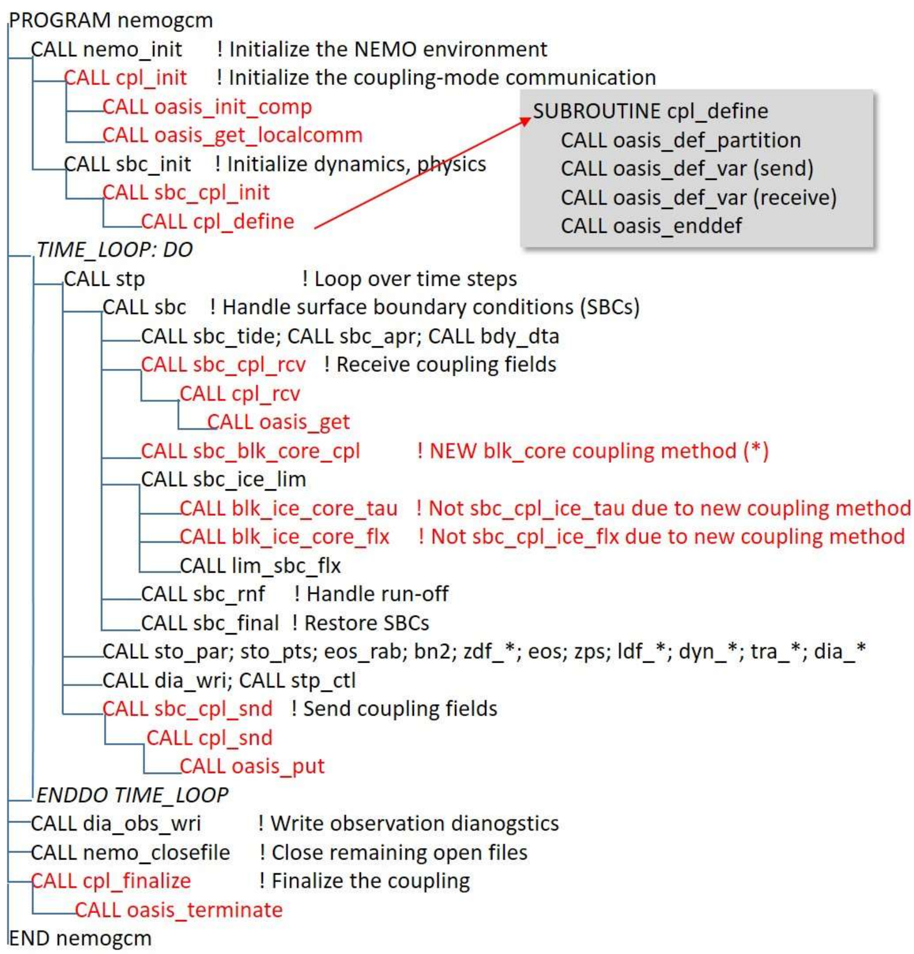
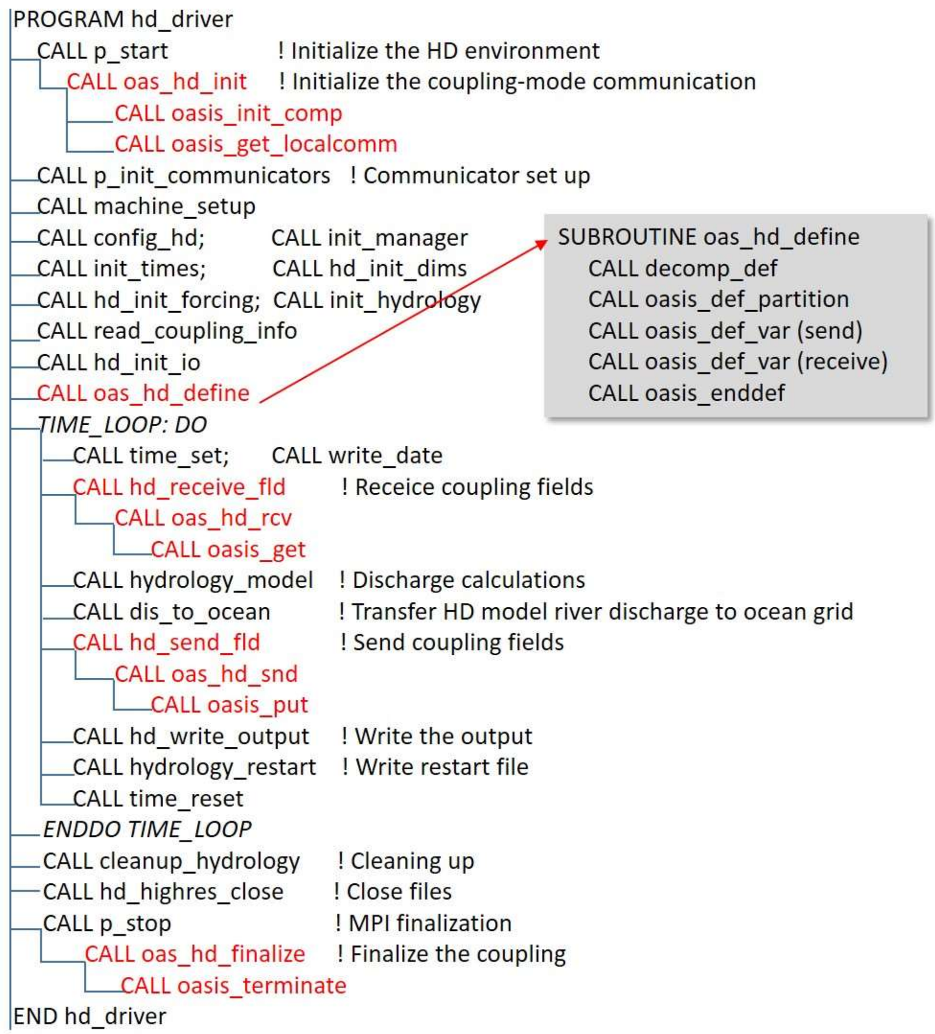
