Aquaplanets with slab ocean in CESM1

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1 DESCRIPTION

This document outlines the steps necessary to run CESM1 configured as an aquaplanet with a slab ocean model. I outline the boundary conditions required along with some options for how to deal with different choices, like seasons and sea-ice. When CAM5 is the atmospheric physics package, there are also several options for aerosol, which I briefly describe. The most important part, though, is the recipe that allows the model to run in this configuration.

1.1 ASSUMPTIONS

In setting up the following cases, we make some basic assumptions. First, the code that is being used as an example is CESM1.2.0, which is the latest release as of writing. I have verified that these modifications work for this version of the code *using the FV dynamical core*, they should work in similar versions and with the SE dycore. That being said, these modified cases have not been rigorously scrutinized, and there may be omissions in these instructions. If you find details that seem important, let me know and I will add them to this pseudo-documentation. All of the following make use of the normal CESM script workflow, which is covered in the CESM tutorial. In the first two steps below, I make changes that require write-permission in the model code, so if you follow this example, it requires checking out a copy of the model into your personal sandbox.

2 BASIC AQUAPLANET

In this first example, we will set up an aquaplanet with a slab ocean with no sea ice. The FV dycore is used on the 2-degree grid with CAM5 physics using prescribed bulk aerosol.

2.1 Grid Definition

I chose to hard-code a grid set up into the model (CESM1.2), though there are other ways to do the same thing. In this case I modified `config_grid.xml` to contain a new case:

```
 config_grid.xml 
  <GRID \
  sname="1.9x2.5_1.9x2.5_AQUA" \
  alias="f19_f19_AQUA"         \
  compset="(DOCN|XOCN|SOCN|AQUAP)">a%1.9x2.5_l%1.9x2.5_oi%1.9x2.5_r%r05_m%null_g%null_w%null \
  </GRID>
```

The important thing that is accomplished here is to put the ocean on the same grid as the atmosphere. Also, this has made the mask grid equal to null. Further into `config_grid.xml`, I also unset the domain file, which we can set via namelists later

```
 config_grid.xml 
  <griddom grid="1.9x2.5" mask="custom">
    <ICE_DOMAIN_FILE>UNSET</ICE_DOMAIN_FILE>
    <OCN_DOMAIN_FILE>UNSET</OCN_DOMAIN_FILE>
  </griddom>
```

(The `config_grid.xml` file is in the directory `cesm1_2_0/scripts/ccsm_utils/Case.template`.)

2.2 A new use case

There are already CAM use cases for aquaplanets, which work well in most regards. When applying the slab ocean, however, these can not be used because the `aqua_planet` namelist parameter triggers the ocean component to be the analytical SST code. To get around this, copy the aquaplanet use case to a new use case file and delete the `aqua_planet` option (or set to `.false.`). The use cases are just lists of namelist parameters that reside in the model directory `cesm1_2_0/models/atm/cam/bld/namelist_files/use_cases`. Below I will assume that this new use case is named `SOM_aquaplanet_cam5`.

2.3 Setting up the case

The first step is to create the case, as usual. Here we can use CESM's option to create a compset on the fly, and supply the atmosphere and slab-ocean models along with stubs for all other components. This will exclude sea-ice, but we will come back to that topic later.

```
 cmd line 
create_newcase -case /glade/p/work/brianpm/my_cases/CAM5AquaSOM_noice \
-user_compset 2000_CAM5_SLND_SICE_DOCN%SOM_SROF_SGLC_SWAV \
-res f19_f19_AQUA -mach yellowstone
```

At this point we are ready to set up the case,

```
 cmd line 
  cd /glade/p/work/brianpm/my_cases/CAM5AquaSOM_noice
  ./cesm_setup
```

In this example configuration with no sea-ice, I also want to use the "traditional" aquaplanet settings of perpetual equinox orbital parameters. This is accomplished by using the `user_nl_cpl` namelist with these values

```
────────── user_nl_cpl ──────────
  orb_eccen = 0.
  orb_obliq = 0.
  orb_mvelp = 0.
  orb_mode  = 'fixed_parameters'
```

We need to make a couple of changes to the CAM namelist as well. First, because the `aqua_planet` namelist parameter is not activated, some convenience code is not triggered during compilation. The most important thing that is excluded is setting the surface geopotential to zero. We can get around this without modifying the code just by supplying a topography boundary condition file that has been modified to be zeros. Second, since the example uses CAM5 physics, we also need to decide what to do with aerosol. One option is to use the bulk aerosol module. So here we can make these changes easily in the `user_nl_cam` namelist

```
────────── user_nl_cam ──────────
  prescribed_aero_model = 'bulk'
  bnd_topo = '/glade/scratch/brianpm/AQUA_TOPO.nc'
```

