Supplement to: Extending the Modular Earth Submodel System (MESSy v2.55) model hierarchy: The ECHAM/MESSy idealized (EMIL) model set-up

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1 User Manual: Set-up of an EMIL simulation

The “EMIL” dynamical core model is implemented as a set-up of ECHAM/MESSy, i.e. it can be run by modifying the namelist files and the initial files (i.e. no recompilation is necessary), as described in the following.

1.1 Namelist set-up

- 5 The namelist set-up for an EMIL simulation is described in the following. An example set-up can also be found in the MESSy source code (under *messy/nml/EMIL*).

The following namelist files need to be modified:

- **switch.nml** In the switch namelist, the only necessary submodel to be switched on is RELAX. Diagnostic submodels and submodels that control the set-up of tracers can optionally be used as usual.
- 10 – **relax.nml** The RELAX namelist file consists of a “coupling” (CPL) namelist, in which the options for temperature relaxation, wind damping and additional diabatic heating can be chosen and the according parameters that define the variables needed (e.g. wind damping coefficients, equilibrium temperature and inverse relaxation time scale) are set (see Sec. 1.2).
- 15 – **ECHAM5.nml** The set-up for the ECHAM-internal sponge layer is controlled here (DYNCTL namelist), and as the sponge is calculated in RELAX in the EMIL set-up, the ECHAM-sponge needs to be switched off (by setting *spdrag* = 0).

Furthermore, it is advisable to change the output via *channel.nml*, as many fields in the standard ECHAM output are meaningless in the EMIL set-up (see example under *messy/nml/EMIL/channel.nml*).

Table 1. Overview of possible settings for the equilibrium temperature (namelist variable *newco_t_inp*) in the RELAX namelist (see line 110 in the example namelist in Fig. 2). The optional parameters and their default values are listed in the example namelist (Fig.1 and 2, lines 47-67).

	channel	object	description
Option 1	'#const'	'value'	set to constant 'value'
Option 2.1	'#fct'	'HS,hfac,p0,T0,T1,Ty,Tz,eps_abs'	set to 'HS' function with given parameters
Option 2.2	'#fct'	'PK,gamma,hfac,p0,T1,Ty,Tz,eps_abs,... ... l0_abs,dl,pT_SH,pT_WH'	set to 'PK' function with given parameters
Option 3	'import_grid'	'object'	set to imported field 'object' (via import.nml)

Table 2. Overview of possible settings for the inverse relaxation time (namelist variable *newco_k_inp*) in the RELAX namelist (see line 115 in the example namelist in Fig. 2). The optional parameters and their default values are listed in the example namelist (Fig. 2, lines 69-72).

	channel	object	description
Option 1	'#const'	'value'	set to constant 'value'
Option 2	'#fct'	'[HS,PK],ta,ts,sigb'	set to 'HS' or 'PK' functions with given parameters (the two functions are identical for the inverse relaxation time)
Option 3	'import_grid'	'object'	set to imported field 'object' (via import.nml)

Table 3. Overview of possible settings for the wind damping coefficient (namelist variable *rayfr_k_inp*) in the RELAX namelist (see line 104 in the example namelist in Fig. 2). The optional parameters and their default values are listed in the example namelist (Fig. 1, lines 33-45).

	channel	object	description
Option 1	'#const'	'value'	set to constant 'value'
Option 2.1	'#fct'	'HS,kmaxHS,sig0'	set to 'HS' function with given parameters
Option 2.2	'#fct'	'HS,kmaxHS,sig0,PK,kmaxPK,psp'	set to 'HS' and 'PK' functions with given parameters
Option 2.3	'#fct'	'HS,kmaxHS,sig0,EH,spdrag,enfac,nlevs'	set to 'HS' and 'PK' functions with given parameters
Option 3	'import_grid'	'object'	set to imported field 'object' (via import.nml)

Table 4. Overview of namelist settings for the diabatic heating routines. For a description of the parameters see lines 74-87 and lines 127-131 in the example namelist in Figs. 1 and 2.

routine	namelist parameter	channel	object (parameter)
<i>tteh_cc_tropics</i>	cct_h_inp	'#fct'	'q0_cct,lat0,sigma_lat,z0,sigma_z'
<i>tteh_waves</i>	waves_h_inp	'#fct'	'q0,m_WN,phi0,sigma_phi,p_bot,p_top'
<i>tteh_mons</i>	reght_h_inp	'#fct'	'pbot,ptop,lat0,latd,lon0,lond'
<i>tteh_mons</i>	tmpht_h_inp	'#fct'	'offset (K/day), amplitude (K/day), heating period (days), spin up (days)'

1.2 The RELAX namelist

As described in Sec. 2.1 of the main paper, the RELAX submodel incorporates functions for three processes: Newtonian cooling (*newco*), Rayleigh friction (*rayfric*), and currently three different diabatic heating routines (*tteh_cc_tropics*, *tteh_waves*, *tteh_mons*). Each process can be switched on/off via namelist entry (see lines 10-14 in the example namelist given in Fig. 1),

5 and for each process the variables to be used can be chosen.

