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APPLICATE

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Deliverable No. 2.1

Demonstrator of a fully coupled SCM

Submission of Deliverable

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Table of Contents

EXECUTIVE SUMMARY

A novel tool to investigate parameterized processes that act in a vertical column that extends from the ocean, through the sea ice and the atmosphere, is presented. The first version of this extended single-column model (SCM), the AOSCM – Atmosphere Ocean SCM, version 1, is developed within the EC-Earth development portal to ensure that it easily can follow the further development of the full model.

Experiments with the AOSCM can be designed to mimic the EC-Earth environment at one specific location or it can be used in more idealized settings for e.g. parameter sensitivity studies. The tool is specifically developed with the aim to investigate how the coupling between the different model components affects the ability of the model to represent the air-sea interactions in areas where there is sea-ice.

The AOSCM will be used in WP2 to evaluate model performance on the process level. It will also be used in sensitivity studies of how coupling choices affect the results and in parameterisation development. Some further development of the technical capabilities of the tool is also planned.

1. INTRODUCTION

1.1. Background and objectives

Model development and testing of parameterisations are mostly performed in the individual model components, i.e. the atmospheric model is developed and tested using SST and observed sea ice conditions as boundary forcing. Similarly, when the ocean or land models are developed, the atmosphere is prescribed using e.g. 6-hourly reanalysis fields. As a consequence, many thing may happen when they are put together in the coupled system. Specially in regions where the coupling is strong such as in the Arctic with the rapidly responding sea ice.

When developing the model parameterisations, often a column out of the 3-D model is picked and run in isolation, a so-called Single Column Model (SCM). This tool has been used for decades, more frequently in the atmospheric community, than in the sea-ice and ocean communities, where standardized experiments have been used to compare the performance of individual parameterisations (boundary-layer turbulence, shallow convective clouds, cloud microphysics, etc) in international model inter-comparisons organised by e.g. GEWEX.

Here, we have developed a fully coupled Atmosphere Ocean SCM, and AOSCM, with the aim to test parameterisations and their interaction through the coupling at the surface. Since it is applied in the Arctic, the sea-ice component, is also included.

1.2. Organisation of this report

The report only briefly discusses the methodology and results since these are outlined in detail in a paper submitted to Geoscientific Model Development and is currently under discussion since March 20, 2018: An EC-Earth coupled atmosphere-ocean single-column model (AOSCM.v1_EC-Earth.v3) for studying coupled marine and polar processes by Kerstin Hartung, Gunilla Svensson, Hamish Struthers, Anna-Lena Deppenmeier, and Wilco Hazeleger, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2018-66, 2018

