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ICON-NWP physics: General overview

Daniel Klocke

4th ICON Training Course, April 17, 2018

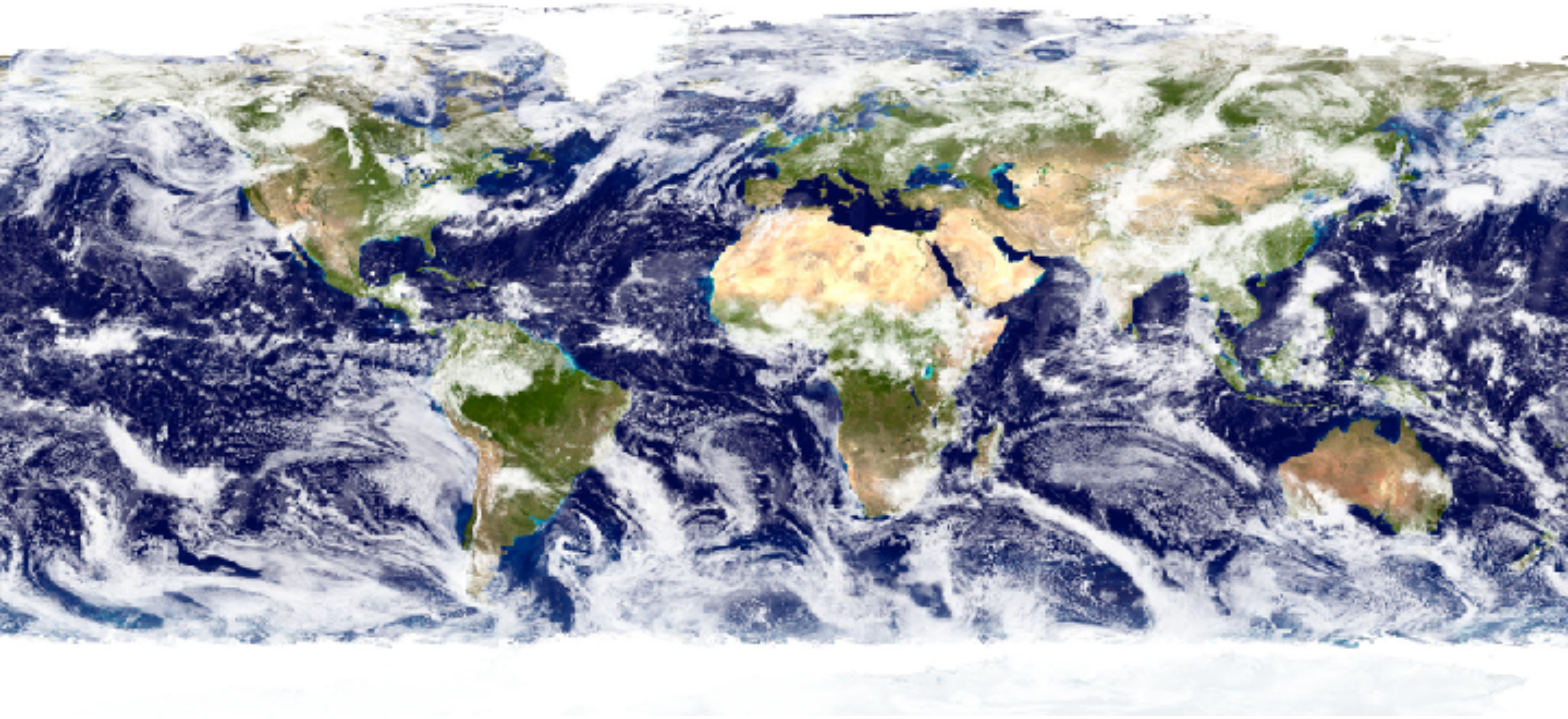
Overview

What is a parameterization?

The ICON (NWP) physics interface and physics time stepping

Physics package of ICON (NWP)

The problem



source NASA earth observatory

Compressible non-hydrostatic equations (Navier-Stokes equation)

$$\partial_t v_n \quad + (\zeta + f)\, v_t \quad + \partial_n K + w\, \partial_z v_n \;=\; - c_{pd} \theta_v \partial_n \pi$$ **Normal wind speed**

$$\partial_t w \quad + \vec{v}_h \cdot \nabla w \quad + w\, \partial_z w \;=\; - c_{pd} \theta_v \partial_z \pi - g$$ **Vertical wind speed**

$$\partial_t \rho \quad + \nabla \cdot (\vec{v} \rho) \;=\; 0$$ **Density of air**

$$\partial_t (\rho \theta_v) + \nabla \cdot (\vec{v} \rho \theta_v) \;=\; 0$$ **Virtuell potential temperature**

(v_n, w, ρ, θ_v : prognostic variables)

Also prognostic equations for water vapour, cloud liquid, ice, rain and snow and TKE.

Solvers:

- ➢Reynolds averaging: $\psi = \overline{\psi} + \psi'$ mit Mittelwert und statistischer Schwankung
- ➢Finite Volumen / finite differences discretisation (mostly 2. order)
- ➢Time integration: Two time level predictor-corrector scheme
- ➢Vertical implicit (vertical sound propagation)
- ➢Mass conserving (dry air and tracer)
- ➢Computing time: 55 minutes for a 7-day forecast (13km including 6.5km over Europe) with 2000 compute cores (Cray XC40)

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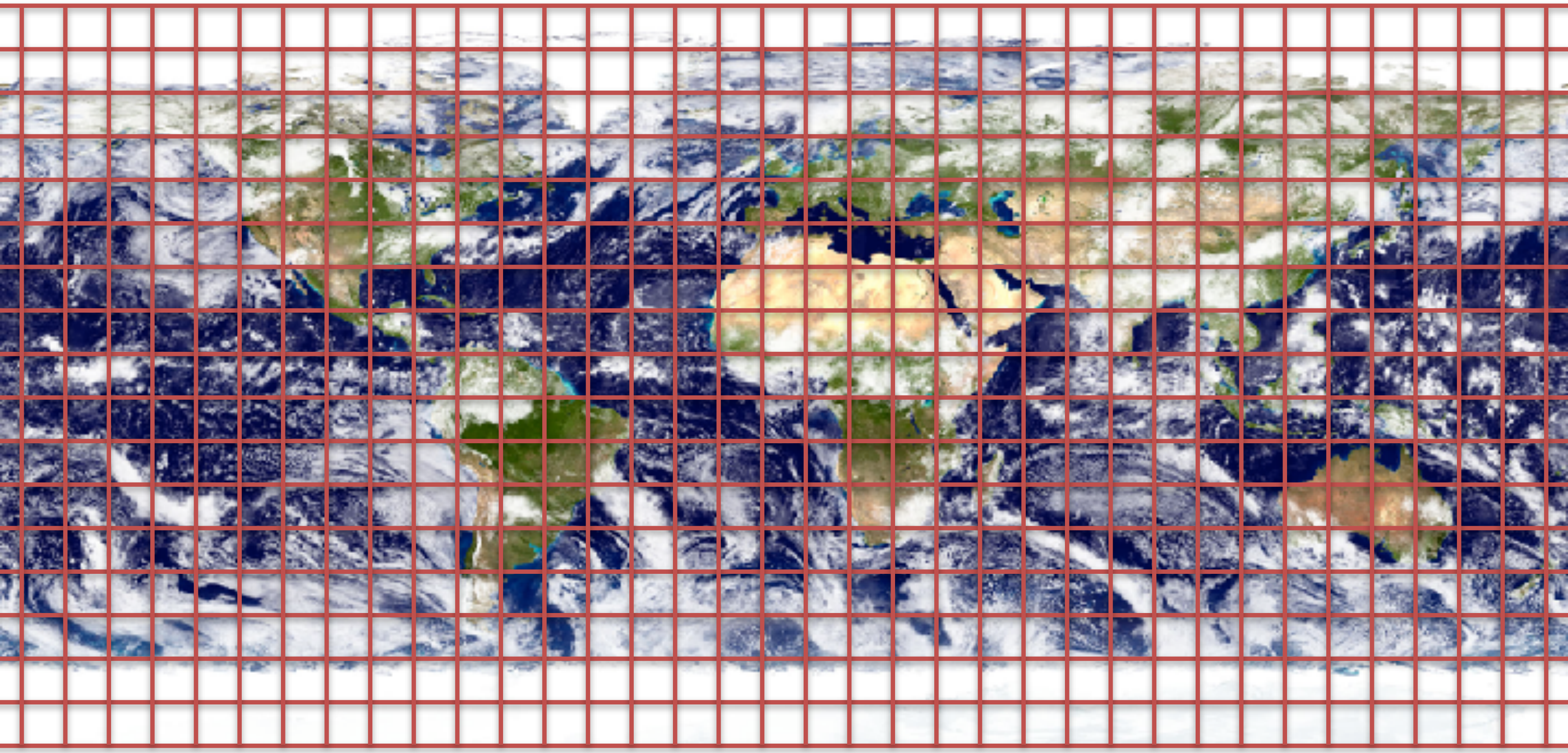
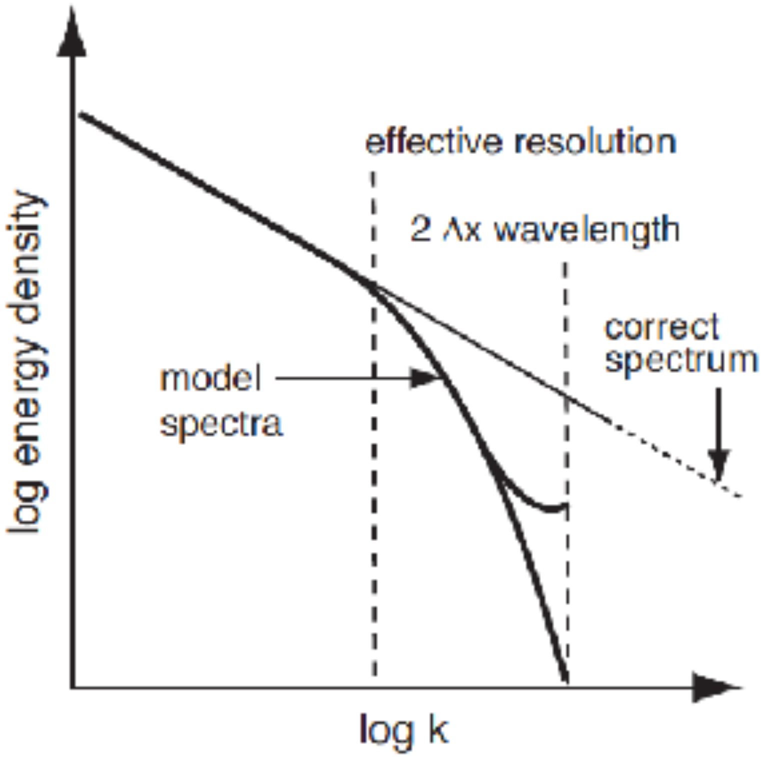
Model grid -> resolution



- Grid cell defines the smallest resolvable scale.
- Many important phenomena and related processes are sub-grid.

source NASA earth observatory

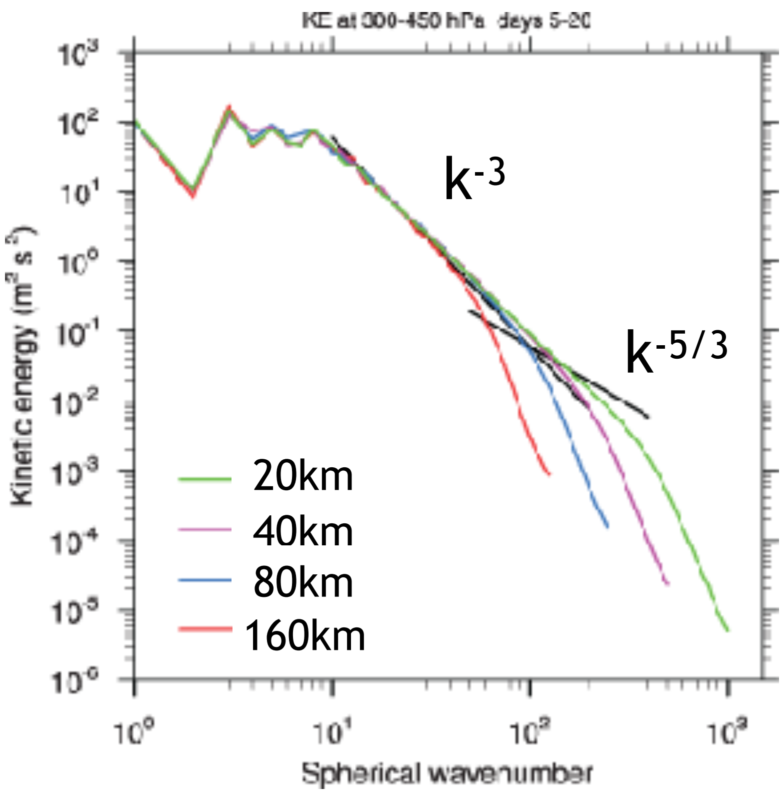
Effective resolution



- The effective resolution is estimated using the total kinetic energy spectra.

- Generally it is in the range of 4-10*dx.

