Supplement of Geosci. Model Dev., 13, 5229–5257, 2020
https://doi.org/10.5194/gmd-13-5229-2020-supplement

Geoscientific
Model Development
Open Access

Supplement of

Extending the Modular Earth Submodel System (MESSy v2.54) model hierarchy: the ECHAM/MESSy IdeaLized (EMIL) model setup

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S1 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.

S1.1 Namelist set-up

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.
- **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. S1.2).
- **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*).

S1.2 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 (*rayfr*), 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. S1), and for each process the variables to be used can be chosen.

For the Newtonian cooling routine, the equilibrium temperature (T_{eq}) to be relaxed to, as well as the inverse relaxation time scale (κ) have to 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 S1 to S2, with the meaning of the parameters explained in example namelists (Figs. S1 and S2) 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. S2). 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 S3.

S1.3 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 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).

Table S1: Overview of parameter setting for the temperature relaxation (Newtonian cooling) for equilibrium temperature (namelist variable *newco_t_inp*) and relaxation time (namelist variable *newco_k_inp*) in the RELAX namelist.

Temperature relaxation (Newtonian cooling)			
Equilibrium Temperature: namelist variable *newco_t_inp*			
newco_t_inp =	channel,	object	description
Option 1	'#const',	'value'	set to constant 'value'
Option 2	'import_grid'	'object'	set to imported field 'object' (via import.nml)
Option 3.1	'#fct',	'HS,hfac,p0,T0,T1,Ty,Tz,eps_abs'	set to 'HS' function with given parameters
Option 3.2	'#fct',	'PK,gamma,hfac,p0,T1,Ty,Tz,... ... eps_abs,l0_abs,dl,pT_SH,pT_WH'	set to 'PK' function with given parameters
Parameters for Options 3.1 and 3.2			
Parameter	Default value	Symbol in Equ.	description
hfac	(HS:0/PK:1)	h_{fac} in (A3)/(A5)	hemispheric factor: $h_{\mathrm{fac}} > / < 0$ NH / SH winter
p0	(101325 Pa)	p_0 in (A1)/(A4)	reference pressure
T0	(200 K)	T_0 in (A1)	minimum equilibrium temperature
T1	(315 K)	T_1 in (A1)/(A4)	maximum equilibrium temperature in troposphere
Ty	(60 K)	δ_y in (A1)/(A4)	meridional temperature gradient in troposphere
Tz	(10 K)	δ_z in (A1)/(A4)	vertical temperature gradient in troposphere
eps_abs	(HS:0/PK:10 K)	$\|\epsilon\|$ in (A3)	absolute value of asymmetry factor in troposphere
gamma	(4 K/km)	γ in (A4)	polar vortex lapse rate
l0_abs	(50)	ϕ_0 in (A5)	transition latitude to polar vortex in stratosphere
dl	(10)	$\delta\phi$ in (A5)	rapidity of transition to polar vortex in stratosphere
pT_SH	(10000 Pa)	p_{Ts} in (A6)	transition pressure in summer hemisphere
pT_WH	(10000 Pa)	p_{Tw} in (A6)	transition pressure in winter hemisphere
Relaxation time: namelist variable *newco_k_inp*			
newco_k_inp =	channel,	object	description
Option 1	'#const',	'value'	set to constant 'value'
Option 2	'import_grid'	'object'	set to imported field 'object' (via import.nml)
Option 3	'#fct',	'[HS,PK],ta,ts,sigb'	set to 'HS' or 'PK' functions with given parameters (the two functions are identical for the relaxation time)
Parameters for Options 3			
Parameter	Default value	Symbol in Equ.	description
ta	(40 days)	$1/\kappa_a$ in (A2)	relaxation time outside of tropical troposphere
ts	(4 days)	$1/\kappa_s$ in (A2)	relaxation time at surface of tropical troposphere
sigb	(0.7)	σ_b in (A2)	topmost sigma level with shorter relaxation time

Table S2: Overview of possible parameter settings for the wind damping coefficient (namelist variable *rayfr_k_inp*) in the RELAX namelist.

