Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Optical properties of atmospheric snow in ICON

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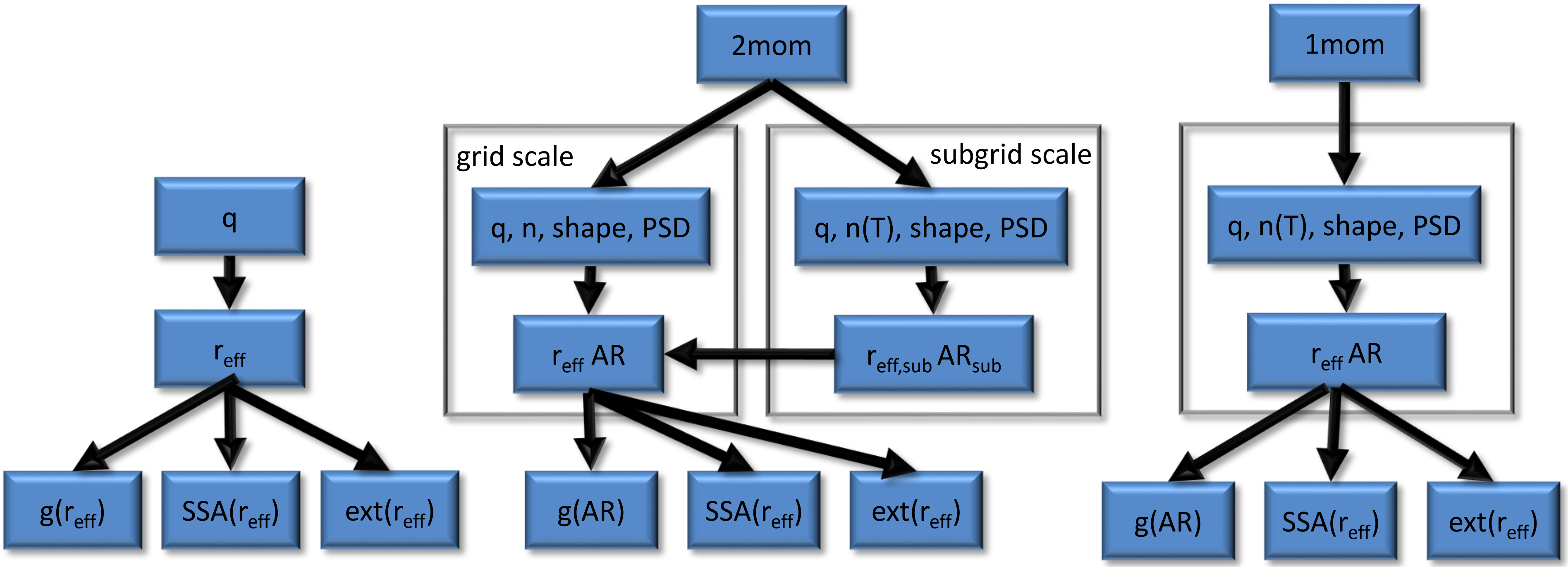
DWD, Israel Meteorological Service

Jeff Kubina on Flickr

Optical Properties of Hydrometeors

- old:
- interpolating tables of $r_{eff}(q)$
- cloud ice, cloud droplets

- new:
- explicitly consider number conc. (2mom)
- cloud ice, cloud droplets, rain, snow, (graupel)
- extension to large ice particles
- fits for RRTM



Optical Properties of Hydrometeors

Fu, 1996; Fu et al., 1998; Fu, 2007

$$r_e = \frac{\int V(L)n(L)dL}{\int \bar{A}(L)n(L)dL}$$

$$AR = \frac{\int \frac{D}{L}\bar{A}(L)n(L)dL}{\int \bar{A}(L)n(L)dL}$$

$$n(D) = N_0 D^{\upsilon} \mathrm{ext}[-\lambda D^{\mu}]$$

$$D = ax^b$$

$$g = \frac{a_0 + a_1\, AR + a_2 AR^2 + a_3 AR^3}{a_4 + a_5\, AR + a_6 AR^2 + a_7 AR^3 + a_8 AR^4}$$

$$SSA = \frac{b_0 + b_1\, r_e + b_2 {r_e}^2 + b_3 {r_e}^3}{b_4 + b_5\, r_e + b_6 {r_e}^2 + b_7 {r_e}^3}$$

$$ext = \frac{c_0 + c_1\, r_e + c_2 {r_e}^2}{c_3 + c_4\, r_e + c_5 {r_e}^2 + c_6 {r_e}^3}$$

Code overview: icon-nwp-cloud-opt

50 pages of additions & changes

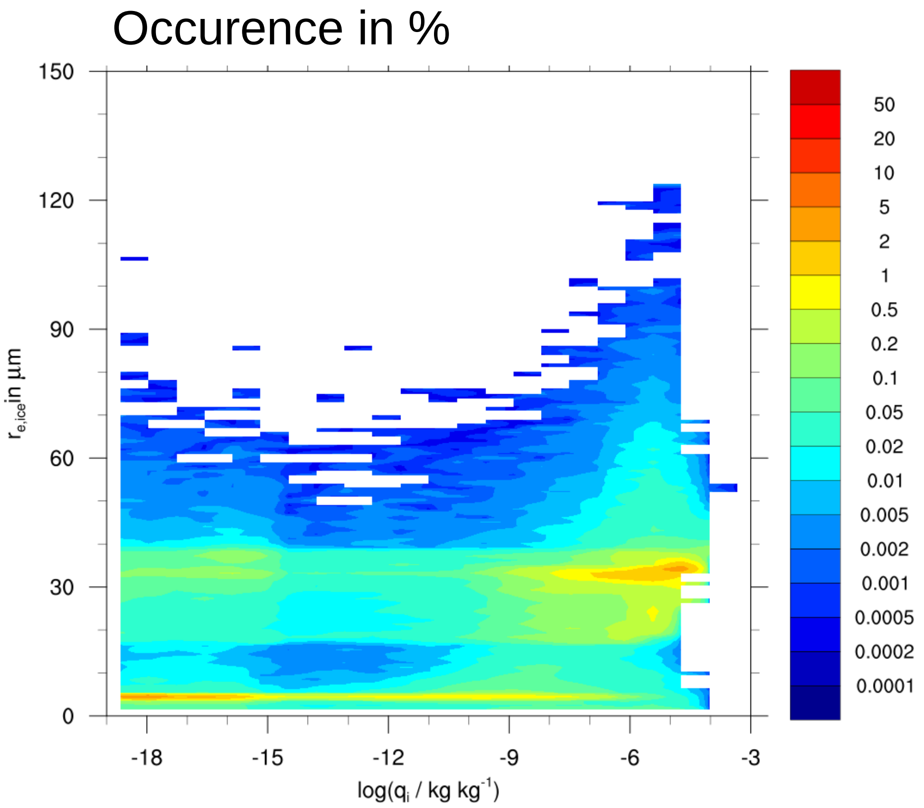
- mo_art_cloud_opt.f90
- mo_art_cloud_opt_calc.f90
- mo_art_cloud_opt_data.f90
- mo_art_cloud_opt_util.f90
- mo_newcld_optics.f90
- mo_nwp_rrtm_interface.f90
  - 6 calls to radiation_nwp (full grid and reduced)
    - icalc_opt=0: qv,qc,qi — OLD
    - irad_use_2mom=1: qv,qc,qi,qr,qs — 1mom
    - irad_use_2mom=2: … & qnc… — 2mom

current namelist parameters:

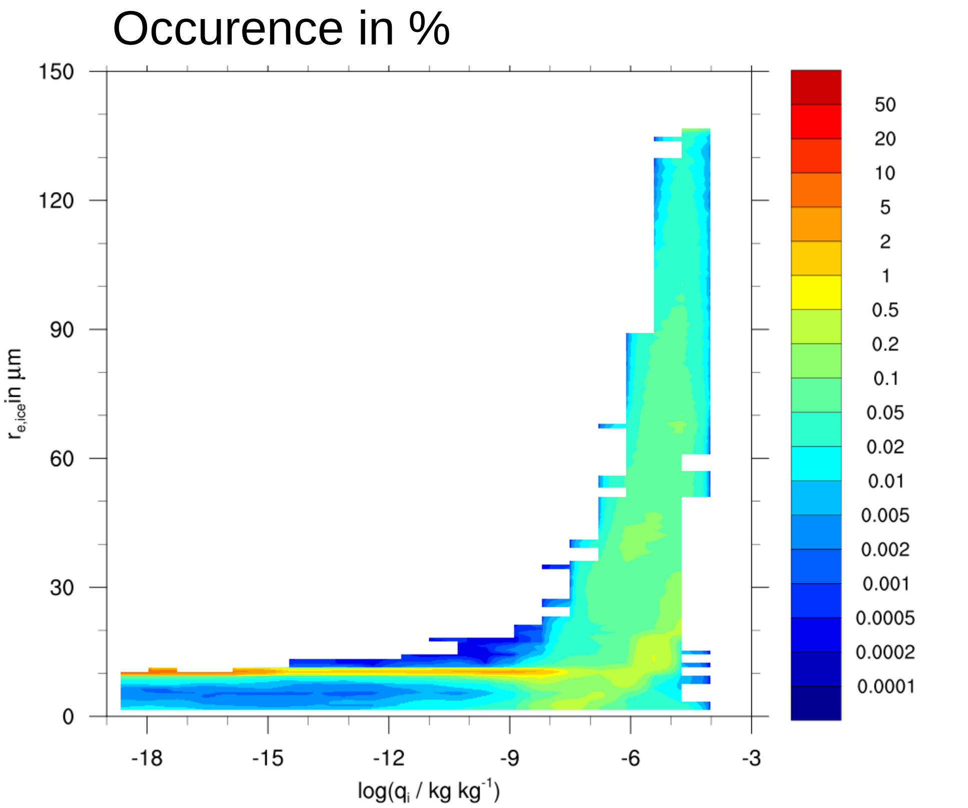
```
icalc_opt                 = 1        ! 0 : ECHAM, 1 : Fu 1996
irad_use_2mom             = 1        ! reff for 1mom; 2mom (1,2)
lrad_incl_qrqsqg          = .true.   ! snow and graupel radiation
lrad_use_largesizeapprox  = .false.  ! true: from 150um new Blahak
lrad_ice_smooth_surfaces  = .false.  ! not used (smooth or rough ice)
lrad_ice_fd_is_gsquared   = .true.   ! not used
```