Effective resolution



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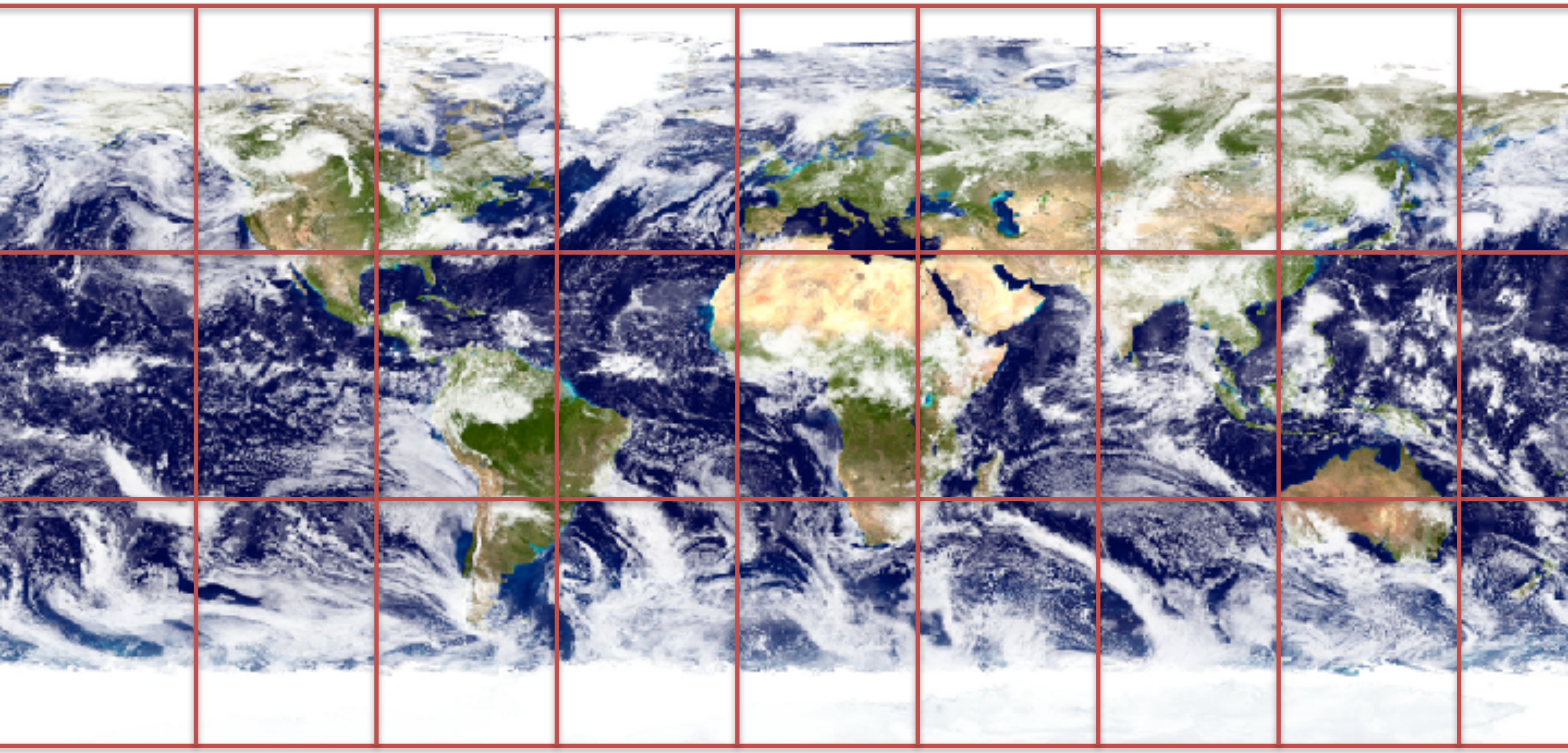
Zängl et al. 2014

Model grid -> effective resolution



• Phenomena and processes properly resolved on this scale.

source NASA earth observatory

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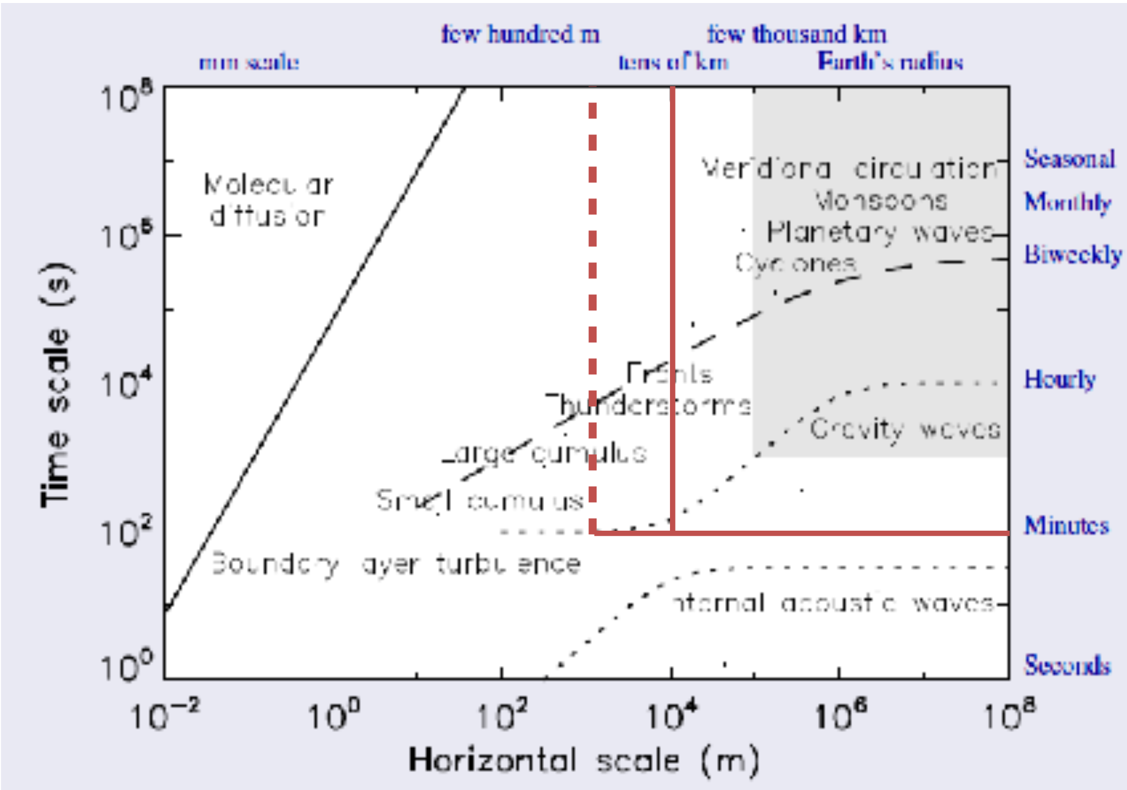
Characteristic scales



Resolved scales:
Current climate models

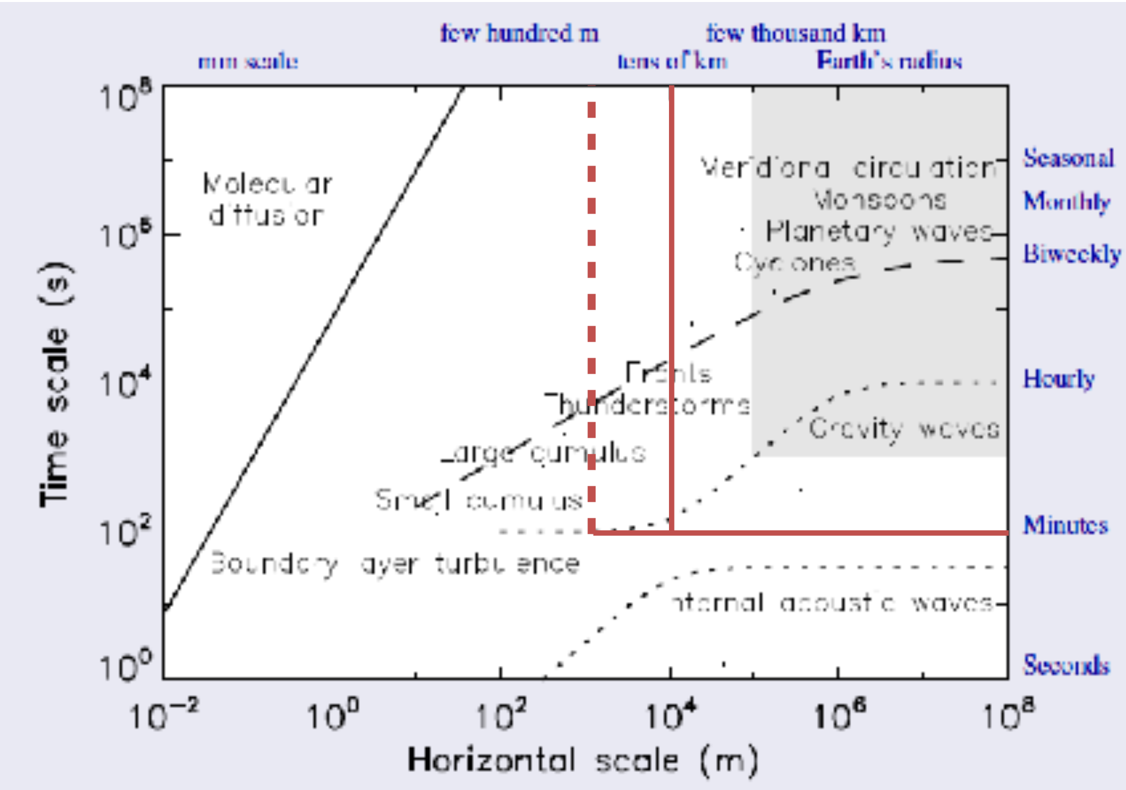
Current global NWP models

Current regional models

-> the resolved processes change and parameterizations might to be redesigned

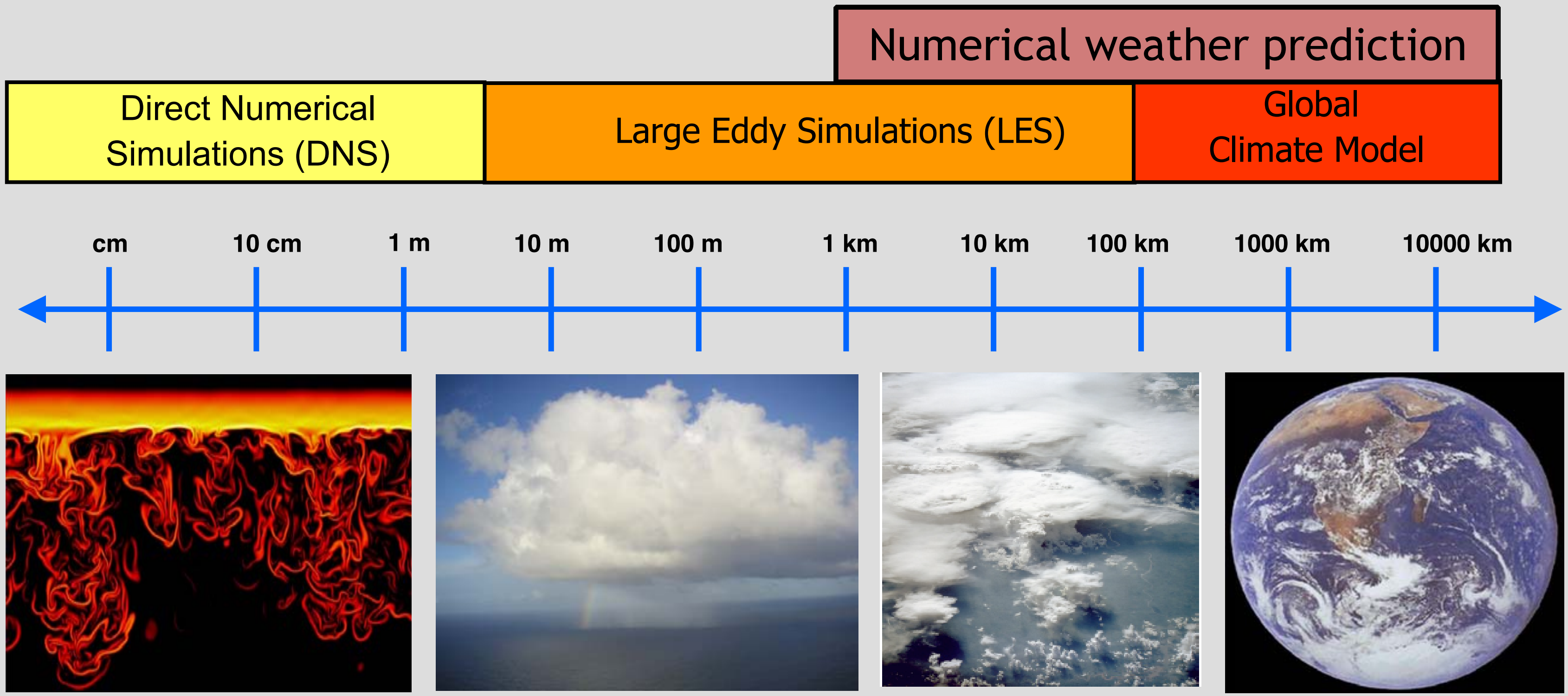
10^4km: large scale circulations (Asian summer monsoon).
10^4km: undulations in the jet stream and pressure patterns associated with the largest scale Rossby waves (called planetary waves)
10^3km: cyclones and anticyclones
10km: the transition zones between relatively warm and cool air masses can collapse in scale to form fronts with widths of a few tens of km

Characteristic scales



10^3km - 100m: convection can be organized on a huge range of different scales
10m - 1mm: turbulent eddies in boundary layer; range in scale from few hundred m's down to mm scale at which molecular diffusion becomes significant.

Models and their scales



courtesy of Pier Siebesma

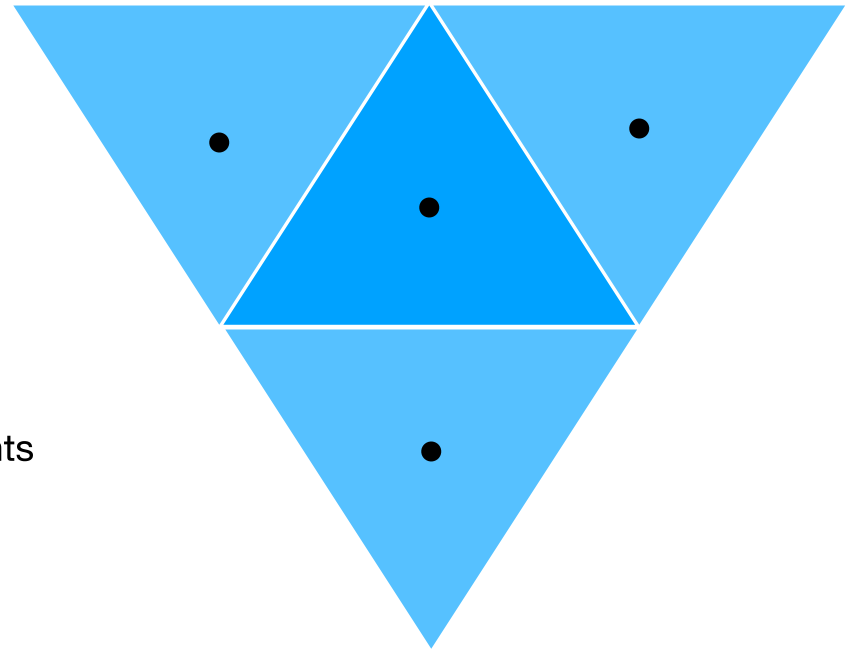
Models and their scales

	Horizontal scale	*Vertical scale*	*Time scale*
Climate model	*100km*	*500m*	*100 years*
Global NWP	*10km*	*200m*	*10 days*
Limited area NWP	*2km*	*200m*	*3 days*
Cloud resolving	*500m*	*100m*	*1 day*
Large eddy models	*100m*	*50m*	*12 hours*
Direct numerical	*1mm*	*1mm*	*10 minutes*

-> Different models need different level of parameterization
More processes resolved, fewer need parameterizations

One more word on resolution:

It is very differently defined between models and often does not mean the same thing



