CESM1/MESSy
Implementation Documentation
(MESSy version 2.50+ and beyond)

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Contents

1 Introduction

The Community Earth System Model (CESM1) is connected as a basemodel to the Modular Earth Submodel System (MESSy). At the current development stage, this gives MESSy users the ability to use two additional atmospheric dynamical cores, and also allows to use the CESM1 components for the other components of the Earth System. Information on the latest development status of MESSy and the CESM1/MESSy activities (including updates of this manual), are available on the MESSy web-pages (`http://www.messy-interface.org`). The `README`, `WARNINGS` and `CHANGELOG` files in the distribution give very useful instructions and further information.

For questions, bug-reports, etc., with respect to the CESM1/MESSy setup, please contact the mailing address `messy@lists.mpic.de`. For the individual submodels, refer to the MESSy web-pages and contact the corresponding submodel maintainer, if necessary.

This documentation introduces the model structure (Sect. 2), details the code changes in CESM1 (Sect. 3), the required modifications to MESSy (Sect. 4), and describes the setup and how to run the model (Sect. 5).

2 Model and input file structure

2.1 Model directory structure

MESSy uses different directories for the SMCL (submodel core layer), SMIL (submodel interface layer), BMIL (basemodel interface layer), and BML (basemodel layer) of the code. The modified CESM1 code has been added analagously to other MESSy basemodels as a BML and is therefore located in the MESSy root directory. An additional directory `messy/cesm1/` contains the basemodel specific SMIL and BMIL files. See Sect. 4 for further details.

2.2 CESM1/MESSy input files

The MESSy runscript and namelist setups expect a structured input file directory which has been extended for the CESM1 basemodel inputfiles. Furthermore, the MESSy input data are provided on the spectral element (SE) grid as pre-regridded input data. For the CESM1 basemodel, the CESM1 original directory structure is used, but for all resolution dependent files links are set to the original files in the CESM1 input data structure following a consistent input file naming convention. For the MESSy input data in SE configuration, the data, firstly, are regridded to different vertical resolutions (currently L26 and L51), and, secondly, horizontally regridded to the `ne16` and `ne30` grids. Scripts for this purpose are provided as MESSy utilities (`messy/util/fv2se_regrid.csh, fv2se_regrid.ncl`. These scripts require the NCL program with the ESMF regridding utility (NCL, 2014).

3 Changes in the CESM1 code

All changes in CESM1 have been implemented using the preprocessor directive

```
#ifdef MESSy
...
#else
...
#endif
```

The main changes encompass the calls to MESSy control, the deactivation of the CAM physics and chemistry, and the corresponding changes in the coupling to MCT (Larson et al., 2005) and the dynamical cores. The modified call structure that shows the entry points in CESM1 to MESSy interfaces is depicted in Fig. 1.

Further changes and details of the coupling to MESSy are detailed below.

3.1 Changes to the CESM1 shared modules

The data types (double precision real etc.), defined in `csm_share/shr/shr_kind_mod.F90`, have been replaced by the analogous MESSy definitions from the CONSTANTS infrastructure submodel (`messy_main_constants_mem`). In order to use identical physical constants through CESM1/MESSy, the relevant constants in `csm_share/shr/shr_const_mod.F90` have been redefined using those from MESSy defined also in the CONSTANTS infrastructure submodel.

3.2 Changes to the CESM1 driver

The CESM1 clock is left in place and controls the MESSy timer[1]. However, the alarm[2] triggering for restart or stop alarms is performed based on MESSy TIMER flags (see Jöckel et al., 2010, for a description of the TIMER infrastructure submodel) in `drv/driver/ccsm_comp_mod.F90`.