For the Newtonian cooling routine, the equilibrium temperature (T_{equ}) to be relaxed to, as well as the inverse relaxation time scale (κ) have to be specified, and for Rayleigh friction the wind damping coefficient (k_{damp}) has to be specified. As described in Sec. 2.1 of the main paper, the options for these variables are either constant values, pre-implemented functions or any field defined by a given *channel* and *object* pair. The options with all parameters are summarized in Tables 1 to 3, with the meaning of the parameters explained in example namelists (Figs. 1 and 2) and in Sec. 2.1 of the main paper. For the equilibrium temperature with 'PK' set-up, there is an additional switch to "turn" the polar vortex off (*l_no_polar_vortex*, line 111-112 in Fig. 2). If this switch is set to TRUE, the equilibrium temperature of the winter polar region is set to the standard US Atmosphere as for all other latitudes (i.e. the weighting function given by Eq. (5) of the main paper is set to zero for all latitudes).

The parameters for the diabatic heating routines described in Sec. 2.1.3 of the main paper, are also set by namelist entry, as summarized in Table 4.

1.3 Initial files

Several modifications to the initial files are necessary for running the EMIL model set-up. For any set-up with the idealized model, the initial values for specific humidity need to be set to zero to obtain dry dynamics (in the ECHAM spectral initial file, set $Q = 0$ everywhere). Since there are no sources of water vapour, the humidity will remain zero throughout the simulation. To run the model with flat or idealized topography, both the surface geopotential in the *surf* input file, as well as the initial values for dynamical variables need to be modified. There are several solutions to set the dynamical variables divergence, vorticity and temperature to appropriate values, with one of them listed below.

Surface initial file: The topography is controlled by the variable surface geopotential (*GEOSP*) within the "surface" initial file. For flat topography, set $GEOSP = 0$ everywhere. For idealized topography, the surface geopotential is set to the height of the chosen topography (e.g. wavenumber-2 mountain). All other variables in this file are not used by the idealized model.

Spectral initial file: The initial values for vorticity, divergence and temperature in spectral coordinates and humidity in latitude-longitude coordinates are given in the spectral initial file. In all cases, the specific humidity has to be set to zero ($Q = 0$) everywhere (to obtain dry dynamics). For running flat topography, the following initial conditions can be used: temperature $STP = 0$ for all wavenumbers > 0 , and for wavenumber zero, STP is set to a global mean mean temperature profile with height (e.g. taken from the initial file from a full ECHAM simulation), divergence $SD = 0$ and vorticity $SVO = 1 \times 10^{-8} s^{-1}$. The small value for vorticity is included to break the zonal symmetry (otherwise, the simulations will always remain in a

zonally symmetric state). For running idealized topography, the initial values need to be modified to be not too far from the atmosphere's state. One way to achieve this is to modify the topography step-wise, e.g. for introducing a wavenumber-2 mountain, the amplitude of the mountain needs to be slowly increased (e.g. by steps of 500 m every year).

2 Implementation of the RELAX submodel

- 5 The RELAX submodel is implemented as MESSy submodel, and the call tree is shown in Fig. 3. During the initialization phase, the namelist is read and depending on the settings, new channel objects for the necessary fields are created or the variables are set to the given channel objects (all in the submodel interface layer, SMIL). During run time, *relax_physc* is called from *messy_physc*. For Newtonian cooling and Rayleigh friction, if the option '#fct' is selected, the chosen functions for the equilibrium temperature, relaxation time and damping coefficient are evaluated at the current time step (call to implemented
- 10 functions within the submodel core layer, SMCL). Then, the temperature / wind tendencies are calculated (call to SMCL routines *relax_newco_smcl* / *relax_rayfr_smcl*) and added to the overall tendencies (in the SMIL routine).