Wind damping (Rayleigh Friction)

Damping coefficient: namelist variable *rayfr_k_inp*

rayfr_k_inp =	channel,	object	description
Option 1	'#const'	'value'	set to constant 'value'
Option 2	'import_grid'	'object'	set to imported field 'object' (via import.nml)
Option 3.1	'#fct'	'HS,kmaxHS,sig0'	set to 'HS' function with given parameters
Option 3.2	'#fct'	'HS,kmaxHS,sig0,PK,kmaxPK,psp'	set to 'HS' and 'PK' functions with given parameters
Option 3.3	'#fct'	'HS,kmaxHS,sig0,EH,spdrag,enfac'	set to 'HS' and 'EH' functions with given parameters

Parameters for Options 3

Parameter	Default value	Symbol in Equ.	description
kmaxHS	(1.1574e-05 1/s)	k_{max}^{HS} in (A7)	maximum wind damping at surface
sig0	(0.7)	σ_0 in (A7)	sigma level at which surface wind damping stops
kmaxPK	(2.3148e-05 1/s)	k_{max}^{PK} in (A8)	wind damping at model top
psp	(50 Pa)	p_{sp} in (A8)	sponge layer above which damping starts
spdrag	(5.0200e-07 1/s)	k_{drag} in (A9)	damping prefactor
enfac	(1.5238)	c in (A9)	enhancement factor

Table S3: Overview of namelist settings for the diabatic heating routines *tteh_cc_tropics* and *tteh_cc_tropics*.

Diabatic heating functions

Zonal mean heating: routine *tteh_cc_tropics*

routine	namelist parameter	channel	object (parameter)
tteh_cc_tropics	*cct_h_inp=*	'#fct'	'q0_cct ,lat0 ,sigma_lat ,z0 ,sigma_z'

Parameters for tteh_cc_tropics

Parameter	Default value	Symbol in Equ.	description
q0_cct	(0.5 K/day)	q_0^{cc} in (A10)	amplitude of heating
lat0	(0 degree)	ϕ_0^{cc} in (A10)	latitudinal center of heating
sigma_lat	(0.4 rad)	$\delta_\phi^{cc} \times (\pi/180)$ in (A10)	latitudinal half width of heating
z0	(0.3)	σ_z^{cc} in (A10)	sigma level center of heating
sigma_z	(0.11)	δ_z^{cc} in (A10)	vertical half width of heating

Wave-like heating: routine *tteh_waves*

routine	namelist parameter	channel	object (parameter)
tteh_waves	*waves_h_inp=*	'#fct'	'q0, m_WN, phi0, sigma_phi, p_bot, p_top'

Parameters for tteh_waves

Parameter	Default value	Symbol in Equ.	description
q0	(6 K/day)	q_0^w in (A11)	amplitude of heating for planetary wave generation
m_WN	(2)	m in (A11)	longitudinal wave number
phi0	(45 degree)	ϕ_0^w in (A11)	latitudinal center of heating
sigma_phi	(0.175 rad)	$\delta_\phi^w \times (\pi/180)$ in (A11)	latitudinal decay rate of heating
p_bot	(80000 Pa)	p_{bot} in (A11)	bottom pressure boundary
p_top	(20000 Pa)	p_{top} in (A11)	top pressure boundary

