WACCM-X: The Whole Atmosphere Community Climate Model - eXtended

WACCM-X is a model of the entire atmosphere that extends into the thermosphere to ~500 km altitude, and includes the ionosphere. It is the work of many people at the National Center for Atmospheric Research in the Geospace section of the High Altitude Observatory, in the Atmospheric Chemistry, Observations, and Modeling Laboratory, the Climate and Global Dynamics division, and external collaborators.

WACCM-X is built on WACCM

WACCM is built on CAM

CAM is the NCAR Community Atmosphere Model

CAM, WACCM, and WACCM-X are run as the atmospheric component within the Community Earth System Model (CESM), which also includes components for land, oceans, sea ice, and land ice.
Because the thermosphere-ionosphere system responds to variability from the Earth’s lower atmosphere as well as solar-driven “space weather”

Including:
- Waves and tides
- Tropospheric weather
- Middle-atmosphere events
- Seasonal variations
- Anthropogenic trace gases

Illustration from the ICON mission, T. Immel et al.
Community Earth System Model (CESM)

CESM components

**Forcings:**
- Greenhouse gases
- Aerosols
- Volcanic eruptions
- Solar variability

**Biogeochemistry**
(Carbon-Nitrogen Cycle)

**Land**
(CLIM)

**Surface Wave**
(WaveWatch)

**Ocean**
(POP)

**Coupler**
(CPL)

**Atmosphere**
(CAM)

**WACCM**

**WACCM-X**

**CAM-CHEM**

**Sea Ice**
(CICE)

**Land Ice**
(CISM)

Biogeochemistry
(Marine Ecosystem)
NCAR Community Earth System Model (CESM) atmosphere components
# CESM2: WACCM6 & WACCM-X

<table>
<thead>
<tr>
<th></th>
<th>WACCM6</th>
<th>WACCM-X</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong># levels</strong></td>
<td>70-88</td>
<td>125-145</td>
</tr>
<tr>
<td><strong>model top</strong></td>
<td>6x10^{-6} hPa (~140 km)</td>
<td>4x10^{-10} hPa (500~600 km)</td>
</tr>
<tr>
<td><strong>Horizontal resolution</strong></td>
<td>0.95°x1.25°</td>
<td>1.9°x2.5°</td>
</tr>
<tr>
<td><strong>Time step</strong></td>
<td>30 min.</td>
<td>5 min.</td>
</tr>
<tr>
<td><strong>Specified Dynamics</strong></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>** Chemistry**</td>
<td>TSMLT, MA</td>
<td>MA</td>
</tr>
<tr>
<td><strong>Non-orographic GW</strong></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Molecular diffusion</strong></td>
<td>minor</td>
<td>minor and major</td>
</tr>
<tr>
<td><strong>Auroral physics</strong></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Ions</strong></td>
<td>E-region or E&amp;D-region</td>
<td>E-region</td>
</tr>
<tr>
<td><strong>Ion transport</strong></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>E Dynamo</strong></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Supported releases (i.e. model versions)
Latest release is CESM1.2 (CESM2.0 coming soon)
In Development - CESM2

About CESM2

TO DO Brief Description of CESM2

- What's New in CESM2
- CESM2 Supported Release Tags and Notes

Scientific Validation

Scientific validation consists of a multi-decadal model run of the given component set at the target resolution, followed by scientific review of the model output diagnostics. All scientifically supported component sets are also accompanied by diagnostic and model output data.

- Experiment Diagnostics
- Experiment Output Datasets on the Earth Systems Grid
- Experiment Case Naming Conventions
- Experiment Output File Naming Conventions

Quick Start Documentation

- CESM2 Quick Start Guide
- CESM2 CASEROOT XML File Settings
- Register and Download
- Getting Help - DiscussCESM Forums

CIME - Documentation

- Common Infrastructure for Modeling the Earth (CIME) User's Guides
  Includes CIME, Driver-Coupler and Data Models Documentation

Related Information

- Downloading the CESM Code
- CESM Data Management & Distribution Plan
- CESM Development Project Policies & Terms of Use
- CESM Support Policy
- DiscussCESM Forums Bulletin Board
Prognostic Components

Each model component page contains descriptions and documentation for active or prognostic models.

