Manual for REcoM2 coupled to FESOM

Vibe Schourup-Kristensen

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1 Overview of REcoM2 coupled to FESOM

When running the Regulated Ecosystem Model (REcoM2) coupled to the Finite Element Sea-ice Ocean Model (FESOM), REcoM2's code is distributed in seven files, which contain a total of 16 subroutines and 5 modules. A list of these files and associated subroutine can be found in sect. (3).

The file `fesom_main.F90` contains the main program of FESOM and controls the overall course of the run. An overview of the structure of the subroutines entailing code for REcoM2 is shown in fig. (1).
In a coupled run, FESOM calls REcoM2 once during initialization, one time for every time step, and every time output is saved. The changes made to the code of FESOM due to REcoM2 is described in sect. (4), and it is described in sect. (2) how to to run the model.

1.1 Initialization

Initialization of FESOM and REcoM2 is controlled by the subroutines `ocean_array_setup` and `ocean_init` (fig. 1, part 1).

- `FESOM_main.F90` calls the subroutine `ocean_array_setup`, where arrays for tracers are allocated and set to zero.

- Salinity and temperature tracers are initialized for ocean restart runs in the subroutine `oce_input`.

- To initialize biogeochemical arrays, the subroutine `oce_input` calls `initialize_REcoM`. Here, initialization of biogeochemical tracers, benthos compartments can be performed as restart or spin-up, depending on settings.

Program main

Part 1
- ocean_array_setup
- Ocean_init
  - └ Initialize_REcoM
    - └ REcoM_init_output

Part 2
- Ocean_step
  - └ Call_REcoM
    - REcoM_init_output
    - Atm_input
    - REcoM_forcing
      - └ Cobeta
      - Depth_calculations
      - CO2flux
        - REcoM_cal_constants
        - └ REcoM_iterate_ph
          - └ REcoM_talk_difference
      - └ REcoM_sms
        - REcoM_sinking
        - REcoM_limiter
        - └ iron_chemistry
    - └ REcoM_add2mean

Part 3
- output
  - └ REcoM_control_output
    - REcoM_write_snapshots
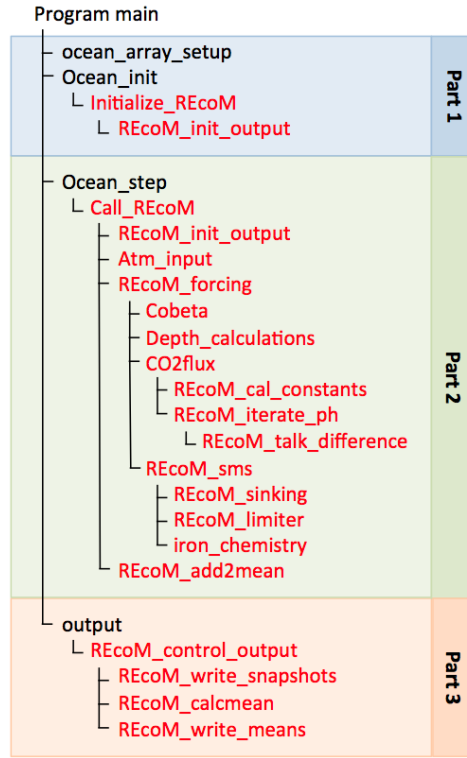   - REcoM_calcmean
    - └ REcoM_write_means

Figure 1: Structure of the subroutines that entail code for REcoM2. Part 1: This part is only performed once in a model run. It initializes fields for REcoM2 and creates netcdf files for output. Part 2: This is main REcoM2 code, and these calls are performed once for every iteration. Part 3: The subroutine `output` is called at every time step and checks whether it is time to save the output. If output must be saved the rest of the routines in this part is called, else, a new step is performed. Subroutines marked with red contain pure REcoM2 code, whereas the subroutines written in black are FESOM subroutines with code added for REcoM2.

- Netcdf files for saving biogeochemical model output are created by the subroutine `REcoM_init_output`, which is called by `initialize_REcoM`.

Whether to do a restart run or not is set in the module `REcoM_params`. To do a restart, the logical `REcoM_restart` must be switched on.

When REcoM2 is initialized as spin-up, the benthos and most tracers are set to a constant arbitrary small value. The dissolved inorganic carbon (DIN) is initialized with values from the Levitus World Ocean Atlas climatology from 2005 (Garcia et al., 2006), dissolved inorganic carbon (DIC) and alkalinity (Alk) are initialized with contemporary values from the GLODAP dataset (Key et al., 2004), and the field of dissolved iron (DFe) is initialized with an output from a run with PISCES (Aumont and Bopp, 2006).