3.3 Changes to the atmosphere model coupling with other component models

The atmospheric physics and chemistry packages in CAM are deactivated and replaced by the corresponding MESSy submodels. Therefore, the couplings of variables to the other component models, performed via the MCT coupling package in the file `atm_comp_mct.F90`, have been replaced with MESSy variables, i.e. channel objects. The following table lists the variables that are copied from the MCT coupler to MESSy:

[1]Note: this is an important difference to the TIMER implementation in EMAC and COSMO, where the TIMER settings overwrite the basemodel time settings

[2]A CESM1 alarm is equivalent to an TIMER event

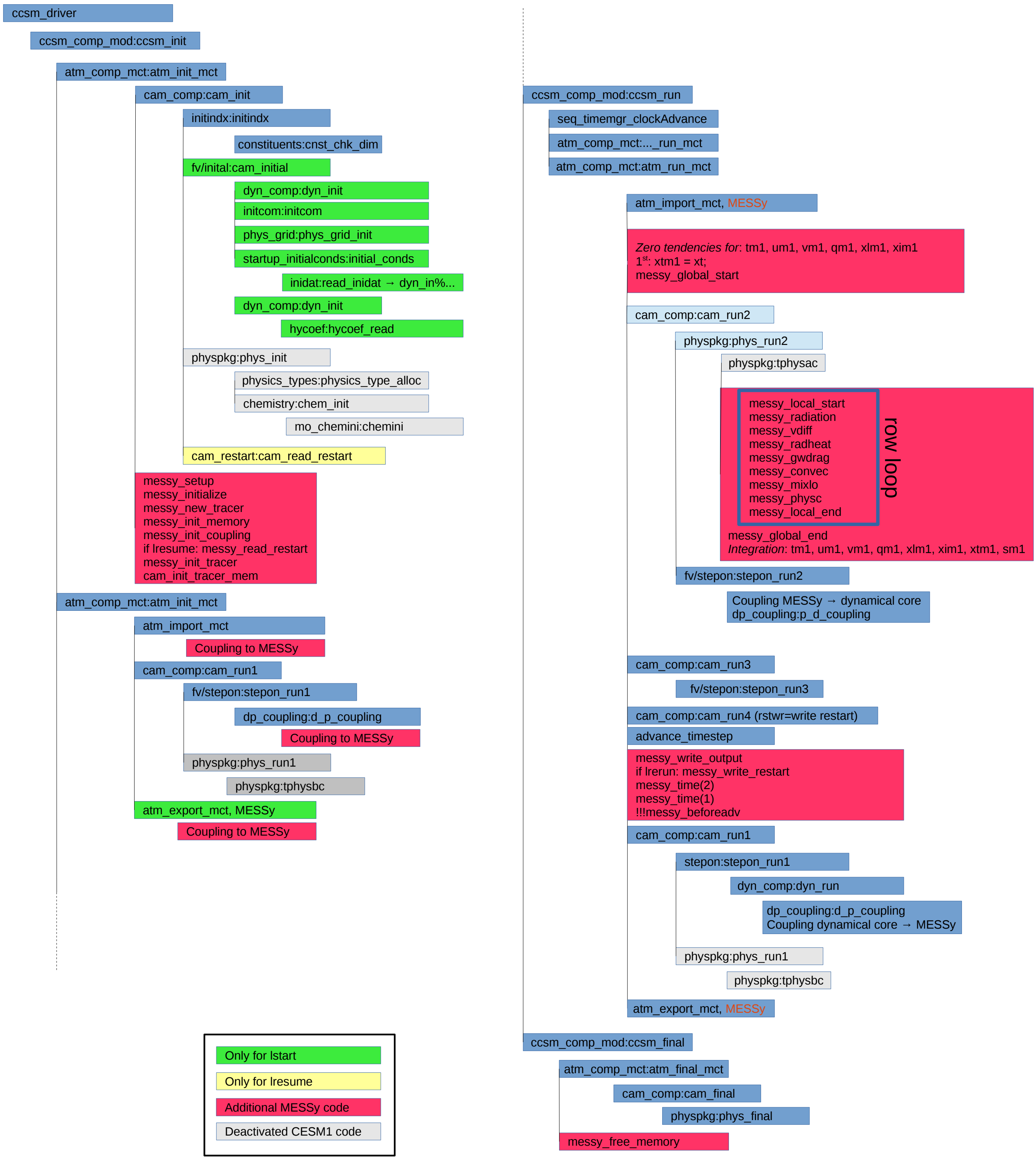

Figure 1: Diagram of CESM1 code changes.