- Atmosphere
- Land
- Land Ice
- Ocean
- Sea Ice
- River Runoff
- Wave

Component Sets, Model Grids, and Machines

TODO - update just prior to release
- Component Sets (components)
- Grid Resolutions
- Supported Machines

Component NameLists

TODO - update just prior to release
- Component NameLists

Performance Data

- Performance and Load Balancing Data
- Running CESM2 on a Small Linux Cluster

External Library Documentation

- Parallel I/O Library (PIO)
- Model Coupling Toolkit (MCT)
- Earth System Modeling Framework (ESMF)
- External Python Based Tools
  * Support for these tools is currently limited to NCAR machines only! Access to these external python based tools are being provided to the community via NCAR Github repositories.

Model Input Data

The input data necessary to run all supported component sets is made available from a public Subversion input data repository. Note that the input data repository has much more data in it than you need to run CESM - DO NOT attempt to svn checkout the whole input data repository. The CIME User’s Guide explains how to obtain the subset of input data required for your needs.
How do I get the WACCM data?

10 Tb of WX output have been placed on the NCAR Earth System Grid

A small (150mb) sample is available at:

https://acomstaff.acom.ucar.edu/marsh/Data/waccmx/
Search for "fxsd"

1 - 5 of 5 results

- CCSM run f.e20.FXSD.f19_f19.001, Atmosphere History Data, 5-day Averages, version 1
- CCSM run f.e20.FXSD.f19_f19.001, Atmosphere History Data, Daily Averages, version 1
- CCSM run f.e20.FXSD.f19_f19.001, Atmosphere History Data, Daily Instantaneous Values, version 1
- CCSM run f.e20.FXSD.f19_f19.001, Atmosphere History Data, Hourly Instantaneous Values, version 1
- CCSM run f.e20.FXSD.f19_f19.001, Atmosphere History Data, Monthly Averages, version 1
WACCM-X output

- **netCDF**: self-describing binary data format used for primary CESM output
- **History files**: WACCM-X output is written to several output streams, each with a particular frequency and averaging characteristic
  - **h0**: monthly averages
    - f.e20.FXSD.f19_f19.001.cam.h0.2000-01.nc (January 2000)
    - f.e20.FXSD.f19_f19.001.cam.h0.2000-02.nc (February 2000)
  - **h1**: hourly instantaneous
  - **h2**: daily instantaneous
  - **h3**: daily averages
  - **h4**: 5-day averages
  - **h5**: daily averages, zonal mean circulation diagnostics
<table>
<thead>
<tr>
<th>Identifier</th>
<th>ucar.cgd.cesm4.f.e20.FXSD.f19_f19.001.atm.hist.hourly_inst</th>
</tr>
</thead>
</table>

**Data Created**
2017-06-21 18:15:08

**Date Last Updated**
2017-06-21 18:15:08

**Authoritative Source**
tds.ucar.edu

**Topic**
Climate

**Data Format**
NetCDF (Network Common Data Format)

**Time Frequency(ies)**
hourly_inst

Yesterday!

Select ‘Download Options’
Community Earth System Model

Earth System Grid at NCAR

Download Files

Files can be downloaded through a Web Browser, downloaded in bulk via a WGET script, or requested from our Deep Storage Archives (SRM).

Filter Files

Filter by Filename

Use * for a wildcard character.

Apply Filter

File Download Selection

CCSM run f.e20.FXSD.f19_f19.001, Atmosphere History Data, Hourly Instantaneous Values, version 1
3653 files