1.2 Performing a time step

For each iteration, REcoM2 is called from the subroutine `Ocean_step` after FESOM has performed advection of all tracers. All subroutines involved in one time step for REcoM2 are shown in part 2 of fig. (1).

subroutine `call_REcoM`
In the FESOM environment, tracers are allocated as arrays. But for calculations of light and gravitational sinking, REcoM2 needs vertical columns of tracer values. This subroutine consequently steps through all surface nodes, and for each node it collects all underlying nodes, as well as associated values needed for calculations in REcoM2. These are sent column-wise to the main body of REcoM2 (fig. 2), which is controlled by the subroutine `REcoM_forcing`.

subroutine `Atm_input`
REcoM2 is forced with atmospheric deposition of iron and with an atmospheric concentration of CO_2. Both are saved in netcdf files. The subroutine `Atm_input` checks whether it is time to open new files, opens them and stores the variables for dust and CO_2.
Atmospheric deposition of iron is a monthly averaged 2D field. It is read in every month and saved in the variable `GloFeDust`, located in the module `REcoM_GloVar`.
For CO_2, a constant monthly averaged atmospheric value is used globally. These 12 values are read in once every year and stored in the variable `AtmCO2`, which is located in the module `REcoM_GloVar`. For more information about the data, see the sect. (1.4).
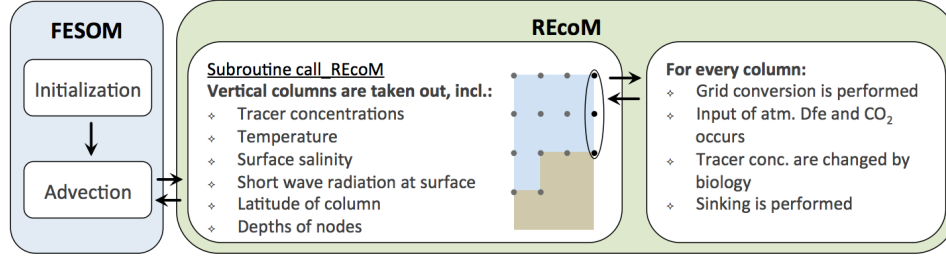
Figure 2: Sorting of variables in subroutine `call_REcoM` for the main body of the biogeochemical module.

subroutine `REcoM_forcing`
This routine controls the main body of REcoM2; it calls the routines preparing values for the biological tracer calculations, it calls the sms-routine that calculates the change in tracer concentration due to biology, and it integrates the diagnostic fields.

1. The subroutine `Cobeta` is called. Here the angle of incidence of the sun is calculated.

2. The subroutine `Depth_calculations` is called. As the sinking routine is based on a C-grid and FESOM on an A-grid, extra calculations of the flux depths are needed for the sinking.

3. The subroutine `CO2flux`, which calculates the flux of CO_2 between the atmosphere and the surface ocean, is called.

4. The subroutine `REcoM_sms` is called.

subroutine `REcoM_sms`
This subroutine calculates the biological changes of the tracer concentrations, the changes in the concentrations of the sediment fields and the diagnostic fields. The diagnostics that are calculated at the moment are: Net and gross primary production for small phytoplankton and diatoms, and net and gross N-assimilation of small phytoplankton and diatoms.

subroutine `REcoM_sinking`
This routine is called from `REcoM_sms` and performs sinking of small phytoplankton, diatoms and detritus. The sinking can be constant or variable as defined in the module `REcoM_params` by the logical `allow_var_sinking`. In

the same module, a constant sinking velocity must be set for detritus and both phytoplankton classes regardless of sinking type. These velocities are denoted `Vdet`, `Vdia` and `Vphy`.

In the subroutine `Depth_calculations`, the surface velocity is set to zero, the velocity at the node below the surface node is set to half of the predetermined velocity and the rest are equal to the predetermined velocity.

The sinking routine is adapted from the original REcoM-code, which is based on a 3rd Order DST Sceheme with flux limiting.

subroutine `REcoMadd2mean`
Following each time step, the subroutine `call_REcoM` calls `REcoMadd2mean`, where the diagnostic and benthos fields are summed up, and the mean of the whole time period is calculated from this summation before saving the fields. FESOM saves both snapshots and means of all tracers, and these are automatically created once the tracers are defined in FESOM.

