The NCAR Community Earth System Model and the IPCC Fifth Assessment Report

BESSIG meeting
Gary Strand
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The Development of Climate Models
Past to the Present

Mid-1960s
- Atmosphere and land surface
- Ocean
- Sea ice

1970s-1980s
- Atmosphere, land surface, vegetation
- Ocean
- Sea ice
- Sulfate aerosols
- Solar forcing, volcanic aerosols

1990s
- Atmosphere, land surface, vegetation
- Ocean
- Sea ice
- Sulfate aerosols
- Solar forcing, volcanic aerosols

2000s
- Atmosphere
- Ocean
- Sea ice
- Sulfate aerosols
- Solar forcing, volcanic aerosols
- Carbon cycle
- Dust, Sea Spray, & Mineral Aerosols

Present day
- Atmosphere
- Ocean
- Sea ice
- Sulfate aerosols
- Solar forcing, volcanic aerosols
- Carbon/Nitrogen cycle
- Dust, Sea Spray, & Mineral Aerosols
- Land surface, interactive vegetation
- Biogeochemical cycles
- Ice sheet
The Development of Climate Models

(From “History of climate modeling”, by Paul Edwards; DOI: 10.1002/wcc.95)
Focus Article

wires.wiley.com/climatechange

one-dimensionally, by latitude bands or 'zones' (as in Arrhenius' 1896 model). EBMs can also be two-dimensional, with both zonal and longitudinal or 'meridional' energy flows. A second type of mathematical climate model, the radiative–convective model, focuses on vertical transfers of energy in the atmosphere. Such models typically simulate the atmosphere's temperature profile in either one dimension (vertical) or two (vertical and meridional). When Callendar revived the carbon dioxide theory of climate change in 1938 (following new, more sensitive measurements that disproved ˚Angström's argument), he used a one-dimensional radiative model that divided the atmosphere into twelve vertical layers.

A third type is the two-dimensional statistical–dynamical model, employed primarily to study the circulatory cells; in these models the dimensions are vertical and meridional.

These three categories of models play key roles in climate science. The simplest of them can be worked out by hand. As their complexity increases, however, it becomes increasingly difficult to solve the systems of equations involved without a computer.

GENERAL CIRCULATION MODELS

In the early 20th century Vilhelm Bjerknes showed how to compute large-scale weather dynamics using what are now known as the 'primitive equations' of motion and state. These equations include Newton's laws of motion, the hydrodynamic state equation, mass conservation, and the thermodynamic energy equation. Bjerknes's mathematical model described how mass, momentum, energy, and moisture are conserved in interactions among individual parcels of air. However, Bjerknes' equations did not have closed-form solutions, and numerical techniques capable of approximate solutions did not yet exist.

During World War I, Richardson developed an umbral forecasting method based on Bjerknes' equations, using a finite-difference grid. Due to an error in the input observations, Richardson's only test of the method led to a surface pressure prediction 150 times larger than the actual observed change. Further, his methods were not sophisticated enough to keep numerical instabilities from building up as he iterated the calculations. These problems led meteorologists to abandon numerical modeling for the next two decades.

Better mathematical methods for minimizing numerical instabilities in massively iterative calculations emerged only after the advent of digital computers, becoming a central preoccupation of weather and climate modeling from the 1940s into the present.

Immediately after World War II, weather prediction was among the first major applications of digital computers, heavily supported by both military agencies and civilian weather services. Early experiments with computerized numerical weather prediction (NWP) followed Richardson's lead in employing Cartesian grids (Figure 2) and finite-difference methods, computing vertical and horizontal mass and

Horizontal grid
Latitude - longitude

Vertical grid
Height or pressure

Physical processes in a model

Atmosphere

Solar radiation
Terrestrial radiation

Advection

Sea ice

Water

Heat

Momentum

Mixed layer ocean

Continent

Sea ice

Mixed layer ocean

Snow

Continent

Mixed layer ocean

Advection

(From “History of climate modeling”,by Paul Edwards; DOI: 10.1002/wcc.95)
### CESM schematic (less simple)

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<th>DOCN-(SOM/DOM)</th>
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<th>Land-Ice Component</th>
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<th>New Wave Component</th>
<th>WW3</th>
<th>DWAV</th>
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### Coupler

Regridding, Merging, Calculation of ATM/OCN fluxes, conservation diagnostic
Replicates the past quite well!