<table>
<thead>
<tr>
<th>File</th>
<th>Size</th>
<th>Format</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>f.e20.FXSD.f19_f19.001.cam.h1.2000-01-01-000000.nc</td>
<td>2.16 GB</td>
<td>SRM</td>
<td></td>
</tr>
<tr>
<td>f.e20.FXSD.f19_f19.001.cam.h1.2000-01-02-000000.nc</td>
<td>2.16 GB</td>
<td>SRM</td>
<td></td>
</tr>
<tr>
<td>f.e20.FXSD.f19_f19.001.cam.h1.2000-01-03-000000.nc</td>
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<td></td>
</tr>
<tr>
<td>f.e20.FXSD.f19_f19.001.cam.h1.2000-01-04-000000.nc</td>
<td>2.16 GB</td>
<td>SRM</td>
<td></td>
</tr>
<tr>
<td>f.e20.FXSD.f19_f19.001.cam.h1.2000-01-05-000000.nc</td>
<td>2.16 GB</td>
<td>SRM</td>
<td></td>
</tr>
<tr>
<td>f.e20.FXSD.f19_f19.001.cam.h1.2000-01-06-000000.nc</td>
<td>2.16 GB</td>
<td>SRM</td>
<td></td>
</tr>
<tr>
<td>f.e20.FXSD.f19_f19.001.cam.h1.2000-01-07-000000.nc</td>
<td>2.16 GB</td>
<td>SRM</td>
<td></td>
</tr>
</tbody>
</table>
WACCM-X history output files may be analyzed with standard analysis tools, including **Matlab**, **IDL**, **NCL**, and **NCO**.

- **Panoply**: netCDF data viewer for macOS, Windows, and Linux from NASA Goddard. Free download at [https://www.giss.nasa.gov/tools/panoply/](https://www.giss.nasa.gov/tools/panoply/)
31 March 2001 Solar Storm

Estimated Planetary K index (3 hour data)

Begin: 2001 Mar 30 0000 UTC

Updated 2001 Apr 2 02:45:02 UTC  
NOAA/SEC Boulder, CO USA
“Storm-enhanced density (SED) stretching from the east coast of the United States diagonally north and west across Canada to high latitudes.”
Electron Column Density

Time: 2001-03-29 00:00 — 2001-03-29 01:00

Electron Column Density (TECU)

Data Min = 3, Max = 168, Mean = 39
Electron Column Density

Time: 2001-03-29 00:00 — 2001-03-29 01:00

Electron Column Density (TECU)

Data Min = 3, Max = 108, Mean = 39
Description

The Meteo AR app provides an Augmented Reality interface for exploring 3D earth science data sets and learning more about the complex environment we live in. Just point your iPhone or iPad's camera to one of our “science sheets” (link below) and see... more
Looking at WACCM-X output: GEOV

**GEOV** is an IDL-based viewer for geophysical history files created by NCAR's CAM, WACCM and MOZART models. GEOV can be downloaded from the WACCM webpage at [http://www.cesm.ucar.edu/working_groups/Whole-Atmosphere/code-release.html](http://www.cesm.ucar.edu/working_groups/Whole-Atmosphere/code-release.html)
Looking at WACCM-X output: GEOV

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• Run GEOV on cheyenne with:

  ```
  module load idl
  setenv IDL_STARTUP ~fvitt/idl_startup
  idl geov
  ```

![Image of temperature map](image)
Hardware and software requirements

• Supported platforms
  • CESM currently runs “out of the box” on NCAR machines (cheyenne and yellowstone), as well as a number of other computing platforms
  • Always review the model version release notes and DiscussCESM Forums (https://bb.cgd.ucar.edu) for up-to-date machine specific issues.

• Running CESM on other platforms
  • Requires porting and software
    • Subversion, Fortran and C compilers, NetCDF library, MPI
  • See model version release notes and DiscussCESM Forums for guidance
NCAR supercomputer access

- Large Allocation Requests
  - > 400,000 core-hours on Cheyenne
  - CISL accepts requests for large allocations of NCAR resources every six months, in March and September.

- Small Allocation Requests
  - ≤ 400,000 core-hours on the Cheyenne system
  - U.S. university researchers who are supported by NSF awards can request a small allocation for each NSF award.
  - Also available to graduate students and post-docs at U.S. universities; no NSF award or panel review is required.
  - Small requests typically receive a partial allocation within a few business days. Once the initial allocation is consumed, you can email alloc@ucar.edu to request additional core-hours up to a total allowed.