1.3 Saving output

The subroutine `output` is called at the end of every time-step. This routine checks whether it is time to save the modeled fields.

If the fields should not be saved, the next iteration is performed.

If it is time to save, the subroutine `REcoM_write_snapshot` saves snapshots. `REcoM_calcmean` calculates the mean fields, which are then saved by the subroutine `REcoM_write_means`.

When the fields from REcoM2 have been saved, FESOM proceeds to save the ocean fields and sets the mean arrays to zero to start calculating new means.

When all fields have been saved, the next iteration is performed.

1.4 Forcing

Forcing for FESOM
FESOM can be forced with the climatological CORE I or the interannually varying CORE II datasets (Large and Yeager, 2004). This gives values for 10 m wind speed, 10 m air temperature, 10 m specific humidity, incoming long- and shortwave radiation, precipitation and runoff.

Atmospheric CO_2
The atmospheric CO_2 can be set to a constant value or it can increase with time.

Files with increasing atmospheric concentrations of CO_2 are taken from the Mauna Loa data series[1] and from ice core data[2].

The Mauna Loa data covers the years 1965 to 2008. It is given as monthly values and thus has seasonality, with higher concentrations in the spring/early summer of the northern hemisphere. To remove seasonality, the yearly average is used. To get monthly values, it is assumed that the yearly average occurs in July and the values are linearly interpolated for the rest of months. In the end and the beginning of the data set, linear extrapolation is performed.

The result is saved in the netcdf file `MonthlyAtmCO2_MaunaLoa.nc`, which entails a variable for each year named `AtmCO2_1965` to `AtmCO2_2008`. Each variable entails 12 monthly values.

Ice core data is used from 1765 to 1964. It comes with semi-annual values, one for January and one for July each year. This is converted to monthly values using linear inter- and extrapolation.

Results are saved in the file `MonthlyAtmCO2_IceCore.nc` with the same type of variable names as above, for example `AtmCO2_1964`. Each variable entails 12 values for atmospheric CO_2, one for each month.

Aeolian deposition of iron

Data for dust input comes from Mahowald et al. (2003) and is given for the years 1979 to 2007. The DFe deposition is a 2D field that is monthly averaged. The data in FESOM is interpolated from Mahowalds data.

We have a monthly climatology stored in the file `DustClimMonthly.nc` and a file, `DustMonthly.nc`, which provides values for each month.

The climatology will automatically be used before 1979, but it can also be turned on for later years. This is done by setting the logical `UseDustClim` to true in the module `REcoM_params`.

The monthly values of aeolian iron input is used from 1979 and on when the logical `UseDustClim` is set to false.

2 Running the coupled model

In this description it is assumed that FESOM has been spun up, and description is given based on this.

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[1]`http://cdiac.ornl.gov/ftp/trends/co2/maunaloa.co2`
[2]`http://cdiac.ornl.gov/ftp/db1009/inputs/co2spl.dat`

When running FESOM with REcoM2 it is necessary to have five directories with files:

`fesom_1.3`: Entails all the code files for FESOM and REcoM2.

`results`: Here, the output and the clock-file is stored.

`forcing`: The CORE-II files and the files entailing data for atmospheric iron deposition and CO_2 concentration are stored here

`mesh`: Stores the mesh used in the run.

The paths to these directories are defined in FESOM's ocean namelist, `namelist_oce.F90`.

2.1 Settings for FESOM

In the namelist for FESOM (`namelist_oce.F90`), several settings can be changed. This includes name of the run (`runid`), length of time step, which is set as steps per day (`step_per_day`), length of the run, paths to the directories needed for the run (`MeshPath, ForcingDataPath, ResultPath`) and how often the model results should be saved (`y, m, d, h, s`).

2.2 Settings for REcoM2

The parameters that should be checked for REcoM2 before each run are located in the module `REcoM_params`. Here REcoM2 is activated through the parameter `use_REcoM` and the parameter `REcoM_restart` decides whether to do restart or not. Iron limitation and the benthic layer can be turned of (`Felimit` and `BenthicLayer`). It can be controlled whether monthly values for aeolian iron input should be used after 1979 (`UseDustClim`) and the atmospheric concentration of CO_2 can be set to be constant. Several more parameters are contained in the module and should be checked before a run is started.