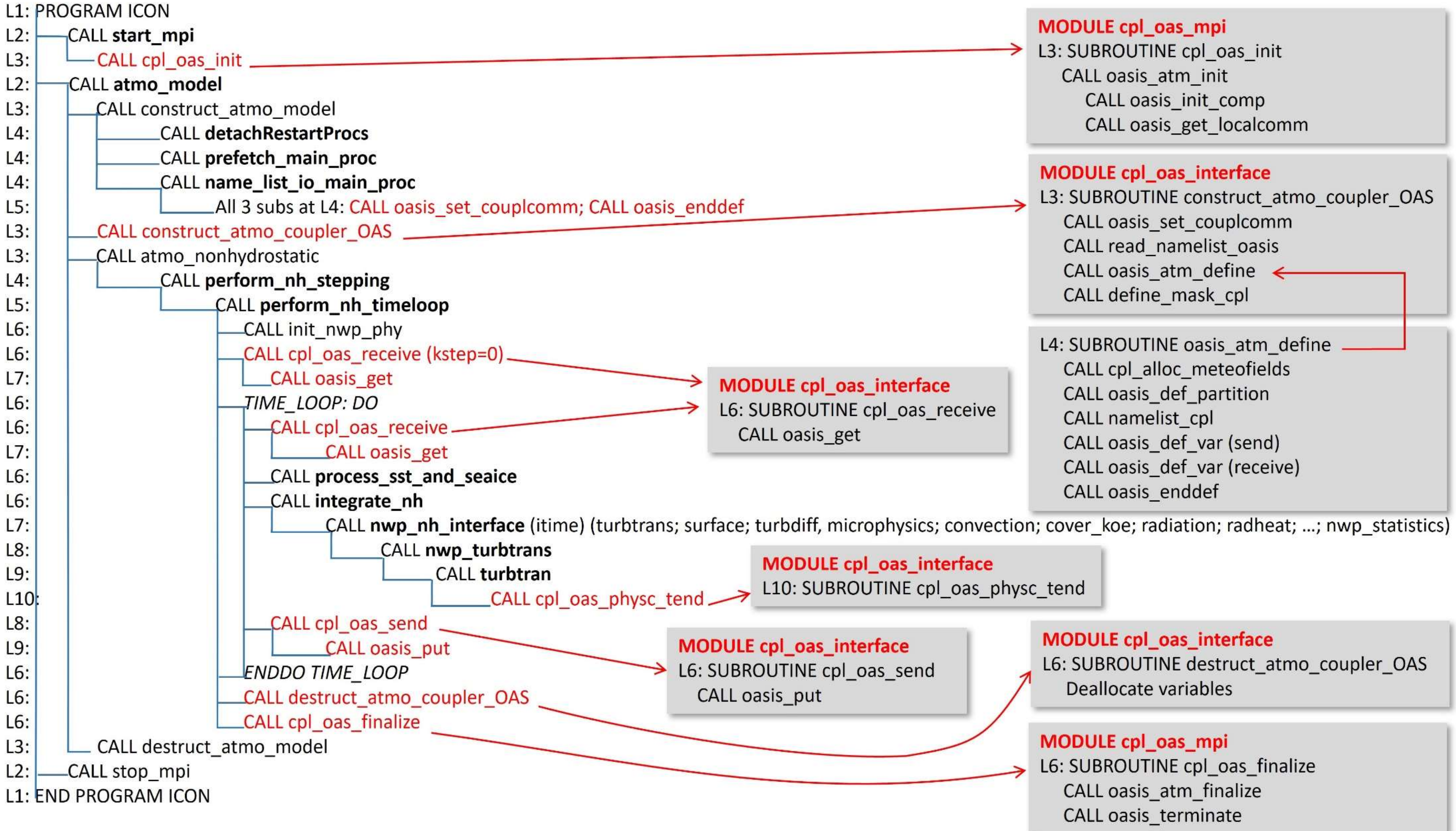