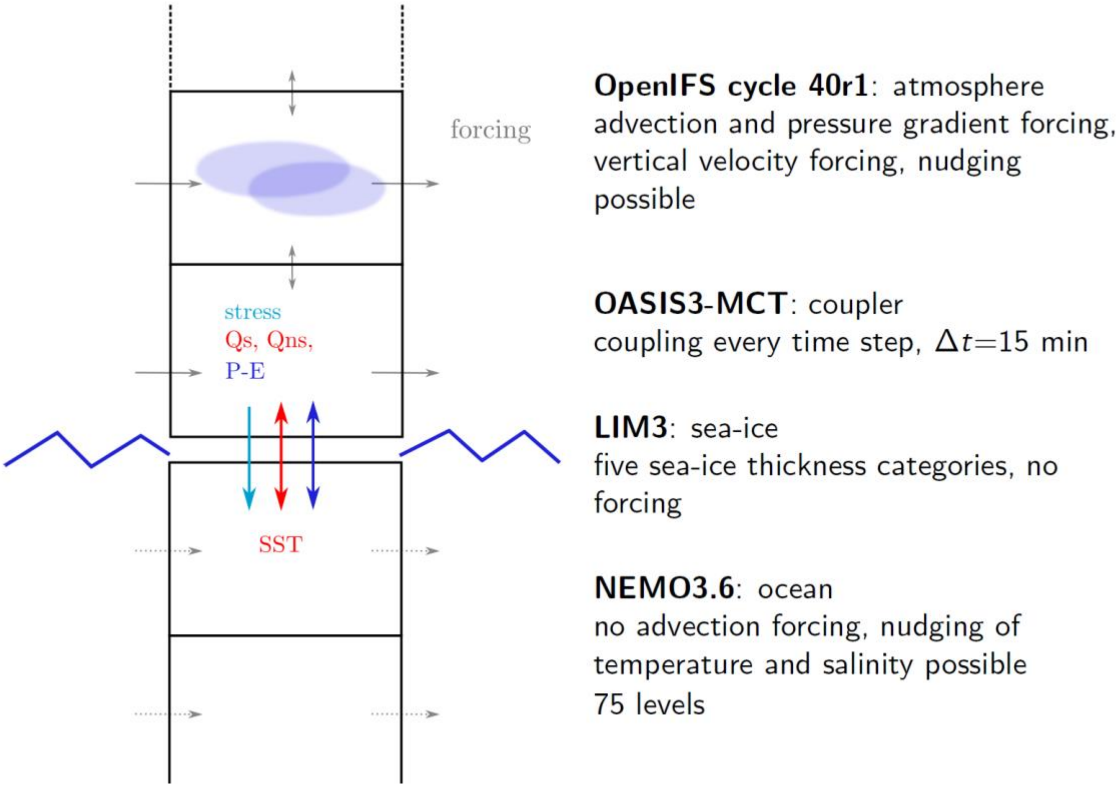

Figure 1. Technical setup of AOSCM.v1

2. METHODOLOGY

The model development has been performed within the structure of the development version of EC-Earth and this first version, AOSCM.v1 is based on version 3 of EC-Earth.v3 that in turn is based on OpenIFS and NEMO/LIM with OASIS as a coupler, see Figure 1 for more technical details. The benefit of having the AOSCM within the development portal of EC-Earth is paving the way to being able to have a tool that relatively easy can follow the progress of the coupled global model. A wiki-page within the portal has been created that provides information on how to download the code, some test cases, and documentation. The usage of and access to the EC-Earth source code is licensed to affiliates of institutions that are members of the EC-Earth consortium. More information can be found at http://www.ec-earth.org. The main document describing the model, the AOSCM-guide is, due to this restricted access, in Appendix 1.

The technical development was done in close collaboration with the National Supercomputer Center at Linköping University, Sweden, mainly with the application expert Hamish Struthers. The testing and debugging of the system was handled at SU with support from ECMWF.

The AOSCM can be used in different configurations and thereby aid in understanding the interactions and performance of the parameterisations as well as the coupling and transfer of properties between the components at the surface. The model can run as a fully coupled system, or the atmosphere or ocean may be run separately. The versatility facilitates different applications of the model that are more or less constrained by observations. Hartung et al., 2018 provides examples of applying the model at three ocean sites in the tropical ocean, north Pacific and in the sea-ice covered Arctic Ocean. This modeling tool is developed with the aim of aiding studies of the more complicated coupling in the Arctic but has great potential to be used at other locations for other problems as well which is discussed in the paper.

3. RESULTS AND DISCUSSION

In this section, we refer to the manuscript Hartung et al., 2018 that describes more details of the model system, what type of experiments that can be performed, what external forcing that needs to be provided as well as results from three test locations including brief scientific discussion.

4. CONCLUSIONS AND OUTLOOK

As show and discussed in Hartung et al., 2018, the AOSCM is a useful tool for studying the physical interaction of oceanic and atmospheric boundary layer processes as well as technical aspects of the coupling between the atmosphere and the ocean. The tool has already been applied to an Arctic warm-advection case and sensitivity to atmosphere only or coupling with the ocean/sea ice is found. Thus, we have demonstrated the tool and shown a few examples of how it can be utilised.

In Hartung et al., 2018, we also outline a few lines of further development that would be useful to aid the science and also to achieve the goals of APPLICATE. These include e.g. improved capability of advective tendencies for cloud variables, ocean and sea-ice properties, and the possibility to nudge the atmosphere above the dynamically variable boundary layer.

Besides the additional development, we will continue to use the AOSCM for scientific studies and develop cases based on existing observations as well as explore the ability of the AOSCM to capture the evolution of the near-surface processes during a field cruise with the Swedish Ice-Breaker Oden during summer 2018.

5. REFERENCES

Hartung K., G. Svensson, H. Struthers, A.-L. Deppenmeier and W. Hazeleger, 2018: An EC-Earth coupled atmosphere-ocean single-column model (AOSCM.v1_EC-Earth.v3) for studying coupled marine and polar processes. Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2018-66, 2018

6. ACRONYMS

AOSCM – Atmosphere Ocean Single Column Model
GEWEX – Global Energy and Water Exchanges
SCM – Single Column Model

7. Appendix 1. User's Guide to the EC-Earth AOSCM

User's Guide to the EC-Earth AOSCM

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1 Installing and running the model

1.1 Access to the model

The model source code is available from the EC-Earth development portal:
svn checkout https://svn.ec-earth.org/ecearth3/branches/development/2016/r2740-coupled-SCM r2740-coupled-SCM.
Configuration setups are available for Triolith (Swedish supercomputer) and personal computer (linux, gcc and openmpi).
The branch contains source required to compile the atmosphere-ocean coupled single-column model (AOSCM), an atmosphere-only single-column model (ASCM) and an ocean-only single-column model (OSCM).
More information and example data can be found on the EC-Earth AOSCM wiki page: `https://dev.ec-earth.org/projects/ecearth3/wiki/Single_Column_Coupled_EC-Earth`.

