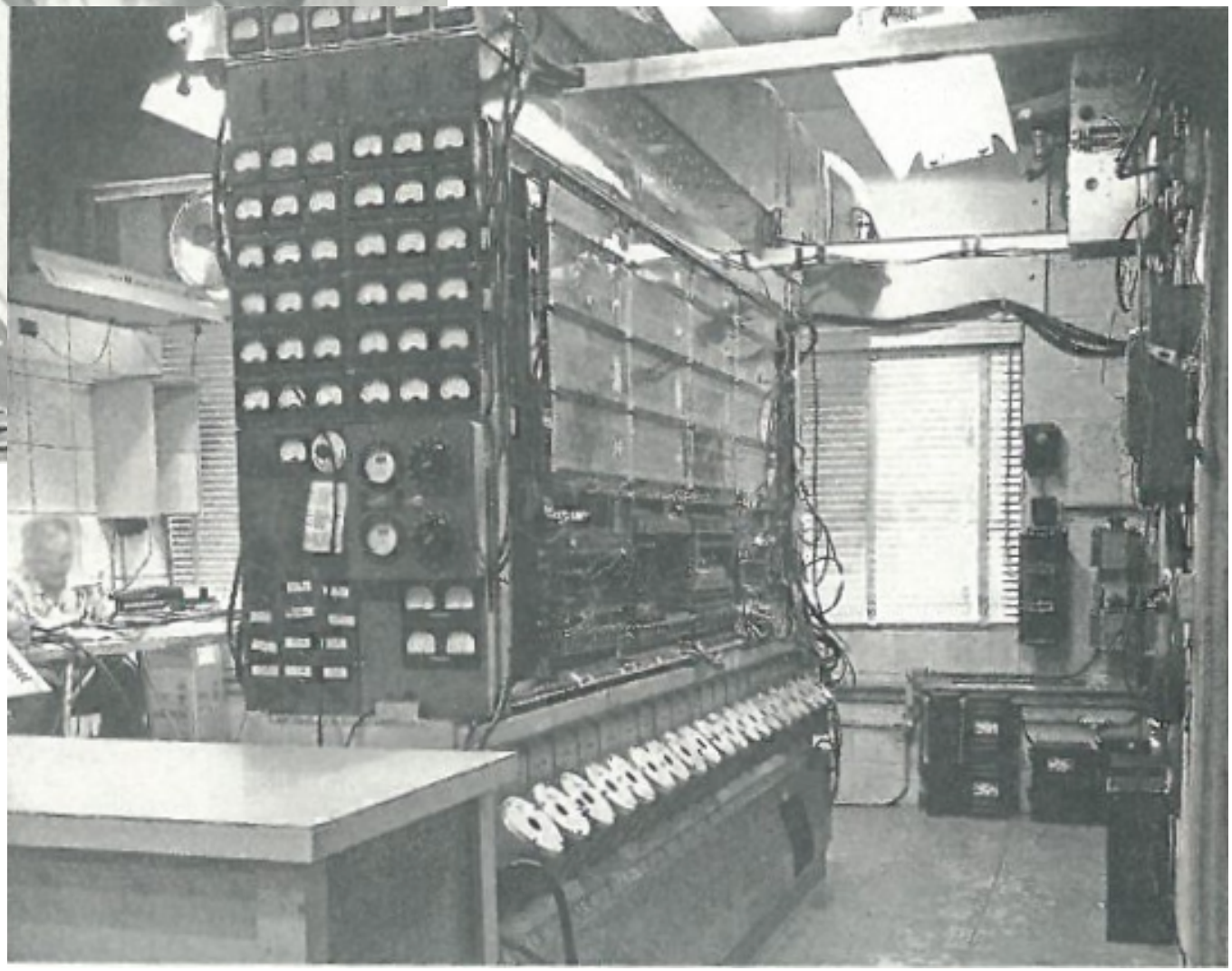
Norman Phillips & Maniac
IAS Princeton, ~1954



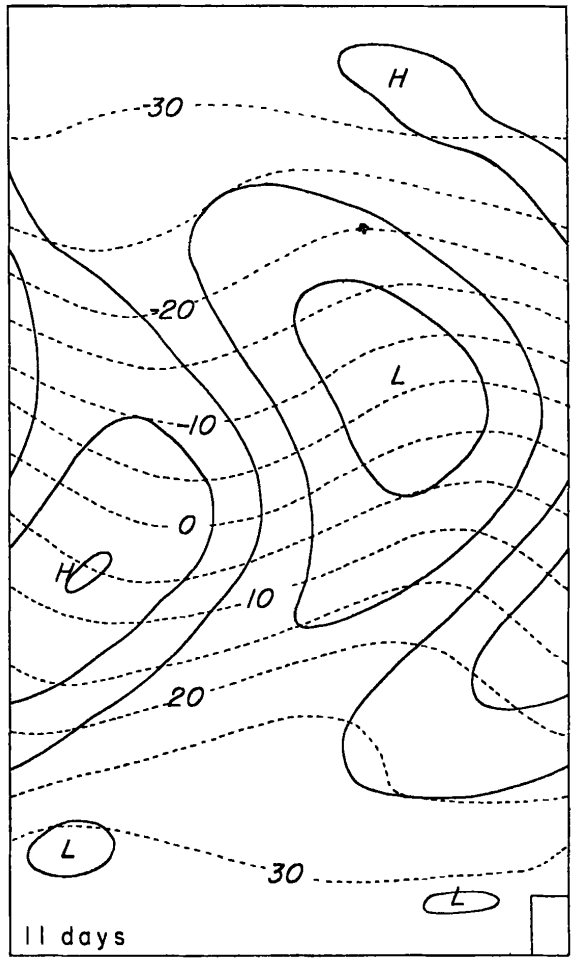


Figure 4. Distribution of 1,000-mb contour height at 200-foot intervals (solid lines) and 500-mb temperature at 5°C intervals (dashed lines) at 11 days. The small rectangle in the lower right corner shows the size of the finite-difference grid intervals Δx and Δy.