S1: Flowchart of NEMO v3.6 with the OASIS3-MCT coupling interface (red text). In the default OASIS interface of NEMO v3.6, sensible and latent heat fluxes are passed from the atmospheric model. With the new coupling method (*), NEMO receives state variables (i.e. air temperature, humidity, etc.) to calculate the fluxes using the bulk formula (blk_core) which is available in NEMO v3.6 for the stand-alone mode.



S2: Flowchart of HD v5.1 with the OASIS3-MCT coupling interface (red text).



3

S3: Flowchart of ICON-NWP/ICON-CLM with the OASIS3-MCT coupling interface. Red text shows the OASIS interface. Bold text displays the modified subroutines of ICON due to the coupling. "L1" indicates Level 1 – the main ICON program, etc.

Table S1: New OASIS coupling files added to ICON-NWP/ICON-CLM.

File	Directory	Fortran File	Modules/Subroutines (Sub.)	Description
1	src/atm_phy_nwp/	cpl_oas_vardef.f90	Module cpl_oas_vardef	Coupling variables definition
2		cpl_oas_mpi.f90	Module cpl_oas_mpi	Initialization/ Finalization for OASIS
			Sub. cpl_oas_init	OASIS initialize
			Sub. cpl_oas_finalize	OASIS finalize and terminate
3		cpl_oas_interface.f90	Module cpl_oas_interface	Main subroutines of OMCI
			Sub. construct_atmo_coupler_OAS	Definition: OASIS decomposition, reading coupling namelist, definite coupling mask
			Sub. interface_nwp_ocean	Data exchange: Receive and send fields to OASIS
			Sub. cpl_oas_physc_tend	Update momentum, latent and sensible heat fluxes
			Sub. cpl_oas_physc_rad_oce_modis	Update albedo over water and sea ice
			Sub. destruct_atmo_coupler_OAS	Deallocate coupling variables

4 *Table S2: Modified ICON's files due to the OASIS3-MCT coupling interface.*

File	Directory	Fortran File	Modules/Subroutines (Sub.)	Description
1	src/parallel_infrastructure/	mo_mpi.f90	Module mo_mpi Sub. start_mpi	Initialization of ICON
2	src/drivers/	mo_atmo_model.f90	Module mo_atmo_model Sub. atmo_model	Atmospheric model ICON
3	src/io/restart/	mo_restart.f90	Module mo_restart Sub. detachRestartProcs	Detach the restart processes
4	src/io/atmo/	mo_async_latbc.f90	Module mo_async_latbc Sub. prefetch_main_proc	Initialize the prefetch processor
5	src/io/shared/	mo_name_list_output.f90	Module mo_name_list_output Sub. name_list_io_main_proc	Initialize name list output
6	src/lnd_phy_nwp/	mo_nwp_sfc_utils.f90 mo_nwp_lnd_state.f90 mo_nwp_lnd_types.f90		Declare new variable sea ice albedo "alb_si_ext" to send to NEMO
7	src/atm_dyn_iconam/	mo_nh_stepping.f90	Module mo_nh_stepping	Initializes and controls the time stepping in the nonhydrostatic model
			Sub. init_nwp_phy	Initial call of physical schemes
			Sub. perform_nh_stepping	Organizes nonhydrostatic time stepping
			Sub. perform_nh_timeloop	Time looping of the nonhydrostatic model
8	src/atm_phy_nwp/	mo_nwp_turbtrans_ interface.f90	Module mo_nwp_turbtrans_interface Sub. nwp_turbtrans	Interface between nwp_nh_interface to the turbulence parameterisations
9	src/atm_phy_schemes/	turb_transfer.f90	Module turb_transfer Sub. turbtran	Computing the coefficients for turbulent transfer

S4: Compile ICON with OMCI on Levante.

a. <u>Environment settings:</u>

```
NETCDFF_DIR=/sw/spack-levante/netcdf-fortran-4.5.3-k6xq5g
NETCDFC_DIR=/sw/spack-levante/netcdf-c-4.8.1-2k3cmu
ECCODES_ROOT=/sw/spack-levante/eccodes-2.21.0-3ehkbb
HDF5_DIR=/sw/spack-levante/hdf5-1.12.1-tvymb5
SZIP_ROOT=/sw/spack-levante/libaec-1.0.5-gij7yv
MKL_ROOT=/sw/spack-levante/intel-oneapi-mkl-2022.0.1-ttdktf/mkl/2022.0.1
MPIINC=/sw/spack-levante/openmpi-4.1.2-yfwe6t/include
MPILIB=/sw/spack-levante/openmpi-4.1.2-yfwe6t/lib
MODULES="'intel-oneapi-compilers/2022.0.1-gcc-11.2.0 openmpi/4.1.2-intel-2021.5.0'"
GCCLIB="/sw/spack-levante/gcc-11.2.0-7jcqrc/lib64"
PYTHON='/sw/spack-levante/mambaforge-4.11.0-0-Linux-x86_64-sobz6z/bin/python3'
```

b. <u>Compiling:</u>

The environment must be the same for the coupler OASIS3-MCT v4.0 as well as for the three model components ICON, NEMO and HD. OASIS3-MCT v4.0 is compiled first and will be used as the library to be linked to the three models. To compile ICON with OMCI, one must adapt the configure file and icon/config/dkrz/levante.intel-2021.5.0_OASIS (see https://doi.org/10.5281/zenodo.10877618).
The command to compile ICON with OMCI using the setup levante.intel-2021.5.0_OASIS is:

```
icon/config/dkrz/levante.intel-2021.5.0_OASIS --disable-coupling --disable-ocean --disable-jsbach --enable-coupling_OAS --disable-art --enable-ecrad
```

Note that “--disable-coupling --disable-ocean --disable-jsbach” is not to couple with YAC, ICON-O and JSBACH, respectively. Meanwhile “--enable-coupling_OAS --enable-ecrad” is to switch on OMCI and to run ICON with the radiation scheme ecRad. Consequently, a binary file icon is located under the directory icon/bin, like in the case without OASIS. ICON with OMCI has also successfully been compiled on other machines of the same architecture as Levante and on NEC-Aurora at DWD.