1mom: reff vs qi

old

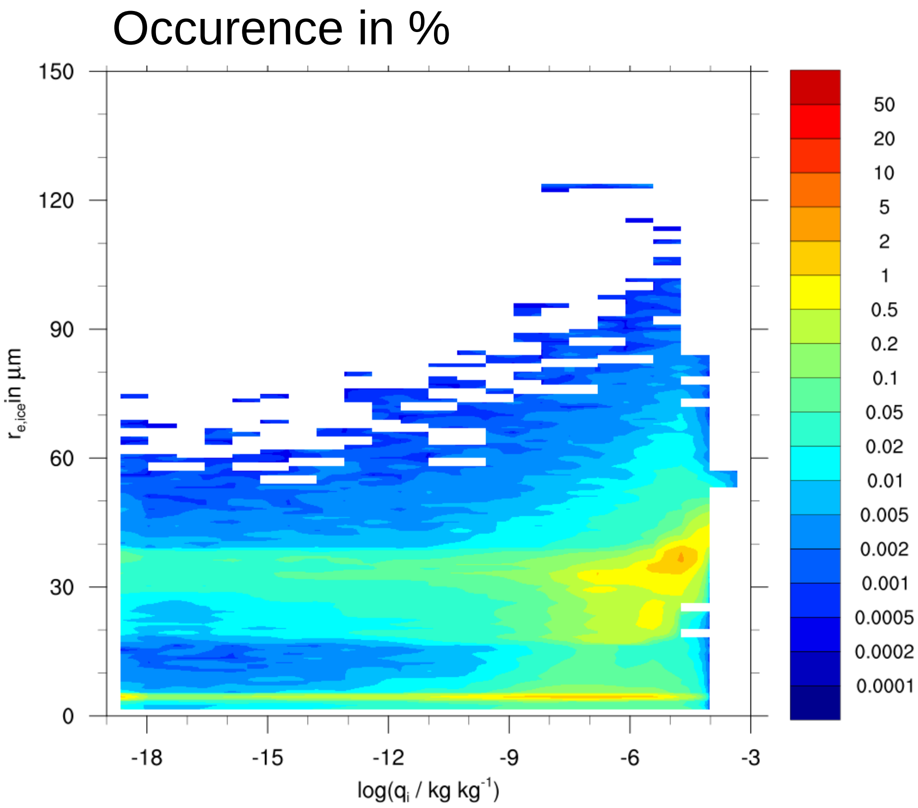


new

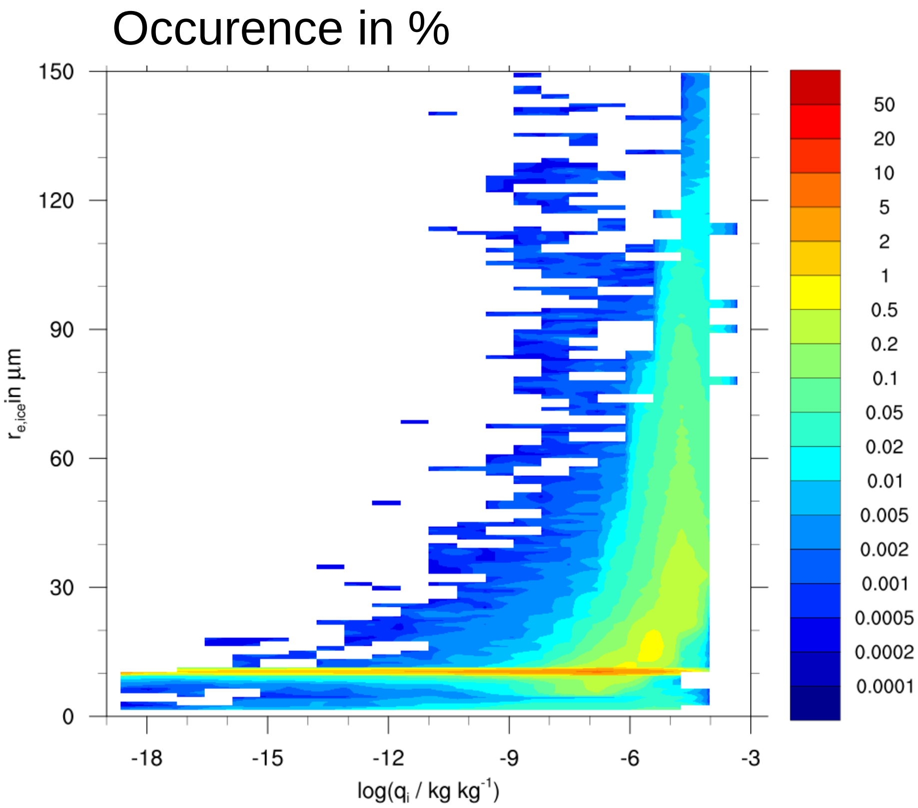


2mom: reff vs qi

old

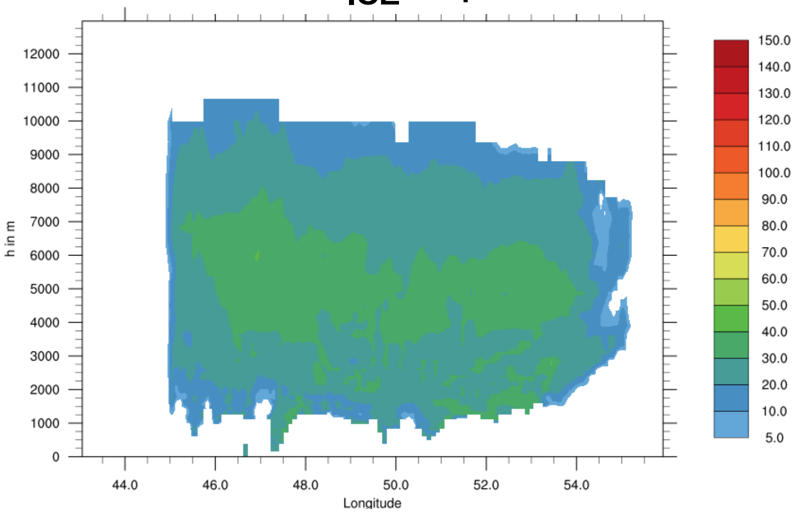


new

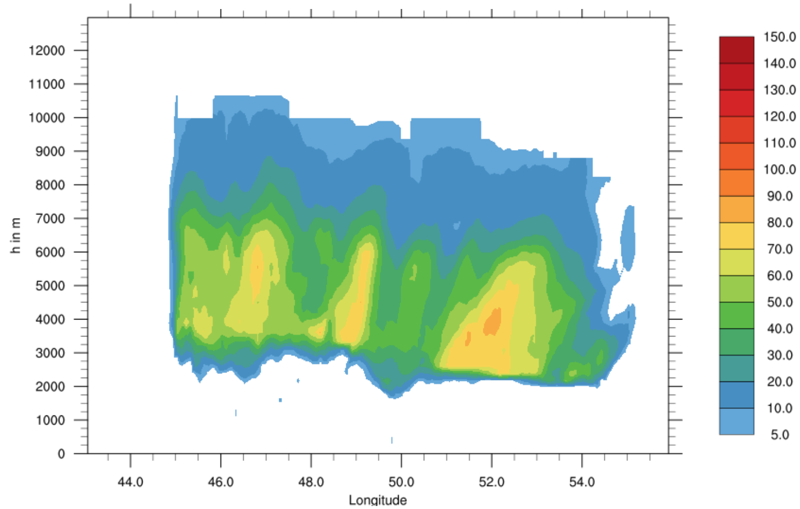


1mom: reff and ddt

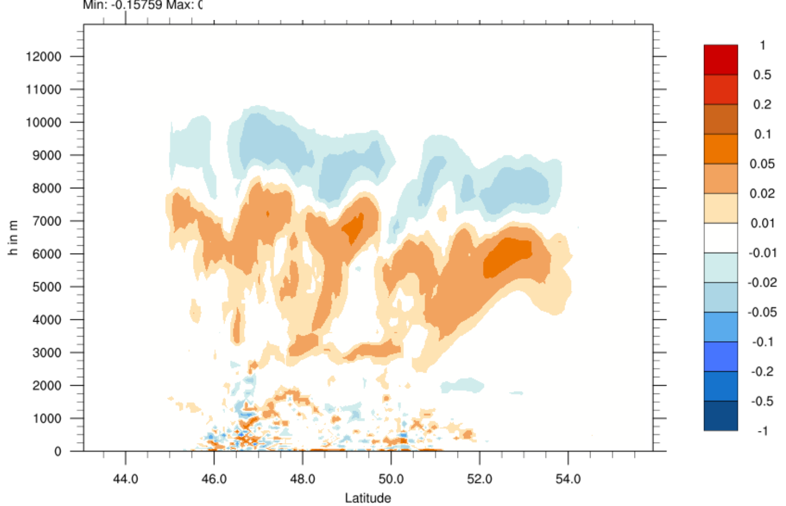
old re_{ICE} in µm



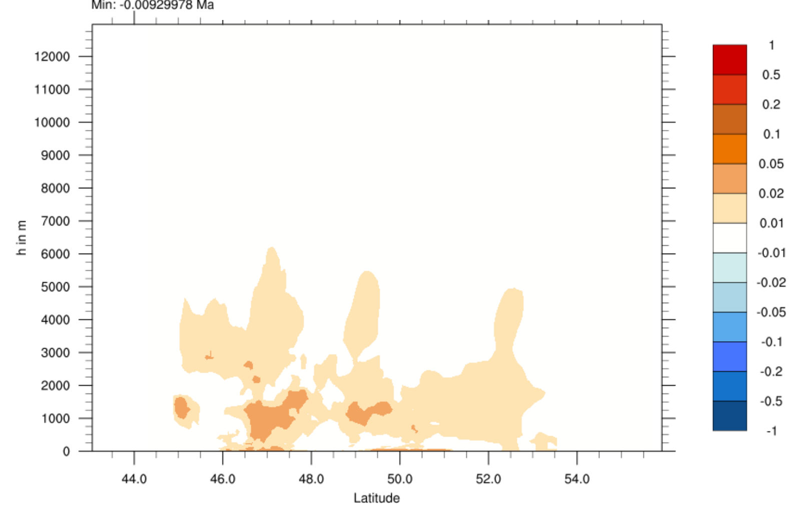
new re_{ICE} in µm



diff ddt lw in K h^{-1}

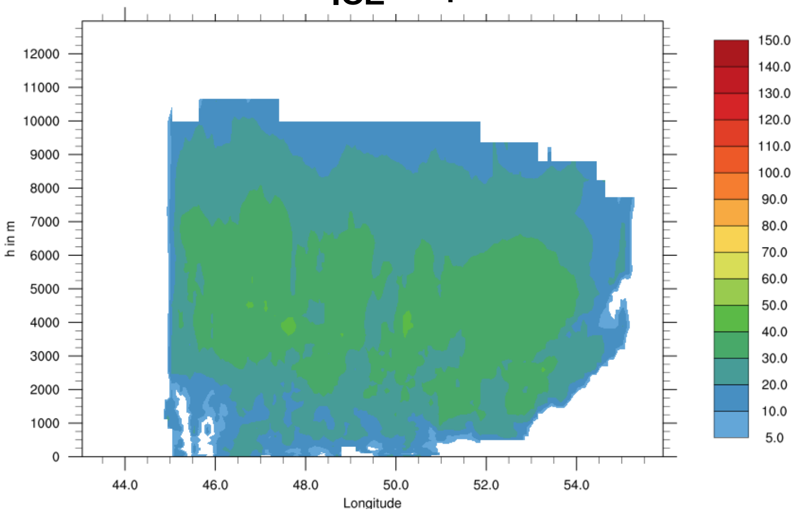


diff ddt sw in K h^{-1}

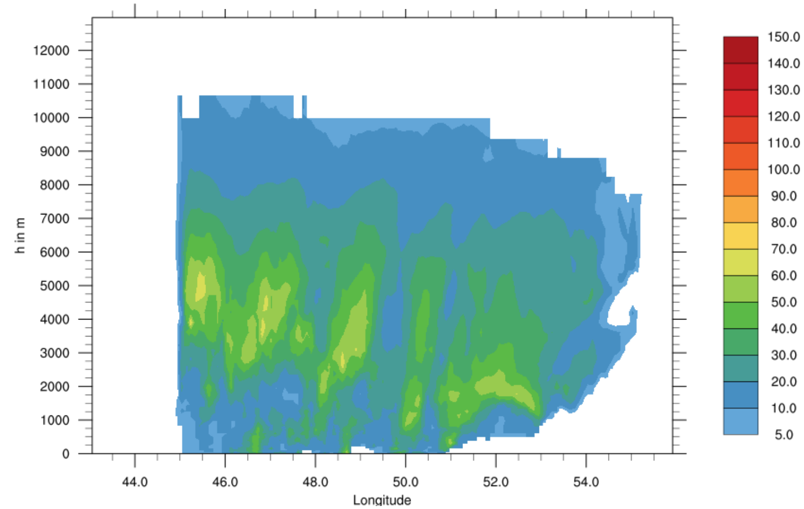


2mom: reff and ddt

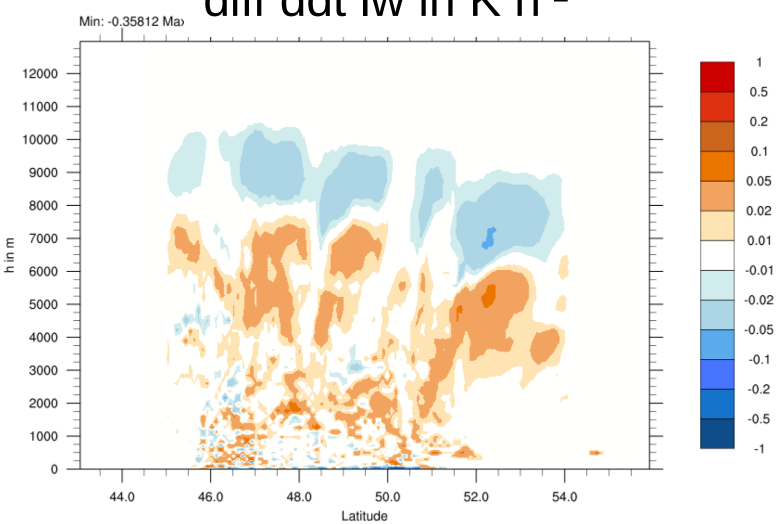
old re_{ICE} in µm



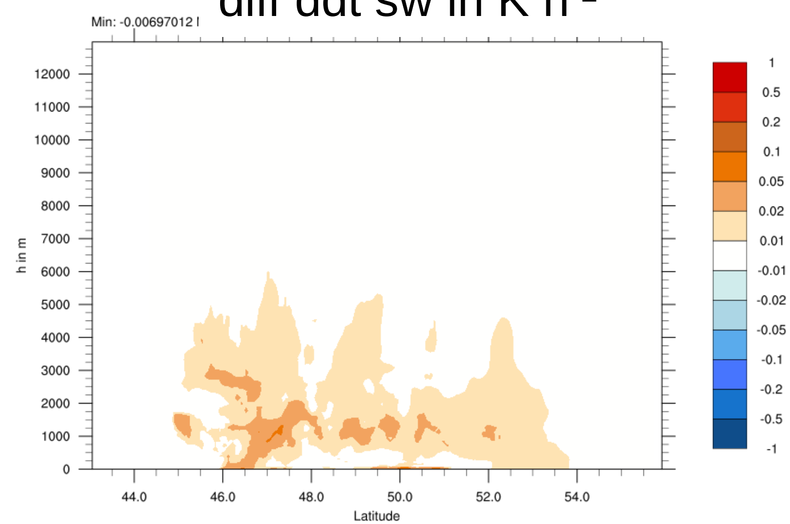
new re_{ICE} in µm



diff ddt lw in K h^{-1}