Temperature anomaly from 1980-1999

- CESM1 20C CAM5
- RSS
- UAH
- NOAA
- GISS
- HadCRUT3v

Temperature anomaly from 1860-2010, deg C

Year
### CESM infrastructure

![CESM RUN DATABASE INTRAWEB](image)

#### Displaying experiments [1 - 25] out of 241

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CMIP5/IPCC AR5

“The Intergovernmental Panel on Climate Change”

• 1990 - First Assessment Report
• 1995 - Second Assessment Report
• 2001 - Third Assessment Report
• 2007 - Fourth Assessment Report
• 2013 - Fifth Assessment Report
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.
# CESM CMIP5 simulations

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<td>1% CO2 increase</td>
<td>1 percent per year CO2</td>
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<td>historical</td>
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<td>historical variations</td>
<td>Single forcing runs, etc.</td>
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<td>Decadal predictions</td>
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<td>Other</td>
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The NCAR CMIP5 model
“Community Earth System Model”, version 1

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

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CESM resolutions

FV 2°

FV 1°

FV ½°

FV ¼°
## CMIP5 variable counts

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CMIP5 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 ~2-5 GB (as practical)
- 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

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

As required by CMIP5

```plaintext
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

As required by CMIP5
Metadata requirements

Standard model global attributes

As required by CMIP5

Acknowledgements = "The CESM project is supported by the National Science Foundation and the Office of Science (BER) of the U.S. Department of Energy. NCAR is sponsored by the National Science Foundation.\n\nComputing resources were provided by the Climate Simulation Laboratory at the NCAR Computational and Information Systems Laboratory (CISL),\n\n\nresolution = "f09_g16 (0.9x1.25_gx1v6)";\n\nforcing_note = "Additional information on the external forcings used in this experiment can be found at\n\nhttp://www.cesm.ucar.edu/CMIP5/forcing_information";\n\nproduct = "output";\n\nexperiment = "historical";\n\nfrequency = "mon";\n\ncreation_date = "2011-07-22T00:05:32Z";\n\nhistory = "2011-07-22T00:05:32Z CMOR rewrote data to comply with CF standards and CMIP5 requirements.";\n\nConventions = "CF-1.4";\n\nproject_id = "CMIP5";\n\ntable_id = "Table Amon (27 April 2011) a5alc518f52ae340313ba0aada03f862";\n\ntitle = "CCSM4 model output prepared for CMIP5 historical";\n\nmodeling Realm = "atmos";\n\nrealization = 1;\n\nCMOR_version = "2.7.1";

Thursday, August 18, 2011
Data volumes by group

CMIP3 by group (GB)

Thursday, August 18, 2011
All over the globe...

- Modeling centers (24)
- Gateways (9)
- Nodes (14)
The ESG federation

**Clients**
- Gateway
- Data Node
- Products

**LLNL/PCMDI Gateway**
- User Registration
- Metadata Handling
- Single Sign-On
- Group Management
- Search and Discovery
- Harvester
- Data Products
- Database
- Workflow Management
- Publishing AP
- Metrics Aggregation
- Security

**PCMDI Data Node**
- TDS Catalogs
- Browsing
- OPeNDAP
- GridFTP
- Product
- Manager
- Publisher
- THREDDS
- Deep Archive
- Disk Cache

**Security Middleware**

**Gateway**
- LBNL/NERSC
- NASA
- ORNL
- NCAR
- ANU
- DKRZ
- BADC

**Compute and Visualization**
- UV-CDAT (remote server)

**UV-CDAT Desktop Client**

**Users**

**Earth System Grid Federation (ESGF)**

**GFDL Data Node**

**NASA/GISS Data Node**

**IPSL Data Node**

**INM Data Node**

**Earth System Grid Federation (ESGF)**
Data QC

Data Published > 10 PB
Data and Metadata QC L1
On globally distributed data nodes

Metadata QC L2 passed?
YES

Data QC L2 passed?
YES

To be replicated among ESGF?
YES

Data QC L3 passed?
YES

Replicated:
Copied to PCMDI, BADC, WDCC & elsewhere ~ 1PB

NO

Discard data

NO

Data NOT formally citable
Modelling group control access manually.

Data NOT formally citable
Automatic access granted after filling in ESGF registration page.

NO

DOI Assigned:
Data formally citable
Data can appear in IPCC-DDC
Automatic access granted after filling in ESGF registration page

(Informal citation still requested where formal citation not available)
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<td>Data consistency checks</td>
<td>Double- and cross-checks of data and metadata and data publication as DataCite DOI</td>
</tr>
<tr>
<td><strong>Access</strong></td>
<td>constrained to CMIP5 modeling centers</td>
<td>constrained to non-commercial research and educational purposes</td>
<td>constrained to non-commercial research and educational purposes, or open for unrestricted use (as specified by the modeling centers)</td>
</tr>
<tr>
<td><strong>Access Control</strong></td>
<td>PCMDI on behalf of WMO/WGCM</td>
<td>PCMDI, BADC, WDCC/DKRZ core data archives on behalf of WMO/WGCM</td>
<td>IPCC-DDC on behalf of TGICA</td>
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<td><strong>Citation</strong></td>
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<td>informal citation reference</td>
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<td><strong>Quality Flag</strong></td>
<td>&quot;automated conformance checks passed&quot;</td>
<td>&quot;subjective quality control passed&quot;</td>
<td>&quot;approved by author&quot; (in case of newer DOI available: &quot;approved by author, but suspended&quot;)</td>
</tr>
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Thursday, August 18, 2011
Some useful URLs

**CESM**
http://www.cesm.ucar.edu

**CMIP5**
http://cmip.llnl.gov/cmip5