1.2 Installation

- Adapt the platform dependent variables in *r2740-coupled-SCM/config-build.xml* and execute

  util/ec-conf/ec-conf -p NAME_OF_CONFIGURATION config-build.xml

  substituting the name of the configuration with the desired setup, possibilities are triolith-intel-intelmpi, triolith-gcc-openmpi and pc-gcc-openmpi. The most important variables are the source code location (Parameter name="ECEARTH_SRC_DIR") and the paths to various libraries (e.g.: "MPI_INC_DIR", "MPI_LIB_DIR", "LAPACK_LIB_DIR", "NETCDF_INC_DIR", "NETCDF_LIB_DIR", "HDF5_INC_DIR", "HDF5_LIB_DIR").

  PC compiler and library dependencies:

  - gcc: `http://gcc.gnu.org/`
  - openmpi: `https://www.open-mpi.org/software/ompi/v3.0/`
  - gnu make: `https://www.gnu.org/software/make/`
  - lapack: `http://www.netlib.org/lapack/`
  - netcdf: `https://www.unidata.ucar.edu/software/netcdf/`
  - hdf5: `https://support.hdfgroup.org/HDF5/`

- Note that the choice of compiler can influence bit-for-bit reproducibility of the AOSCM results (e.g. Baker et al. (2015)).

- Compile model components, first OASIS, then either NEMO or OIFS (location and command).

  - oasis3/util/make_dir: make BUILD_ARCH=ecconf -f TopMakefileOasis3

- nemo-3.6/CONFIG: ./makenemo -n C1D_PAPA -m ecconf -j 4 (coupled-model executable) or ./makenemo -n C1D_PAPA_standalone -m ecconf -j 4 (ocean-only executable)

- scm-40r1v1.1.ref-oifs/make: ../fcm/bin/fcm make -f scm-ecconf.cfg (executable used both for AOSCM and ASCM simulations)

- Reversing compilation of components, e.g. in case of problems:

  OASIS: make BUILD_ARCH=ecconf -f TopMakefileOasis3 cleanlibs

  NEMO: ./makenemo -n C1D_PAPA_standalone clean

  OpenIFS: ../fcm/bin/fcm make –new -f scm-ecconf.cfg

- Architecture with several parallel executables:

  change name of OIFS executable in run script and make copy of master1.exe (paths in Fig. 1.1), nemo.exe needs to be copied before re-compiling as the folder containing the executable is overwritten during compilation

1.3 Model configuration and running a simulation

- Adapt storage paths and model settings in *runtime/scm-classic/config-run.xml* (see Fig. 1.1), then compile run file in runtime

  ../../sources/util/ec-conf/ec-conf - -platform PLATFORM_NAME config-run.xml

  Available platform names are pc-gcc-openmpi and triolith. This will produce run scripts (ending in .sh) from run script templates (ending in .sh.tmpl). For running the AOSCM the file name includes *scm_oifs+nemo*, for the ASCM *scm_oif* and for the OSCM *scm_nemo*. The AOSCM can also be run with alternative restart files, see Sec. 2.1, it is then called *scm_oifs+nemo_rst*.

- Initial conditions and forcing data should be stored in INI_DATA_DIR set in (config-run.xml) in the sub-directories: nemo/init, nemo/forcing, oifs and oasis.

- A coupled run needs the following initial conditions and forcing data (in subdirectories of scm-inidata):

  (i) an atmospheric initial condition and forcing file (in oifs, renamed in run script to scm_in.nc),

  (iia) an ocean initial condition file (in nemo/init) and possibly (iib) a chlorophyll timeseries (nemo/init) and (iic) a file containing ocean relaxation timescales (nemo/forcing),

  (iii) restart files rstos.nc and rstas.nc (in oasis).

  For an uncoupled atmosphere-only run only data from step (i) is required and an uncoupled ocean-only run needs a file containing atmospheric forcing (in nemo/forcing) in addition to the data (iia) - (iic).