2.3 Initialization of FESOM

When REcoM2 is started, the ocean and ice must be in a spun-up state, and consequently restart files for FESOM must be located in the `results` directory. These files are named `[runid].[year].ice.nc` and `[runid].[year].oce.nc`. For example, if a run with runid BIO21 should be made for 1949, it is necessary to have the files: `BIO21.1948.ice.nc` and `BIO21.1948.oce.nc`.

In addition to the restart files, a clockfile should be placed in the directory `results`. This entails the date from which to startup and the first

time to calculate. The name of a clock file is `[runid].clock`, for example `BIO21.clock`.

2.4   Output files

The results of the run are saved at the times specified in the file `namelist_oce.F90` as described above. The saved files are:

`[runid].[year].oce.nc` and `[runid].[year].oce.mean.nc`:
Contain snapshots and means of the ocean fields, including all biogeochemical tracers described by REcoM2, as well as sea surface elevation and velocities.

`[runid].[year].bio.nc` and `[runid].[year].bio.mean.nc`:
Contain snapshots and means of all fields that are only needed for REcoM2; benthos concentrations, fields relevant for CO_2 flux between ocean and atmosphere and vertically integrated primary production and N-assimilation.

`[runid].[year].ice.nc` and `[runid].[year].ice.mean.nc`:
Contains snapshots and means of the ice field; ice concentration, effective thickness of snow and ice and velocity.

`[runid].[year].forcing.diag.nc`:
Contains the fields that forces the run such as 10 m wind speed, precipitation, runoff, evaporation, radiation, heat fluxes.

`[runid].[year].oce.diag.nc`:
Contains diagnostic fields for the ocean; mixed layer depth, advective fluxes of temperature and salt, vertical diffusivity and eddy induced advection.

`[runid].[year].ice.diag.nc`:
Contains diagnostic fields for the ice, such as thermodynamic growth rates, melting rates and advective fluxes.

3   Names of files, subroutines and modules for REcoM2

3.1   Subroutines

Here, the files and the subroutines they contain are listed:

```
ini_REcoM.F90        ctrl_REcoM.F90        sms_REcoM.F90
initialize_REcoM     call_REcoM            REcoM_sms
                     REcoM_forcing         Cobeta


sink_REcoM           Atm_REcoM.F90         out_REcoM
REcoM_sinking        CO2flux               REcoM_init_output
Depth_calculations   REcoM_cal_constants   REcoM_control_output
                     REcoM_iterate_ph      REcoM_write_snapshots
                     Atm_input             REcoMadd2mean
```

3.2 Modules

In addition, REcoM2 needs a number of modules, which are stored in the file `mod_REcoM.F90`:

`REcoM_params`: Here, the parameters that should be checked before each run is set. For instance whether a restart run is to be performed or if iron should be limiting.

`REcoM_constants`: The parameters that are generally not changed are set here, for example half saturation constants.

`REcoM_declarations`: Declares variables for REcoM2.

`REcoM_GloVar`: Stores the 2D and 3D fields that are necessary for REcoM2, for instance benthos and iron deposition. The 21 main biogeochemical tracers are stored through FESOM.

`REcoM_LocVar`: REcoM_sms only receives one vertical water column at a time. The subroutine `call_REcoM` finds the correct variable for each surface node and stores them temporarily in this module for `REcoM_sms`.

4 Changes in FESOM due to REcoM2

REcoM2 is called during initialization, after tracer advection during each time step, and for saving the output.

4.1 Initialization

For now, REcoM2 can only be initialized when the ocean has been spun up. Initialization of ocean tracers is performed in the subroutine `ocean_init`, which is located in the file `oce_init.F90`.
Here, the code is changed to only initialize tracer 1 and 2 (temperature and salinity).
The old code:

```
do j=1, num_tracer !  Here all tracers are initialized
```

The new code:

```
do j=1, 2 !!!num_tracer!!!  Here T and S are initialized
```

Also in subroutine `ocean_init` a line is added to call the subroutine `initialize_REcoM`, which controls initialization of all biogeochemical fields:

```
if (use_REcoM) call initialize_REcoM
```

4.2 Time stepping

For every time-step, REcoM2 is called after the tracer advection has been carried out by FESOM. This is done in the subroutine `ocean_step` in the file `oce_step.F90`.
In the end of the routine just before writing how long the computations have taken, the following line is added:

```
call call_REcoM
```

4.3 Saving output

In the subroutine `output`, which is located in the file `gen_output.F90`, an extra line is added after the snapshots, but before the means have been written:

```
call REcoM_control_output
```

References

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