Distance between center points

Edge length

Square root of area

Flavours of ICON

Weather
ICON-NWP

Research
ICON-LES

Climate
ICON-ECHAM

Aerosols and reactive tracers
ICON-ART

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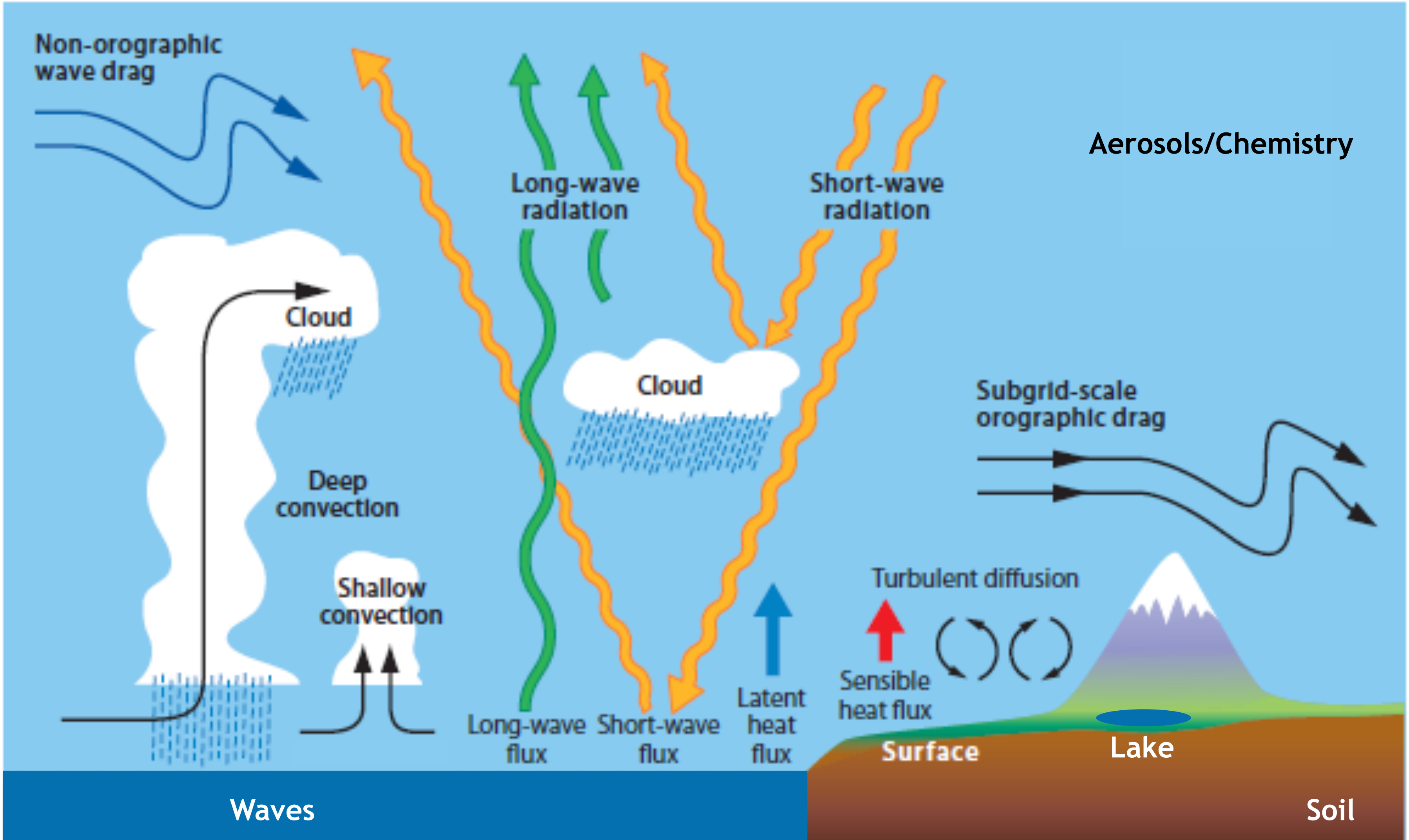

ecmwf.int

Basic requirements of the parameterizations:

Accommodate different applications like global and limited-area numerical weather prediction, environmental forecasts, climate projections and research.

Work on a wide range of scales (horizontal, vertical and time). For example with the global (13km) and high resolution European nest (6.5km) at DWD, or ensemble forecasts (25km) and seasonal predictions later.

The numerics need to be efficient and robust, especially for time critical numerical weather prediction.

Interactions between processes are important and should be considered in the design of schemes.

Parameterized processes control quantities which interest us the most from weather forecasts.

General

Tendencies from sub-grid processes are substantial and contribute to the evolution of the atmosphere even in the short range.
Diabatic processes drive the general circulation.

Synoptic development

Diabatic heating and friction influence synoptic development.

Weather parameters

Diurnal cycle
Clouds, precipitation, fog
Wind, gusts
Temperature and humidity at 2m level.

Data assimilation

Forward operators are needed for observations.

Physics interfaces

nwp (weather forecast)

les (large-eddy simulations)

echam (climate simulations)

Physics interfaces

nwp (weather forecast)

les (large-eddy simulations)

echam (climate simulations)

Physics interfaces

nwp (weather forecast)
src/atm_phy_nwp/mo_nh_interface_nwp.f90

les (large-eddy simulations)
src/atm_phy_les/mo_interface_les.f90

echam (climate simulations)
src/atm_phy_echam/mo_interface_iconam_echam.f90

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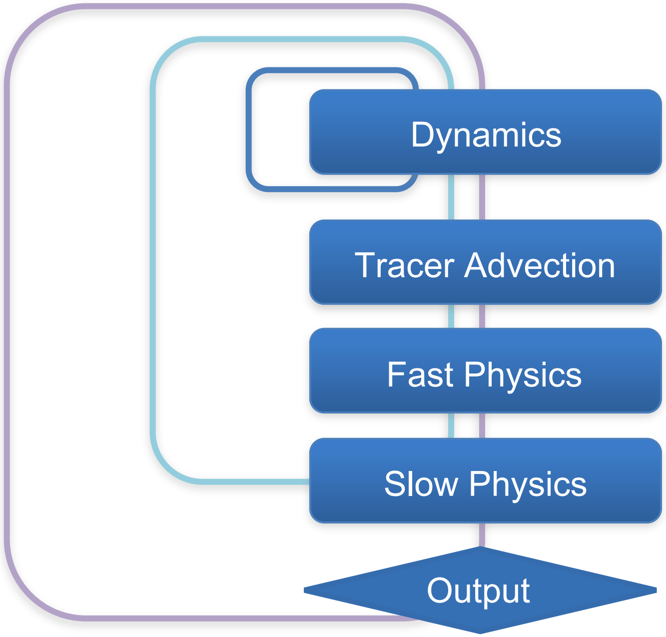
Dynamics - Physics coupling



dt_dyn = dtime/nsubs

dtime (1.8 x res_in_km x nsubs)

dtime

dt_conv dt_rad dt_sso dt_gwd

dt_output

Dynamics - Physics coupling

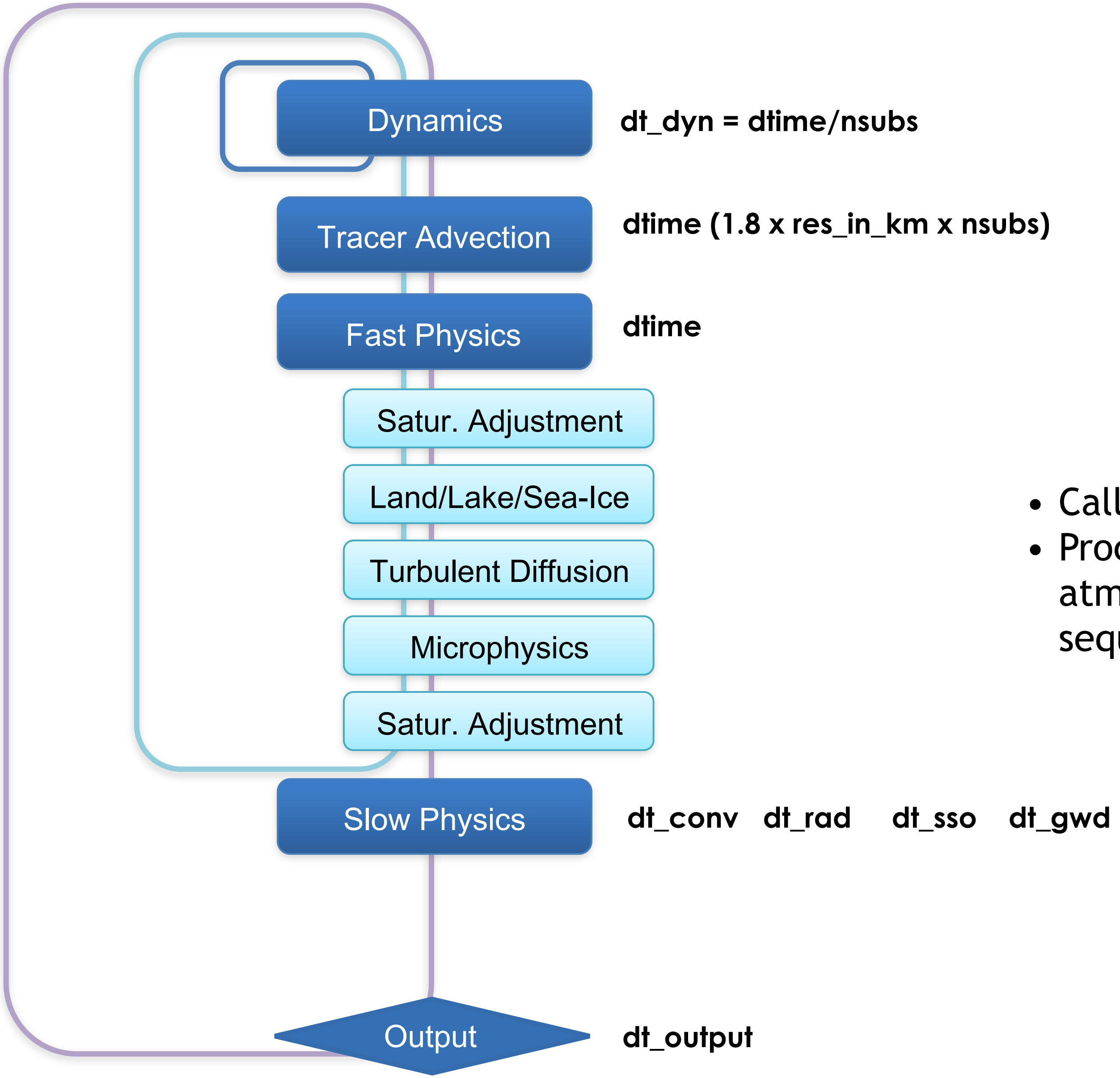
The coupling is performed at constant density (volume)
-> heating rates have to be converted to temperature change using c_v.

The physics parameterizations work on mass points.
->Diagnose pressure and temperature, interpolate v_n to u,v

Conversion between the set of thermodynamical variables is reversible, but the interpolation between velocity points and mass points can introduce errors.

After the atmospheric state was updated by the fast processes the atmospheric state has to be converted back to the ICON prognostic variables.

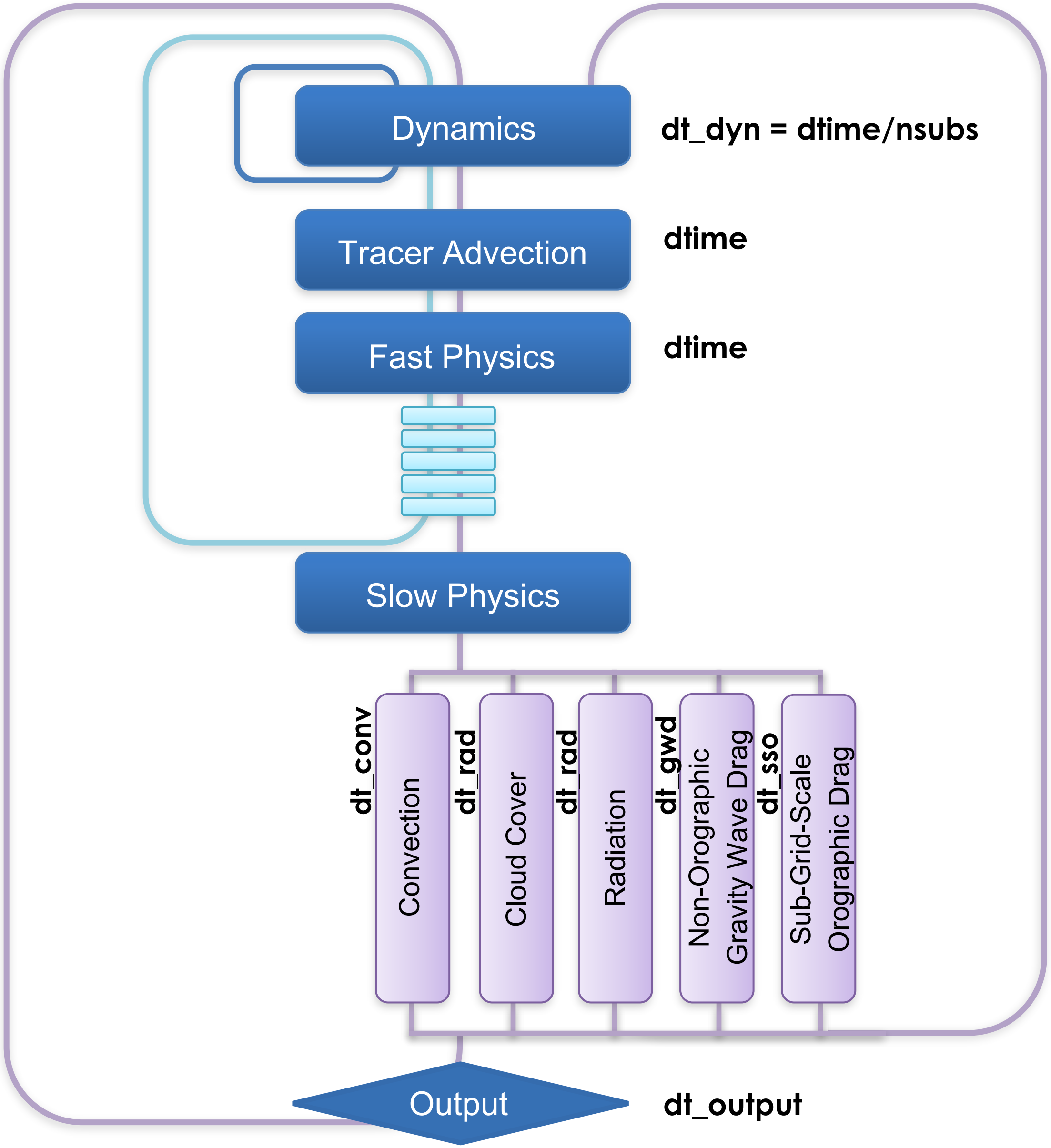
Dynamics - Physics coupling



Fast physics:

- Called every time step
- Processes update atmospheric state sequentially

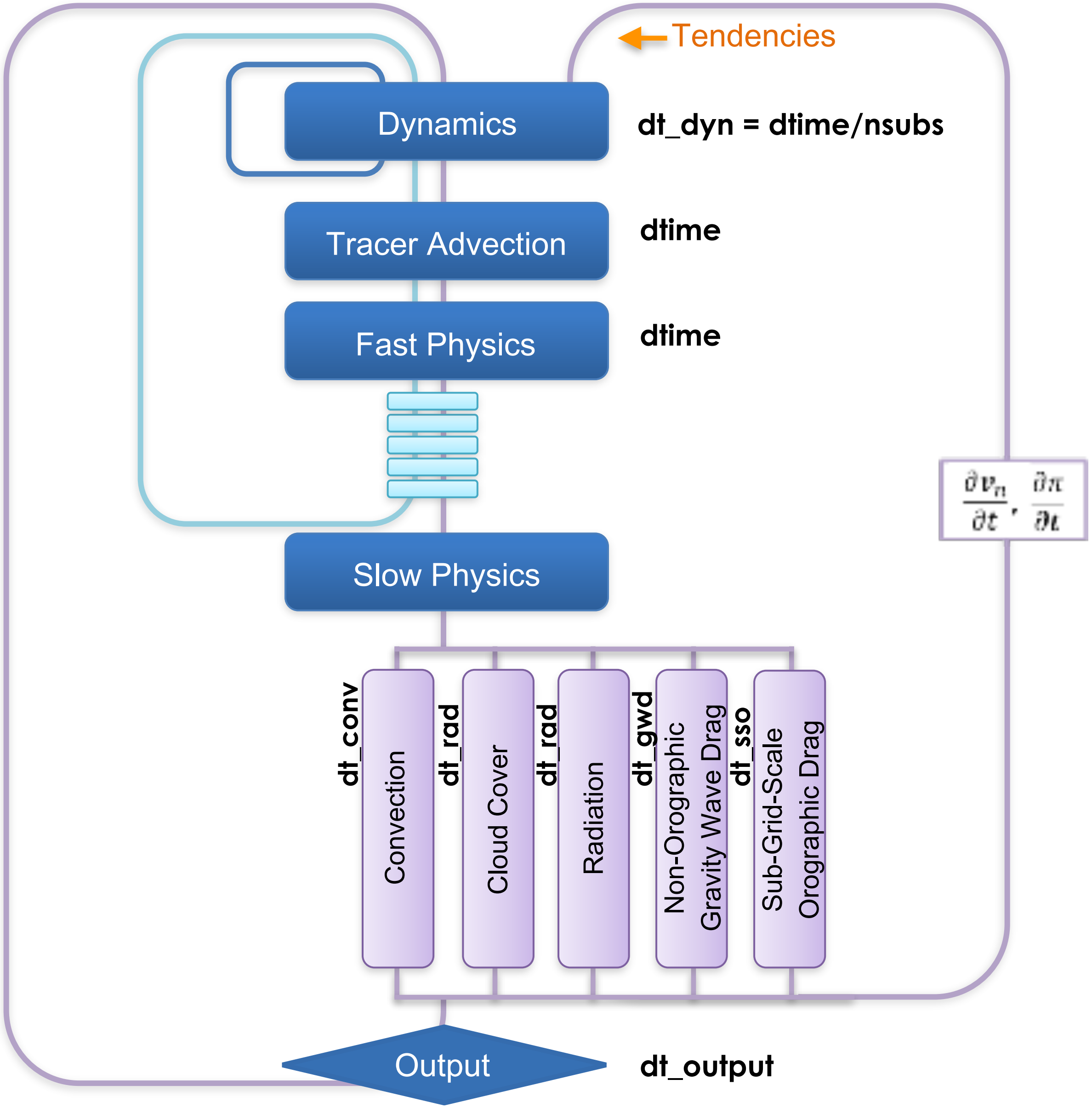
Dynamics - Physics coupling



Slow physics:

- Called every k^{th} time step
- All processes computed on the same state

Dynamics - Physics coupling



Slow physics:

- Called every k^{th} time step
- All processes computed on the same state
- Tendencies are passed to the dynamical core

Namelist controls

```
&nwp_phy_nml
! fast physics
 inwp_satad                         = 1
 inwp_surface                       = 1
 inwp_turb                          = 1
 inwp_gscp                          = 1
! slow physics
 inwp_convection                    = 1
 inwp_cldcover                      = 1
 inwp_radiation                     = 1
 inwp_sso                           = 1
 inwp_gwd                           = 1
!
 dt_conv                            =  600
 dt_rad                             = 1800
 dt_sso                             = 1200
 dt_gwd                             = 1200
/
```

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Namelist controls with nest

```
&nwp_phy_nml
! fast physics
 inwp_satad                        = 1,1,1
 inwp_surface                      = 1,1,1
 inwp_turb                         = 1,1,5
 inwp_gscp                         = 1,1,5
! slow physics
 inwp_convection                   = 1,0,0
 inwp_cldcover                     = 1,1,5
 inwp_radiation                    = 1,1,1
 inwp_sso                          = 1,1,1
 inwp_gwd                          = 1,1,0
!
 dt_conv                           =  600
 dt_rad                            = 1800
 dt_sso                            = 1200
 dt_gwd                            = 1200
/
```

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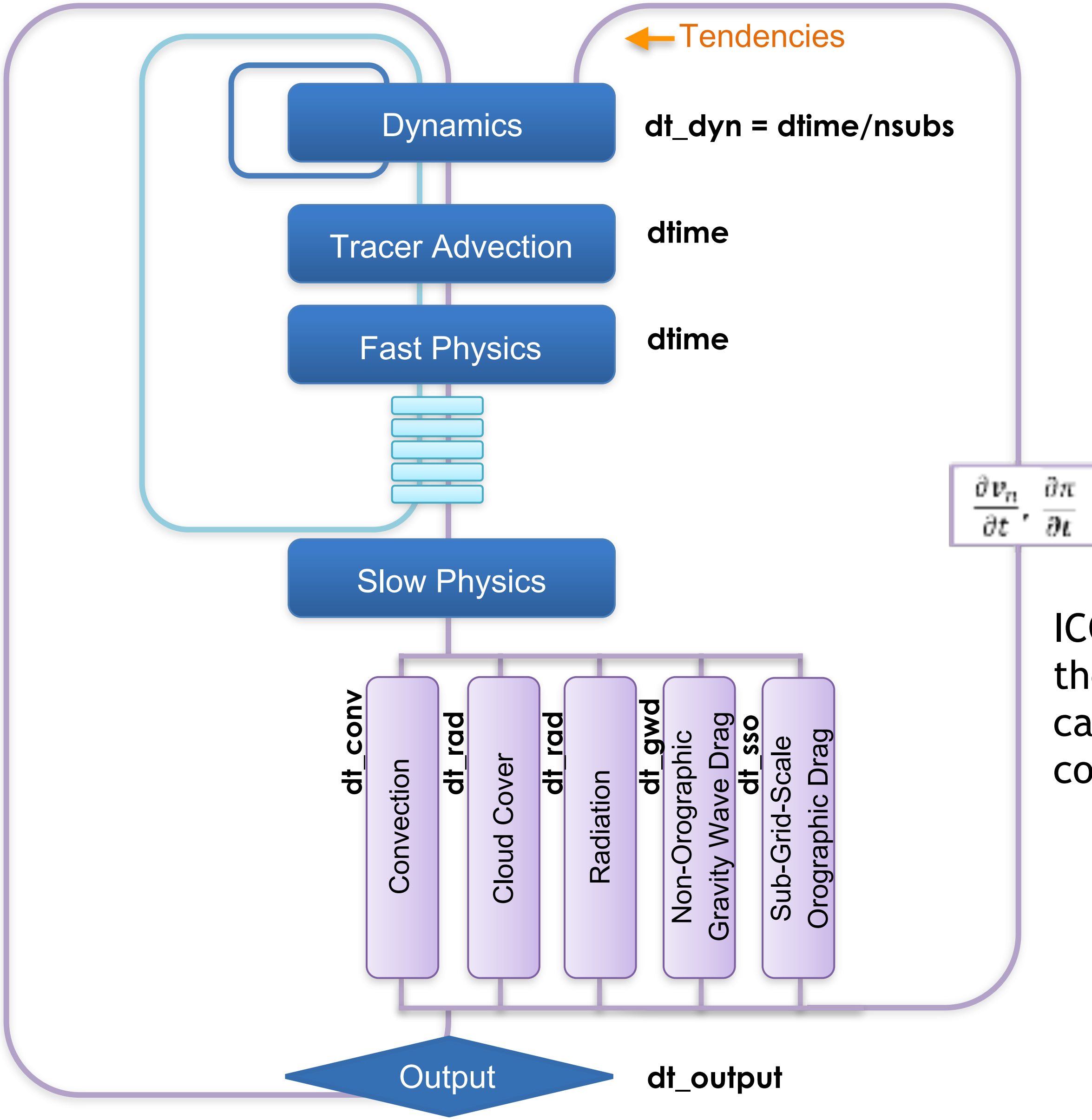
Reduced radiation grid



ICON also allows to sub-sample the radiation in space and calculate the radiation on a coarser grid.

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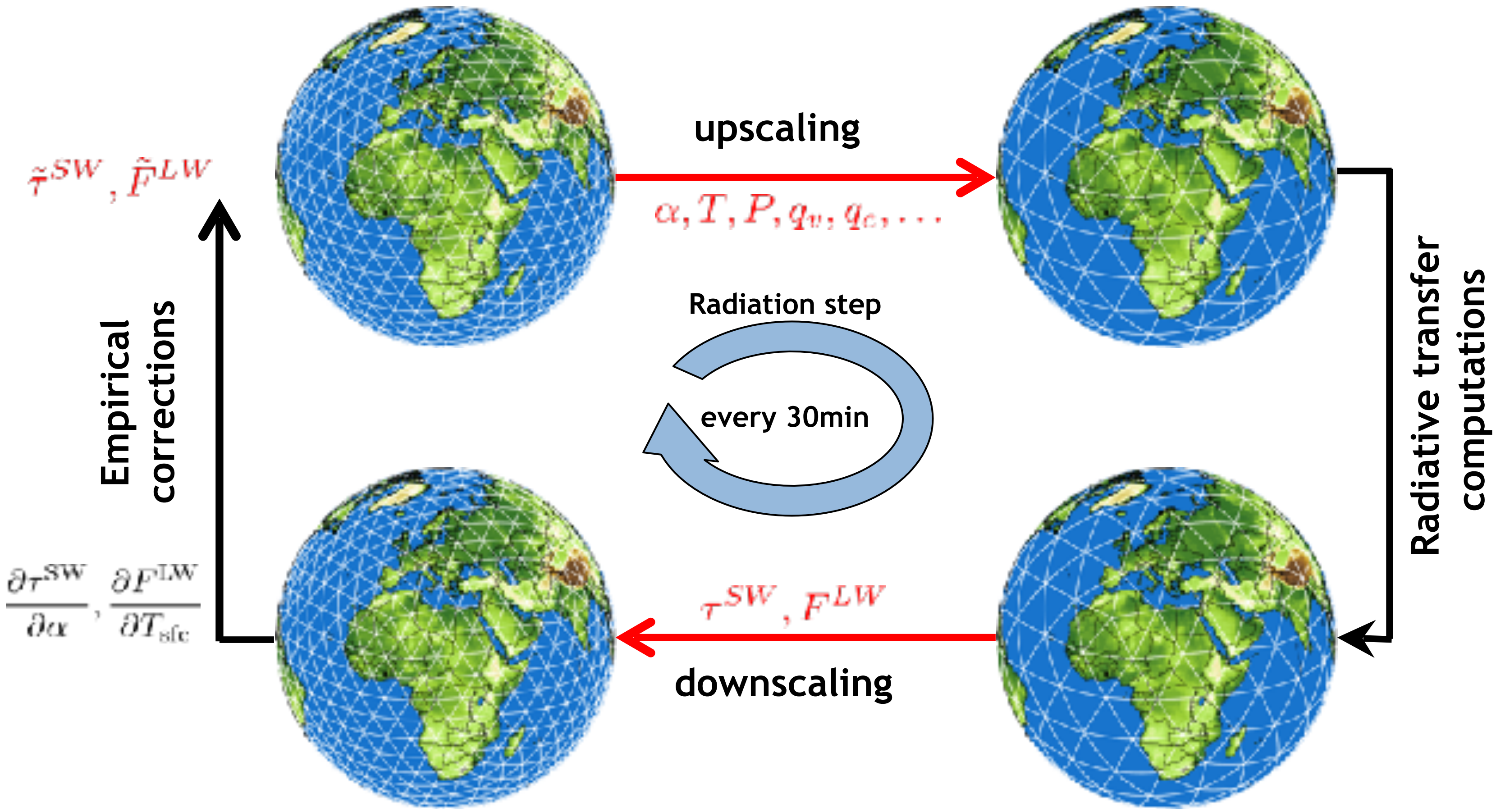
Reduced radiation grid

The hierarchical structure of the triangular mesh allows to calculate physical processes (e.g. radiative transfer) with different spatial resolution compared to dynamics.