For the diabatic heating functions, the selected routines implemented in the SMCL are called from *relax_physc* as function of selected parameters and current pressure. The routines directly return the temperature tendency to be added.

```

! *- f90 *-
&CPL
!
!-----
! switches whether to calculate rayleigh fricion (damping of horizontal winds)
5 ! newtonian cooling (relaxation of temperature)
! idealized diabatic heating for climate change-like tropical upper-tropospheric warming
! idealized diabatic heating for planetary-wave generation (substitute for topography)
! idealized diabatic heating for monsoon
!
10 ! rayfr      = T      ! (T)rue / (F)alse
! newco      = T      ! (T)rue / (F)alse
! liheat_cc_tropics = F      ! (T)rue / (F)alse
! liheat_waves  = F      ! (T)rue / (F)alse
! liheat_mons   = F      ! (T)rue / (F)alse for monsoon-like idealized heating op_mn_20180620
15 !
!-----
! set horizontal wind damping coefficient kdamp (rayfr_k_inp),
! equilibrium temperature      tequ (newco_t_inp),
! inverse relaxation time scale kappa (newco_k_inp)
20 ! as 'channel','object'
!
! options:
! 1. channel = '#const', object = 'value' : set to constant value given by 'value'
! 2. channel = '#fct', object = ', , , ' : set to functions explained below
25 ! 3. channel = 'import_rgt', object = 'var name' : set to imported field from file (via import nml)
!
!-----
! Explanation of parameters with default values in brackets:
! HS Held-Suarez set-up
30 ! PK Polvani-Kushner set-up
! EH ECHAM-like wind damping in sponge layer
!
! ---Rayleigh friction-----
! wind damping close to surface: [HS]
35 ! [HS] kmaxHS (1.1574e-05 1/s) maximum wind damping at surface
! sig0 (0.7) sigma level at which surface wind damping stops
!
! wind damping at model top: [PK,EH]
! [PK] kmaxPK (2.3148e-05 1/s) approximate wind damping at model top
40 ! psp (50 Pa) sponge layer above which damping starts
!
! [EH] spdrag (5.0200e-07 1/s) damping prefactor
! enfac (1.5238) enhancement factor
! nlevs (10) number of levels with wind damping counted from model top
45 !
! ---Newtonian cooling-----
! Equilibrium temperature: [HS,PK]
! [HS] hfac (0) hemispheric factor, hfac>0 winter in NH (January), hfac<0 winter in SH (July)
! p0 (101325 Pa) reference pressure
50 ! T0 (200 K) minimum equilibrium temperature
! T1 (315 K) maximum equilibrium temperature in troposphere
! Ty (60 K) meridional temperature gradient in troposphere
! Tz (10 K) vertical temperature gradient in troposphere
! eps_abs (0) absolute value of asymmetry factor in troposphere
55 !
! [PK] gamma (4 K/km) polar vortex lapse rate
! hfac (1) hemispheric factor, hfac>0 winter in NH (January), hfac<0 winter in SH (July)
! p0 (101325 Pa) reference pressure
! T1 (315 K) maximum temperature in troposphere
60 ! Ty (60 K) meridional temperature gradient in troposphere
! Tz (10 K) vertical temperature gradient in troposphere
! eps_abs (10 K) absolute value of asymmetry factor in troposphere
! l0_abs (50) absolute value of transition latitude from inversion to polar vortex in stratosphere
! later in messy_relax.f90, the values for x = (eps,l0) are set to: x = sign(hfac) * x_abs
65 ! dl (10) rapidity of transition from inversion to polar vortex in stratosphere
! pT_SH (10000 Pa) transition pressure in summer hemisphere

```

Figure 1. Example of RELAX namelist file, part 1

Purpose: relaxation of variables:

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- 1) Temperature: calculates newtonian cooling as $dT/dt = -kappa * (T - T_{eq})$
- 2) horizontal winds: calculates rayleigh friction as $du/dt = -K * u$ (and the same for v)
- 3) Diabatic heating: additional fixed temperature tendencies as $dT/dt = Q$

Input: Temperature tm1, winds um1,vm1, temperature tendency tte, wind tendencies vol,vom, pressure apm1

Output: Temperature and wind tendencies

Needs: Equilibrium Temperature T_{equ} , Time scale τ , Damping coefficients K , Diabatic heating parameters

&CPL

```
newco = T/F illogical switch for newco
rayfric = T/F illogical switch for rayfric
lineat_cc_tropics = T/F illogicals for
lineat_waves      = T/F diabatic heating
lineat_mons       = T/F ! functions
```

```

isettings
newco_l_inp = 'channel','object'(TEQU)
newco_k_inp = 'channel','object'(KAPPA)
rayfr_k_inp= 'channel','object'(KDAMP)

for diabolic_heating_functions
cct h_inp=#cct,'parameter'(tth_cc,tropics)
cct h_inp=#cct,'parameter'(tth_waves)
waves_h_inp=#cct,'parameter'(tth_mons)
reght_h_inp=#cct,'parameter'(tth_mons)
tmplt_h_inp=#cct,'parameter'(tth_mons)

```

In Physc.f90:

CALL_messy_physc

In messy_main_control_e5.f90
Subroutine messy_physc

```
IF (USE_RELAX) CALL relax_physc
```

Figure 3. Call tree for RELAX submodel.