- Note that initial condition and forcing files are per default only linked in the run script. The starting files can be renamed as necessary but the destination names are required by the model to be fixed.

  Files scm_in.nc and chlorophyll.nc can not be renamed, but init_PAPASTATION and forcing_PAPASTATION can be renamed if the namelist settings are adapted accordingly.

- Adapt namelists (see Figure 1.1, runtime/scm-classic/ctrl). For ocean and sea-ice it is recommended to not adapt the reference namelists but to configure setup specific namelists. If the name of the configuration is changed the nemo_grid variable in the run-script needs to be updated.

- Ensure that starting names of initial condition and forcing files match with those in the run script templates ece-scm*.sh.tmpl ("Files needed for IFS/NEMO/OASIS"). The same should be checked for the namelists (in run script: "Create some control files").

- r2740-coupled-SCM
  - runtime
    - scm-classic *run-script and namelists*
      - platform *platform descriptions*
      - config-run.xml *run settings*
      - ece-scm_.sh.tmpl *run script templates*
      - ece-scm-oifs *run-script (after configuration)*
      - ctrl *namelists*
        - namcouple.sh *oasis namelist*
        - namelist.scm-oifs.sh *oifs namelist*
        - namelist.nemo.ref.sh *nemo reference namelist*
        - namelist.nemo-CFG.cfg.sh *nemo namelist for configuration CFG*
        - namelist.lim.ref.sh *lim reference namelist*
        - namelist.lim-CFG.cfg.sh *lim namelist for configuration CFG*
  - source *source code*
    - oasis3-mct *Coupler*
    - scm-40r1v1.1.ref-oifs *Atmospheric model*
      - make/ecconf/build/bin/master1.exe *Atmospheric executable*
    - nemo-3.6 *Ocean model*
      - CONFIG/$cfg/BLD/bin/nemo.exe *Oceanic executable*
    - lpjg, tm5mp *EC-Earth model components not currently coupled*
  - doc *documentation*

Figure 1.1: Structure of r2740-coupled-SCM branch

- Date of run needs to agree with naming of ocean initial conditions file in run directory ("Files needed for NEMO" in run script).
- Run model by executing the appropriate ece-scm*sh script for an AOSCM, ASCM or OSCM experiment.
- After the simulation, namelist parameters used and more output is available in the run directory. Information of the ocean is contained in *output_namelist_dyn* or *_ice* and of the atmosphere in *fort.4* (before run) and *fort.20* (after run). Re-running a model setup overwrites all output.

2 Information on model components

Main settings of models are similar to their 3D versions and information can be obtained from the respective manuals and namelists. Here we give an overview of settings specifically of interest to the SCM.
OIFS manuals: `https://www.ecmwf.int/search/elibrary/IFS?secondary_title=%22IFS%20Documentation%20CY40R1%22`
NEMO and LIM manuals: `http://forge.ipsl.jussieu.fr/nemo/wiki/Documentation`
OASIS manual: `https://portal.enes.org/oasis/oasis3-mct_3-0-official-release`

2.1 OASIS

- restart files give information to the coupled model before the time of the initial condition
- in the default setup restart files are linked and thus updated in the initial conditions folder after every run

- restart files can also be calculated based on the case and copied to the run directory to ensure that the restart conditions are always consistent with the initial condition

  0. ensure that python and python packages netCDF4, numpy, shutil and sys are available for use in compile-rst.py

  1. run a (short) ASCM simulation of the AOSCM experiment

  2. calculate restart files from atmospheric run and ocean initial conditions (compile-rst.py)

  3. use these files to initialize the AOSCM experiment, note that the name of the ASCM simulations needs to be adapted in the AOSCM runscript (scm_oifs+nemo_rst) in the section "Files needed for OASIS"

- update restart files in txt-form and run ncgen command to produce new netcdf-files manually

2.2 OIFS

- Forcing data can be compiled based on ECMWF data as described at `https://software.ecmwf.int/wiki/display/OIFS/How+to+extract+Single+Column+Model+forcing+data+from+ECMWF+analysis`.
- Namelist parameters NSTOP, NLEVG, TSTEP, OUTFORM are automatically set from the run script.
- Numbers of levels for the atmospheric component needs to match one of the standard resolutions 60, 91 or 137 levels (see vtable_L files in runtime/scm_classic)
- Variable "time" needs to be set correctly in scm_in.nc, basis for calculation of forcing frequency.
- Variable "seconds" need to be set correctly in scm_in.nc when using NSTRTINI to start model run later than from first forcing time step.
- If running the model in ASCM-mode SST and sea-ice conditions need to be included in the scm_in.nc file. It is possible to provide the model with varying longitude, latitude and SST.
- If running the model in ASCM-mode the albedo for ocean and sea-ice are per default taken from climatology. By adding a scm_in.nc parameter sfc_ice_albedo (possibly varying in time) the albedo boundary condition over sea-ice can be adapted.
- Currently the albedo output in diagvar.nc is not consistent with the shortwave impact the atmosphere sees because broadband albedos are internally extended to be wavelength dependent. It is recommended to calculate the albedo from the shortwave budget at the surface.

