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.
CESM components

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

Biogeochemistry (Carbon-Nitrogen Cycle)

Land (CLM)

Surface Wave (WaveWatch)

Biogeochemistry (Marine Ecosystem)

Atmosphere (CAM)

WACCM

CAM-CHEM

Ocean (POP)

Coupler (CPL)

WACCM-X

Sea Ice (CICE)

Land Ice (CISM)
NCAR Community Earth System Model (CESM)

atmosphere components

CESM

ATM

LAND | SEA ICE | OCEAN

WACCM | WACCM-X

CAM

EXOSPHERE

THERMOSPHERE

IONOSPHERE

MESOSPHERE

STRATOSPHERE

TROPOSPHERE

Temperature (K)

Electron density (cm$^{-3}$)
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
## CESM2: WACCM6 & WACCM-X

<table>
<thead>
<tr>
<th>Feature</th>
<th>WACCM6</th>
<th>WACCM-X</th>
</tr>
</thead>
<tbody>
<tr>
<td># levels</td>
<td>70-88</td>
<td>125-145</td>
</tr>
<tr>
<td>Model top</td>
<td>6x10^{-6} hPa (~140 km)</td>
<td>4x10^{-10} hPa (500~600 km)</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>0.95°x1.25°</td>
<td>1.9°x2.5°</td>
</tr>
<tr>
<td>Time step</td>
<td>30 min.</td>
<td>5 min.</td>
</tr>
<tr>
<td>Specified Dynamics</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Chemistry</td>
<td>TSMLT, MA</td>
<td>MA</td>
</tr>
<tr>
<td>Non-orographic GW</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Molecular diffusion</td>
<td>minor</td>
<td>minor and major</td>
</tr>
<tr>
<td>Auroral physics</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Ions</td>
<td>E-region or E&amp;D-region</td>
<td>E-region</td>
</tr>
<tr>
<td>Ion transport</td>
<td>E Dynamo</td>
<td></td>
</tr>
<tr>
<td>E Dynamo</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
CESM Web Page: http://www.cesm.ucar.edu

Supported releases (i.e. model versions)
CESM Models Web Page: http://www.cesm.ucar.edu/models/current.html

Latest release is CESM2.0

CESM Models | CESM Supported Releases

You should use the most recent version of the model that is available unless you are trying to replicate previous results or create a branch run from a previous experiment. A complete list of CESM scientifically validated configurations is available for users needing to run the model in one of these configurations.

Supported CESM Release Versions
- CESM2.0.0: What's New
- CESM1.2.z: Release Notes
- CESM 1.1.z: Notable Improvements
- CESM 1.0.z: Notable Improvements

CESM Model Version Naming Conventions

CESM X.Y.Z - CESM model release versions include three numbers separated by a dot (.) where:

- X corresponds to the major release number indicating significant science changes.
- Y corresponds to the addition of new infrastructure and new science capabilities for targeted components.
- Z corresponds to release bug fixes and machine updates.

Each release includes the complete collection of component model source code, documentation, and input data. For model output data, see the Experiments and Output Data section of this website.

Users should read the CESM Data Management & Distribution Plan which documents the procedures for the storage and distribution of data associated with the CESM project.
CESM2 Web Page: http://www.cesm.ucar.edu/models/cesm2/

**Quick Start**
See the selected links below to help you quickly get started with CESM2
- Getting Help
- CESM2 Use Cases
- CESM2 Quick Start Guide
- Download the CESM2 Code

**CIME Documentation**
Common infrastructure for Modeling the Earth contains the coupling infrastructure, support scripts, data models and utility libraries needed to create a single-executable coupled Earth System Model.
* CIME does not contain any prognostic components and is available in a stand-alone package that can be compiled and tested with just its data components.
  - CIME User Guide

**Prognostic Components**
Each model component page contains descriptions and documentation for active or prognostic models.
- Atmosphere
- Land
- Land Ice
- Ocean
- River Runoff
- Sea Ice
- Wave

**Configurations and Grids**
Component configurations include settings required for CIME enabled models; both prognostic and data model components. These settings include:
- Grid Resolutions
- Component Sets
- Component Configuration Settings
* Includes Fortran namelists and CASEROOT variable definitions

**Supported Machines & Performance Data**
- Supported Machines and Compilers
- Performance and Load Balancing Data
- Running on a Medium-Sized Linux Cluster
- Verify a Machine Port

**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

**Model Input Data**
As of CESM2, the input data necessary to run all supported component sets is made available from a number of different public repositories including:
- GridFTP
- Anonymous FTP
- Subversion

**Important**
Do not attempt to checkout the whole input data repository, it is currently over 20 TB

**Note**
The CIME User Guide explains how to obtain the subset of input data required for your needs
Looking at 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
WACCM-X history output files may be analyzed with standard analysis tools, including Matlab, IDL, NCL, and NCO.