S5: Prepare OASIS input files.

a. Grid and mask files

Using CDO and NCO libraries is a convenient manner to produce information about grids and masks used by OASIS (i.e. grids.nc and masks.nc), as well as the remapping files requested by OASIS before running the coupled system. The file grids.nc should contain longitude (Lon) and latitude (Lat) of the ICON, NEMO and HD grids. Although three models are considered, there are five grids which are named icon, nemo, nico, nmhd, and hdmd. Lon and Lat of icon and nico have the same dimension of (1, 231660). Lon and Lat of nemo and nmhd have the same dimension of (902, 777). Lon and Lat of hdmd have the dimension of (960, 540). The reason to create five grids is that the masks of them are different. OASIS will do the interpolation/exchange on points which have the mask value of zero and ignore the points with mask of one. File masks.nc contains five masks i.e. icon.msk, nemo.msk, nico.msk, nmhd.msk and hdmd.msk as following:

- The masks icon.msk and hdmd.msk are both zero. They are used for the source grids (see namcouple in S6 below); therefore, OASIS should send results from all points to other grids.
- The nemo.msk has values of zero on the ocean grid points and values of one on the land points. nemo is also a source grid, but results are only available on ocean points.
- The nico.msk has zero values only in the area overlapped between the NEMO domain and the ICON domain, i.e. the dark blue area in Figure 3. The other grid points have a value of one, thus, sea surface temperature or sea ice fraction from NEMO/LIM3 is updated in ICON only over grid points inside of the dark blue area, also known as the coupling domain.
- The nmhd.msk has values of one everywhere, only on river mouth points the values are zero.

b. Remapping files

Remapping files are netcdf files containing interpolation matrix, based on that OASIS can exchange data between different model grids. The remapping files can be either generated by OASIS or prepared manually. Applying the first method, OASIS does the interpolation using the *SCRIPR* function as described in the *namcouple* file, GROUP 2 (see S6). Options for the *SCRIPR* function can be DISTWGT, GAUSWGT, BILINEAR or CONSERV. With this method, the grids.nc and masks.nc files will be taken into account, and a remapping file (e.g. **rmp_icon_to_hdmd_DISTWGT.nc**) will be generated. One can conduct one month simulation with the coupled model and wait until the remapping file is generated, which would take about 10-20 minutes. Then one can stop the simulation and rerun the coupled model using the saved remapping file and the *MAPPING* function, as shown in GROUP 1 or GROUP 3 of S6.

Method 2 is to prepare the remapping files using CDO functions outside and before running the coupled model. First, we extracted Lon and Lat information of grids nemo, nico and hdmd from the above-mentioned grids.nc file to obtain the nemogrid.nc, nicogrid.nc, hdmhgrid.nc, respectively. Specifically, for the icogrid.nc, the Lon and Lat of grid icon in grids.nc must be converted to a 1-dimension field of length “ncells” (similar to clon (231660) and clat (231660)), adding vertices information from the ICON grid. We use these netcdf files in the script *remap_ICON_NEMO_HD.sh* to generate several remapping files (rmp_*CONSERV.nc and rmp_*DISTWGT.nc). This script uses “gencon” and “gendis” functions of CDO to produce the remapping files. Note that the HD grid has no corner lon-lat information, therefore only the “cdo gendis” can be used for remapping the ICON to HD grid, while “cdo gencon” is applied for the other two cases. The remapping files are used in the file namcouple as shown in GROUP 1 and 3 of S6 below.

script remap_ICON_NEMO_HD.sh:

```
rm -f rmp_icon_to_nemo_*.nc
rm -f rmp_nemo_to_nico_*.nc
rm -f rmp_icon_to_hdmd_*.nc
CDO gencon,nemogrid.nc icogrid.nc rmp_icon_to_nemo_CONSERV.nc
CDO gencon,nicogrid.nc nemogrid.nc  rmp_nemo_to_nico_CONSERV.nc
CDO gendis,hdmdgrid.nc icogrid.nc rmp_icon_to_hdmd_DISTWGT.nc
```

c. File namcouple

One field of each exchange group (i.e. atmosphere → ocean; atmosphere → river run-off; ocean → atmosphere; river-runoff → ocean) in the file namcouple is given as an example in S6. In total, 19 fields are exchanged between the three models via OMCI. For all exchanges where ICON is taking part, the *Send_var* and *Receive_var* in the file namcouple must be the same to what is defined in the OMCI/oasis_atm_define as well as in the namelist *&cpl_nml* in the namelist_cpl_atm_oce file (see example in S7). Coupling time step is 3600 seconds. LAG=+0 is set in the GROUP 1 meaning NEMO receives output of ICON at every hour, without any delay. LAG=+100 in GROUP 2 means that HD receives run-off from ICON at every hour plus one running time step (i.e. 100 seconds) of ICON. For any field which is exchanged with a LAG larger than 0, a restart file (i.e. atmin.nc, sstoc.nc or rivin.nc) is needed by OASIS. However, one must prepare the file only once at the first simulation month. These restart files are generated and overwritten by OASIS at the end of each run. One should, therefore, save the restart files right after any run for each month so that they are available in case a later re-running of the simulation is desired for a specific month.