Reduced radiation grid

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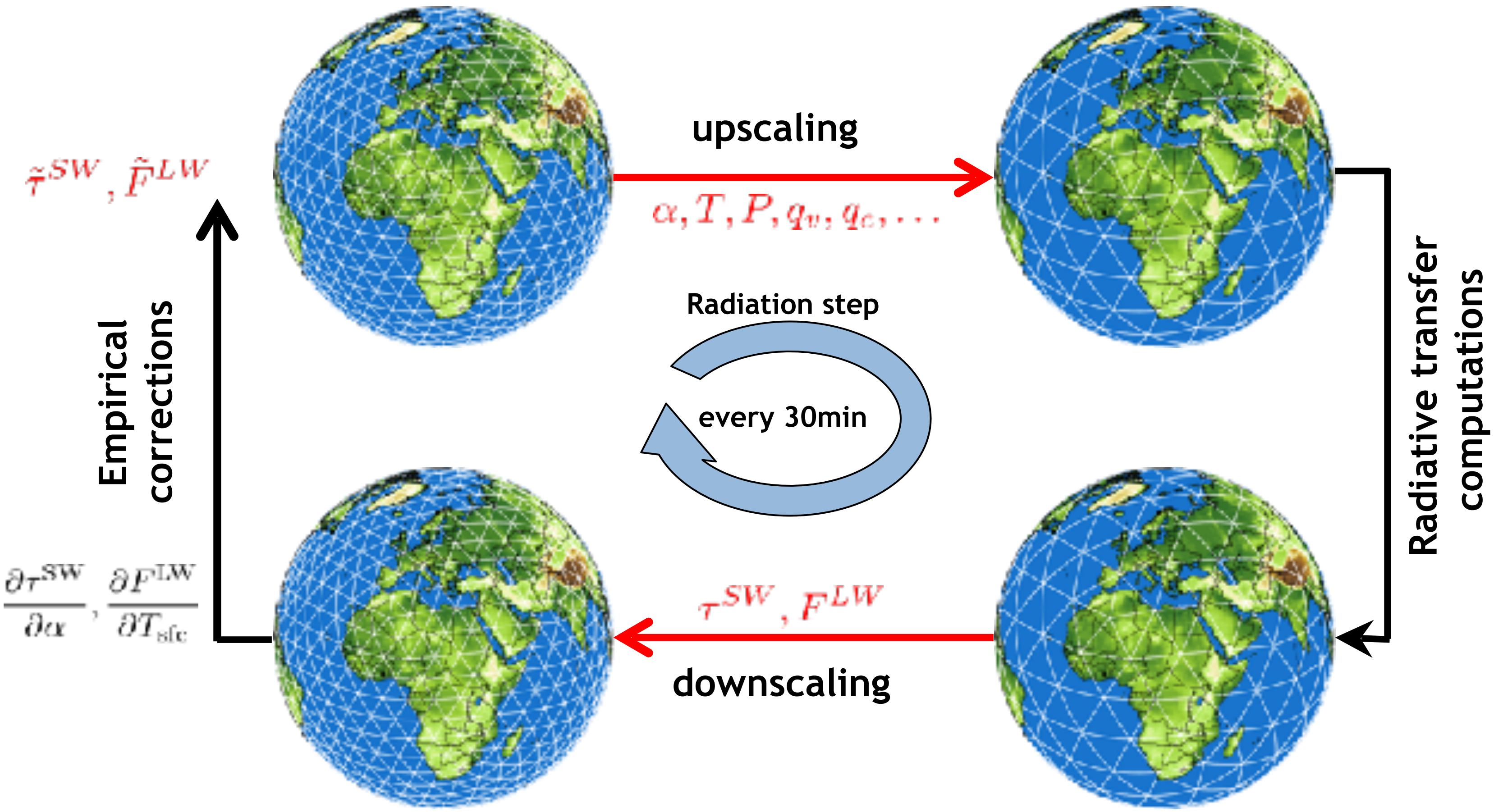
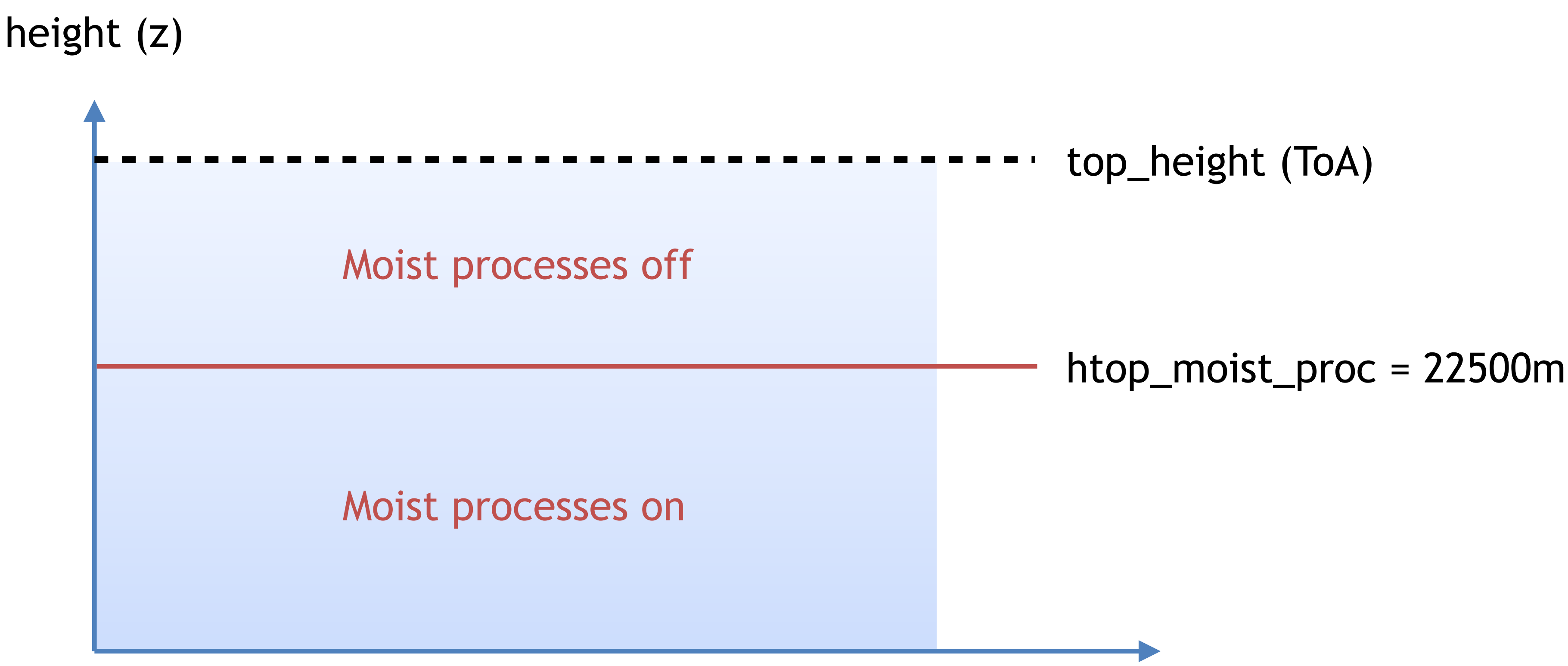



```
&grid_nml
 lredgrid_phys              = .TRUE.
 radiation_grid_filename    = <name>
/
```

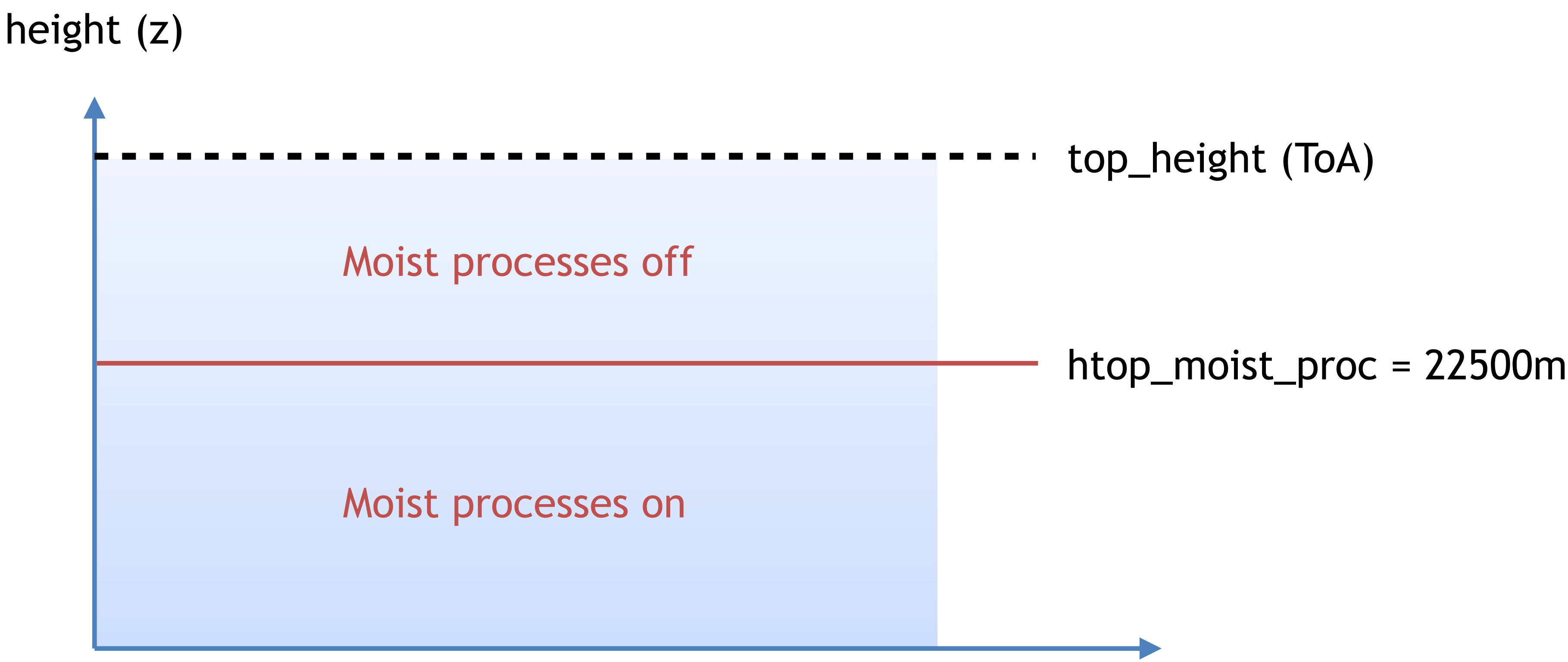
Default for NWP at DWD

Moist physics off in stratosphere



For efficiency reasons the moist physics can be switched off above a certain level, as well as transport of all water species but vapor.

Moist physics off in stratosphere



For efficiency reasons the moist physics can be switched off above a certain level, as well as transport of all water species but vapor.

```
&nonhydrostatic_nml
 htop_moist_proc              =  22500
/
```

ICON (NWP) physics packages

Process	Scheme	Settings
Radiation	RRTM (Rapid Radiative Transfer Model) Mlawer et al. (1997), Barker et al. (2003)	inwp_radiation=1
	PSRAD Pincus and Stevens (2013)	inwp_radiation=3
Non-orographic gravity wave drag	Wave dissipation at critical level Orr et al. (2010)	inwp_gwd=1
Sub-grid scale orographic drag	Lott and Miller scheme Lott and Miller (1997)	inwp_sso=1
Cloud cover	Diagnostic PDF *M. Köhler et al. (DWD)*	inwp_cldcover=1
	All-or-nothing scheme (grid-scale clouds)	inwp_cldcover=5
Microphysics	Single-moment scheme Doms et al. (2011), Seifert (2008)	inwp_gscp=1
	Double-moment scheme Seifert and Beheng (2006)	inwp_gscp=4

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Not all schemes are working or tested in all configurations!

More and even less used/tested parameterization options exists -> use at your own risk!

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Convection	Mass-flux shallow and deep Tiedtke (1989), Bechtold et al. (2008)	inwp_convection=1
Turbulent transfer	Prognostic TKE (COSMO) Raschendorfer (2001)	inwp_turb=1
	EDMF-DUALM (Eddy-Diffusivity/Mass-Flux) Neggers et al. (2009)	inwp_turb=3
	3D Smagorinsky diffusion (for LES)	inwp_turb=5
Land	Tiled TERRA Schrodin and Heise (2002)	inwp_surface=1
	Flake: Mironov (2008) Sea-ice: Mironov et al. (2012)	llake=.TRUE. lseaice=.TRUE.

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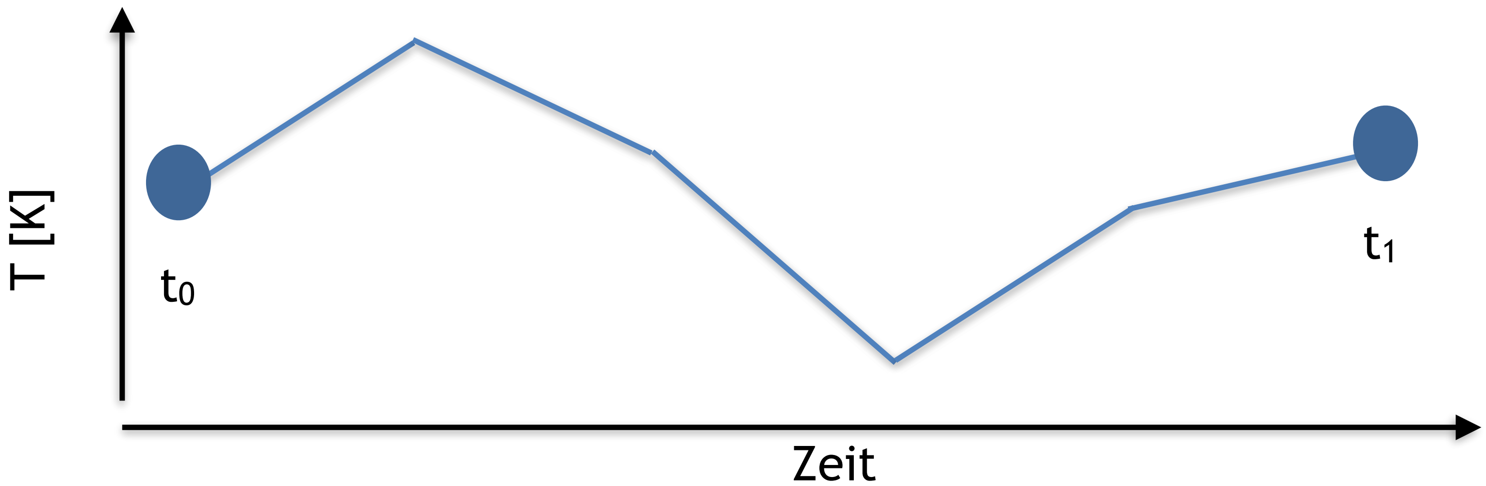
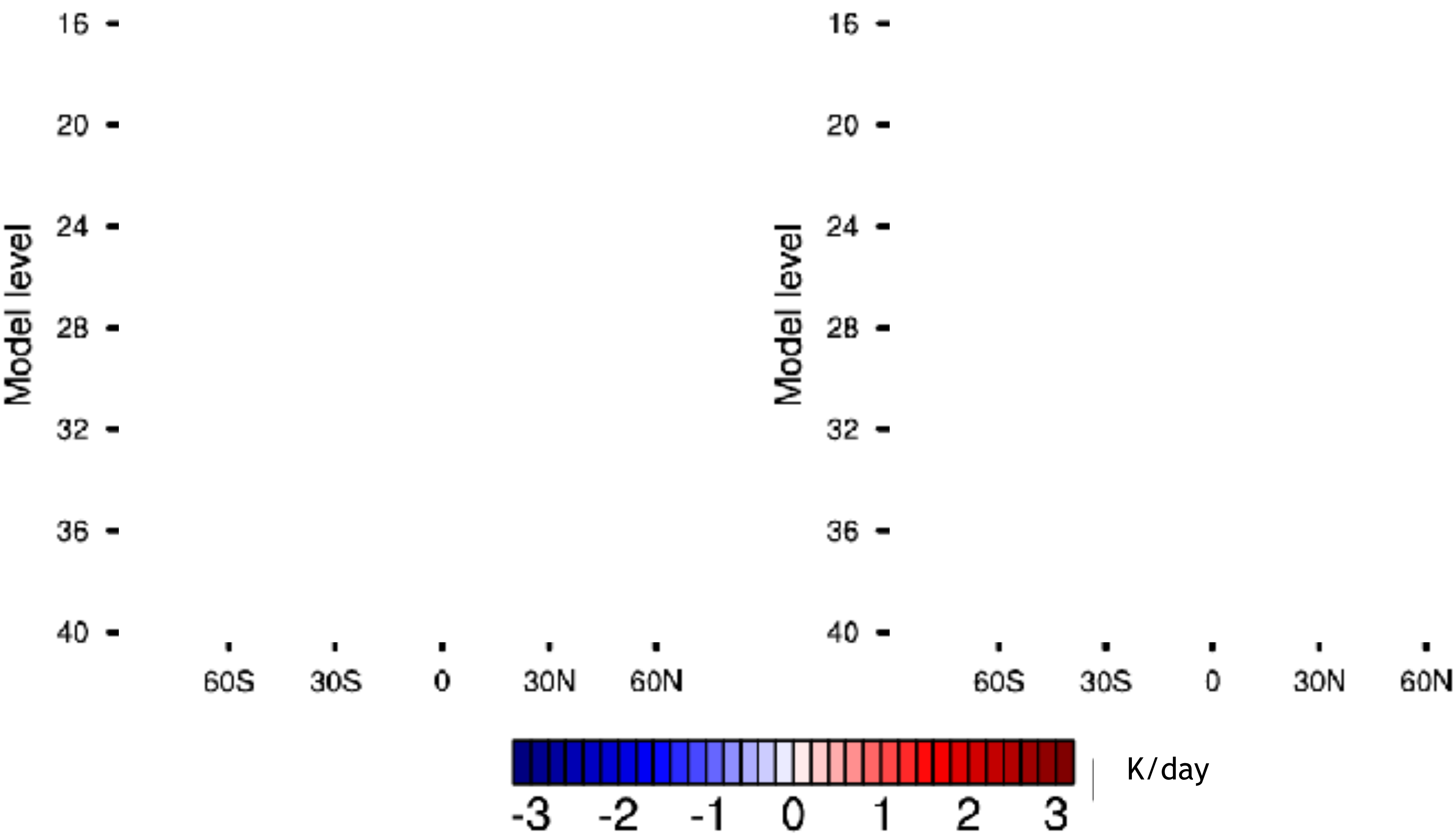


$$\frac{\partial T}{\partial t} = \sum_i \frac{\partial T_i}{\partial t} = \frac{\partial T_{dyn}}{\partial t} + \frac{\partial T_{phy}}{\partial t}$$