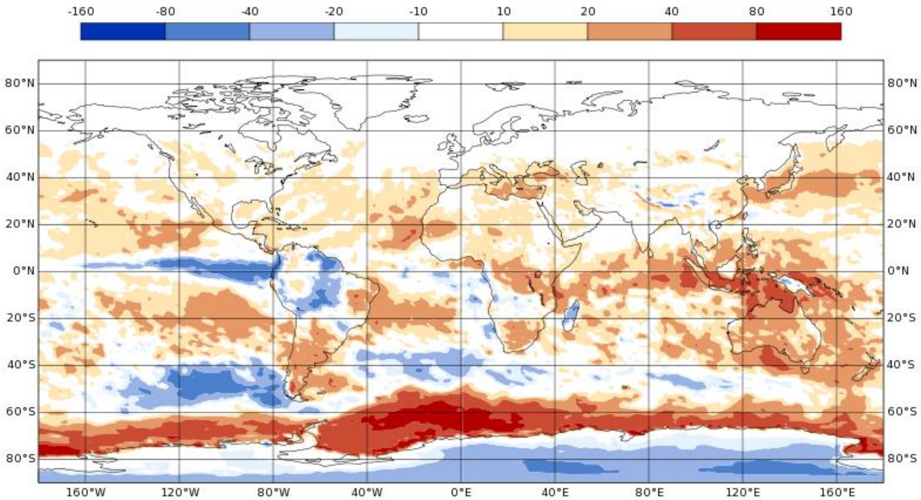
diff ddt sw in K h^{-1}



net top solar

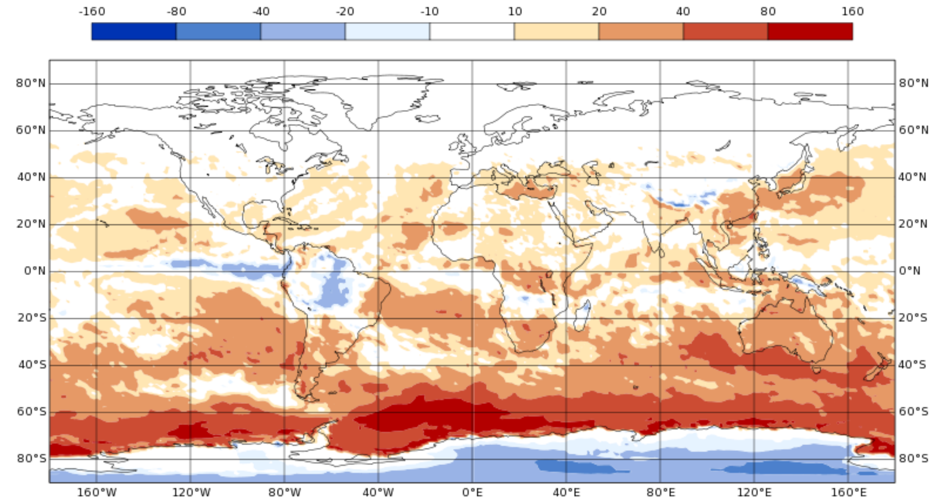
new-optic - CERES

bias:
9.9 W/m²



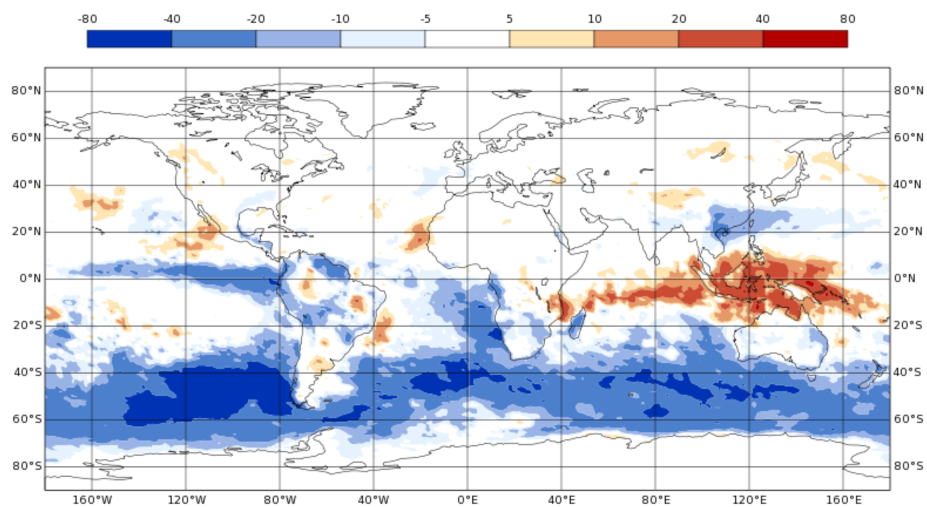
ICONdefault - CERES

bias:
16.2 W/m²



new-optic - ICONdefault

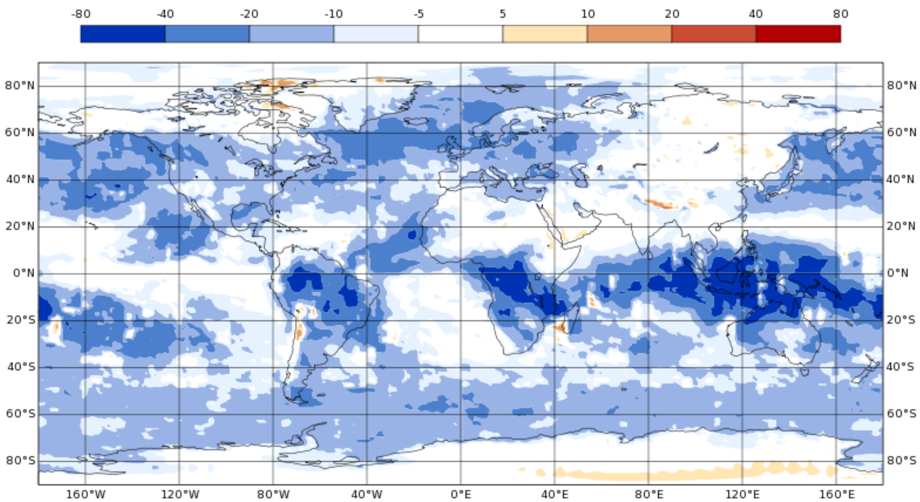
diff:
- 6.3 W/m²



outgoing long-wave

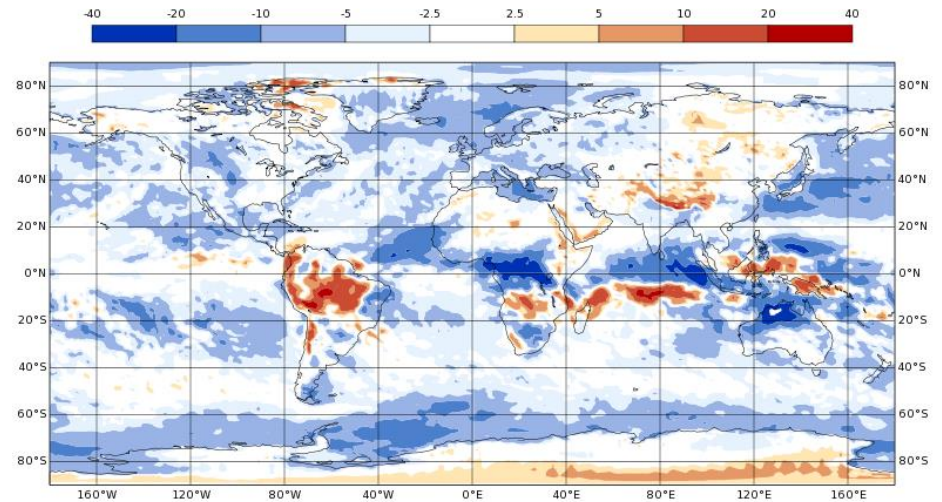
new-optic - CERES

bias:
- 13.8 W/m^2



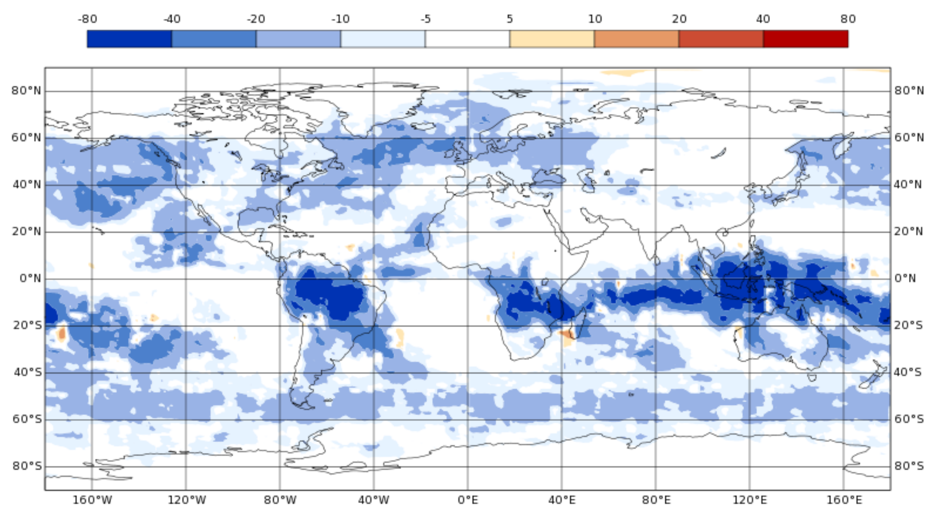
ICONdefault - CERES

bias:
- 3.7 W/m^2



new-optic - ICONdefault

diff:
-10.1 W/m^2

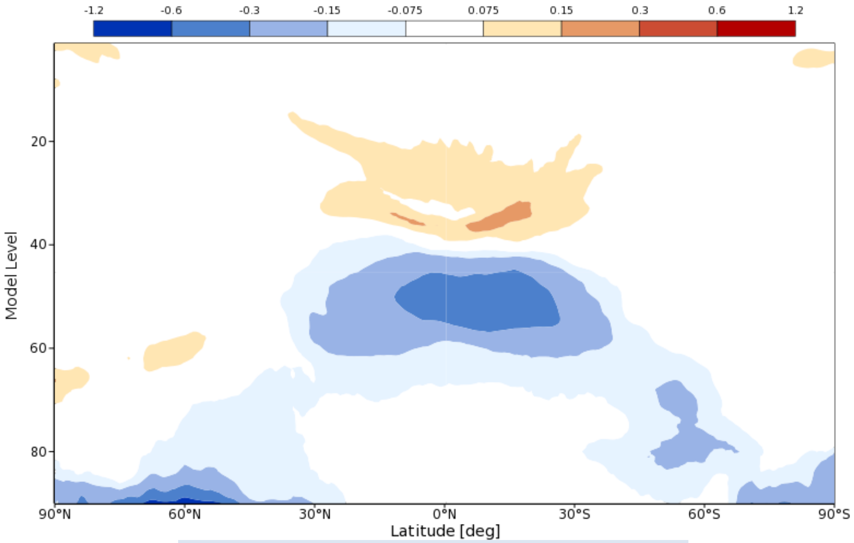


cloud-opt vs default

201201 24h forecast

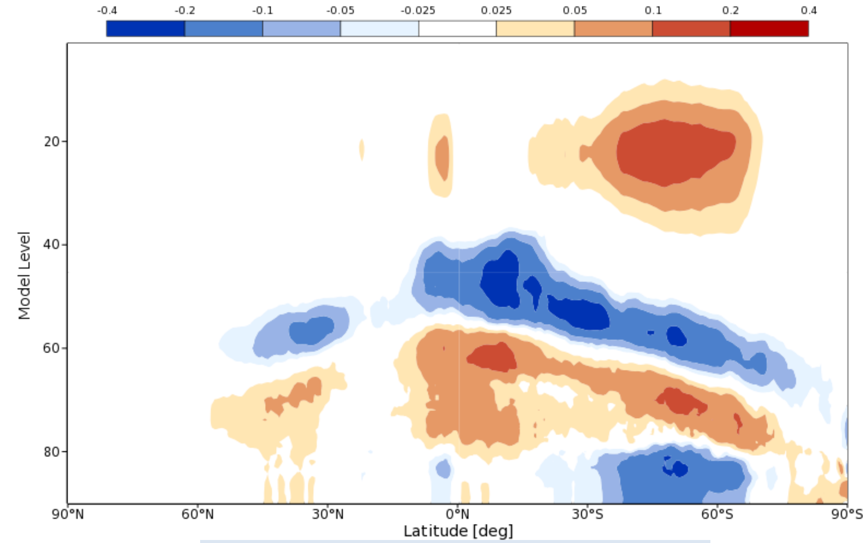
temperature [K]