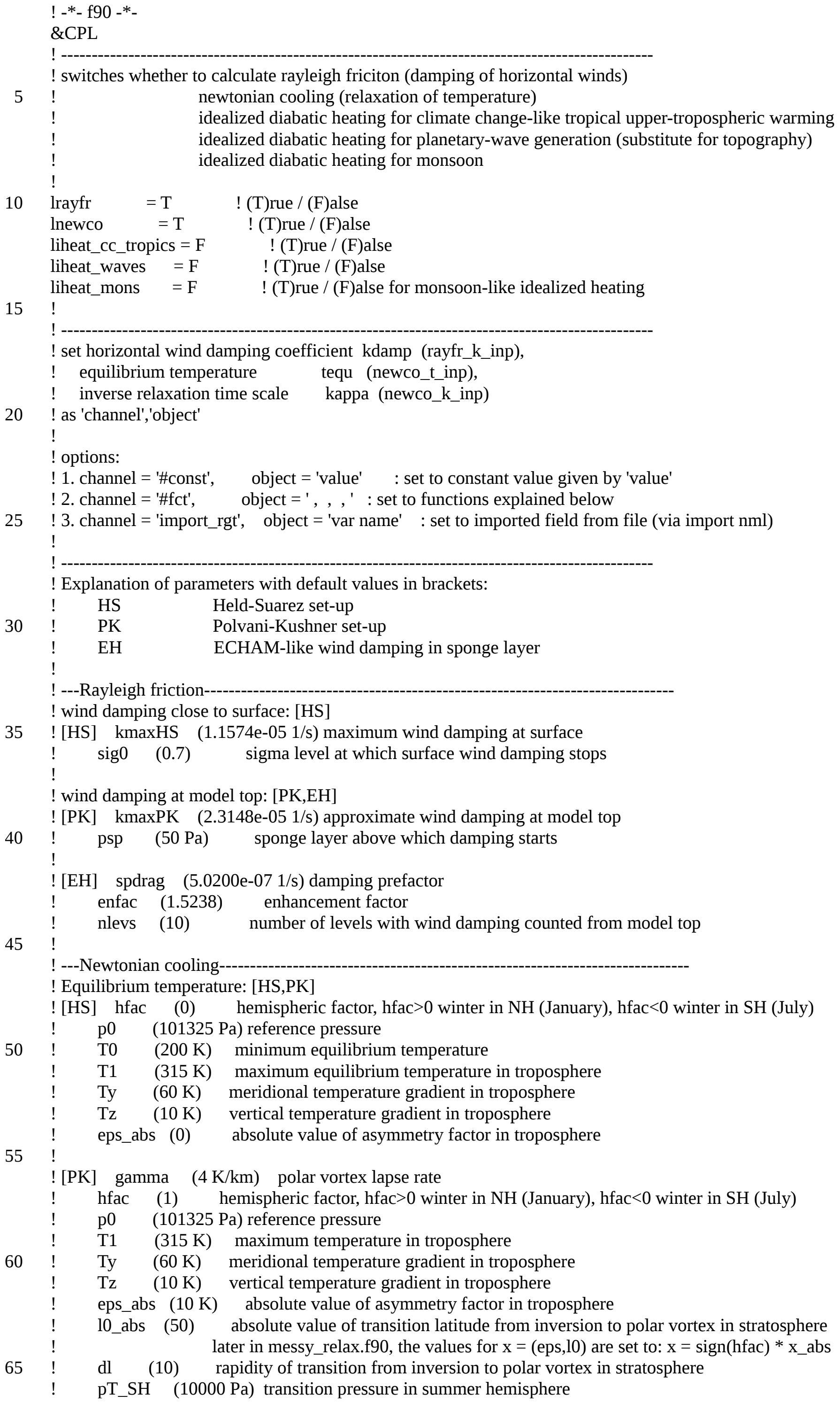
Table S4: Overview of namelist settings for the diabatic heating routine *tteh_mons*.

Diabatic heating functions			
Localized heating: routine *tteh_mons*			
routine	namelist parameter	channel	object (parameter)
tteh_mons	*tmpht_h_inp*	'#fct'	'offset, amplitude, heating period, spin up'
tteh_mons	*reght_h_inp*	'#fct'	'pbot, ptop, lat0, latd , lon0, lond'
Parameters for tteh_mons (NOTE: no default values implemented)			
Parameter	Unit	Symbol in Equ.	description
offset	(K/day)	q_0^m in (A13)	heating strength without temporal variation
amplitude	(K/day)	q_{temp}^m in (A13)	amplitude of heating with temporal variation
heating period	(days)	δt^m in (A13)	period of temporal heating variations
spin up	(days)	t_s^m in (A13)	spin up time of heating
pbot	(Pa)	p_{bot}^m in (A14)	bottom pressure boundary
ptop	(Pa)	p_{top}^m in (A14)	top pressure boundary
lat0	(deg)	ϕ_0^m in (A15)	latitudinal center of heating
latd	(deg)	$\delta\phi^m$ in (A15)	latitudinal decay rate of heating
lon0	(deg)	λ_0^m in (A16)	longitudinal center of heating
lond	(deg)	$\delta\lambda^m$ in (A16)	longitudinal decay rate of heating

S2 Implementation of the RELAX submodel

The RELAX submodel is implemented as MESSy submodel, and the call tree is shown in Fig. S3. 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 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.