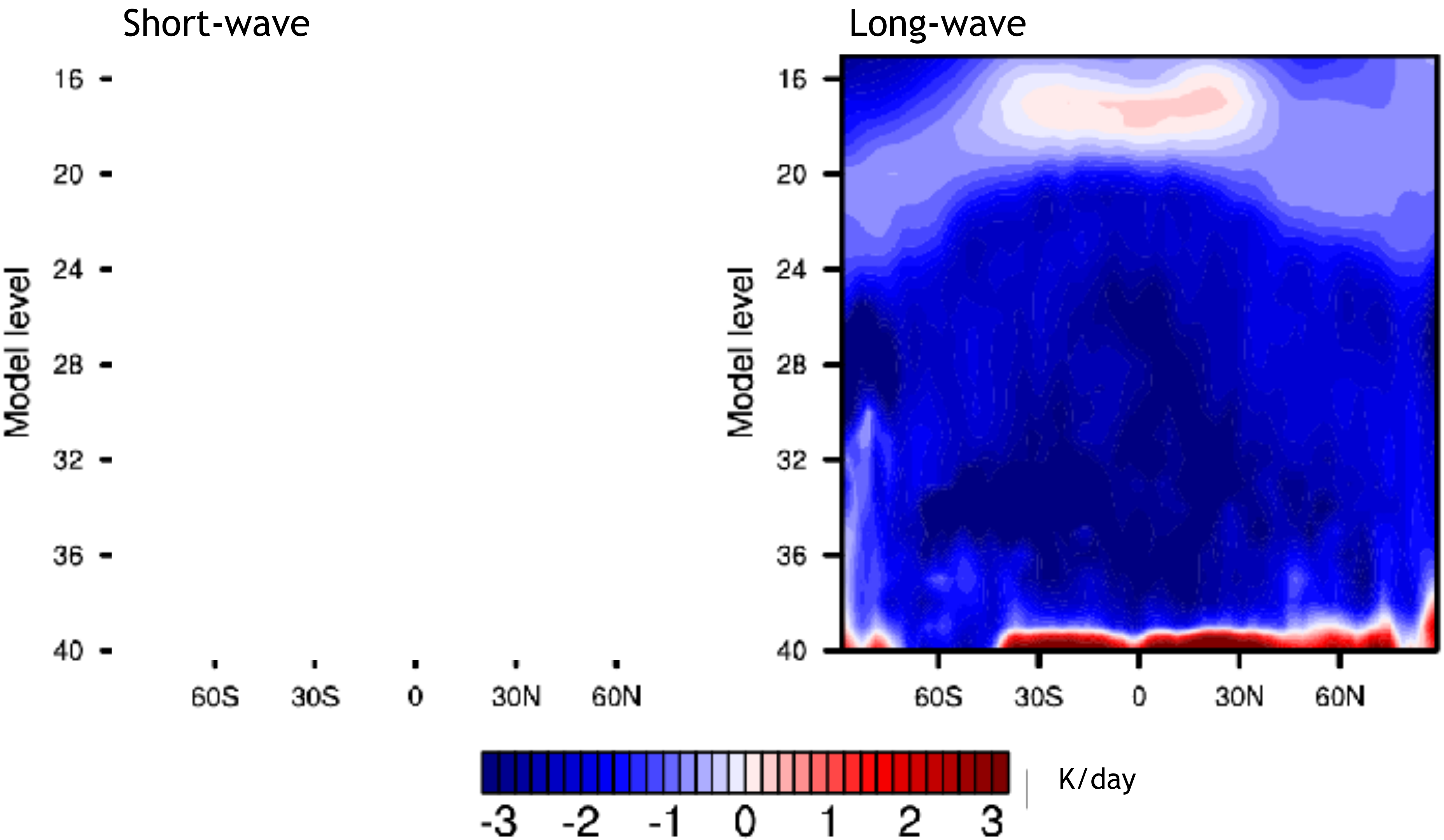
$$= \frac{\partial T_{dyn}}{\partial t} + \frac{\partial T_{tur}}{\partial t} + \frac{\partial T_{cld}}{\partial t} + \frac{\partial T_{con}}{\partial t} + \frac{\partial T_{rad}}{\partial t}$$

dT/dt from radiation

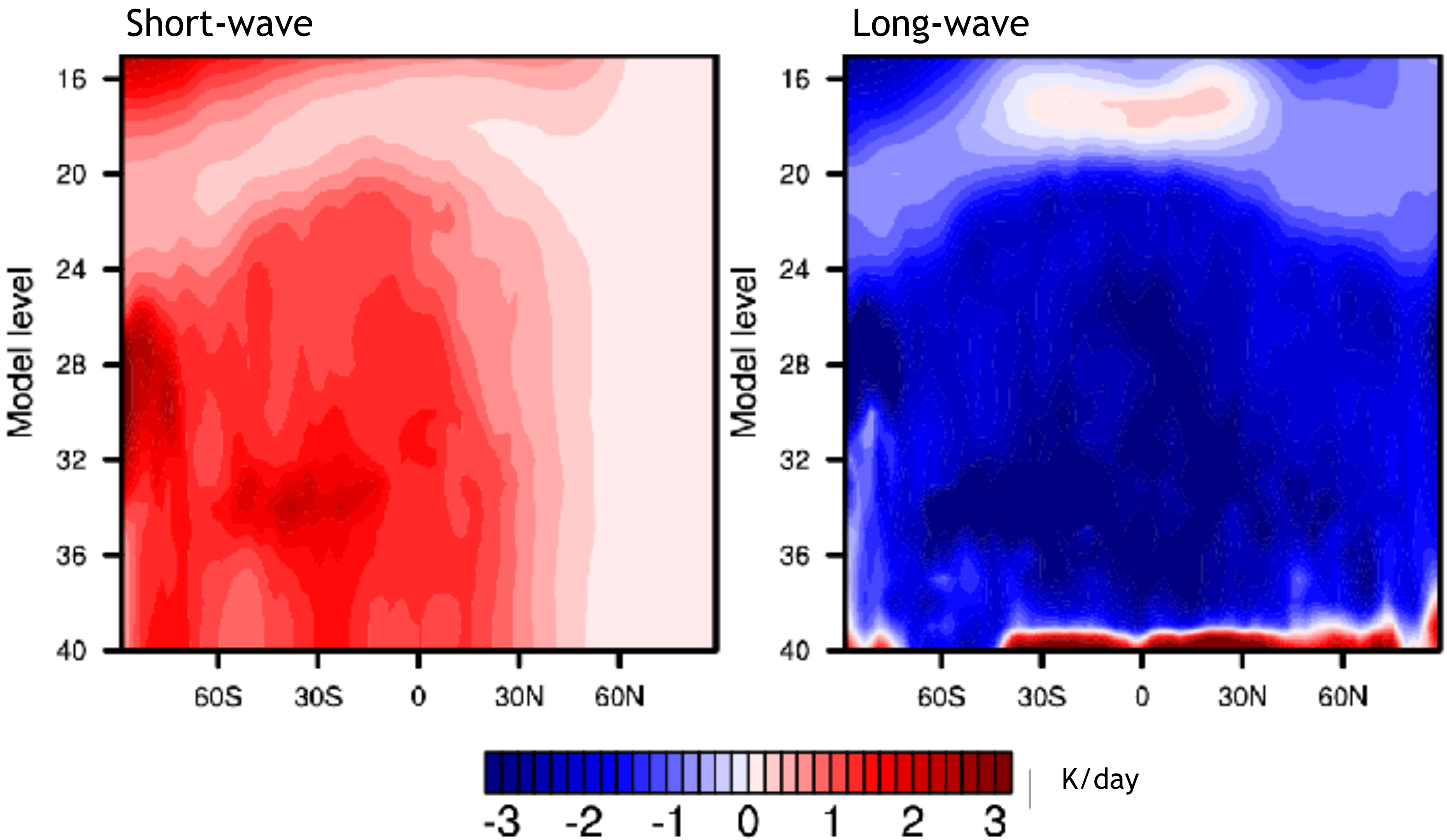
Short-wave Long-wave



dT/dt from radiation



dT/dt from radiation



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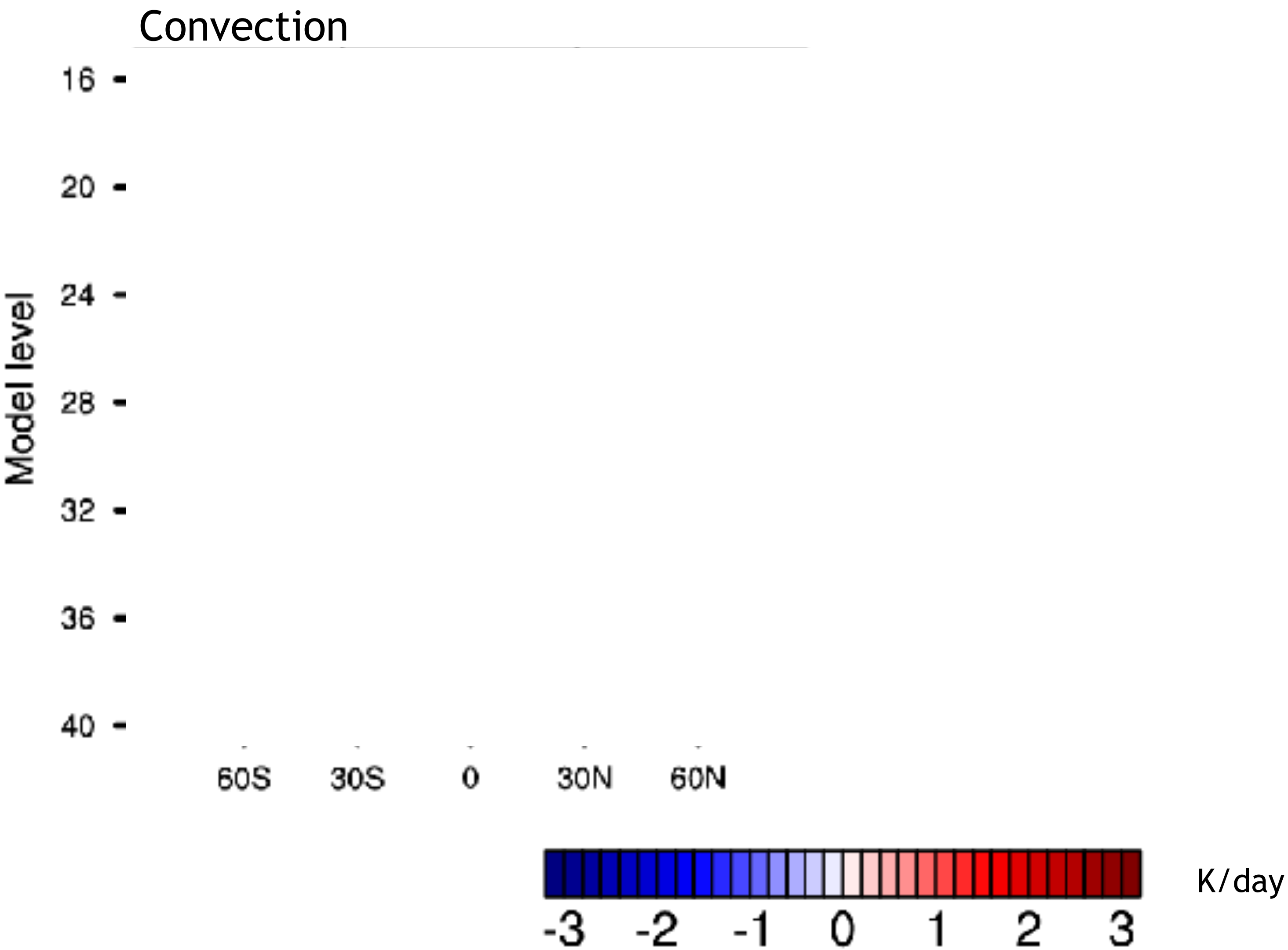
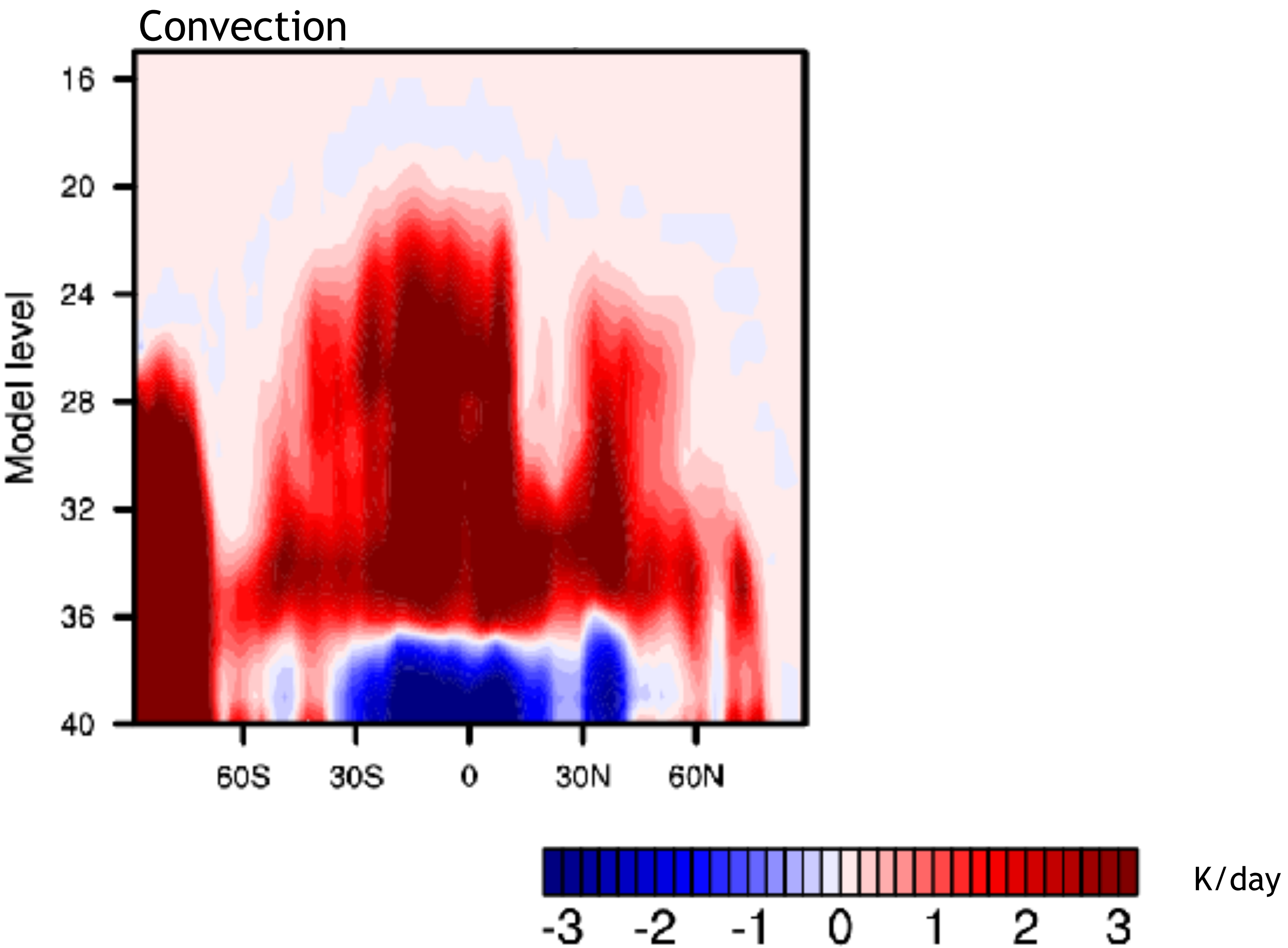
dT/dt from convection