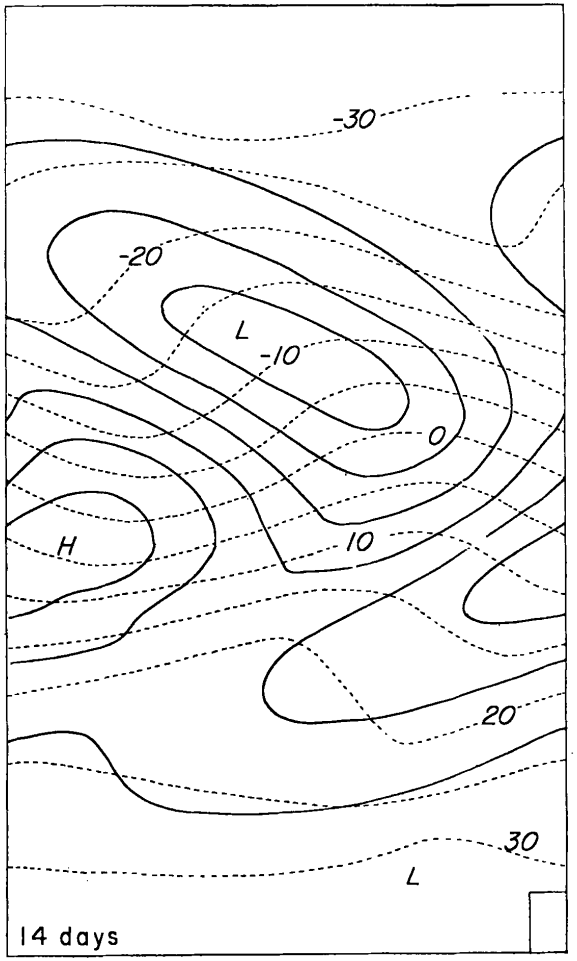


Figure 5. Distribution of 1,000-mb contour height at 200-foot intervals (solid lines) and 500-mb temperature at 5°C intervals (dashed lines) at 14 days. The small rectangle in the lower right corner shows the size of the finite-difference grid intervals Δx and Δy.

so as to allow rapid recovery after recognized errors) resulted in a choice of a 17×16 lattice of grid points, 17 in the y-direction, and 16 in the x-direction. Δy was set equal to 625 km, so that the distance $2W$ was equal to 10,000 km. A large value for Δx would presumably allow several eddies to form in the distance $L = 16\Delta x$, but would produce

Phillips, 1956

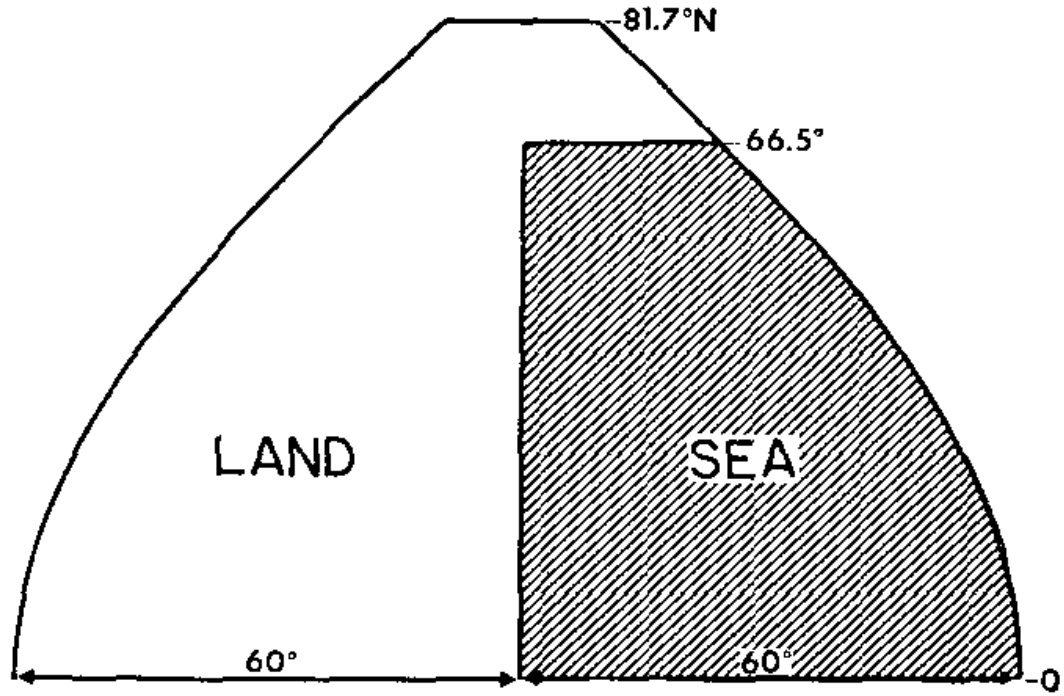


FIG. 1. Diagram illustrating the distribution of continent and "ocean." Cyclic continuity is assumed at the eastern and western ends of the domain.

The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model[1]