Min: -1.02 Max: 0.2052 Mean: -0.04179 RMS: 0.1041 Mem: 31



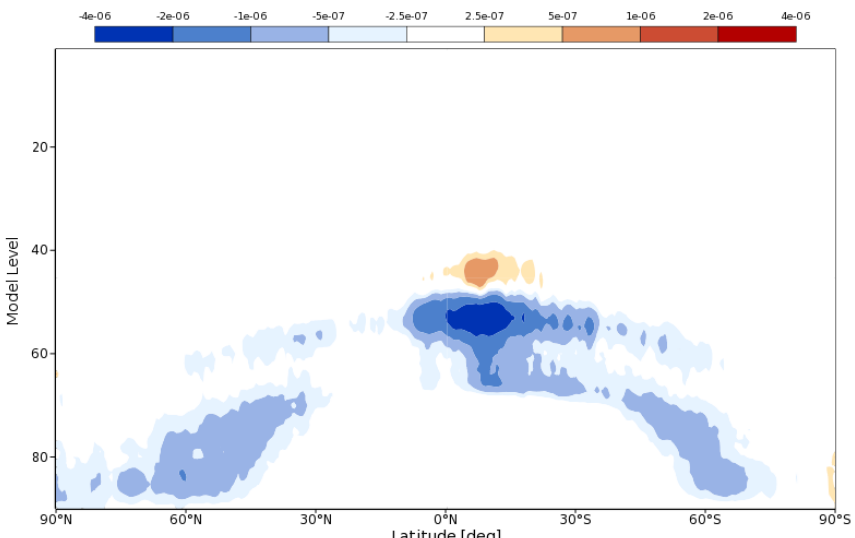
SW tendency [K/day]

Min: -0.298 Max: 0.1746 Mean: -0.001798 RMS: 0.05299 Mem: 31



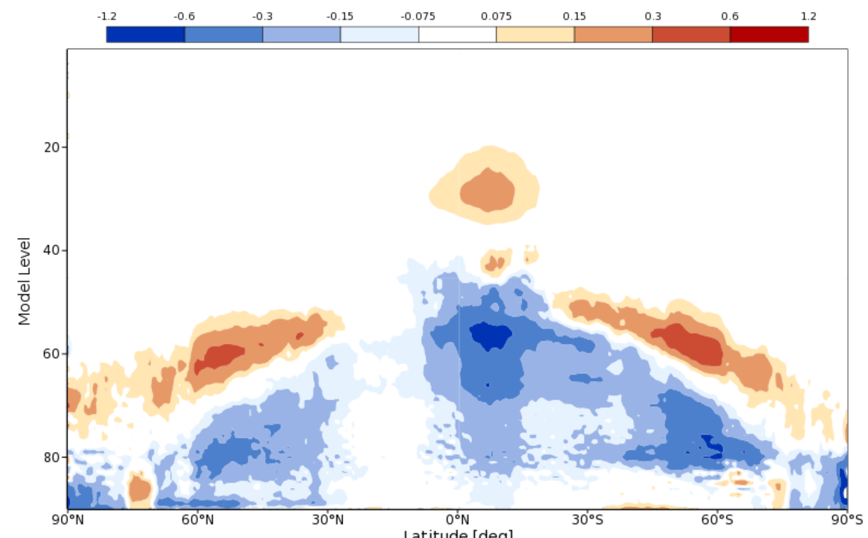
diag. ice water content [kg/kg]

Min: -3.719e-06 Max: 9.746e-07 Mean: -1.272e-07 RMS: 3.191e-07 Mem: 31



LW tendency [K/day]

Min: -1.244 Max: 0.4671 Mean: -0.03985 RMS: 0.1424 Mem: 31



issues: radiation workshop 201709 at DWD

- bias:
  - optically thicker in SW (6.3 W/m2) good
  - warmer OLR (10.1 W/m2) bad
  - tune $r_{e,ice}$ (=>N_{eff})
- debugging (calc_n0_snow)
- code cleaning:
  - 6 radiation calls with different argument lists