- Small Data Access Requests
  - Faculty and research staff at U.S. universities, U.S. non-profit research organizations, and UCAR affiliates can request read-only access to NCAR-housed data at no charge.
  - These accounts are granted sufficient access to read data from GLADE and HPSS for up to three years. They may be renewed by sending email to alloc@ucar.edu and stating the additional time period needed.

https://www2.cisl.ucar.edu/user-support/allocations/university-allocations
Basic Work Flow: Creating and Running WACCM-X

- If not running at NCAR, some one-time set-up steps are needed (not covered here):
  - Registration
  - Downloading the CESM code
  - Creating an input data root directory
  - Porting
- Creating and running a case
  - Create a new case
  - Invoke case.setup
  - Build the executable
  - Run the model and output data flow
YubiKey authentication tokens enable authorized users to access a variety of UCAR resources. For detailed instructions, see:

https://www2.cisl.ucar.edu/user-support/authentication-and-security/yubikey

Logging in:

```bash
ssh -X -l username cheyenne.ucar.edu
```

Source code for released model versions can be found here:

```bash
ls /glade/p/cesm/releases
```

When released, CESM2.0 will be there under cesm2_0_0. To create a new case, go to the “cime/scripts” subdirectory under the model version source code directory:

```bash
cd /glade/p/cesm/releases/cesm2_0_0/cime/scripts
```

There you will find the tool used to create a new run: create_newcase.
WACCM-X can be run with a set of 4 commands.

Set of commands to build and run the model on Cheyenne:

1. Go into the scripts directory in the source code:
   ```bash
cd /glade/p/cesm/releases/cesm2_0_0/cime/scripts
   ```
2. Create a new case in the directory “cases/cheyenne” in your home directory:
   ```bash
   ./create_newcase --res f19_f19 --compset FXHIST --case ~/cases/cheyenne/f.e20.FXHIST.f19_f19.001
   ```
   Go into the case you just created in the last step:
   ```bash
   cd ~/cases/cheyenne/f.e20.FXHIST.f19_f19.001
   ```
3. Invoke case.setup
   ```bash
   ./case.setup
   ```
4. Build the executable
   ```bash
   ./case.build
   ```
5. Submit your run to the batch queue
   ```bash
   ./case.submit
   ```
Creating a new case

In the cime/scripts directory, `create_newcase` is the tool that generates a new model case.

`create_newcase` requires 3 arguments:

- Which resolution?
- Which model configuration?
- Which set of components?
- What is the casename?

```
./create_newcase --res f19_f19 --compset FXHIST --case ~/cases/cheyenne/f.e20.FXHIST.f19_f19.001
```

To check the current syntax of `create_newcase`:

```
./create_newcase --help
```
“FXHIST” is an example of a component set, or “compset”, which defines the configuration of the CESM component models: atmosphere, land, ocean, sea ice, and land ice.

All WACCM-X components use non-interactive data models for ocean and sea ice, and do not include interactive land ice. Such compsets all begin with the letter “F”.

To list available WACCM-X compsets, while under cime/scripts type:

```
./query_config --compsets | grep %WXIE
```

<table>
<thead>
<tr>
<th>short name</th>
<th>long name</th>
</tr>
</thead>
<tbody>
<tr>
<td>FXHIST</td>
<td>FRC1_CAM40%WXIE_CLM45%SP_CICE%PRES_DOCN%DOM_RTM_SGLC_SWAV</td>
</tr>
<tr>
<td></td>
<td>WACCM-X historical 2000-2014</td>
</tr>
<tr>
<td>FX2000climo</td>
<td>2000_CAM40%WXIE_CLM45%SP_CICE%PRES_DOCN%DOM_RTM_SGLC_SWAV</td>
</tr>
<tr>
<td></td>
<td>WACCM-X climatological present-day, static year 2000</td>
</tr>
<tr>
<td>FXSD</td>
<td>SDYN_CAM40%WXIE_CLM45%SP_CICE%PRES_DOCN%DOM_RTM_SGLC_SWAV</td>
</tr>
<tr>
<td></td>
<td>WACCM-X nudged with specified dynamics (SD) 2000-2009</td>
</tr>
</tbody>
</table>

For more help on query_config:

```
./query_config --help
```
What horizontal resolution does WACCM-X use?