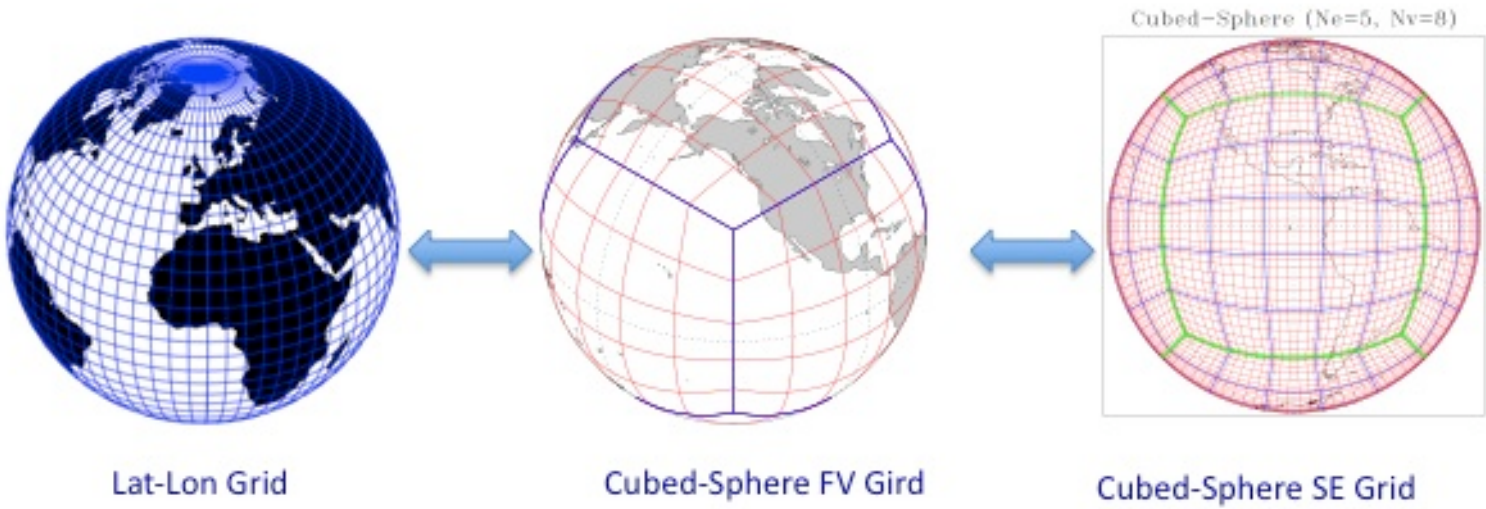
SYUKURO MANABE AND RICHARD T. WETHERALD

Atmosphere: Six (+n) equations in Six (+n) unknowns

- Conservation of Momentum: 3 equations. Hydrostatic in vertical and time-dependent momentum equations in each horizontal dimension.
- Conservation of Mass: 2 + *n* equations keeping track of dry air and water. Add in equations for additional trace species (recent).
- Conservation of Thermal energy.

Unknowns in this formulation: two horizontal velocity components, pressure, temperature, density, water mixing ratio, and as many other mixing ratios as needed for the trace gases.

Conservative Remapping on the Sphere



- Grid-to-Grid conservative Remapping based on Cascade interpolation
- Model pre/post-processing applications (data transfer)
- Regular latitude-longitude sphere to various cubed-sphere grids or vice versa
- Option for monotonic and high-order accurate data transfer

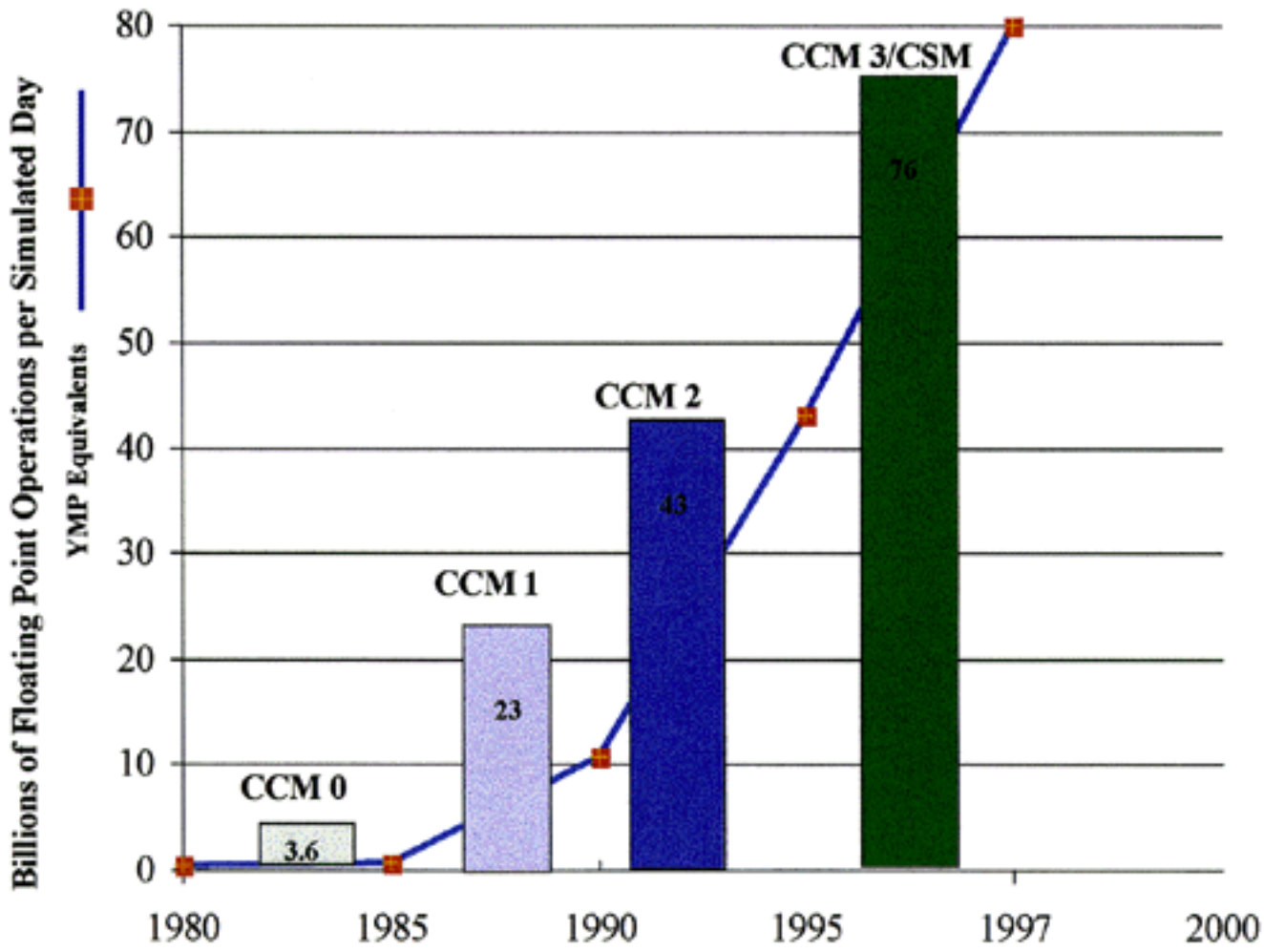
CAM5: nominal 0.9° lat by 1.25°longitude, 30 vertical levels

POP
(Parallel Ocean Program)
60 vertical levels
zonal: 1.11° spacing
meridional:
0.27° at equator,
increases to
0.54° poleward of 35°.