variable	MESSy	coupler	unit
sea/land fraction	slf	Sf_lfrac	fraction
latent heat flux at the surface	l_heatflux	Faxx_lat	W/m2
Surface sensible heat flux	shflx	Faxx_sen	W/m2
temperature of the ground surface (soil)	tslm1	Sx_t	K
temperature of the ground surface (water)	tsw	Sx_t	K
land surface temp. for sensible heat flux	tslnew	Sx_t	K
surface temperature of ice	tsi	Sx_t	K
10 m wind speed	u10	Sx_u10	m/s
snow depth on ice (water equivalent)	sni	Si_snowh	m
snow depth (water equivalent)	sn	Sl_snowh	m
sea-ice areal fraction	icecov	Sf_ifrac	fraction
evaporation water flux[a]	cflx_q	Faxx_evap	kg/m2/s
x surface stress[a]	taux	Faxx_taux	N/m2
y surface stress[a]	tauy	Faxx_tauy	N/m2
specific humidity[b]	qref_2m	Sx_qref	kg/kg

[a]opposite sign in CAM vs MESSy
[b]converted to relative humidity in main_data_global_start

Analagously, the relevant MESSy data is copied to the coupler:

variable	coupler	MESSy	unit
Sea level pressure	Sa_pslv	tropop.slp	Pa
height[a]	Sa_z	geopot_3d[b]/g	m
zonal wind[a]	Sa_u	um1[b]/coslat	m/s
meridional wind[a] level	Sa_v	vm1[b]/coslat	m/s
temperature[a]	Sa_tbot	tm1[b]	K
potential temperature[a]	Sa_ptem	tm1[b]*exner[b]	K
pressure[a]	Sa_pbot	press_3d[b]	Pa
specific humidity[a]	Sa_shum	qm1[b]	kg/kg
density[a]	Sa_dens	press_3d[b]/(rd*tm1)	kg/m3
Convective precipitation rate	Faxa_rainc	max(cv_precflx[b],0)	kg m-2 s-1
Large-scale (stable) precipitation rate	Faxa_rainl	max(rainflux[b],0)	kg m-2 s-1
Convective snow rate[c]	Faxa_snowc	max(cv_snowflx[b],0)	kg m-2 s-1
Large-scale (stable) snow rate[c]	Faxa_snowl	max(snowflux[b],0)	kg m-2 s-1
Net shortwave radiation	Faxa_swnet	max(FLXS[d],0)	W m-2
Downward longwave heat flux	Faxa_lwdn	FLXT[d]-TRADSU[d]	W m-2
sw: nir direct downward	Faxa_swndr	0.83*max(FLXNIR[d]-sradsu/2,0)	W m-2
sw: vis direct downward	Faxa_swvdr	0.76*max(FLXSW1[d]-sradsu/2,0)	W m-2
sw: nir diffuse downward	Faxa_swndf	0.17*max(FLXNIR[d]-sradsu/2,0)	W m-2
sw: vis diffuse downward	Faxa_swvdf	0.24*max(FLXSW1[d]-sradsu/2,0)	W m-2
Black Carbon hydrophilic dry dep.	Faxa_bcphidry	BCPHIDRY	
Black Carbon hydrophobic dry dep.	Faxa_bcphodry	BCPHODRY	
Black Carbon hydrophilic wet dep.	Faxa_bcphiwet	BCDEPWET	
Organic Carbon hydrophilic dry dep.	Faxa_ocphidry	OCPHIDRY	
Organic Carbon hydrophobic dry dep.	Faxa_ocphodry	OCPHODRY	
Organic Carbon hydrophilic wet dep.	Faxa_ocphiwet	OCDEPWET	
wet/dry deposition of dust	Faxa_dstwet/wet$x$		
CO_2	Sa_co2diag	367	ppmv

[a]at the lowest model level
[b]level index *nlev*, i.e., index of lowest atmospheric layer
[c]water equivalent
[d]level index *nlevp1*, i.e. *nlev+1*

3.4 Coupling to dynamical cores

3.4.1 Finite Volume (FV)

The coupling to the dynamical core is performed in `dp_coupling.F90`. The subroutine `p_d_coupling` copies the atmospheric data from the physics grid to the FV grid.