S6: Example of namcouple file.

```
###########################################################################
 $NFIELDS
        19
 $END
###########################################################################
 $STRINGS
###########################################################################
#       GROUP 1:       ATMOSPHERE  --->>>  OCEAN
# Field 8: U wind component at 10M [m/s]
# Send_var   Receive_var   Var_number   Coupling_interval(s)  Transformations   Restart_file   Field_Status
U10MtNB      O_WNDI        8            3600                  2                 atmin.nc       EXPORTED
231660    1    902    777    icon    nemo    LAG=+0
R  0  R  0
LOCTRANS     MAPPING
 INSTANT
 rmp_icon_to_nemo_CONSERV.nc src
###########################################################################
#        GROUP 2:     ATMOSPHERE  --->>>  RIVER RUN-OFF
# Field 22:  Surface run-off [kg/m2], sum over forecast of 1hr, converted to m/s
# Send_var   Receive_var   Var_number   Coupling_interval(s)  Transformations   Restart_file   Field_Status
RO_StNB      RUNOFF_S      22           3600                  2                 atmin.nc       EXPORTED
231660     1     960    540    icon    hdmd    LAG=+100
R  0  R  0
LOCTRANS      SCRIPR
 INSTANT
 DISTWGT    LR    SCALAR    LATLON    10    4
###########################################################################
#        GROUP 3:      OCEAN  --->>>  ATMOSPHERE
# Field 1:  Sea surface temperature [K]
# Send_var   Receive_var   Var_number   Coupling_interval(s)  Transformations   Restart_file   Field_Status
O_TepMix     SSTfNB        1            3600                  2                 sstoc.nc       EXPORTED
902    777    231660    1      nemo   nico     LAG=+90
R  0  R  0
LOCTRANS       MAPPING
 AVERAGE
 rmp_nemo_to_nico_CONSERV.nc src
###########################################################################
#       GROUP 4:     RIVER RUN-OFF  --->>>  OCEAN
# Field 19:  River discharge [m3/s]: already on NEMO's grid
# Send_var   Receive_var   Var_number   Coupling_interval(s)  Transformations   Restart_file   Field_Status
RDC2NEMO   O_Runoff        19           3600                  1                 rivin.nc       EXPORTED
nmhd    nmhd      LAG=+3600
R  0  R  0
LOCTRANS
 AVERAGE
END
```

S7: Example of namelist_cpl_atm_oce

```
&cpl_nml
!------------------------------------------------------
! ATMOSPHERE send              !   OCEAN receive
  atm_snd_u10 = 'U10MtNB'     !, 'O_WNDI'
  atm_snd_u10 = 'V10MtNB'     !, 'O_WNDJ'
  atm_snd_swd = 'SWDNtNB'     !, 'O_SWDN'
  atm_snd_lwd = 'LWDNtNB'     !, 'O_LWDN'
  ...
!------------------------------------------------------
! ATMOSPHERE send              !   RIVER receive
  atm_snd_ros = 'RO_StNB'     !, 'RUNOFF_S'
  atm_snd_rog = 'RO_GtNB'     !, 'RUNOFF_G'
!------------------------------------------------------
! ATMOSPHERE receive           !   OCEAN send
  atm_rcv_sst = 'SSTfNB'       !, 'O_TepMix'
  atm_rcv_ifr = 'FRIfNB'       !, 'OIceFrc'
  atm_rcv_ial = 'ALBIfNB'      !, 'O_AlbIce'
  ...
/
```

S8: Running GCOAST-AHOI.

The command to conduct the experiment using the job scheduling system SLURM installed on Levante is:

```
srun -l   --hint=nomultithread   --distribution=block:cyclic   --multi-prog mpmd.lst
```

in which mpmd.lst is a text file listing the number of processors given to each model component. For example, if 25 nodes are used to run the coupled model on Levante, with each node comprising 128 processors, the number of processors given to ICON, NEMO and HD can be 1599, 1600 and 1 processor, respectively. The mpmd.lst file would look like this:

```
$cat mpmd.lst
0-1598 icon
1599-3198 oceanx
3199-3199 hdmd.x
```

S9: Using LUCIA to estimate model computing performance.

To use LUCIA, first step is to compile the LUCIA source code included the OASIS3-MCT released package by

```
cd ${OASIS_DIR}/util/lucia
lucia -c
```

to obtain the executable file lucia.exe. ${OASIS_DIR} is the path referring to the OASIS3-MCT directory. Then, in the namcouple file, under the section $NLOGPRT we set:

```
$NLOGPRT
   1 -1
```

and then the coupled model for one month as normal. Consequently, in the working directory, some files with name of lucia.xx.xxxxxx will be generated. In this working directory, we have to run two commands:

```
${OASIS_DIR}/util/lucia/lucia                          # generate oasis_balance.eps
ps2pdf  oasis_balance.eps  oasis_balance.pdf          # convert to pdf file oasis_balance.pdf
```

to obtain oasis_balance.eps and then oasis_balance.pdf. File oasis_balance.pdf includes a bar-chart showing the calculation time and the coupling exchange duration including time spent to wait for the other model components.