  - logicals as integers
- turn off old $q_{i,adj}=q_i+0.1q_s$
- n(T,snow) from Fields et al (2005)
  - mid-latitude
  - tropics (data needed)
- n_{ice}(T) separately for
  - microphysics (for sedimentation)
  - radiation

Extra slides

work to do

- results:
  - optically thicker in SW (6.3 W/m2) good
  - warmer OLR (10.1 W/m2) bad

- model dies in subroutine calc_n0_snow
  - calculate snow number concentration
  - T-dependent moment relations (Field et al 2005)

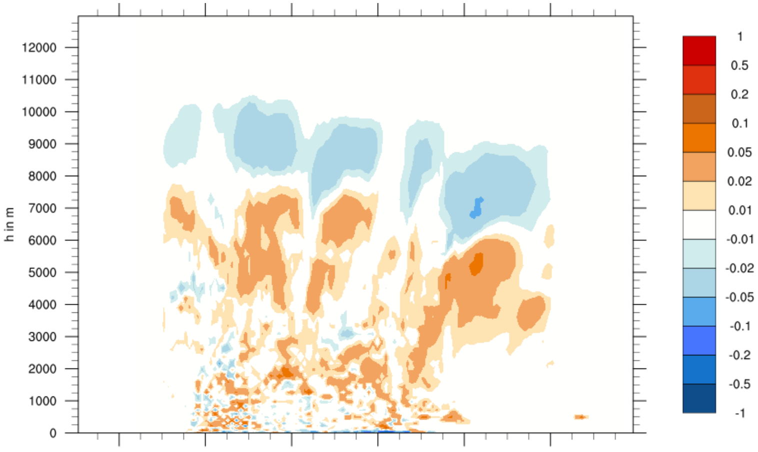
- single-scattering albedo (a-1?), extinction coefficient

- any missing physics?
  - cloud optics for sub-grid and mixed-phase clouds
    (shallow cumulus, artic stratus, Southern oceans)