As the dynamical core advects wet tracers, the tracer variables are converted from dry to wet:

```
do jt=1,ntrac_gp
   IF (ti_gp(jt)%tp%meta%cask_i(I_Advect) == ON) THEN
      xtm1(:ncol,:,jt,jrow) = xtm1(:ncol,:,jt,jrow) &
                             *pdeldry_3d(:ncol,:,jrow)/pdel_3d(:ncol,:,jrow)
   END IF
end do
```

where `xtm1` is the tracer mixing ratio, and `pdeldry_3d/pdel_3d` is the ratio of dry pressure level thickness to wet pressure level thickness.

Then, the following MESSy variables are coupled to the FV dynamics:

variable	MESSy	unit
temperature	`tm1`	K
zonal wind tendency	`vom_3d/cos(lat)`	m/s
meridional wind tendency	`vol_3d/cos(lat)`	m/s
pressure layer thickness	`pdel_3d`	Pa
specific humidity	`qm1`	kg/(kg wet air)
cloud liquid water	`xlm1`	kg/(kg dry air)
cloud ice water	`xim1`	kg/(kg dry air)
mixing ratios of advected tracers	`xtm1`	mol/mol

After the dynamics in the subroutine `d_p_coupling`, the prognostic and derived variables are rearranged and redistributed into the physics decomposition, and copied to the MESSy variables:

variable	MESSy	unit
zonal wind	`um1`	m/s
meridional wind	`vm1`	m/s
vertical velocity	`vervel_3d`	Pa/s
temperature	`tm1`	K
Inverse exner function	`exner`	-
pressure at level interfaces	`pressi_3d`	Pa
specific humidity	`qm1`	kg/(kg wet air)
cloud liquid water	`xlm1`	kg/(kg dry air)
cloud ice	`xim1`	kg/(kg dry air)
relative vorticity	`vom1`	1/s
surface geopotential	`geosp`	m2 s-2
surface pressure	`aps`	Pa
trace gas mixing ratios	`xtm1`	mol/mol

Subsequently, the midlevel pressures are calculated based on the interface pressures. While CAM uses geopotential height as a state variable, MESSy uses geopotential. Additionally, it employs the original ECHAM5 notation, where the geopotential is infinite at the upper boundary, and the interface geopotential variable contains the geopotential at interfaces below the full levels. Therefore, the geopotential fields of CESM1 need to be shifted by one for MESSy. Furthermore, `geopoti_3d(:,nlevp1,:) = 0`

```
geopoti_3d(:,:,jrow)=geopoti_3d(:,:,jrow)*g
geopot_3d(:,:,jrow) =geopot_3d(:,:,jrow)*g
geopoti_3d(:,nlevp1,jrow) = 0._r8
DO k = 1, nlev
   geopoti_3d(:,k,jrow) =  geopoti_3d(:,k+1,jrow)
ENDDO
```

MESSy also expects the pressure to be 0 at the upper boundary, so:

```
pressi_3d(:,1,jrow) = 0._r8
```

Dry static energy is calculated from temperature, geopotential height, and surface geopotential. Finally, the tracer variables are converted from wet to dry mixing ratio.

3.4.2 Spectral element (SE)

Analgously to the FV dynamical core, the coupling between MESSy and the SE dynamical core is performed in the module `dp_coupling`.