dT/dt from convection



SSO and GWD

Sub-grid scale orography (Lott & Miller 1997):

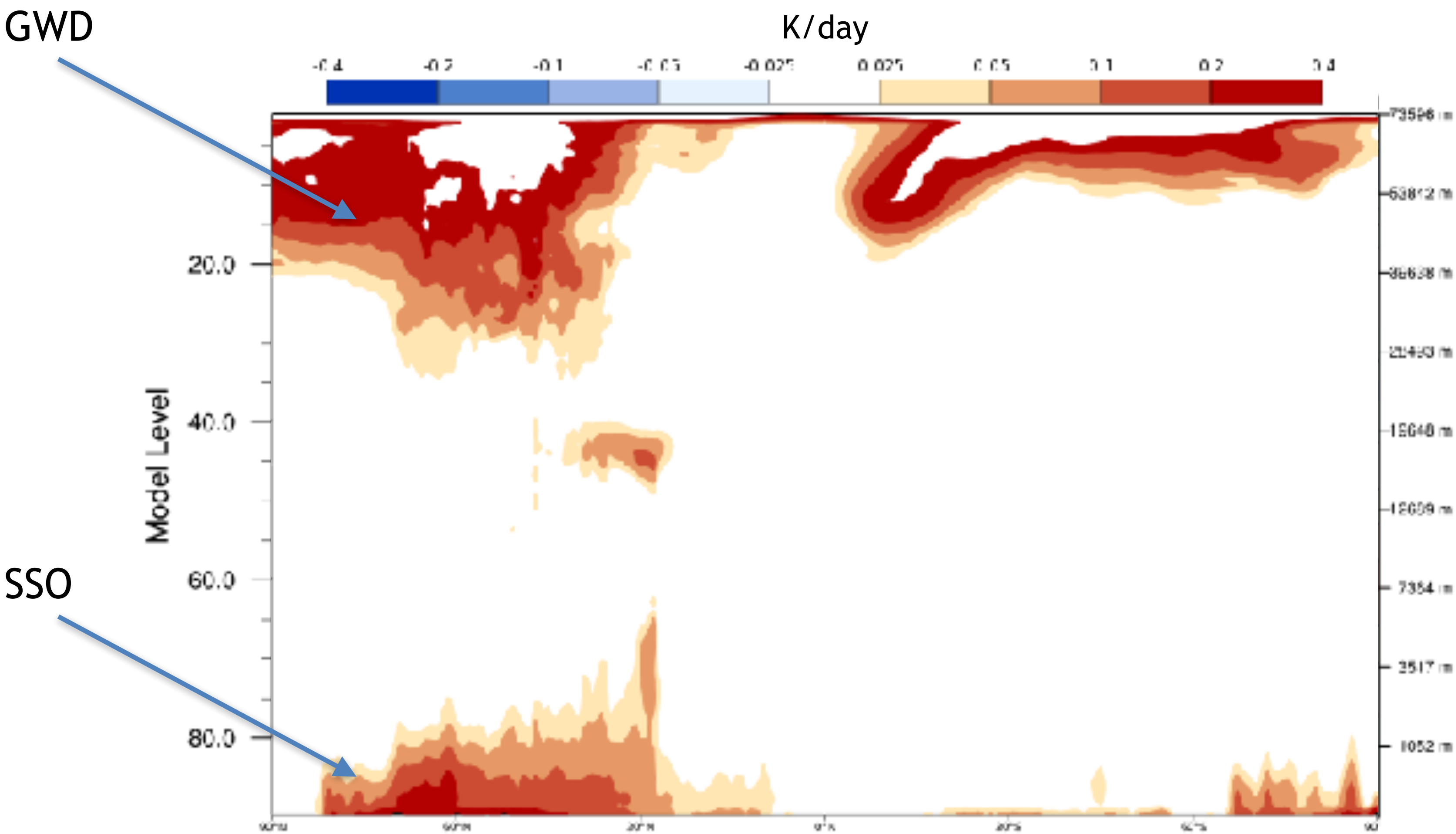
The effects of unresolved orography on the atmosphere are a sink for momentum (drag). In stably stratified flows the parameterization represents the effects of low-level blocking and the reflection and/or absorption of vertically propagating gravity waves due to unresolved orography on the momentum budget.

->The sub-grid information of the orography is based on observations and included in the external parameters.

Non-orographic gravity wave drag (Orr et al. 2010):

The parameterization represents wave breaking effects through changing horizontal winds and air density vertically. Theses waves are generated by convection, shear zones, or frontal disturbances and travel from the troposphere up and break in the middle atmosphere exerting a drag on the flow.

dT/dt from SSO and GWD



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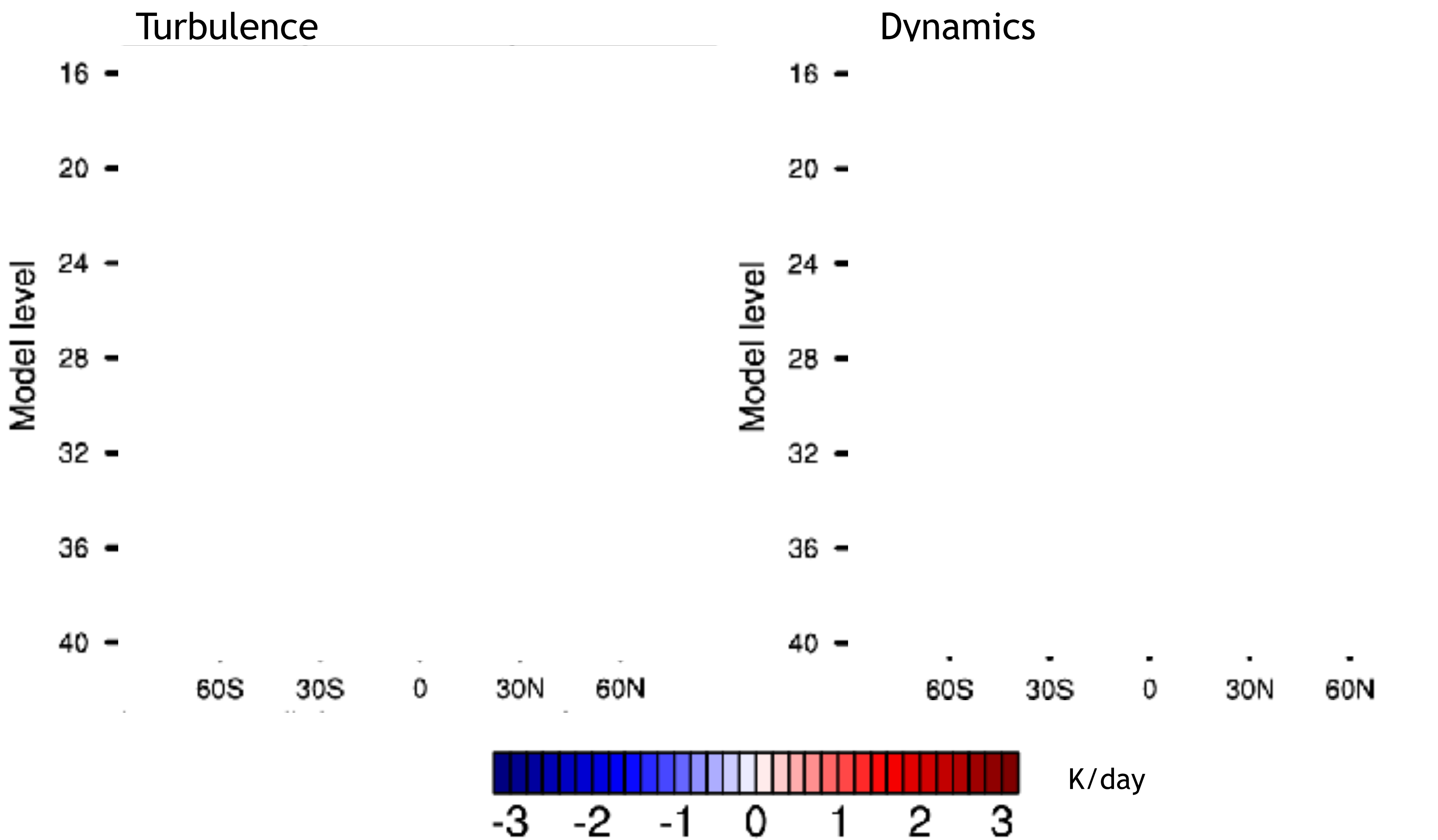
dT/dt turbulence and dynamics



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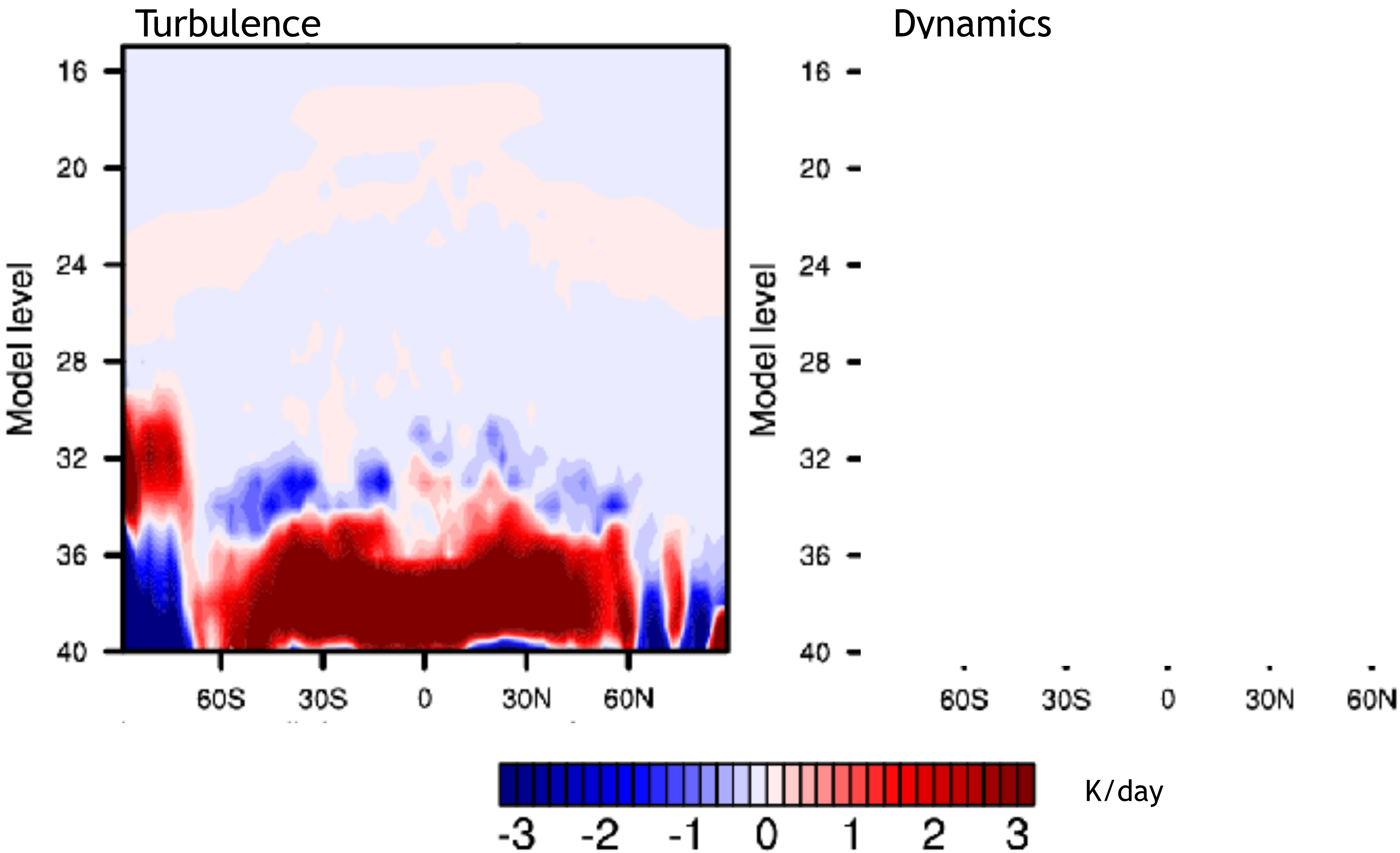
dT/dt turbulence and dynamics