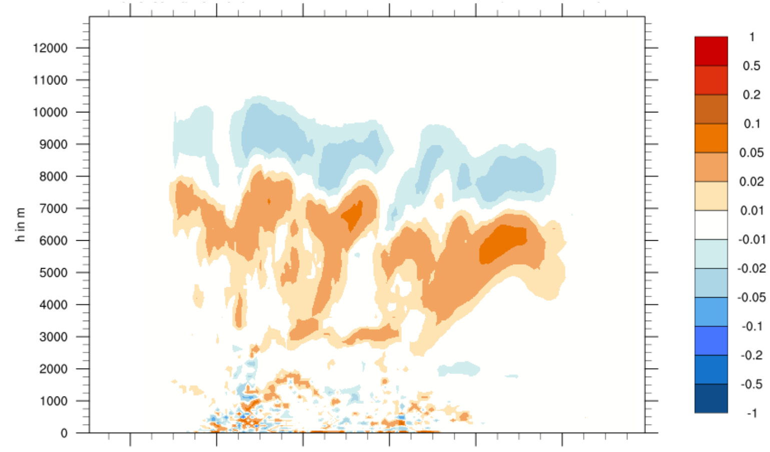
- make a list of work items left to do

Including Snow, diff ddt lw in K h^{-1}

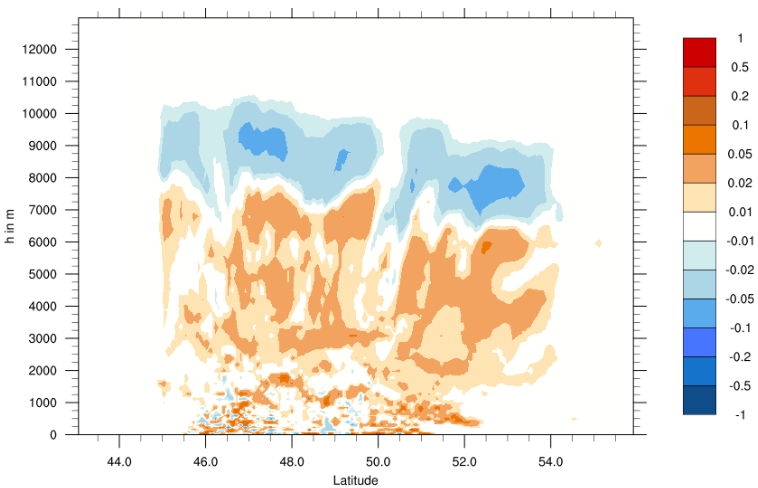
2mom, without snow



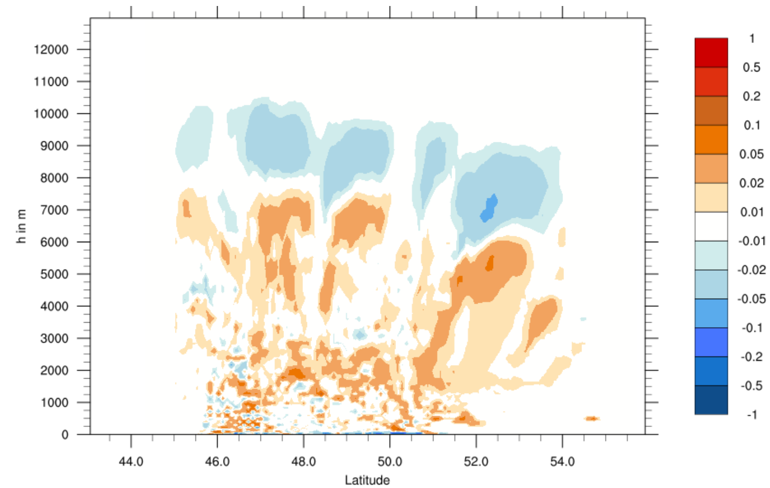
1mom, without snow



2mom, with snow



1mom, with snow



cloud and snow optics: ICON physics

- Ice optics: Fu 96 (SW) and Fu 98 (LW)
- Liq. optics: Key/Stamnes

  (r_e=5um or r_e=f(w*,…) or $r_e = \alpha \left(\frac{q_l}{CNC}\right)^{\beta}$)

- 2-moment cloud optics (qc, qi, qr, qs, qg and number concentrations)

- 1-moment cloud optics (qc, qi, qr, qs, (qg))

- snow optics: extension to large particles from Uli Blahak

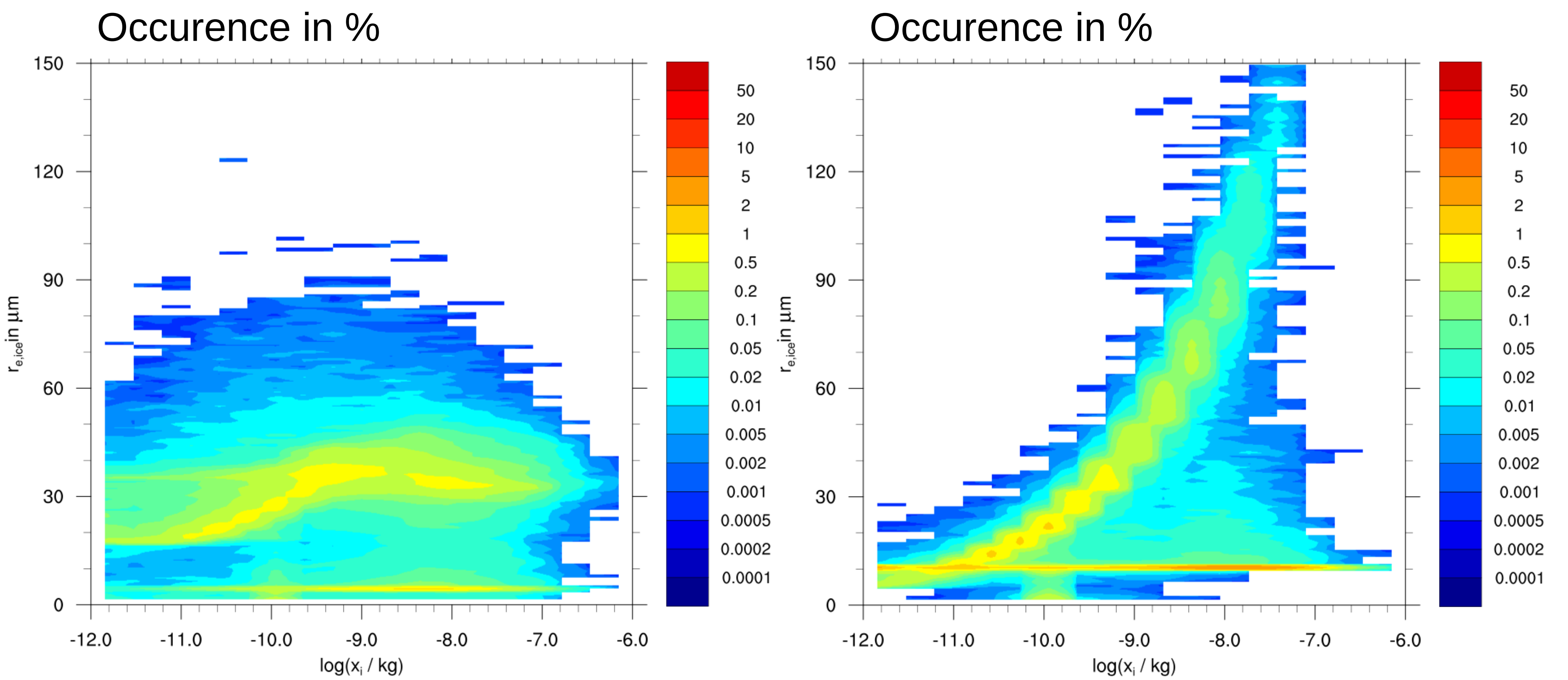
Current Status

- done
  - calculation of re(xi)
    - cloud ice, cloud droplets, rain, snow, graupel
  - fits for RRTM bands
  - „cloud cover“ for rain, snow and graupel
  - works with 1mom and 2mom