Before going further, we also need to make sure that the aerosol choice is recognized during model configuration by supplying it in the `env_build.xml` file

```
────────── env_build.xml ──────────
<entry id="CAM_CONFIG_OPTS"   value="-phys cam5 -chem none"  />
```

To run with the slab ocean, two more files are required. First is the domain file, specified in the data ocean namelist. This file specifies which grid points are ocean and land. To construct an aquaplanet version, an existing file was modified to have no land. Second is the "forcing" file, which specifies the depth and temperature of the ocean layer and the "qflux." In this example, I supply a version of this file that has a uniform 50m mixed layer, a uniform temperature of 288K, and no qflux. In `user_nl_docn` specify the domain file as

```
────────── user_nl_docn ──────────
  domainfile = '/glade/scratch/brianpm/domain.ocn.1.9x2.5_AQUAPLANET.nc'
```

The forcing file gets specified in a file called `user_docn.streams.txt.som`. The contents of that file can be copied from a previous slab ocean case. For this example, the file contents are:

```
────────── user_docn.streams.txt.som ──────────

     <dataSource>
        GENERIC
     </dataSource>
     <domainInfo>
        <variableNames>
           time     time
           xc       lon
           yc       lat
           area     area
           mask     mask
        </variableNames>
        <filePath>
           /glade/scratch/brianpm
        </filePath>
        <fileNames>
           cam5.som.forcing.aquaplanet.Q0h50m.fv19.nc
```

```
            </fileNames>
        </domainInfo>
        <fieldInfo>
            <variableNames>
                T       t
                S       s
                U       u
                V       v
                dhdx    dhdx
                dhdy    dhdy
                hblt    h
                qdp     qbot
            </variableNames>
            <filePath>
                /glade/scratch/brianpm
            </filePath>
            <fileNames>
                cam5.som.forcing.aquaplanet.Q0h50m.fv19.nc
            </fileNames>
            <offset>
                0
            </offset>
        </fieldInfo>
```

We also need to specify our new use case in `env_run.xml`:

```
————————————————— env_run.xml ——————————————————
<entry id="CAM_NML_USE_CASE"   value="SOM_aquaplanet_cam5"  />
<entry id="DOCN_SOM_FILENAME"   value="/glade/scratch/brianpm/som.forcing.aquaplanet.Q0h50m.fv19.nc"  />
```

At this point, the model can be compiled and run. Remember to adjust account numbers, runtime settings, etc.

```
————————————————— cmd line ——————————————————
./[case].build
bsub < [case].run
```

3 SEA-ICE

The main issue with the aquaplanet using a slab ocean is the dynamic sea-ice model. Essentially, the sea-ice dynamics only work on the displaced-pole grid (e.g., gx1v6). When we remove the land, the poles are exposed, and the sea-ice model breaks. In the above example, we ran the slab ocean model on the same grid as the atmosphere, but without the sea-ice model. If sea-ice is desired in the aquaplanet setting, currently the only viable option is to run the sea-ice in thermodynamic mode. One way to accomplish this is to set up an AMIP-like case, and then modify the sea-ice to use the thermodynamic code.

```
————————————————— cmd line ——————————————————
create_newcase -case /glade/scratch/[case] -compset F_2000 -res f19_f19 -mach yellowstone
```

Now edit `user_nl_cice`

```
──────── user_nl_cice ────────
kitd           = 1
prescribed_ice = .false.
tr_aero        =  .true.
tr_fy          =  .true.
tr_iage        =  .true.
```

The parameter `kitd` controls whether the ice thermodynamics are used. We could include `kdyn = 0` for parity, specifying not to use the ice dynamics (this is not needed because it will already be set to zero in this compset).

Change to slab ocean mode by changing `env_run.xml` to read

```
──────── env_run.xml ────────
<!--"DOCN mode, valid values: prescribed,som,copyall,null (char) " -->
<entry id="DOCN_MODE"    value="som"  />

<!--"Sets SOM forcing data filename for pres runs, only used in D and E compset (char) " -->
<entry id="DOCN_SOM_FILENAME"   value="[forcing file]"  />
```

Then proceed as a normal.

This method does not *quite* work for the aquaplanet-SOM with thermodynamic sea ice. The problem is just that the compset assumes there will be land points, and even specifying the domain files does not appear to completely remove the land, and the model crashes.

To run the aquaplanet-SOM with thermodynamic sea ice, we can follow a similar path, but with a more elaborate `create_newcase` call. Here is an example:

```
──────── cmd line ────────
create_newcase -case /glade/scratch/brianpm/AquaSOM_CICE \
               -user_compset 2000_CAM5_SLND_CICE_DOCN%SOM_SROF_SGLC_SWAV \
               -res f19_f19_AQUA -mach yellowstone
```

Note that I have used the same grid specification as used in the above no-ice case. The only change is to specify an ice model.