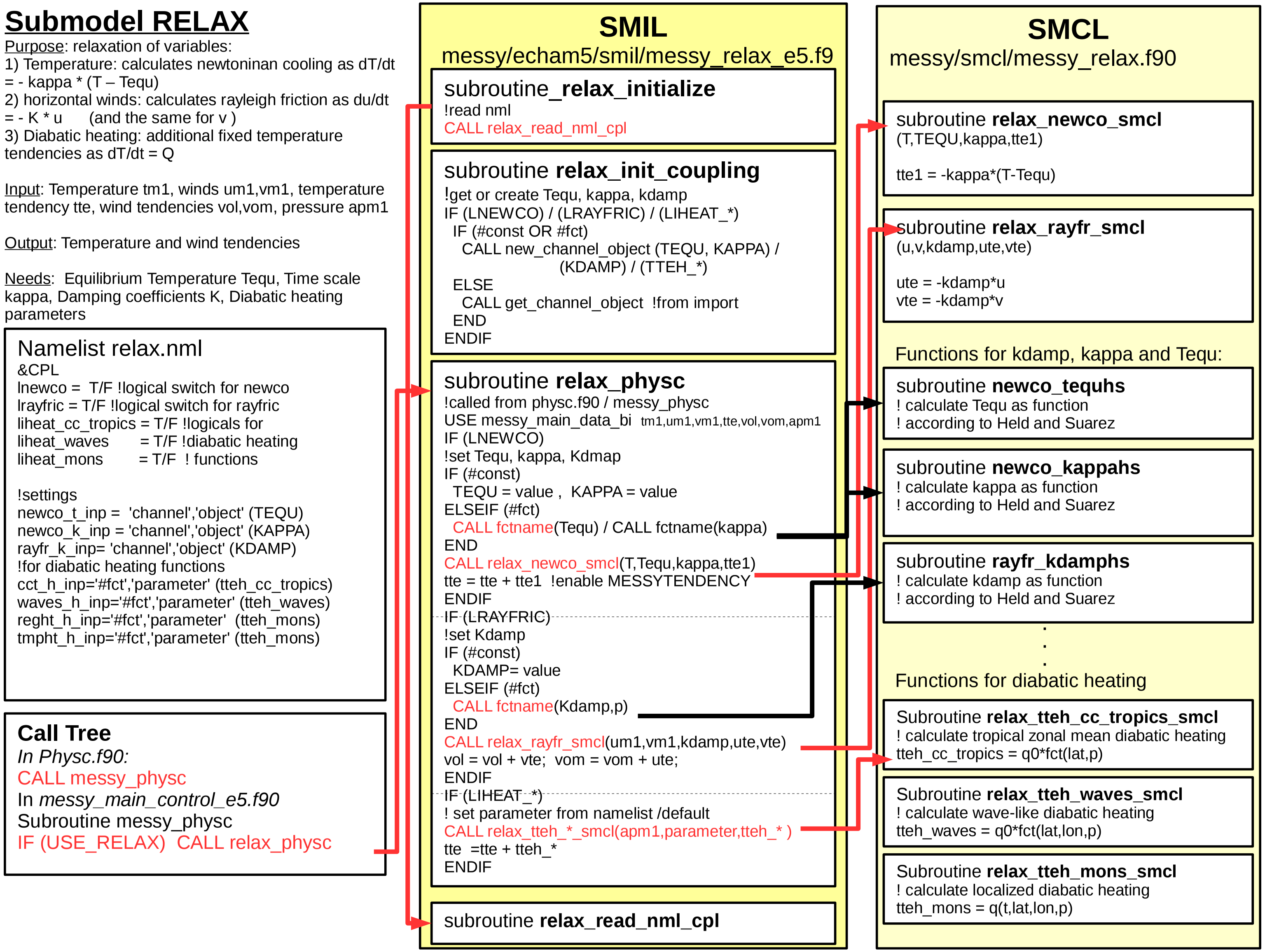


```
! -*- f90 -*-
&CPL
! -----------------------------------------------------------------------------------------------
! switches whether to calculate rayleigh friciton (damping of horizontal winds)
!                           newtonian cooling (relaxation of temperature)
!                           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
!
lrayfr           = T             ! (T)rue / (F)alse
lnewco           = 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
!
! -----------------------------------------------------------------------------------------------
! set horizontal wind damping coefficient  kdamp  (rayfr_k_inp),
!     equilibrium temperature              tequ   (newco_t_inp),
!     inverse relaxation time scale        kappa  (newco_k_inp)
! 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
! 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
!        PK                    Polvani-Kushner set-up
!        EH                    ECHAM-like wind damping in sponge layer
!
! ---Rayleigh friction---------------------------------------------------------------------------
! wind damping close to surface: [HS]
! [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
!         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
!
! ---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
!         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
!
! [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
!         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
!         dl        (10)        rapidity of transition from inversion to polar vortex in stratosphere
!         pT_SH     (10000 Pa)  transition pressure in summer hemisphere
```