- to do
  - proper implementation into radiation interfaces
  - (fine-) tuning

2mom: reff vs xi

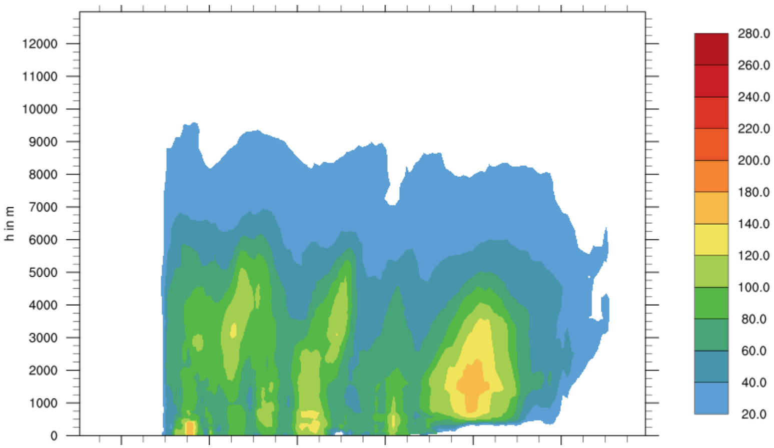
- old
- new



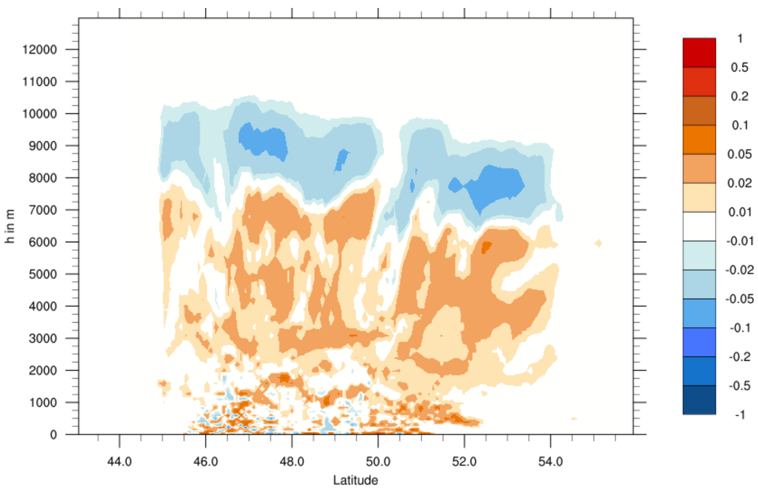
Snow

2mom

re_{SNOW} in µm

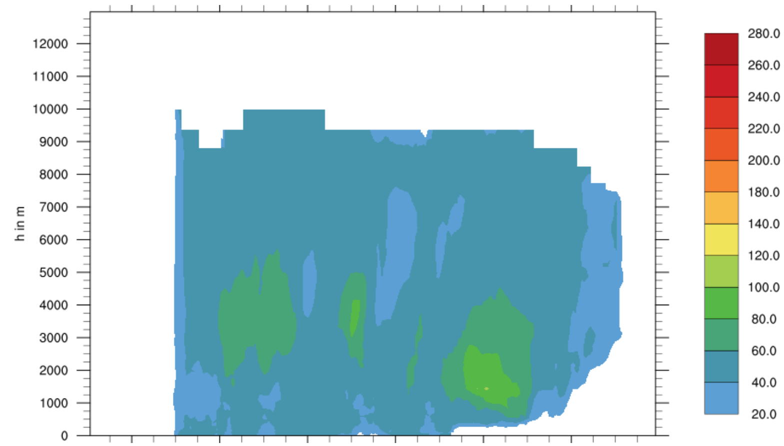


diff ddt lw in K h^{-1}

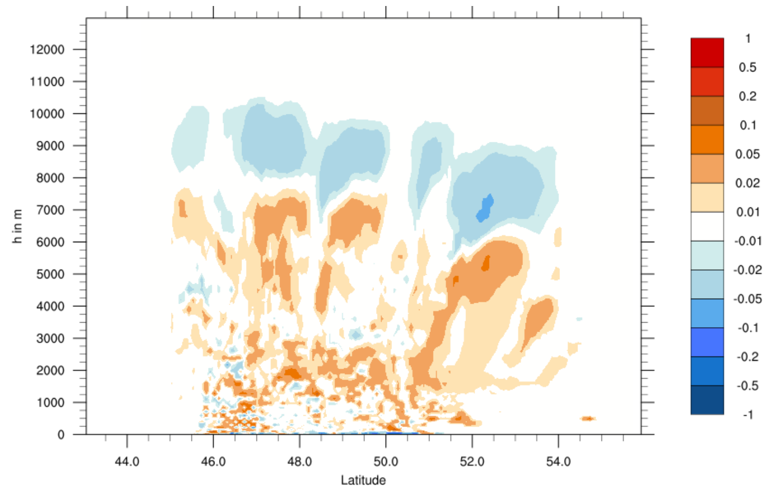


1mom

re_{SNOW} in µm

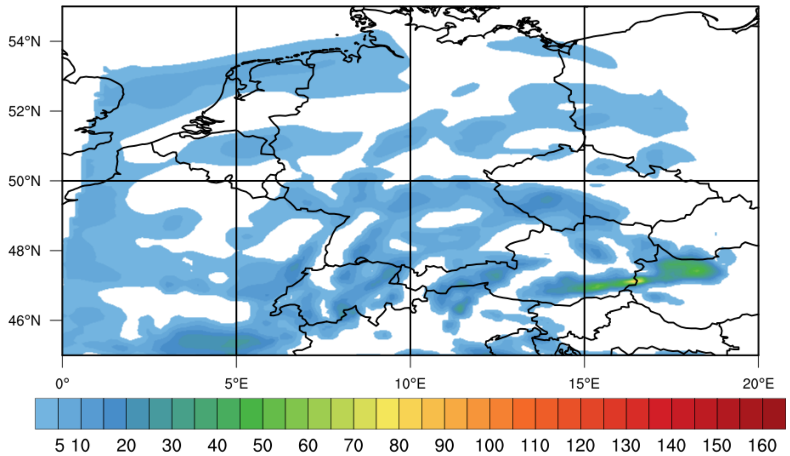


diff ddt lw in K h^{-1}



1mom: upper Troposphere, h = 8000 m

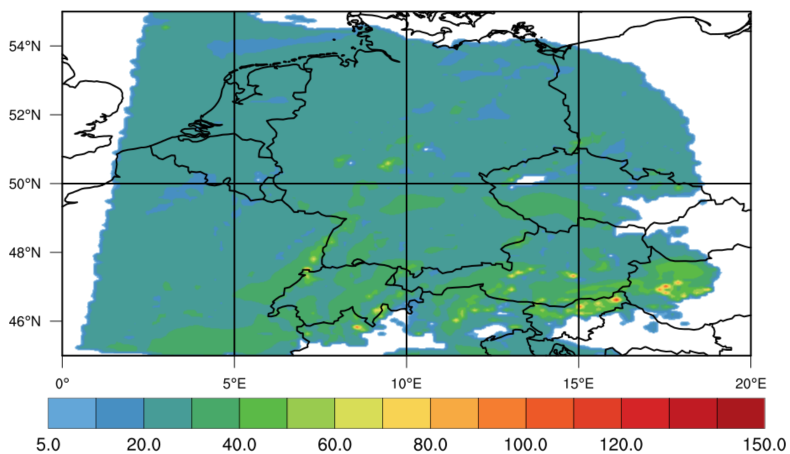
q_{ICE} in mg m^{-3}



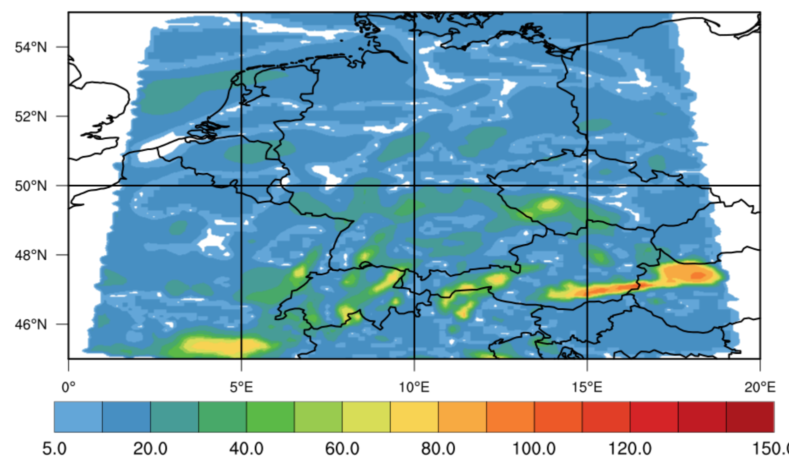
Case Study

- 2016.01.18 12 UTC
- ICON LAM