The SE dycore also advects wet tracer mixing ratios, so the advected tracers are converted from dry to wet. The following variables are then copied to the dynamical core:

variable	MESSy	unit
temperature tendency	`tte`	K/s
zonal wind tendency	`vom_3d/cos(lat)`	m/s2
meridional wind tendency	`vol_3d/cos(lat)`	m/s2
specific humidity	`qm1`	kg/(kg wet air)
cloud liquid water	`xlm1`	kg/(kg dry air)
cloud ice water	`xim1`	kg/(kg dry air)
mixing ratios of advected tracers	`xtm1`	mol/mol

After the dynamics substeps, the following results are copied back to the physics variables (`p_d_coupling`):

variable	MESSy	unit
surface pressure	`aps`	Pa
surface geopotential	`geosp`	m2 s-2
zonal wind	um1	m/s
meridional wind	vm1	m/s
vertical pressure velocity (ω)	`vervel_3d`	Pa/s
temperature	tm1	K
relative vorticity	vom1	1/s
specific humidity	qm1	kg/kg
cloud liquid water	xlm1	kg/kg
cloud ice	xim1	kg/kg
trace gas mixing ratios	xtm1(m)	mol/mol

Subsequently, the pressure at midlevels and interfaces is derived. In addition, the inverse exner function (`exner_3d`), geopotential height, and dry static energy are calculated. Finally, the advected tracers are converted back from wet to dry mixing ratio.

3.5 I/O filename structure

For consistency with the MESSy namelist and output filename structure, CESM1 namelists and restart files have been renamed in all component models, using preprocessor directives. The `rpointer` file usage was deactivated. When writing restart files, MESSy uses the filename structure `restart_<restart-counter>_<submodel-name>.nc`. The CESM1 models have been modified to use the fortmat `restart_<restart-counter>_cesm_<component-model-name>.nc`. When the model writes the restart files and stops, the runscript moves the files to the `save` subdirectory and links the last set of restart files to the rundirectory, omitting the restart-counter number in the filename (`restart_<submodel-name>.nc`). To be consistent with this scheme, CESM1 models have been modified to read restart files with the fortmat `restart_cesm_<component-model-name>.nc`.

4 Changes to MESSy

Additional to the integration of the CESM1 code as a BML, the MCT and PIO are added as libraries. As with the other MESSy basemodels, CESM1 specific changes are implemented in the BMIL and the SMIL layer as described below. No changes were made to the SMCL.

4.1 BMIL

The MESSy infrastructure submodel CHANNEL provides data structures for geophysical data types including meta data. For a documentation and terminology see the CHANNEL supplement provided by Jöckel et al. (2010). All CESM1 specific requirements are implemented in `messy_main_channel_bi` analagous to

ECHAM5, using the preprocessor directive. For simulations with the FV dynamical core, the regular dimensions (`DIMID_LAT` etc.) are used as with ECHAM5. `DIMID_LAT_SE`, `DIMID_LON_SE` are dimensions only used for simulations with the SE dynamical core. Since for SE the grid is unstructured, they both have the size of the total number of columns `ncol` (i.e. the number of gridpoints in the horizontal). The regular dimension `DIMID_LON` then gets the name "column" and also has length `ncol`. `DIMID_LAT` becomes a singleton dimension of length 1. The regular representations then use `DIMID_LON` and `DIMID_LAT`, so that the global fields are stored as a single-dimension array, but locally are stored as two-dimensional matrices with rows and columns. The CHANNEL submodel writes the global fields in the single-dimension form into the output files.

The CESM1/MESSy representations as well as the infrastructure submodel CHANNEL and its channel objects are defined in the file `bmil/messy_main_channel_c1.inc`, which is included in `messy_main_channel_bi` for CESM1/MESSy configurations.

The MPI infrastructure module (`messy_main_mpi_bi`) provides MPI datatypes, broadcast, gather, and scatter subroutines for the employed decompositions. It uses the CESM1(CAM) datatypes as well as the `gather_chunk_to_field`, and `scatter_field_to_chunk` routines from the `spmd_utils` module, which itself interfaces to the linked MPI library.

The DATA infrastructure submodel (`messy_main_data_bi`) has been extended with a code block for CESM1 containing:

variable declarations covering all additional variables.

`main_data_initialize` initializes basic variables such as the MESSy definitions of the hybrid vertical coordinate system.

`main_data_init_memory` allocates memory to variables that are not variables of the basemodel and therefore not defined in CHANNEL, and also initializes some variables that cannot be initialized earlier.