WACCM-X runs at 1.9° latitude x 2.5° longitude, which is abbreviated as “f19_f19”.

To list the grids available:

```
./query_config --grids
```

alias: f19_f19 (only for compsets that are not _POP )
non-default grids are: atm:1.9x2.5 lnd:1.9x2.5 ocnice:1.9x2.5
mask is: gx1v6

Again, to create a WACCM-X case:

```
./create_newcase --compset FXHIST --res f19_f19
--case ~/cases/cheyenne/f.e20.FXHIST.f19_f19.001
```
Overview of directories

Source
$SRCROOT
/glade/p/cesm/releases/cesm2_0_0/

Components
Cime
Scripts
create_newcase

Case
$CASEROOT

Case setup
&
Case build:

Scripts used in the next step

Env_*.xml files with xml variables used by CESM

Xmlchange: script to edit env_*.xml files

Source Mods

Run
$RUNDIR

/glade/scratch/$CCSMUSER/$CASE/run

Input data
$DIN_LOC_ROOT
/glade/p/cesm/cseg/inputdata

Subdirectory used for case specific code modifications
After creating your case, go to the case directory:

```
cd ~/cases/cheyenne/f.e20.FXHIST.f19_f19.001
```

Set up the case:

```
./case.setup
```

Build the case:

```
./case.build
```

Problems? Try:

```
./case.setup --reset
./case.build --clean
./case.build
```
Is this case ready to run?

- `xmlquery BUILD_COMPLETE --full`
  
  **BUILD_COMPLETE**: value=TRUE  
  valid_values: ['FALSE', 'TRUE']  
  description: Status output: if TRUE, models have been built successfully. (DO NOT EDIT)>

- `xmlquery STOP_OPTION,STOP_N --full`
  
  **STOP_OPTION**: value=ndays  
  valid_values: ['none', 'end', 'nminutes', 'nhour', 'nmonths', 'never', 'nhours', 'nseconds', 'nstep', 'nyear', 'nmonth', 'nminute', 'nsecond', 'ifdays0', 'date', 'nyears', 'nday', 'nsteps', 'ndays']  
  description: Sets the run length along with STOP_N and STOP_DATE

**STOP_N**: value=5  
description: Provides a numerical count for $STOP_OPTION.
About env_* .xml files

- env_* .xml files contain variables used by scripts. Some can be changed by the user.
  - env_case.xml: set by create_newcase and cannot be modified
  - env_mach_pes.xml: specifies layout of components
  - env_build.xml: specifies build information
  - env_batch.xml: sets arguments for batch submit command
  - env_run.xml: sets run time information (such as length of run, frequency of restarts, ...) User interacts with this file most frequently.

- Here's a snippet of the env_run.xml file:

```xml
<entry id="STOP_OPTION" value="ndays" />
<entry id="STOP_N" value="5" />

CESM will run for 5 days
```

“id” - variable name
“value” – variable value

- To modify a variable in an xml file, use xmlchange
  - xmlchange STOP_N=20
Okay, let’s run!

```bash
./case.submit
```

Monitor the job status:

```
qstat -u $USER
```

<table>
<thead>
<tr>
<th>Job ID</th>
<th>Username</th>
<th>Queue</th>
<th>Jobname</th>
<th>SessID</th>
<th>NDS</th>
<th>TSK</th>
<th>Memory</th>
<th>Time</th>
<th>Req'd Time</th>
<th>S Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1297725.chadmin</td>
<td>marsh</td>
<td>regular</td>
<td>f.e20.FXSD</td>
<td>32730</td>
<td>8</td>
<td>288</td>
<td>--</td>
<td>--</td>
<td>12:00 R</td>
<td>00:00</td>
</tr>
<tr>
<td>1297726.chadmin</td>
<td>marsh</td>
<td>regular</td>
<td>f.e20.FXSD</td>
<td>--</td>
<td>1</td>
<td>36</td>
<td>--</td>
<td>--</td>
<td>12:00 H</td>
<td>--</td>
</tr>
</tbody>
</table>

Kill the running job and resubmit?

```
qdel 1297725
./case.submit
```

Current throughput is \(~0.4\ \text{model years / wallclock day}\)
Questions?