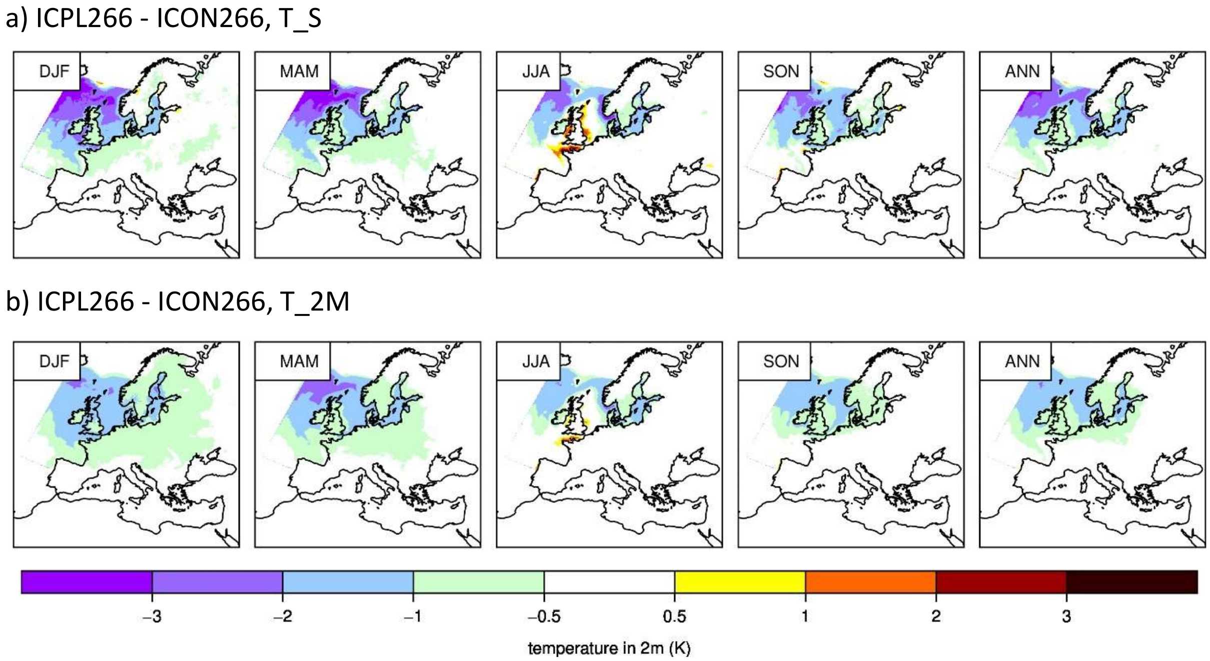


Figure S1: Seasonal (DJF, MAM, JJA, SON) and annual (ANN) T_S and T_2M (K) difference between ICPL266 compared to ICON266 for the period of 2010-2018.

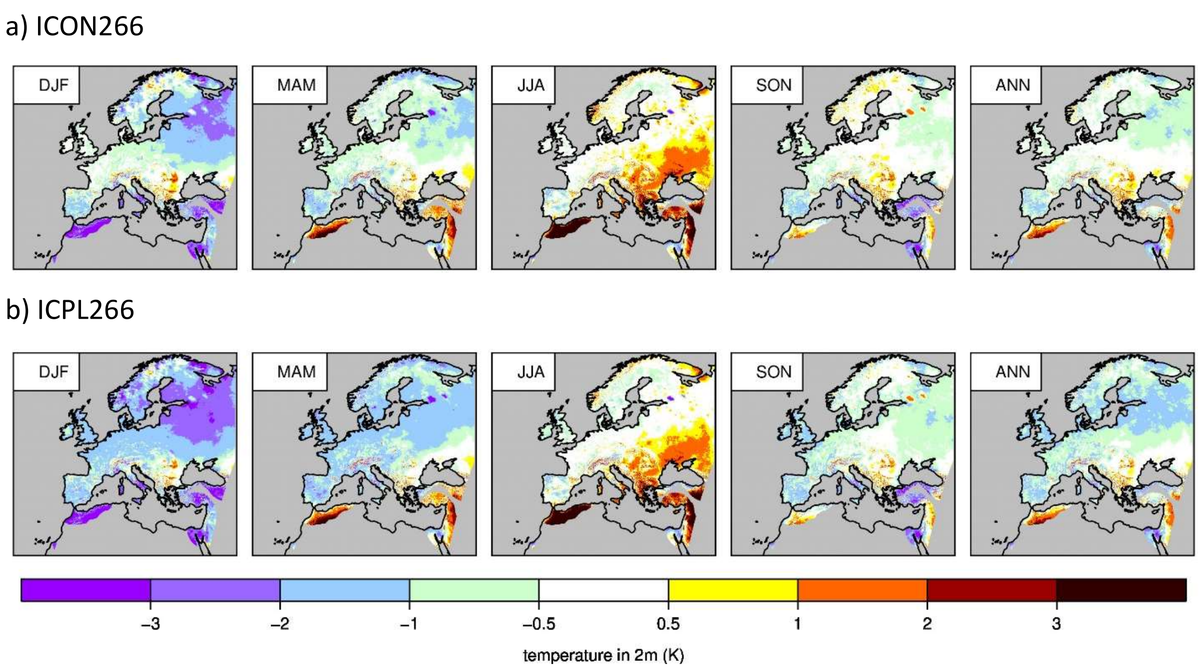


Figure S2: Seasonal (DJF, MAM, JJA, SON) and annual (ANN) mean of T_2M (K) difference between a) ICON266 and b) ICPL266 compared to the E-OBS data for the period of 2010-2018.