`main_data_init_coupling` As the land model CLM currently does not provide the grid-box fractions for forest, lake, and plant cover, as well as surface roughness length, soil wetness and field capacity, these are imported from an input file and coupled to the respective MESSy variables.

`main_data_global_start` : Several basic variables are calculated here, including grid box volume (`grvol`), dry (interface) pressure (`press(i)dry_3d`), relative humidty (`rhum_3d`), density (`rho_air_dry_3d`), potential temperature (`tpot_3d`), surface virtual temperature (`tvir`), and the soil moisture stress function (`fws`). Also, the 2 m specific humidity, calculated in the land model, is converted to relative humidity as required by MESSy. For details on the respective equations see the ECHAM5 documentation and Jacobson (2005).

`main_data_local_start` : Within the local loop, it sets 2D pointers to 3D variables. It calculates the current timestep virtual temperature (`tvm1`), and estimates of the water covered (also called wet skin) fraction (`cvw`), snow covered fraction (`cvs`), snow covered canopy (`cvsc`), leaf stomatal resistance (`rco_leaf`), and the field capacity of soil (`wsmx`) analagously to ECHAM5.

The GRID, IMPORT, and TRACER submodels have been extended to handle also the special SE variables. Other changes are analagous to ECHAM5, as the same gridpoint decomposition is used. For TRACER, only three time levels are used.

4.2 SMIL

The SMIL files shared between all basemodels (subdir `messy/smil`) have only been modified where a basemodel-specific preprocessor directive was required. Most importantly, this includes the different treatment of the row length, which is always a function of the row number:

```
#ifndef CESM1
IF ( zjrow    == ngpblks ) THEN
   zkproma = npromz
ELSE
   zkproma = nproma
ENDIF
#else
   zkproma = npromz(zjrow)
#endif
```

Further, similar to the MESSy implementation into the COSMO model, submodels treating surface emissions of trace gases have to exclude the EMAC specific emission method as a surface flux lower boundary condition, as the vertical diffusion submodel does not currently include this possibility.

Several submodels have a CESM1 specific SMIL. Currently, this includes AEROPT, CLOUD, CLOUDOPT, CONVECT, NCREGRID, RAD, and VERTDIFF. Most of these submodels are not applicable for a regional model, therefore no COSMO SMIL files exist. However, the CESM1 specific SMIL files are mostly identical to the ECHAM5 SMIL, thus requiring no further description here. Note that the convection parametrisation uses a tuning of the evaporation flux for the Tiedtke schemes, which is different to the ECHAM5 tuning.

The NCREGRID SMIL files are analagous to the respective ECHAM5 SMIL files for the finite volume core. However, for configurations with the spectral element core, currently NCREGRID is used only for importing data that has already been regridded onto the unstructured grid, i.e. it cannot be used for regridding. It expects the variable `i_col` in the namelist, referring to the column variable in the file, rather than `i_lat/lon` for latitude and longitude. For further details on the CHANNEL representation used for spectral element configurations see Sect. 4.1.

5 Running CESM1/MESSy

Before a simulation can be started, the following steps need to be taken.

5.1 Makefile generation with configure

MESSy uses the `configure` and `make` tools to build the executable. The the horizontal resolution and the vertical resolution can be specified as options to the call of `configure`:

`configure --enable-CESM1 CESM1HRES=1.9x2.5 CESM1VRES=26`

For the horizontal resolution, currently supported are 1.9x2.5 and 4x5 for FV, ne16 and ne30 for SE. Note that the specification of the resolution also selects the type of dynamical core. In the vertical, 26 levels for the lower atmosphere version are supported, and 51 for the middle atmosphere (both FV and SE). However, for choosing component models other than CLM4.0 (land component model), DOCN (data ocean component), ROF (river-runoff model), CICE (sea-ice component), and SGLC (land-ice model), the paths to these need to be edited in `Makefile.in` before the call of `configure`.