Figure S1: Example of RELAX namelist file, part 1

```
!        pT_WH     (10000 Pa)  transition pressure in winter hemisphere
!
! Inverse relaxation time: [HS,PK]
! [HS,PK] ta        (40 days)   relaxation time outside of tropical troposphere
!        ts        (4 days)    relaxation time at surface of tropical troposphere
!        sigb      (0.7)       sigma level below which a short relaxation time is used in the tropics
!
! ---idealized heating for climate change-like tropical upper-tropospheric warming-----------------
!        q0_cct    (0.5 K/day) amplitude of heating                              [K/day]
!        lat0      (0)         latitudinal center of heating                     [degree]
!        sigma_lat (0.4)       latitudinal half width of heating                 [rad]
!        z0        (0.3)       sigma level center of heating                     [1]
!        sigma_z   (0.11)      vertical half width of heating                    [1]
!
! ---idealized heating for generation of planetary-wave activity-----------------------------------
!        q0        (6 K/day)   amplitude of heating for planetary wave generation [K/day]
!        m_WN      (2)         longitudinal wave number                          [1]
!        phi0      (45)        latitudinal center of heating                     [degree]
!        sigma_phi (0.175)     latitudinal decay rate of heating                 [rad]
!        p_bot     (80000 Pa)  bottom pressure boundary                          [Pa]
!        p_top     (20000 Pa)  top pressure boundary                             [Pa]
!
!
! ATTENTION: maximum number of characters stored in object file string = 133
!
! ATTENTION: You can leave parameters of rayfr_k_inp (except the first [HS] and the fourth [PK,EH])
!                                  of newco_t_inp (except the first [HS,PK])
!                                  of newco_k_inp (except the first [HS])
!                                  of cct_h_inp
!                              and of waves_h_inp
!          empty to use the default values written in brackets above.
!
! -----------------------------------------------------------------------------------------------
!Params kdamp
!with HS,PK set-up:'HS,kmaxHS,sig0,PK,kmaxPK,psp'
!rayfr_k_inp='#fct','HS,      ,    ,PK,      ,   '
!with HS,EH set-up:'HS,kmaxHS,sig0,EH,spdrag,enfac'
rayfr_k_inp='#fct','HS,      ,    ,EH,      ,    '
!
!Params tequ
!with HS set-up:   'HS,hfac,p0,T0,T1,Ty,Tz,eps_abs'
!newco_t_inp='#fct','HS,    ,  ,  ,  ,  ,  ,        '
!with PK set-up:   'PK,gamma,hfac,p0      ,T1    ,Ty  ,Tz  ,eps_abs,l0_abs,dl  ,pT_SH,pT_WH'
newco_t_inp='#fct','PK,    4,    ,        ,     ,    ,    ,        ,      ,    ,     ,10000'
! Logical parameter for turn on/off polar vortex; if True, W_function is set to zero in relax_tequpk
l_no_polar_vortex = F ! (T)rue / (F)alse
!
!Params kappa:'[HS,PK],ta,ts,sigb' (both HS and PK represent the same function for inverse relaxation time scale)
newco_k_inp='#fct','HS,  ,  ,    '
!
! -----------------------------------------------------------------------------------------------
!Params tteh_cc_tropics:'q0_cct,lat0,sigma_lat,z0,sigma_z'
cct_h_inp='#fct','  ,  ,  ,  ,  '
!
! -----------------------------------------------------------------------------------------------
!Params tteh_waves:'q0, m_WN, phi0, sigma_phi, p_bot, p_top'
waves_h_inp='#fct','  ,     ,     ,          ,      ,      '   ! (heating for planetary wave generation)
!
! -----------------------------------------------------------------------------------------------
!
!The following parameters are needed for monsoon-like idealized heating
!Parameter pbot (Pa), ptop (Pa), lat0(deg) , latd , lon0(deg), lond
reght_h_inp='#fct','80000,10000,20.0,10.0,90.0,30.0'
!Parameter  offset (K/day), amplitude (K/day), heating period (days), spin up (days)
tmpht_h_inp='#fct','8.0,0.0,15.0,20.0'     ! offset (K/day), amplitude (K/day), heating period (days), spin up (days)
/
```