Poles shifted to be on land

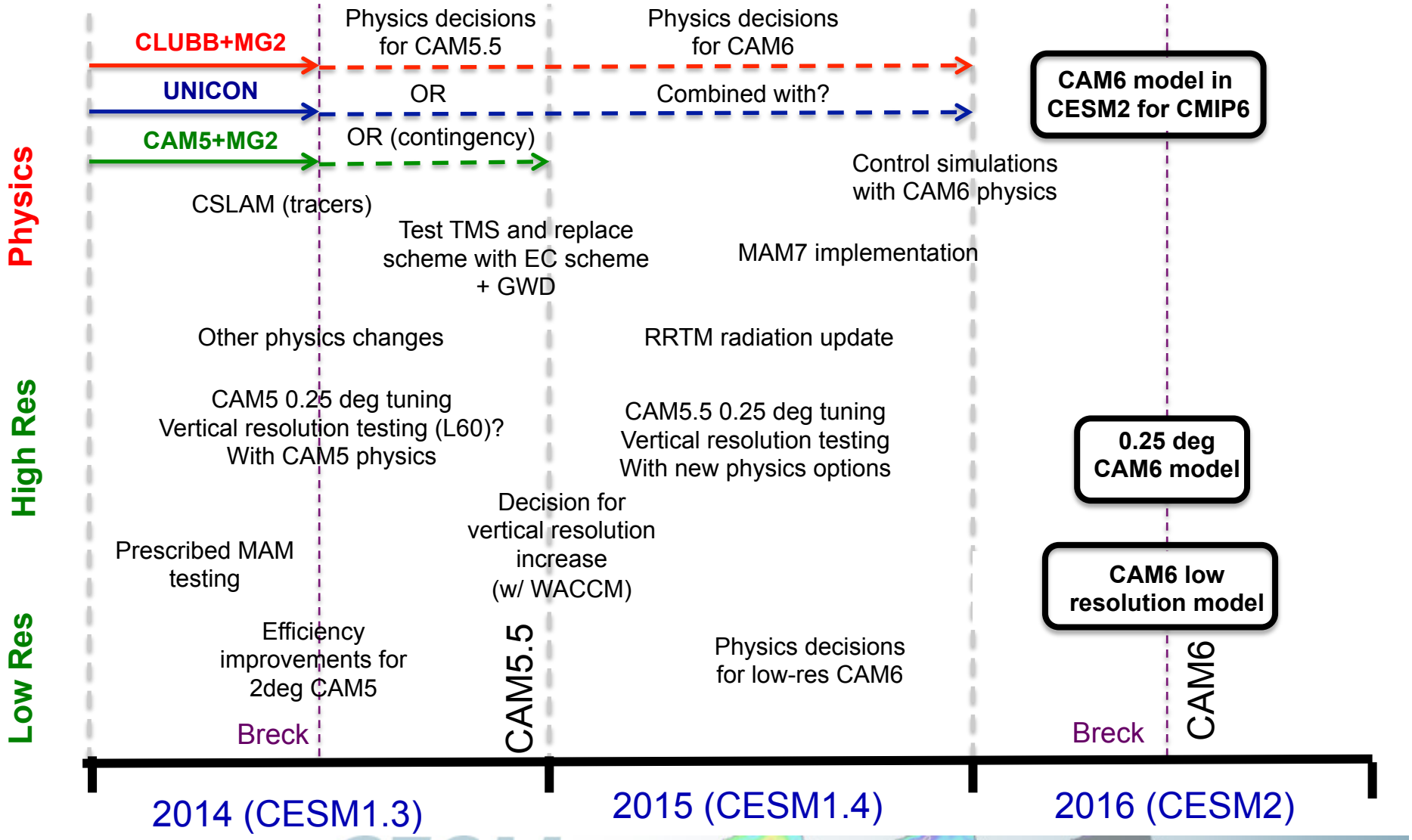
NCAR Community Model Version History

- CCM0 Community Climate Model, 1982 – Spectral solution, R15
  "Community" was NCAR + universities and national labs
- CCM1, 1987
- CCM2, 1992 – portable beyond Crays, Biosphere submodel
- CCM3, 1995 – first version run at UD (Strauss)
- CAM2 Community Atmospheric Model, 2003
  Name change: Atmospheric part of CCSM2 –
  Community Climate System Model
  (Klingaman, Sklut)
- CAM3, 2004
- CAM4, 2010 – Finite Volume numerical formulation, urban land type
- CAM5, 2010 – beginning of CESM1
  Community Environment System Model


Billions of Floating Point Operations per Simulated Day
YMP Equivalents
80
70
60
50
40
30
20
10
0
CCM 0
3.6
CCM 1
23
CCM 2
43
CCM 3/CSM
76
1980
1985
1990
1995
1997
2000

CAM Development Timelines

The path towards CESM2 and CMIP6 (as of Jun 2014)



RANK	SITE	SYSTEM	CORES	RMAX (TFLOP/S)	RPEAK (TFLOP/S)	POWER (KW)
36	NCAR (National Center for Atmospheric Research) United States	**Yellowstone** - iDataPlex DX360M4, Xeon E5-2670 8C 2.600GHz, Infiniband FDR IBM	72,288	1,257.6	1,503.6	1,437

CESM Components:

Active Climate System Elements:

CAM: Atmosphere, including dynamics, clouds, radiation

CLM: Vegetation and soil

OCN: Ocean

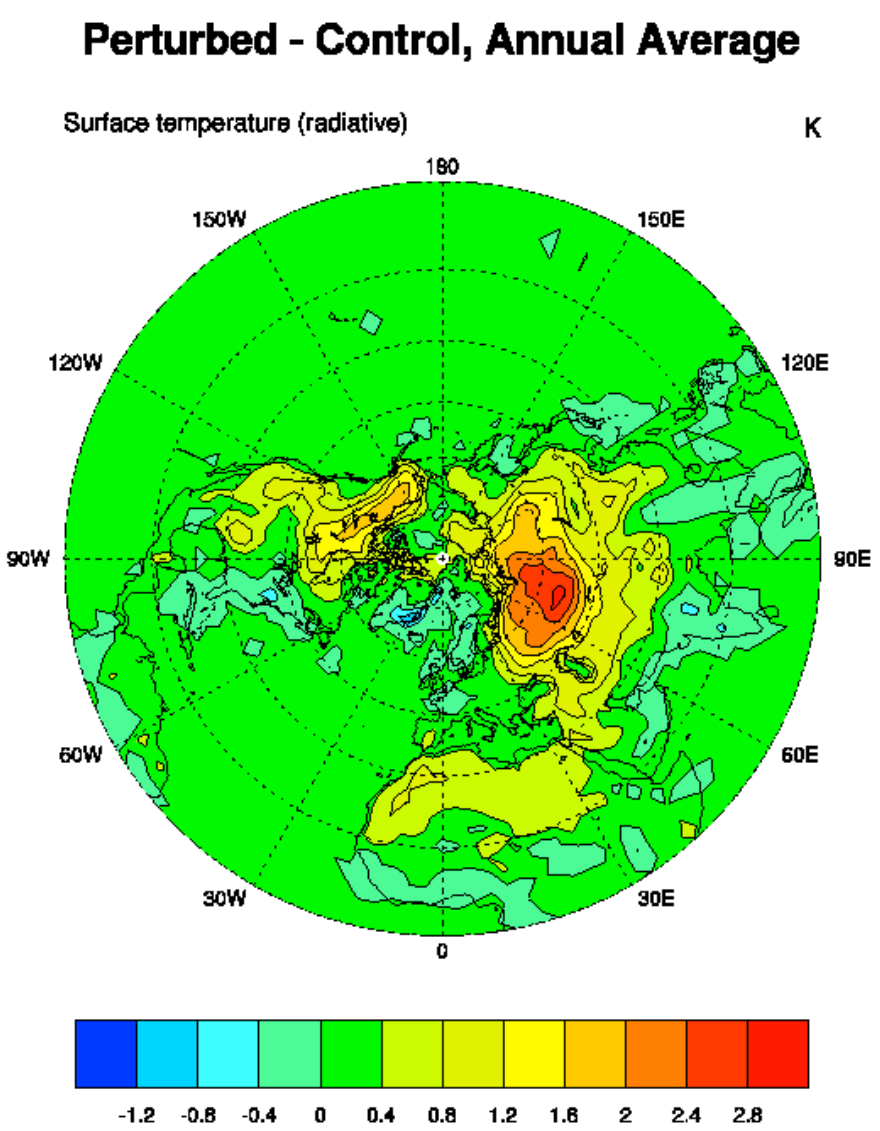
ROF: River-runoff

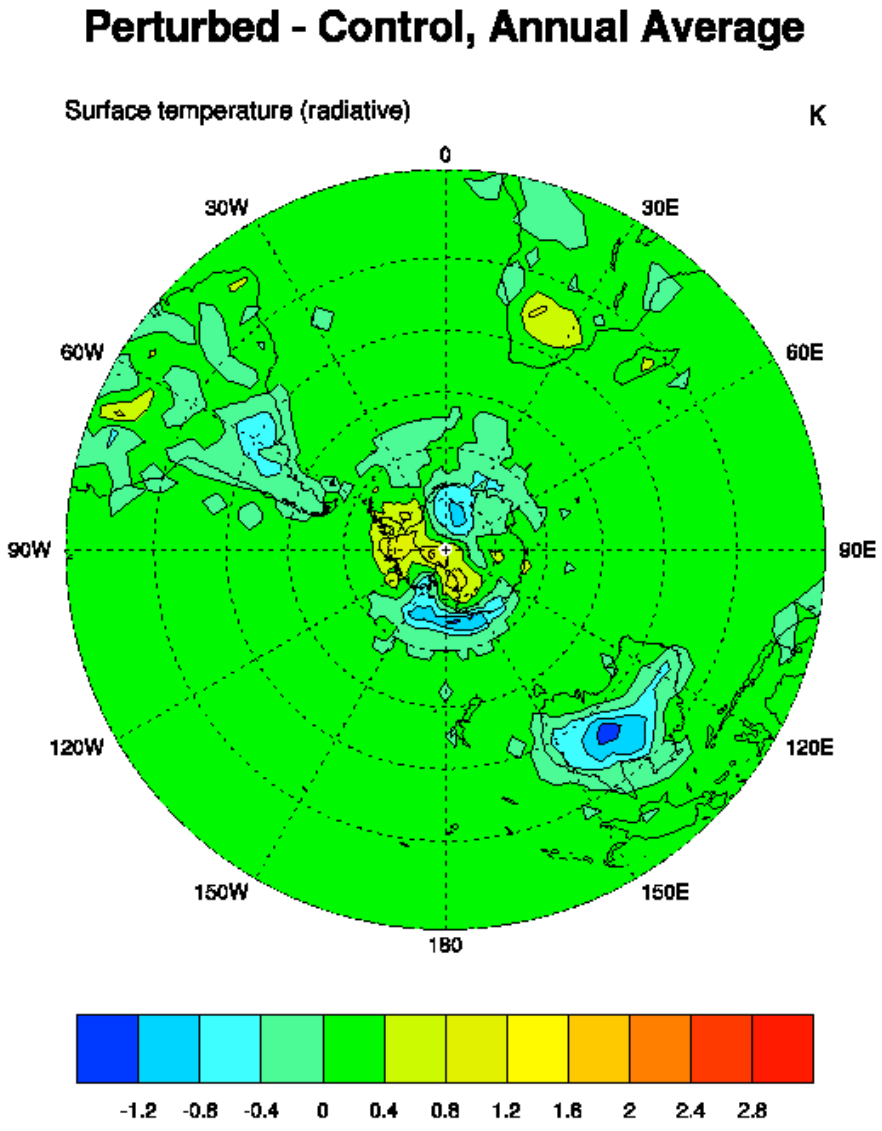
ICE: Sea Ice

GLC: Land Ice

Four versions of each component: Active, Data, Dead, and Stub:

CPL: Coupler, ties combinations together





CAM3: 5x methane, difference from control run.
10 year single simulations. Data ocean model

Porting CAM5

1. Get the source code and related scripts
2. Configure a case combination starting with dead
3. Build the appropriate components
4. Run the model to test a dead model
5. Generalize the configuration into a machine type.
6. Proceed with useful modeling.