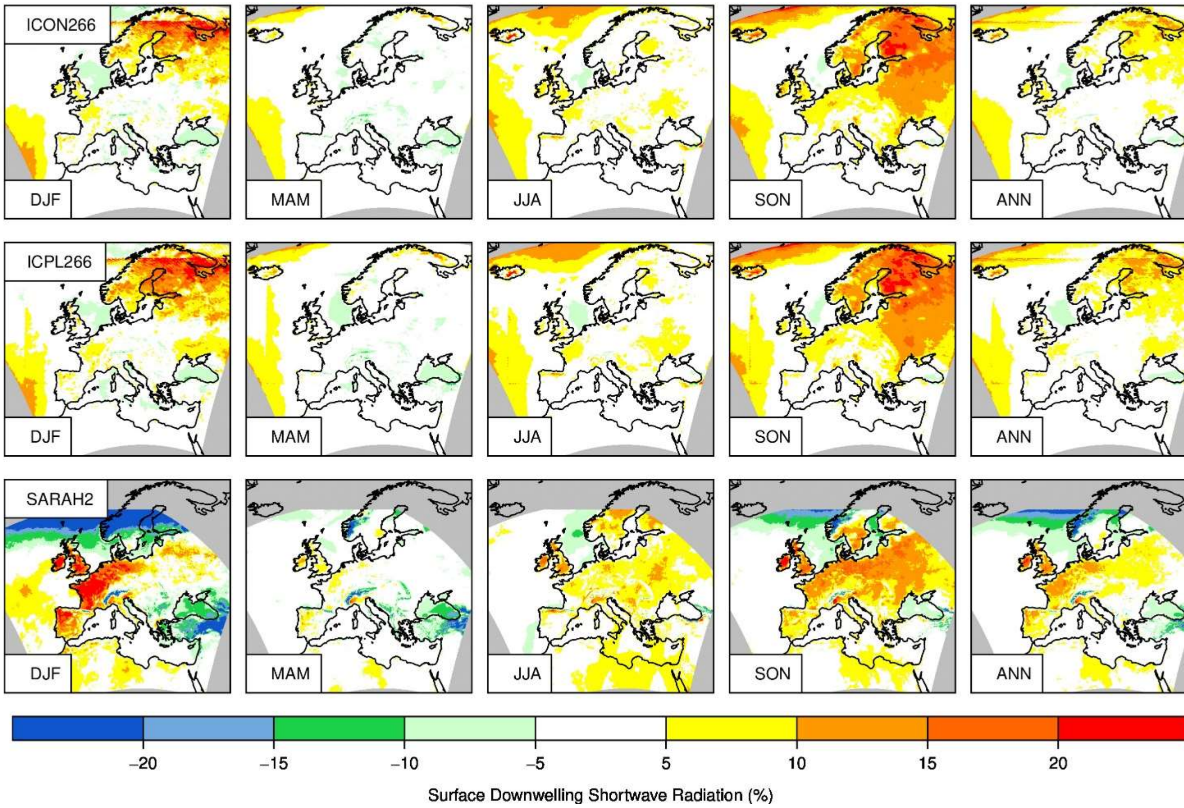


Figure S3: Seasonal (DJF, MAM, JJA, SON) and annual (ANN) of shortwave downward radiation bias (%) of ICON266 (top), and ICPL266 (middle) and the SARAH2 data (bottom) compared to the ERA5 data for the period of 2010-2018.

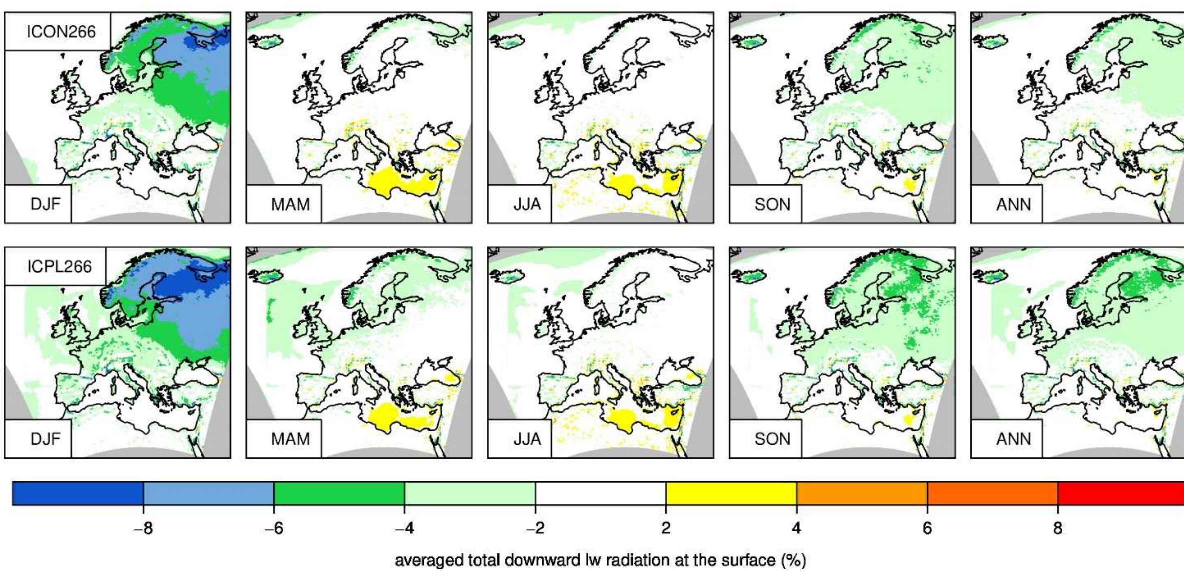


Figure S4: Seasonal (DJF, MAM, JJA, SON) and annual (ANN) of longwave downward radiation bias (%) of ICON266 (top), and ICPL266 (bottom) compared to the ERA5 data for the period of 2010-2018.