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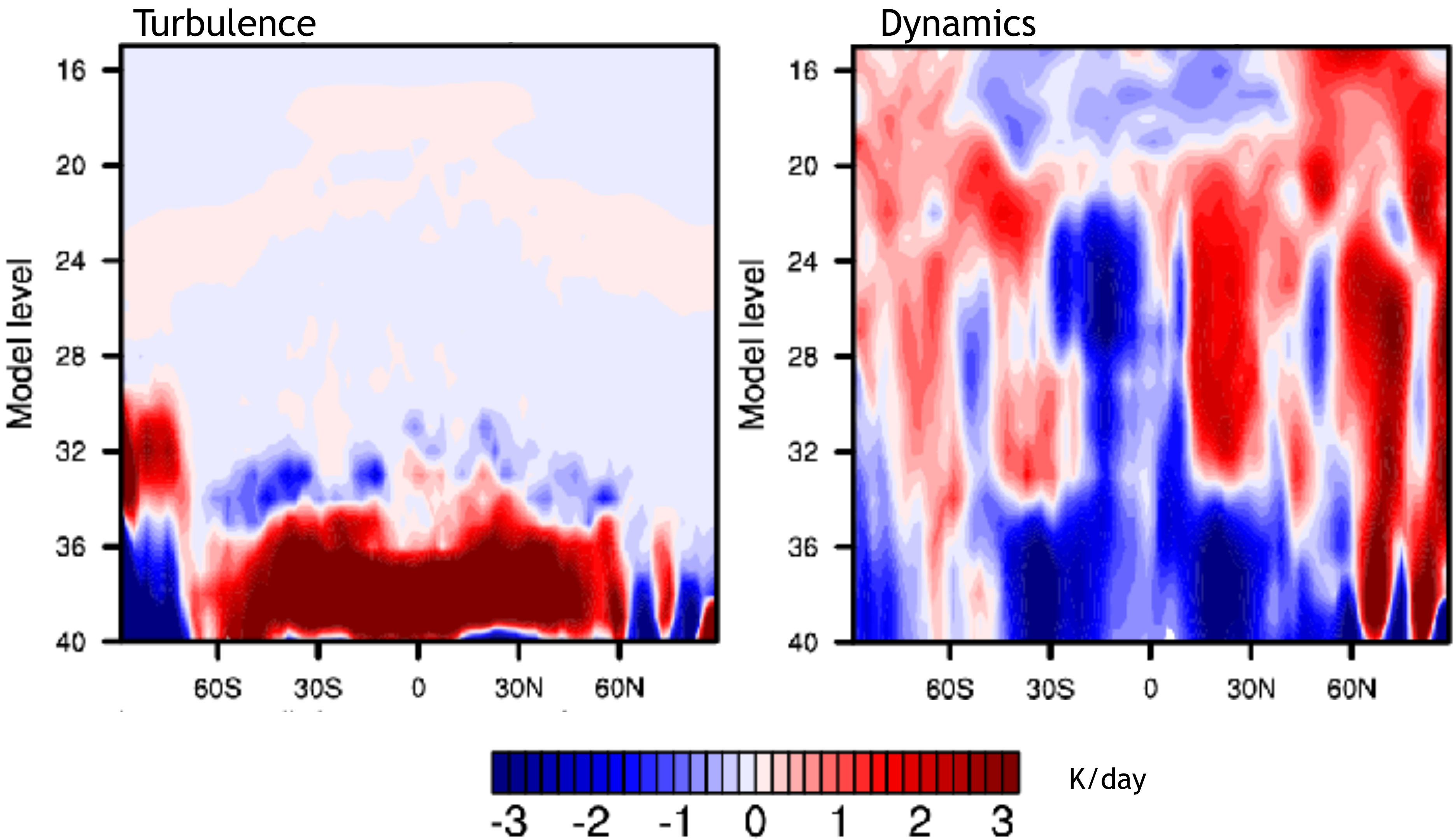
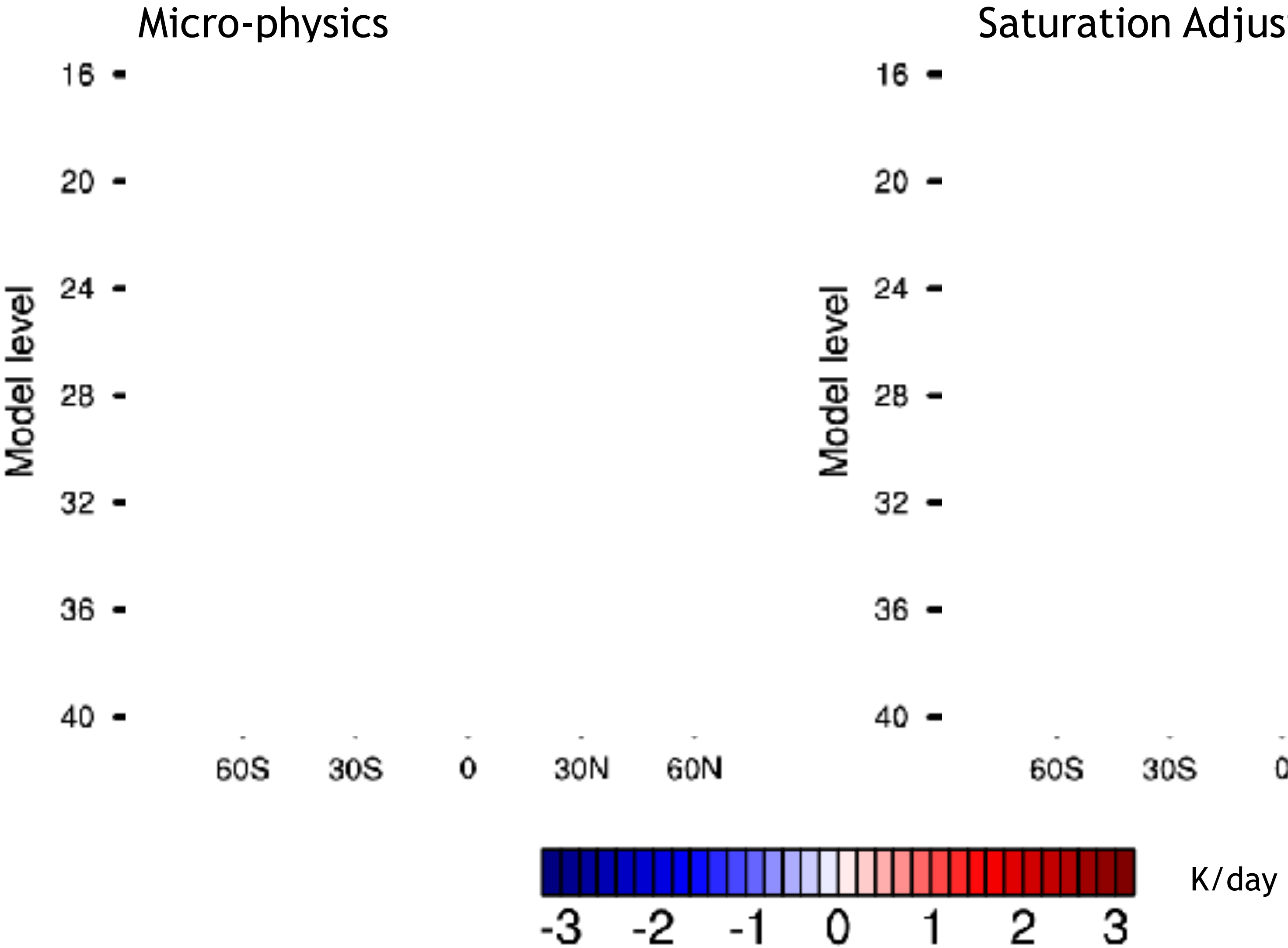
dT/dt turbulence and dynamics



January 2012

dT/dt microphysics and sat. adj.



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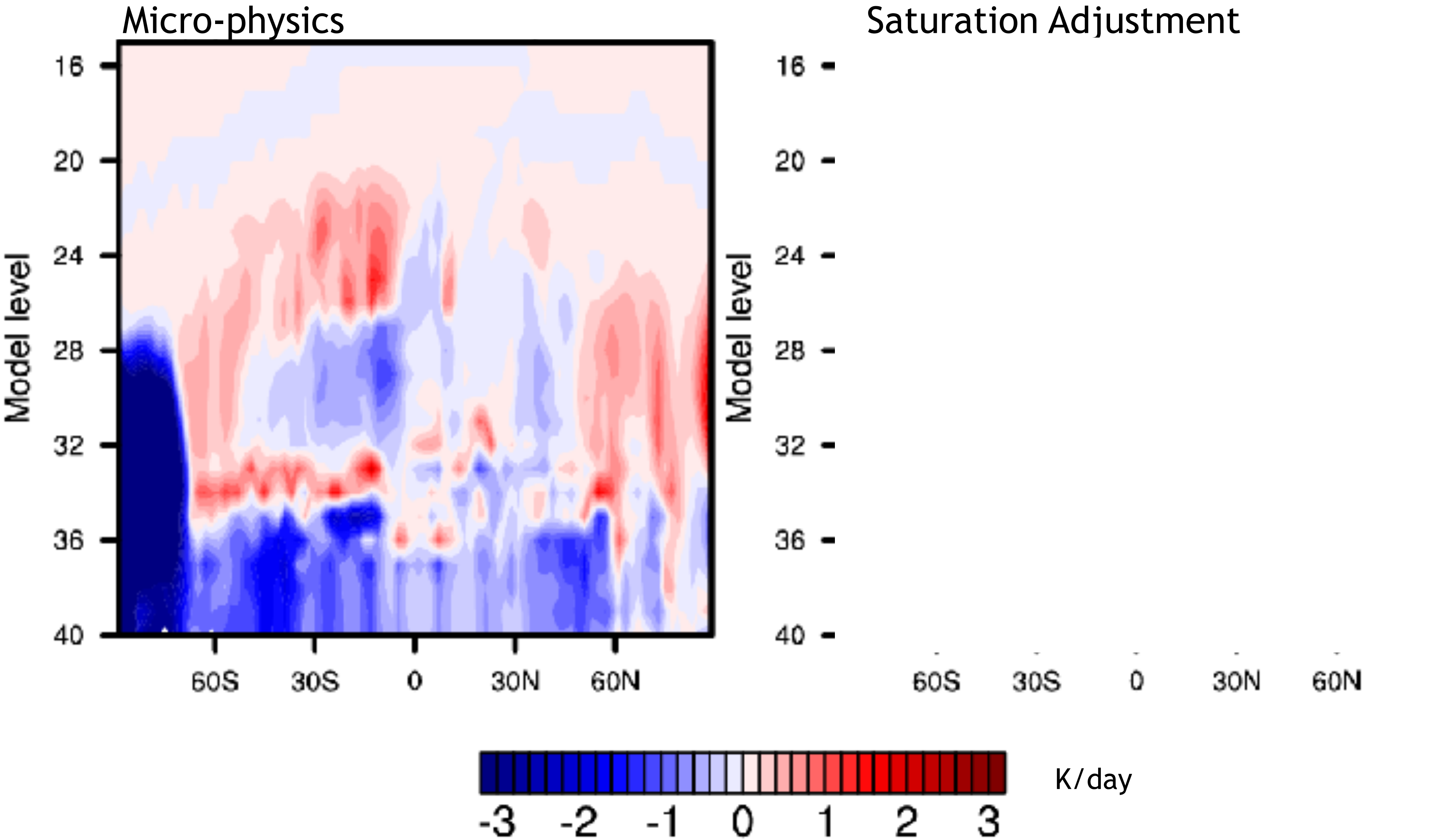

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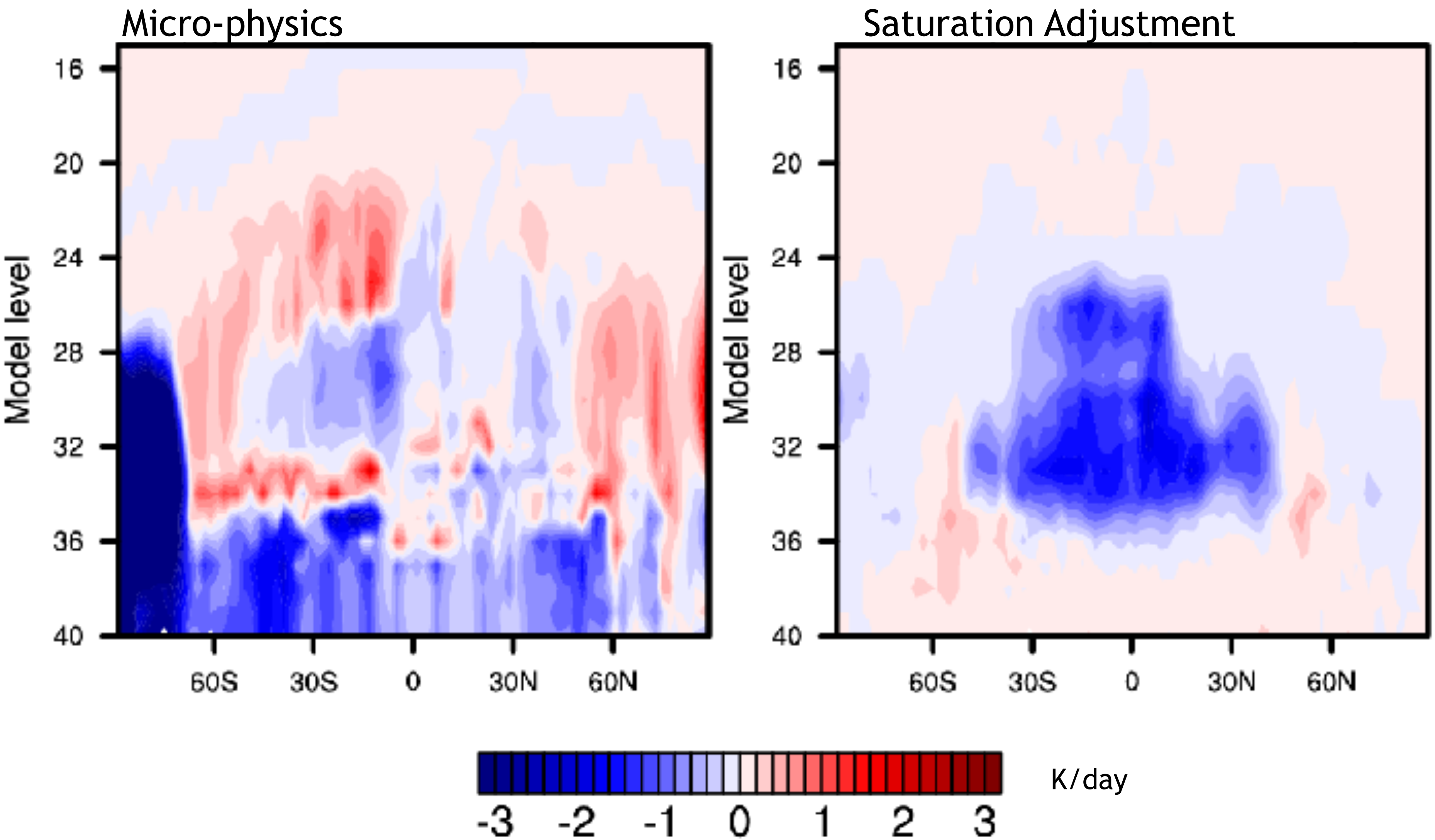

An in-depth introduction to some of the individual schemes used for numerical weather prediction in ICON at DWD will be given later today and tomorrow.

Thank you!