5.2 Adjusting the namelists

All other settings can be controlled via the namelists. MESSy2.50 provides several tested namelist setups for basic simulations without atmospheric chemistry and prescribed climatologies for the radiatively active trace gases (denoted `01`), as well as setups for simulations with interactive chemistry (denoted `02`). The following list describes the variables for the infrastructure submodels, as well as the additional namelists for CESM1/MESSy. Only settings which are not set through the runscript are described here. A full description of all CESM1 namelist variables is available on the CESM website[3]. For the regular MESSy submodel namelists, please refer to the respective submodel documentation.

CHANNEL The namelist `channel.nml` controls the model output during the simulation. Here you can modify or design new channels, control the output type statistics with respect to time (instantaneous, averaged, etc.) and output output frequency of channels and individual channel elements. For more details on the CHANNEL submodel refer to its manual available at:
`http://www.geosci-model-dev.net/3/717/2010/gmd-3-717-2010-supplement.zip`

TIMER The namelist `timer.nml` controls the time-stepping, start/stop, and restart functionality. The variable `IO_RERUN_EV` controls the restart interval, `delta_time` sets the model time step length. For more details on the TIMER submodel refer to its manual available at:
`http://www.geosci-model-dev.net/3/717/2010/gmd-3-717-2010-supplement.zip`

cesm_drv.nml : The namelists contains groups that control the CESM driver settings, including information on the horizontal grids, timer settings, and the MPI task layout for the parallelisation.

[3]http://www.cesm.ucar.edu/models/cesm1.2/cesm/doc/modelnl/modelnl.html

cesm_atm.nml : The namelist for the atmosphere component contains variables that specify the input files and settings for the dynamical core.

cesm_docn.nml : The namelist contains settings for the ocean data model DOCN.

cesm_docn_ocn.nml : The namelist contains further settings for DOCN including the filename for the XML stream file.

cesm_ice.nml : The sea-ice component model ICE requires several namelist groups that are specified here.

cesm_lnd.nml : The land component model settings including specific settings for CLM are contained in this namelist.

cesm_rof.nml : The namelist contains settings for the river outflow model ROF, including specific settings for the RTM model.

5.3 Adjusting the runscript

The runscript `xmessy_mmd` is a multi-model runscript and requires some specific settings before each simulation. The most important variables are listed below:

`EXP_NAME` name of the experiment

`WORKDIR` working directory, where all data relevant for the particular experiment will be stored (namelists, binary, runscript, output)

`START_YEAR`, `START_MONTH`, `START_DAY`, `START_HOUR` start date and time of the experiment

`STOP_YEAR`, `STOP_MONTH`, `STOP_DAY`, `STOP_HOUR` stop date and time of the experiment

`RESTART_INTERVAL` = `<integer>`, e.g. 1

`RESTART_UNIT` = `<string>`: days, months, years

`NML_SETUP` namelist setup (equivalent to subdirectoryname in subdirectory `nml`) for the desired experiment

`INSTANCE[1]` : choose `cesm1` for CESM1/MESSy.

`NPX,NPY` Decomposition information for FV dynamical core. Note that `NPX*NPY` will be the number of MPI tasks required. The above namelist setups will use the total number of MPI tasks for every domain model, controlled via the CESM1 driver, but this can be changed in the driver namelist as discussed above.

`CESM1_ATM_NTRAC` Number of advected tracers. CESM1/MESSy checks this during the initialisation phase, and will tell the user if the setting doesn't agree with the actual number of advected tracers set through MECCA and other submodels. However, for memory allocation purposes in the dynamical cores this has to be set as a namelist variable in addition. Note that this is an improvement compared to CESM1, which required to recompile the code for any changes in the number of advected tracers.

`INPUTDIR_CESM` input data directory

5.4 Regridding the SE output data

For simulations with the SE dynamical core, the data is currently saved on the simulation's unstructured grid. For displaying global mean vertical profiles, this can be used directly. However, currently available software cannot display the horizontal information without prior regridding. Therefore, a script is provided for regridding to a Gaussian grid. The script `se2fv_regrid.csh` uses the NCL (NCAR Command Language: NCL, 2014) ESMF regridding tools for conversion to a specified grid. The input and output grid can be set in the script, and the channel list for regridding, to be called from a working directory, has to be given as command line argument.

References

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