The `user_nl_cice` namelist should now contain:

```
──────── user_nl_cice ────────
kdyn = 0
kitd = 1
prescribed_ice = .false.
tr_aero        =  .true.
tr_fy          =  .true.
tr_iage        =  .true.
grid_file      = '/glade/scratch/brianpm/domain.ocn.1.9x2.5_AQUAPLANET.nc'
kmt_file       = '/glade/scratch/brianpm/domain.ocn.1.9x2.5_AQUAPLANET.nc'
grid_type      = 'latlon'
grid_format    = 'nc'
kstrength      =  0
```

This is more extensive than above. We now need to specify `grid_file` and `kmt_file` to be our domain file. The `kdyn` parameter is included just to be explicit. The other additions – `grid_type`, `grid_format`, `kstrength` – were determined to be necessary by trial and error.

Otherwise, the changes follow the previous description

- Modify `env_run.xml`, including `DOCN_MODE`, `DOCN_SOM_FILENAME`, and (optionally) `CAM_NML_USE_CASE`.

- `user_nl_cam` should specify the topography boundary condition, along with any other CAM options (like aerosol).

- `user_nl_docn` should specify the domain file.

- `user_docn.streams.txt.som` should contain the same information as above.

- `user_nl_cpl` should specify any necessary orbital parameter changes.

- `env_build.xml` should be consistent with any choices made here.

- `[case].run` should be modified with project numbers and wall-clock time, etc.

4 AEROSOL

What aerosol should occupy the aquaplanet's atmosphere? It's arbitrary, but the decision can affect some aspects of the simulation. With CAM4 physics, there is a more well-defined convention, which is that aerosols do not interact with radiation; combine this with there being no interaction between aerosol and clouds in CAM4, and the result is a "no aerosol" aquaplanet. This is the recommendation for CFMIP2 aquaplanet experiments, and follows from the APE. With CAM5, there are indirect effects of aerosol on clouds, and there is not a standard way to "turn off" aerosol effects. Here are some options that can be applied in the CAM5 aquaplanet configuration. Each option can be controlled in `env_build.xml`, as above

```
———————————————————————— env_build.xml ————————————————————————
<entry id="CAM_CONFIG_OPTS"   value="-phys cam5 -chem OPTION"  />
```

where `OPTION` can be filled with any of a number of values, but the only options that need to be considered here are `none` and `trop_mam3`.

4.1 PRESCRIBED AEROSOL

If we want to use prescribed aerosol, then we must specify either `modal` or `bulk` in the CAM namelist parameter `prescribed_aero_model` along with setting the chem option to `none`. This is the only method to override the default, which is based on the physics package (i.e.., CAM4 or CAM5); when the chem option is set to none, `prescribed_aero_model` is set to modal for CAM5 by default.

The prescribed modal aerosol is based on the modal aerosol module (MAM) code, and uses conditional sampling based on cloud fraction to mimic the aerosl-cloud-radiation interaction that would be predicted using the interactive aerosol.

The prescribed bulk aerosol is the bulk aerosol module (BAM) that was used in CAM4. It does not contain any indirect effects of aerosol. Cloud droplet activation uses the prescribed aerosol concentration in the grid cell.

Both versions require netCDF files for the prescribed aerosol boundary condition. For use in the aquaplanet, the default files can be copied to a local directory and modified as needed. The path to those files can then be specified in the CAM namelist.

4.2 MODAL AEROSOL MODULE

The modal aerosol module (MAM) is the default treatment of aerosol in CAM5, and as such it might represent the most attractive option for the aquaplanet configuration. It is more computationally expensive than prescribed aerosol. There are two versions of MAM, one with three aerosol modes (i.e., size bins) and one with seven modes; only the three-mode version is routinely run outside of the aerosol-modeling community.

MAM3 also requires netCDF files to supply boundary conditions, but these are aerosol emissions from the surface (or near surface) rather than aerosol concentrations. As with the BAM files, the default values can be copied to a local directory and modified. For the aquaplanet configuration, it makes sense to remove all the land-based emissions. That only leaves emissions of dimethylsulfide (DMS), which is produced by ocean biology. Whether an aquaplanet should have ocean life is a matter of taste.

When DMS is also removed from the picture, the only aerosol emission left is the diagnostic flux of sea-salt into the atmosphere. In experiments comparing this 'salt-only' configuration with configurations where DMS emissions are allowed, there are only slight differences. Comparing with AMIP runs of CAM5 with MAM3, the biggest issue related to aerosol appears to be that aquaplanets have more upper-tropospheric water in the form of snow than the AMIP configuration which has more cloud ice. Both are radiatively active, but with somewhat different optical properties. The difference is currently thought to be due to a lack of ice nuclei reaching the upper troposphere in the aquaplanet, and this is likely because mineral dust is the main contributor to CAM5's ice nuclei.