Goal at UD:

- get CAM5 with DOM operating on one of our clusters

Purpose:

- Education of any climate students
  GEOG 657 *Climate Dynamics*
  (Currently using CAM3 on departmental Linux server)
- Education of students who will use CMIP data
  (More on next slide)
- Education of students who will do global climate modeling for thesis research, at least for proof-of-concept runs

Table 1. List of experiments with official CMIP5 identifying labels, type of model(s) used to perform experiments, and major purposes (with the overall purpose of all experiments being to further scientific understanding of the climate system).

Experiment description	CMIP5 label	AOGCM	ESM or EMIC	High resolution[a]	Major purposes
Preindustrial control run	piControl	X	X		Evaluation, unforced variability
Past ~1.5 centuries (1850–2005)	historical	X	X		Evaluation
AMIP run (observed SSTs and sea ice prescribed for 1979–present)	amip	X	X	X	Evaluation
Future projection (2006–2300) forced by RCP4.5	rcp45	X	X		Projection
Future projection (2006–2300) forced by RCP8.5	rcp85	X	X		Projection
Future projection (2006–2300) forced by RCP2.6	rcp26	X	X		Projection
Future projection (2006–2100) forced by RCP6	rcp60	X	X		Projection
Benchmark 1% yr^{-1} increase in CO_2 (to quadrupling)	1pctCO2	X	X		Climate sensitivity, feedbacks
Quadruple CO_2 abruptly, then hold fixed	abrupt4xCO2	X	X		Climate sensitivity, feedbacks, fast responses[b]
Climatological SSTs and sea ice imposed from piControl	sstClim	X	X		Fast responses[b]
As in sstClim, but with 4XCO_2 imposed	sstClim4xCO2	X	X		Fast responses[b]
As in sstClim, but with aerosols specified from year 2000 of the historical run	sstClimAerosol	X	X		Fast responses[b]
As in sstClim, but with sulfate aerosols specified from year 2000 of the historical run	sstClimSulfate	X	X		Fast responses[b]
Preindustrial conditions imposed as in piControl, but with atmospheric CO_2 determined by the model itself	esmControl		X		Evaluation, carbon cycle
Simulation of past, as in historical, but driven by CO_2 emissions rather than concentrations	esmHistorical		X		Evaluation, carbon cycle
Future projection as in rcp85, but driven by CO_2 emissions rather than concentrations	esmrcp85		X		Projection
Radiation code sees piControl CO_2 concentration, but carbon cycle sees 1% yr^{-1} rise	esmFixClim1[c]		X		Carbon feedback
Carbon cycle sees piControl CO_2 concentration, but radiation sees 1% yr^{-1} rise	esmFdbk1[c]		X		Carbon feedback
As in AMIP, but with radiation code seeing 4 × CO_2	amip4xCO2	X	X	X	Clouds, fast responses[b]
Patterned SST anomalies added to AMIP conditions (as called for by CFMIP)	amipFuture	X	X	X	Cloud feedbacks
Zonally uniform SSTs imposed on an ocean-covered Earth (as called for by CFMIP)	aquaControl	X	X	X	Clouds
As in aquaControl, but with 4 × CO2	aqua4xCO2	X	X	X	Clouds, fast responses[b]
As in aquaControl, but with a uniform 4-K increase in SST	aqua4K	X	X	X	Cloud feedbacks
As in AMIP, but with a uniform 4-K increase in SST	amip4K	X	X	X	Cloud feedbacks
Historical simulation but with natural forcing only	historicalNat	X	X		Detection and attribution
Historical simulation but with GHG forcing only	historicalGHG	X	X		Detection and attribution
Historical simulation but with other individual forcing agents or combinations of forcings	historicalMisc	X	X		Detection and attribution
Extension of historical through year 2012	historicalExt	X	X		Evaluation, detection, attribution

Taylor, Stouffer, & Meehl, 2012

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Past ~1.5 centuries (1850–2005)	historical	X	X		Evaluation
AMIP run (observed SSTs and sea ice prescribed for 1979–present)	amip	X	X	X	Evaluation
Future projection (2006–2300) forced by RCP4.5	rcp45	X	X		Projection
Future projection (2006–2300) forced by RCP8.5	rcp85	X	X		Projection
Future projection (2006–2300) forced by RCP2.6	rcp26	X	X		Projection
Future projection (2006–2100) forced by RCP6	rcp60	X	X		Projection
Benchmark 1% yr^{-1} increase in CO_2 (to quadrupling)	1pctCO2	X	X		Climate sensitivity, feedbacks

Taylor, Stouffer, & Meehl, 2012

1. Get the source code and related scripts

- Registration required
- svn the tarball and unpack

- CESM 1.2.1:
  - 5274 files
  - 2314 of the files are Fortran
  - 1673016 lines in the Fortran files
  - 581 Mb unpacked w/o data or build

- CAM5 active atmosphere
  - 1750 files
  - 1175 of the files are Fortran
  - 767251 lines in the Fortran files

CESM User's Guide (CESM1.2 Release Series User's Guide) (PDF)

CESM Software Engineering Group (CSEG)

NCAR

Table of Contents

http://www.cesm.ucar.edu/models/cesm1.2/cesm/doc/usersguide/book1.html

Step 1: Use create_newcase with a userdefined machine name

This section describes how to set up a case using a userdefined machine name and then within that case, how to modify the scripts to get that case running on a local machine.