Figure S2: Example of RELAX namelist file, continued (part 2)



Submodel RELAX

Purpose: relaxation of variables:
1) Temperature: calculates newtoninan cooling as dT/dt = - kappa * (T – Tequ)
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 Tequ, Time scale kappa, Damping coefficients K, Diabatic heating parameters

Namelist relax.nml

```
&CPL
lnewco =  T/F !logical switch for newco
lrayfric = T/F !logical switch for rayfric
liheat_cc_tropics = T/F !logicals for
liheat_waves       = T/F !diabatic heating
liheat_mons        = T/F  ! functions

!settings
newco_t_inp =  'channel','object' (TEQU)
newco_k_inp = 'channel','object' (KAPPA)
rayfr_k_inp= 'channel','object' (KDAMP)
!for diabatic heating functions
cct_h_inp='#fct','parameter' (tteh_cc_tropics)
waves_h_inp='#fct','parameter' (tteh_waves)
reght_h_inp='#fct','parameter'  (tteh_mons)
tmpht_h_inp='#fct','parameter' (tteh_mons)
```

Call Tree

In Physc.f90:
CALL messy_physc
In *messy_main_control_e5.f90*
Subroutine messy_physc
IF (USE_RELAX) CALL relax_physc

SMIL
messy/echam5/smil/messy_relax_e5.f9

subroutine_**relax_initialize**

```
!read nml
CALL relax_read_nml_cpl
```

subroutine **relax_init_coupling**

```
!get or create Tequ, kappa, kdamp
IF (LNEWCO) / (LRAYFRIC) / (LIHEAT_*)
 IF (#const OR #fct)
   CALL new_channel_object (TEQU, KAPPA) /
                          (KDAMP) / (TTEH_*)
 ELSE
   CALL get_channel_object  !from import
 END
ENDIF
```

subroutine **relax_physc**

```
!called from physc.f90 / messy_physc
USE messy_main_data_bi  tm1,um1,vm1,tte,vol,vom,apm1
IF (LNEWCO)
!set Tequ, kappa, Kdmap
IF (#const)
  TEQU = value ,  KAPPA = value
ELSEIF (#fct)
  CALL fctname(Tequ) / CALL fctname(kappa)
END
CALL relax_newco_smcl(T,Tequ,kappa,tte1)
tte = tte + tte1  !enable MESSYTENDENCY
ENDIF
IF (LRAYFRIC)
!set Kdamp
IF (#const)
  KDAMP= value
ELSEIF (#fct)
  CALL fctname(Kdamp,p)
END
CALL relax_rayfr_smcl(um1,vm1,kdamp,ute,vte)
vol = vol + vte;  vom = vom + ute;
ENDIF
IF (LIHEAT_*)
! set parameter from namelist /default
CALL relax_tteh_*_smcl(apm1,parameter,tteh_* )
tte  =tte + tteh_*
ENDIF
```

subroutine **relax_read_nml_cpl**

SMCL
messy/smcl/messy_relax.f90

subroutine **relax_newco_smcl**

```
(T,TEQU,kappa,tte1)

tte1 = -kappa*(T-Tequ)
```

subroutine **relax_rayfr_smcl**

```
(u,v,kdamp,ute,vte)

ute = -kdamp*u
vte = -kdamp*v
```

Functions for kdamp, kappa and Tequ:

subroutine **newco_tequhs**

```
! calculate Tequ as function
! according to Held and Suarez
```

subroutine **newco_kappahs**

```
! calculate kappa as function
! according to Held and Suarez
```

subroutine **rayfr_kdamphs**

```
! calculate kdamp as function
! according to Held and Suarez
```

.
.
.

Functions for diabatic heating

Subroutine **relax_tteh_cc_tropics_smcl**

```
! calculate tropical zonal mean diabatic heating
tteh_cc_tropics = q0*fct(lat,p)
```

Subroutine **relax_tteh_waves_smcl**

```
! calculate wave-like diabatic heating
tteh_waves = q0*fct(lat,lon,p)
```

Subroutine **relax_tteh_mons_smcl**

```
! calculate localized diabatic heating
tteh_mons = q(t,lat,lon,p)
```

Figure S3: Call tree for RELAX submodel.