2.3 NEMO

- Physical parameterization schemes (keys) need to be chosen in *C1D_PAPA/cpp_C1D_PAPA.fcm* before compilation. The file contains standard OSCM settings.
- Change bathymetry (rn_bathy), longitude (rn_lon1d and ppglam0) and latitude (rn_lat1d and ppghi0) in the nemo namelist according to position of column model. It is possible to run the model with less than 75 levels over shallow bathymetry, the grid spacing is then taking as in the default 75 level grid.
- If changing the location of the AOSCM the name of the initial conditions file init_PAPASTATION can be adapted in the namst1d section of the namelist and in the runscript.
- The type of tracer (temperature, salinity) initial conditions required depends on the equation of state formulation set in the nn_eos section of the namelist.

- Initialisation and relaxation forcing possible for variables temperature and salinity (tracers) as well zonal and meridional current with option of only forcing below the mixed layer. More description on relaxation is available in the NEMO manual (5.6.1 Generating resto.nc using DMP TOOLS).
- As NEMO internally distributes the column onto a 3x3 grid initial conditions, forcing, chlorophyll and ocean restart file rstos need to be in a 3x3 structure. The values for each point in the grid are the same and the centre column is coupled with the atmosphere.
- When running the model in OSCM-mode atmospheric forcing needs to be provided in scm-inidata/nemo/forcing containing downward SW and LW radiation, temperature and moisture (either at 2 m or at 10 m), total precipitation and snow, zonal and meridional wind at 10 m height.

  In the OSCM-mode the standalone namelists of NEMO and LIM are used.
- Table 2.1 gives information on where parameters prescribed in the atmospheric forcing file for an atmosphere-only simulation. In a coupled simulation variables are overwritten with values as set in the NEMO model.

2.4 LIM

- At the first model time step, if no a priori information is available, sea-ice is initialized if the ocean is sufficiently cold, e.g., if (SST-T_f) $<$ *rn_thres_sst*, with the namelist parameter *rn_thres_sst* describing the freezing threshold and T_f the seawater freezing point.
- The namelist parameter nn_catbnd determines the functionality of the distribution of thickness in the sea-ice categories. The default is nn_catbnd=2 and a $h^{-\alpha}$ functionality for a default number of categories of five.

  The concentrations for the different sea-ice thickness categories are calculated following a Gaussian distribution.
- Surface shortwave albedo is determined for each category in nemo-3.6/NEMO/OPA_SRC/SBC/albedo.F90 and depends on the thickness of the sea-ice and snow layer as well as on the thermodynamic properties of the surface (melting or freezing snow).
- Column mean sea-ice properties $\overline{x}$ are determined from the values $x(i)$ in the individual components i with use of the concentration in each category $a(i)$ via $\overline{x} = \frac{\sum_i x(i)a(i)}{\sum_i a(i)}$.

  All coupling variables are category mean properties.

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Table 2.1: List of variables connected to coupling and where their values are obtained from in an uncoupled and in a coupled simulation.

variable	ASCM, scm_in.nc	AOSCM
Momentum Roughness Length	mom_rough	src/surf/module/vupdz0_mod.F90 (general) and src/surf/module/suvexc_mod.F90 (sea-ice value)
Heat Roughness Length	heat_rough	as momentum roughness
Sea Ice Fraction	sea_ice_frct	namelist.lim3, coupling variable
Sea Ice Temperature	t_sea_ice	namelist.lim3, coupling variable
Open SST	open_sst	ocean initial conditions, coupling variable
Snow Depth	snow	namelist.lim3, coupling variable
Snow Temperature	t_snow	namelist.lim3
Snow Albedo	albedo_snow	
Snow Density	density_snow	$\rho_s = 330\ kgm^{-3}$, NEMO/OPA_SRC/DOM/phycst.F90
Ice Albedo	sfc_ice_albedo	NEMO/OPA_SRC/SBC/albedo.F90