1. Run **create_newcase** wtih a "userdefined" machine name. Then run **cesm_setup** in the new case directory.

http://www.cesm.ucar.edu/models/cesm1.2/cesm/doc/usersguide/x1748.html

```
[(geography:hanson)@mills hanson]$ cd cesm1_2_1/scripts
[(geography:hanson)@mills scripts]$ ./create_newcase -case test4 -res f45_g37 -compset X -mach userdefined
--------------------------------------------------------------------------------
For a list of potential issues in the current tag, please point your web browser to:
https://svn-ccsm-models.cgd.ucar.edu/cesm1/known_problems/
--------------------------------------------------------------------------------
 grid longname is f45_g37
Component set: longname (shortname) (alias)
  2000_XATM_XLND_XICE_XOCN_XROF_XGLC_XWAV (X) (X)
Component set Description:
  XATM: XLND: Xrof: XICE: XOCN: XGLC: XWAV: present day:
Grid:
  a%4x5_l%4x5_oi%gx3v7_r%r05_m%gx3v7_g%null_w%null (4x5_gx3v7)
  ATM_GRID = 4x5  NX_ATM=72 NY_ATM=46
  LND_GRID = 4x5  NX_LND=72 NX_LND=46
  ICE_GRID = gx3v7  NX_ICE=100 NX_ICE=116
  OCN_GRID = gx3v7  NX_OCN=100 NX_OCN=116
  ROF_GRID = r05  NX_ROF=720 NX_ROF=360
  GLC_GRID = 4x5  NX_GLC=72 NX_GLC=46
  WAV_GRID = null  NX_WAV=0 NX_WAV=0
Grid Description:
  null is no grid: 4x5 is FV 4-deg grid: gx3v7 is Greenland pole v7 3-deg grid: r05 is 1/2 degree river routing grid:
Non-Default Options:
  ATM_NCPL: 48
  BUDGETS: FALSE
  CCSM_CO2_PPMV: 379.000
  COMP_ATM: xatm
  COMP_GLC: xglc
  COMP_ICE: xice
  COMP_LND: xlnd
  COMP_OCN: xocn
  COMP_ROF: xrof
  COMP_WAV: xwav
  CPL_ALBAV: false
  CPL_EPBAL: off
  GLC_NEC: 10
  OCN_NCPL: 1
  OCN_TIGHT_COUPLING: FALSE
  ROF_NCPL: $ATM_NCPL
  SCIENCE_SUPPORT: NO

The PE layout for this case match these options:
GRID =  a%4x5
CCSM_LCOMPSET =  XATM
Creating /lustre/work/geography/hanson/cesm1_2_1/scripts/test4
Created /lustre/work/geography/hanson/cesm1_2_1/scripts/test4/env_case.xml
Created /lustre/work/geography/hanson/cesm1_2_1/scripts/test4/env_mach_pes.xml
Created /lustre/work/geography/hanson/cesm1_2_1/scripts/test4/env_build.xml
Created /lustre/work/geography/hanson/cesm1_2_1/scripts/test4/env_run.xml
Locking file /lustre/work/geography/hanson/cesm1_2_1/scripts/test4/env_case.xml
Successfully created the case for userdefined
[(geography:hanson)@mills scripts]$
```

```
[(geography:hanson)@mills scripts]$ cd test4
[(geography:hanson)@mills test4]$ ls
archive_metadata.sh  CaseStatus  check_case        create_production_test  env_case.xml      env_mach_specific
LockedFiles        README.case             SourceMods   test4.clean_build  Tools      xmlquery
Buildconf            cesm_setup  check_input_data  env_build.xml           env_mach_pes.xml  env_run.xml
preview_namelists  README.science_support  test4.build  test4.submit       xmlchange
[(geography:hanson)@mills test4]$ ./cesm_setup
ERROR: must set xml variable OS to generate Macros file
ERROR: must set xml variable MPILIB to build the model
ERROR: must set xml variable RUNDIR to build the model
ERROR: must set xml variable DIN_LOC_ROOT to build the model
ERROR: must set xml variable COMPILER to build the model
ERROR: must set xml variable EXEROOT to build the model
ERROR: must set xml variable MAX_TASKS_PER_NODE to build the model
Correct above and issue cesm_setup again

[(geography:hanson)@mills test4]$ x env_build.xml
[(geography:hanson)@mills test4]$ x env_case.xml
[(geography:hanson)@mills test4]$ x env_mach_pes.xml
[(geography:hanson)@mills test4]$ x env_run.xml
```

```
<!--"operating system - DO NOT EDIT UNLESS for userdefined machine - ignored once Macros has been created   (char) " -->
<entry id="OS"   value="USERDEFINED_required_macrosLINUX"  />
<!--"Machine compiler (must match one the supported compilers) (char) " -->
<entry id="COMPILER"   value="USERDEFINED_required_buildpgi"  />
<!--"mpi library (must match one of the supported libraries) - ignored once Macros has been created (char) " -->
<entry id="MPILIB"   value="USERDEFINED_required_buildopenmpi"  />
```

```
[(geography:hanson)@mills test4]$ ./cesm_setup
 LockedFiles/env_case.xml.locked has been modified and is different than the LockedFiles version
Cannot change env_case.xml, please recover the original copy from LockedFiles
Creating batch script test3.run
Locking file env_mach_pes.xml
Creating user_nl_xxx files for components and cpl
Running preview_namelist script
 infile is /lustre/work/geography/hanson/cesm1_2_1/scripts/test3/Buildconf/cplconf/cesm_namelist
See ./CaseDoc for component namelists
If an old case build already exists, might want to run test3.clean_build before building
[(geography:hanson)@mills test4]$
[(geography:hanson)@mills test4]$ x Macros
```

```
SLIBS+= -L$(NETCDF_PATH)/lib -lnetcdf -lnetcdff

CFLAGS:= -gopt -Mlist -time -O -Mvect=nosse

CONFIG_ARGS:=

…

MPI_PATH:= /opt/shared/openmpi/1.6.1-pgi11

NETCDF_PATH:= /home/software/netcdf/4.1.3-pgi
```

```
[(geography:hanson)@mills test4]$ ./test4.build
------------------------------------------------------------------------
 CESM BUILDNML SCRIPT STARTING
 - To prestage restarts, untar a restart.tar file into /lustre/work/geography/hanson/cam/run
 infile is /lustre/work/geography/hanson/cesm1_2_1/scripts/test4/Buildconf/cplconf/cesm_namelist
 CESM BUILDNML SCRIPT HAS FINISHED SUCCESSFULLY
------------------------------------------------------------------------
------------------------------------------------------------------------
 CESM PRESTAGE SCRIPT STARTING
 - Case input data directory, DIN_LOC_ROOT, is /lustre/work/geography/hanson/inputdata
 - Checking the existence of input datasets in DIN_LOC_ROOT
 CESM PRESTAGE SCRIPT HAS FINISHED SUCCESSFULLY
------------------------------------------------------------------------
------------------------------------------------------------------------
 CESM BUILDEXE SCRIPT STARTING
 COMPILER is pgi
 - Build Libraries: mct gptl pio csm_share
Tue Apr 28 12:43:40 EDT 2015 /lustre/work/geography/hanson/cam/mct/mct.bldlog.150428-124337
Tue Apr 28 12:44:16 EDT 2015 /lustre/work/geography/hanson/cam/gptl/gptl.bldlog.150428-124337
Tue Apr 28 12:44:18 EDT 2015 /lustre/work/geography/hanson/cam/pio/pio.bldlog.150428-124337
Tue Apr 28 12:45:19 EDT 2015 /lustre/work/geography/hanson/cam/csm_share/csm_share.bldlog.
150428-124337
Tue Apr 28 12:48:56 EDT 2015 /lustre/work/geography/hanson/cam/atm.bldlog.150428-124337
Tue Apr 28 12:48:58 EDT 2015 /lustre/work/geography/hanson/cam/lnd.bldlog.150428-124337
Tue Apr 28 12:48:59 EDT 2015 /lustre/work/geography/hanson/cam/ice.bldlog.150428-124337
Tue Apr 28 12:49:00 EDT 2015 /lustre/work/geography/hanson/cam/ocn.bldlog.150428-124337
Tue Apr 28 12:49:02 EDT 2015 /lustre/work/geography/hanson/cam/glc.bldlog.150428-124337
Tue Apr 28 12:49:03 EDT 2015 /lustre/work/geography/hanson/cam/wav.bldlog.150428-124337
Tue Apr 28 12:49:04 EDT 2015 /lustre/work/geography/hanson/cam/rof.bldlog.150428-124337
Tue Apr 28 12:49:06 EDT 2015 /lustre/work/geography/hanson/cam/cesm.bldlog.150428-124337
 - Locking file env_build.xml
 CESM BUILDEXE SCRIPT HAS FINISHED SUCCESSFULLY
------------------------------------------------------------------------
[(geography:hanson)@mills test4]$
```