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
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
  ```
Hardware and software requirements

• Supported platforms
  • CESM currently runs “out of the box” on NCAR machines (cheyenne), 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
    • git, Subversion, Fortran and C compilers, NetCDF library, ESMF, 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](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:
  - Download the current CESM release code in 3 lines:
    ```
    > git clone -b release-cesm2.0.0 https://github.com/ESCOMP/cesm.git
    > cd cesm
    > ./manageExternals/checkoutExternals
    ```
  - Creating an input data root directory (not covered here)
  - Porting (not covered here)
  - Creating and running a case
    - Create a new case
    - Invoke case.setup
    - Build the executable
    - Run the model and output data flow
Installing the ESMF library on non-NCAR computers

• If not running at NCAR, and the Earth System Modeling Framework (ESMF) library isn’t installed, you will need to install it yourself. Use the same compiler you will use for CESM. This example uses the (recommended) Intel compiler:

```
#!/bin/tcsh -f
#
module purge
module load intel/16.0.3
module load mpt/2.15

setenv ESMF_INSTALL_PREFIX /glade/u/home/fvitt/esmf_7_0_0
setenv ESMF_DIR /glade/u/home/fvitt/esmf_7_0_0/esmf
#setenv ESMF_BOPT 'g'
setenv ESMF_BOPT 'O'
setenv ESMF_ABI 64
setenv ESMF_COMM mpi
setenv ESMF_COMPILER intel

cd $ESMF_DIR
gmake lib
```
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:

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

Source code for released model versions can be found here:

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

CESM2.0 is there under cesm2_0. To create a new case, go to the “cime/scripts” subdirectory under the model version source code directory:

```
cd /glade/p/cesm/releases/cesm2_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:
   cd /glade/p/cesm/releases/cesm2_0_0/cime/scripts

2. create a new case in the directory “cases/cheyenne” in your home directory:
   ./create_newcase --res f19_f19 --compset FXHIST
   --case ~/cases/cheyenne/f.e20.FXHIST.f19_f19.001
   --run-unsupported

   Go into the case you just created in the last step:
   cd ~/cases/cheyenne/f.e20.FXHIST.f19_f19.001

3. invoke case.setup
   ./case.setup

4. build the executable
   ./case.build

5. submit your run to the batch queue
   ./case.submit
In the cime/scripts directory, `create_newcase` is the tool that generates a new model case.

`create_newcase` requires 3 arguments:

- `./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`
**What is a compset?**

“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 1850-2014</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)</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

**Case** $\$CASEROOT$

- case.setup & case.build: scripts used in the next step
- env_*.xml files with xml variables used by CESM

**Run** $\$RUNDIR$

- /glade/scratch/$\$CCSMUSER/$\$CASE/run

**SourceMods**

- subdirectory used for case specific code modifications

**Input data** $\$DIN_LOC_ROOT$

- /glade/p/cesm/cseg/inputdata
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 (Cheyenne):
   qcmd -- case.build

Build the case (elsewhere):
   ./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:

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

- "id" - variable name
- "value" – variable value

- To modify a variable in an xml file, use xmlchange
  - xmlchange STOP_N=20

CESM will run for 5 days
Okay, let’s run!

./case.submit

Monitor the job status:

```bash
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>S Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1283009.chadmin</td>
<td>mmills</td>
<td>regular</td>
<td>68.nonudge</td>
<td>50344</td>
<td>16</td>
<td>576</td>
<td></td>
<td>--</td>
<td>12:00</td>
</tr>
</tbody>
</table>

Who’s paying for this run?

```bash
xmlquery PROJECT
```

Let’s change that!

```bash
xmlchange PROJECT=newaccount
```

Kill the running job and resubmit?

```bash
qdel 1283009
```

./case.submit