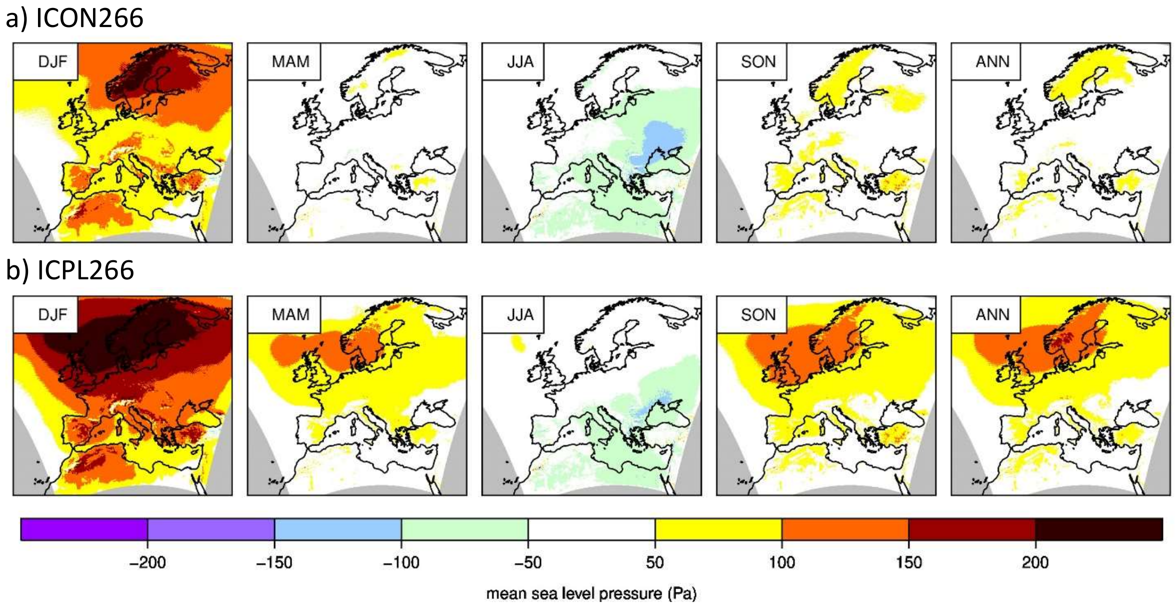


Figure S5: Seasonal (DJF, MAM, JJA, SON) and annual (ANN) mean of mean sea level pressure (Pa) difference between a) ICON266 and b) ICPL266 compared to the ERA5 reanalysis data for the period of 2010-2018.

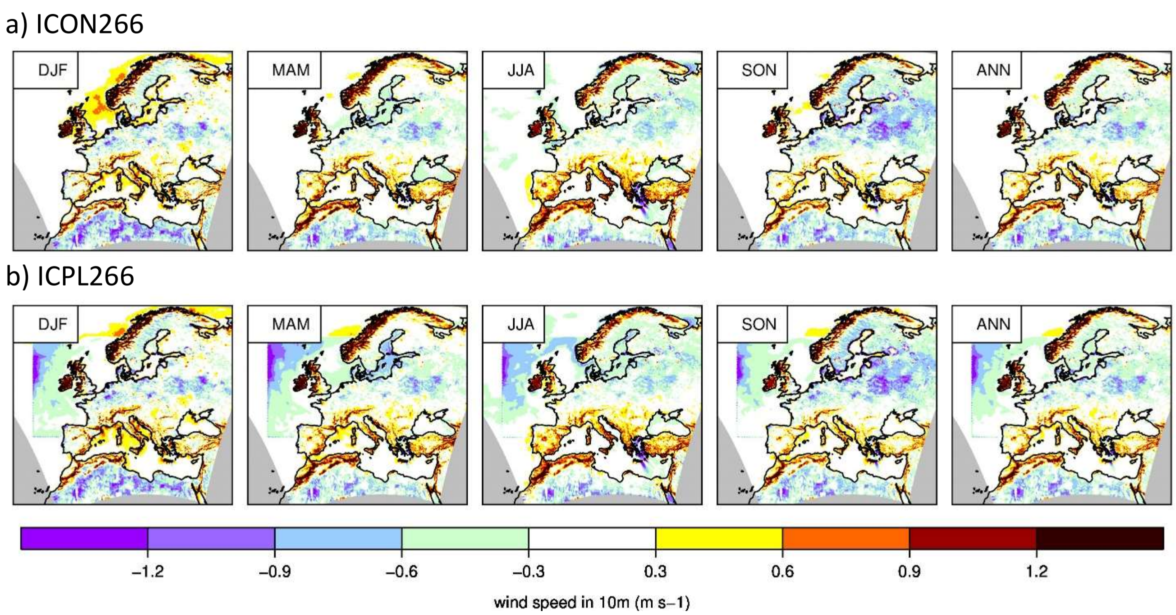


Figure S6: Seasonal (DJF, MAM, JJA, SON) and annual (ANN) mean of 10-M wind speed (m/s) difference between a) ICON266 and b) ICPL266 compared to the ERA5 data for the period of 2010-2018.