casename.run script

```
#===============================================================================
# USERDEFINED
# edit job launching
#===============================================================================

#mpiexec -n 16 $EXEROOT/cesm.exe >&! cesm.log.$LID
#mpirun -np 16 $EXEROOT/cesm.exe >&! cesm.log.$LID


set OPENMPI_FLAGS="--display-map --mca btl ^tcp --mca mtl ^psm"

#mpiexec -n 16 $EXEROOT/cesm.exe >&! cesm.log.$LID
/home/software/openmpi/1.6.1-pgi11/bin/mpirun -np 16  ${OPENMPI_FLAGS} $EXEROOT/
cesm.exe  >&! cesm.log.$LID
```

```
[(geography:hanson)@mills test3]$ qsub -S /bin/csh test3.run
Your job 955144 ("test3.run") has been submitted
[(geography:hanson)@mills test3]$ more test3.run.o955144
Warning: no access to tty (Bad file descriptor).
Thus no job control in this shell.
-------------------------------------------------------------------------
 CESM BUILDNML SCRIPT STARTING
 - To prestage restarts, untar a restart.tar file into /lustre/work/geography/hanson/cam/run
 infile is /lustre/work/geography/hanson/cesm1_2_1/scripts/test3/Buildconf/cplconf/cesm_namelist
 CESM BUILDNML SCRIPT HAS FINISHED SUCCESSFULLY
-------------------------------------------------------------------------
-------------------------------------------------------------------------
 CESM PRESTAGE SCRIPT STARTING
 - Case input data directory, DIN_LOC_ROOT, is /lustre/work/geography/hanson/inputdata
 - Checking the existence of input datasets in DIN_LOC_ROOT
 CESM PRESTAGE SCRIPT HAS FINISHED SUCCESSFULLY
-------------------------------------------------------------------------
Tue Apr 28 13:13:04 EDT 2015 -- CSM EXECUTION BEGINS HERE
Tue Apr 28 13:13:04 EDT 2015 -- CSM EXECUTION HAS FINISHED
grep: cpl.log.150428-131238: No such file or directory
Model did not complete - see /lustre/work/geography/hanson/cam/run/cesm.log.150428-131238
[(geography:hanson)@mills test3]$
```

```
[(geography:hanson)@mills test3]$ more /lustre/work/geography/hanson/cam/run/cesm.log.150428-131238

 ========================   JOB MAP   ========================

 Data for node: n185    Num procs: 16
        Process OMPI jobid: [32415,1] Process rank: 0
        Process OMPI jobid: [32415,1] Process rank: 1
        Process OMPI jobid: [32415,1] Process rank: 2
        Process OMPI jobid: [32415,1] Process rank: 3
        Process OMPI jobid: [32415,1] Process rank: 4
        Process OMPI jobid: [32415,1] Process rank: 5
        Process OMPI jobid: [32415,1] Process rank: 6
        Process OMPI jobid: [32415,1] Process rank: 7
        Process OMPI jobid: [32415,1] Process rank: 8
        Process OMPI jobid: [32415,1] Process rank: 9
        Process OMPI jobid: [32415,1] Process rank: 10
        Process OMPI jobid: [32415,1] Process rank: 11
        Process OMPI jobid: [32415,1] Process rank: 12
        Process OMPI jobid: [32415,1] Process rank: 13
        Process OMPI jobid: [32415,1] Process rank: 14
        Process OMPI jobid: [32415,1] Process rank: 15

 =============================================================
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
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/lustre/work/geography/hanson/cam/cesm.exe: error while loading shared libraries: libnetcdf.so.7: cannot open shared object file: No such file or directory
--------------------------------------------------------------------------
mpirun noticed that the job aborted, but has no info as to the process
that caused that situation.
--------------------------------------------------------------------------
[(geography:hanson)@mills test3]$
```

Ongoing questions (to me):

- valet on csh, path to vpkg_require
- csh in general
- pio: pnetcdf
- LibXML