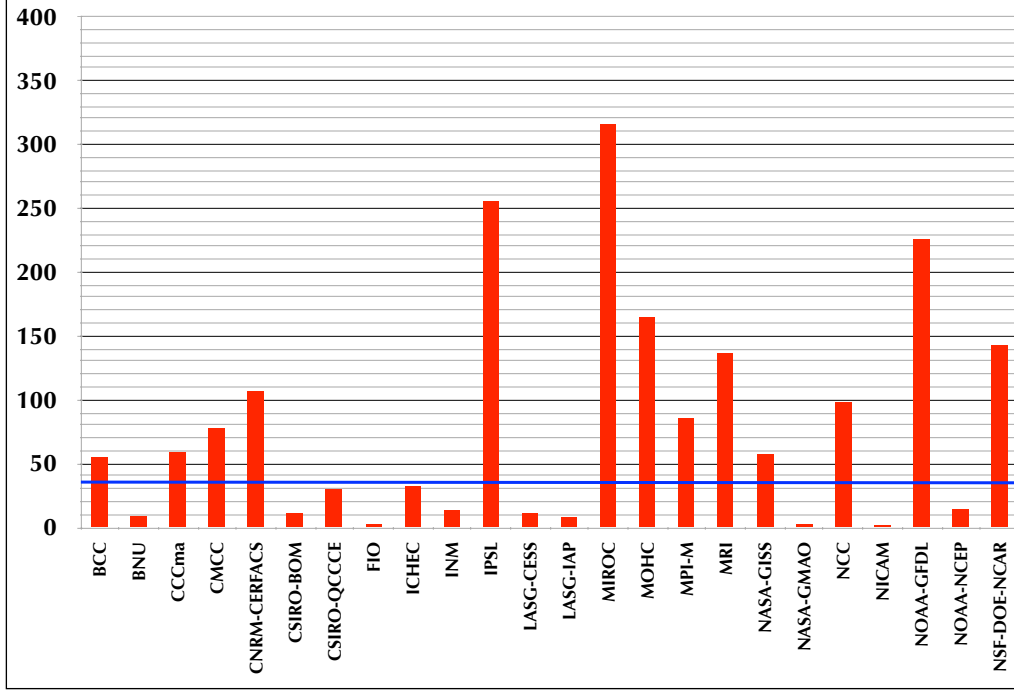


IPCC AR4 distribution

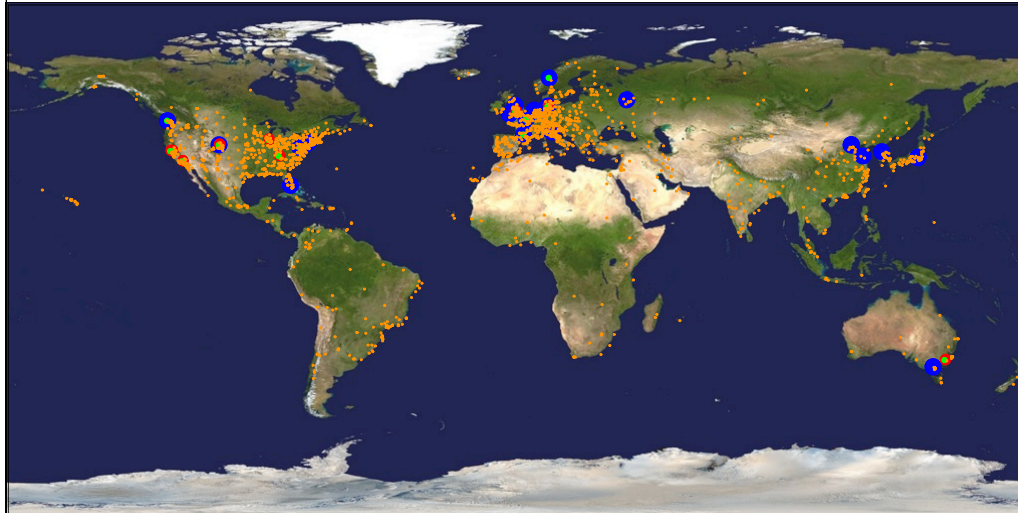


● Modeling centers (16) ● Gateway (1) ● Users (1000s)

CMIP5 data volumes by group (TB)



IPCC AR5 distribution



Some lessons

- Know your data - very well
- Exploit the pre-existing standards for your data **AND** metadata!
- Metadata - the **more**, the **better**
- Publish your data - earn the credit
- Make the lives of those who use your data easier - and that will make your life easier too

Some useful references

CESM website:

<http://www.cesm.ucar.edu>

CMIP5 website:

<http://cmip.llnl.gov>

NetCDF Climate and Forecast (CF) Metadata Convention:

<http://cf-pcmdi.llnl.gov>

NetCDF Operators (NCO):

<http://nco.sourceforge.net>

Climate Data Operators (CDO):

<http://www.mpimet.mpg.de/fileadmin/software/cdo>