- R3B08 (~6.5 km)
- IFS init

old re_{ICE} in µm

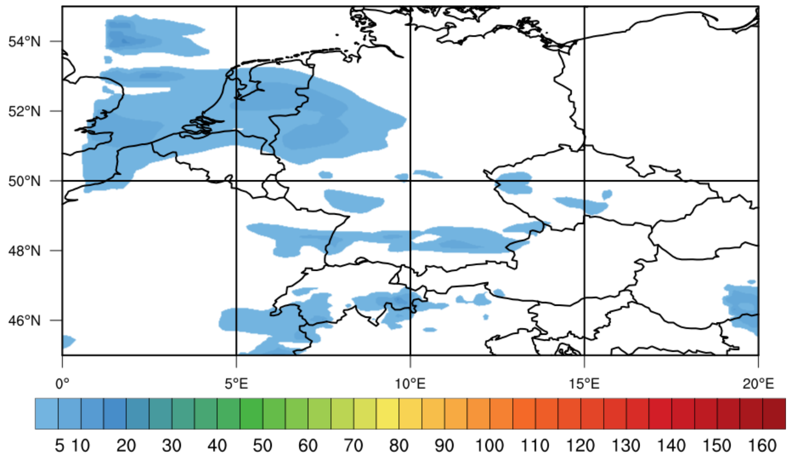


new re_{ICE} in µm

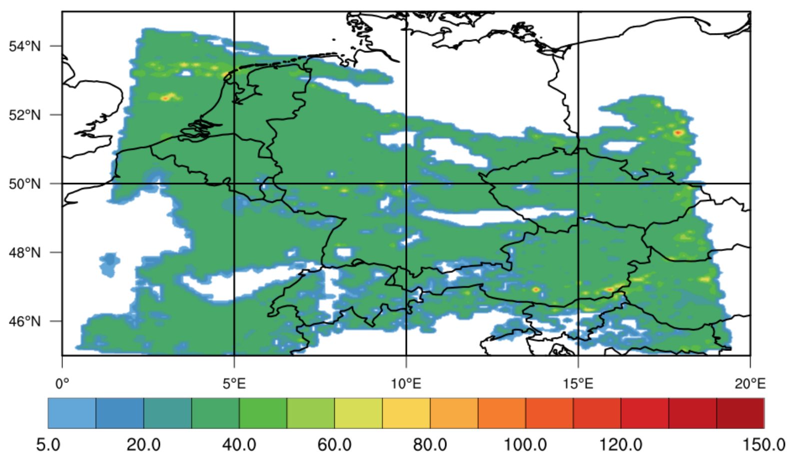


1mom: lower Troposphere, h = 3000 m

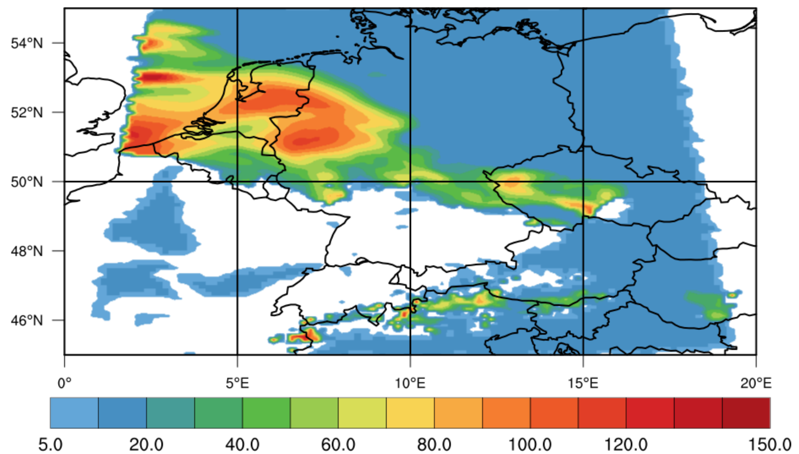
q_{ICE} in mg m^{-3}



old re_{ICE} in µm

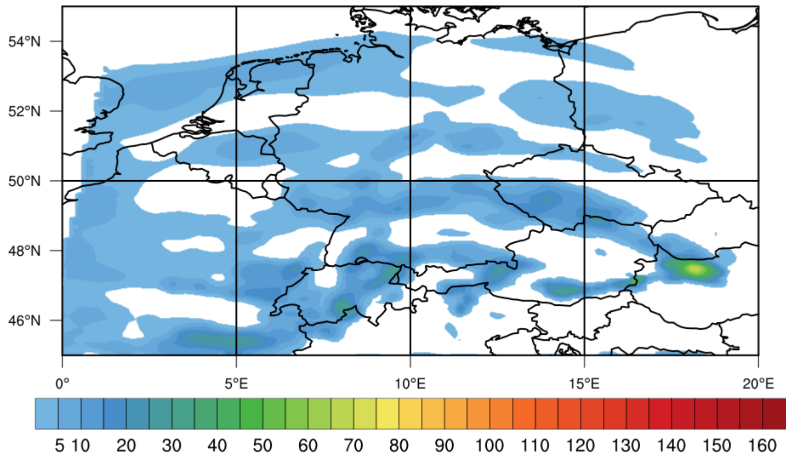


new re_{ICE} in µm

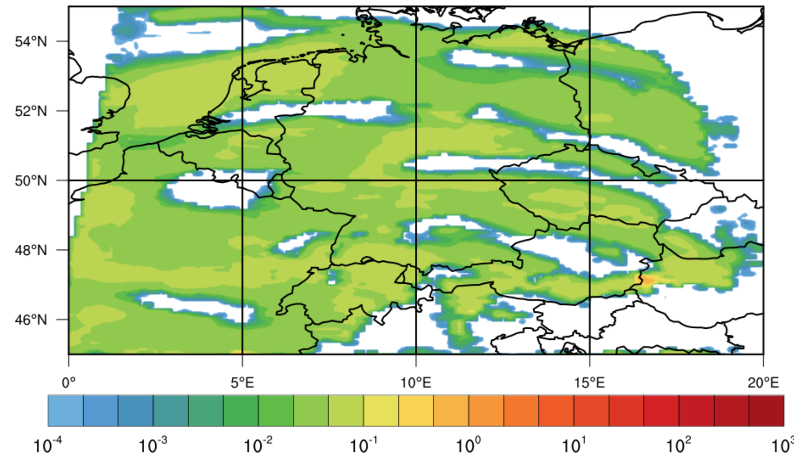


2mom: upper Troposphere, h = 8000 m

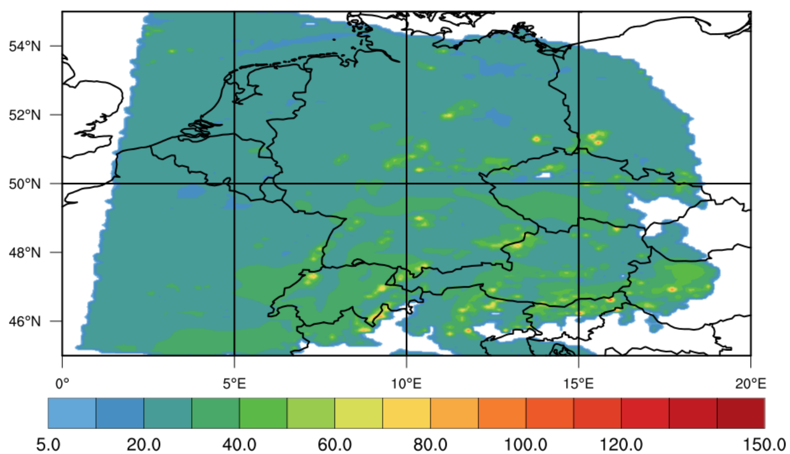
q_{ICE} in mg m^{-3}



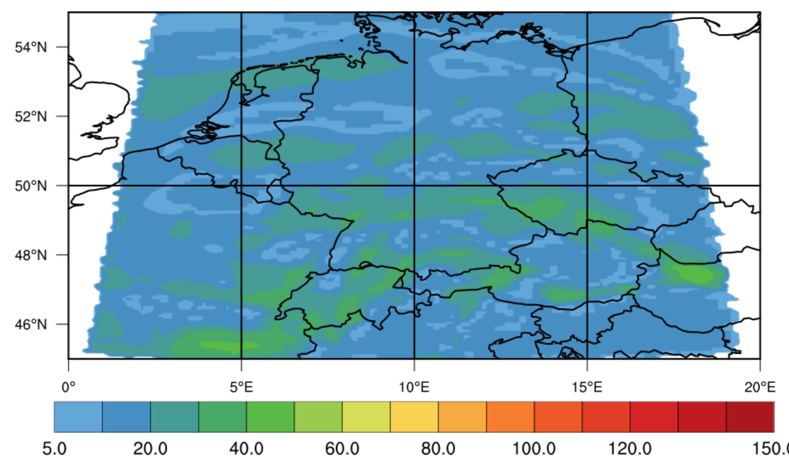
n_{ICE} in cm^{-3}



old re_{ICE} in µm

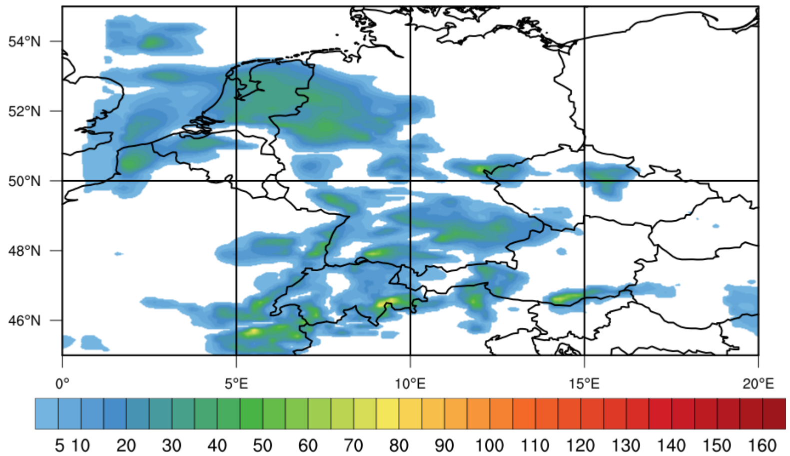


new re_{ICE} in µm

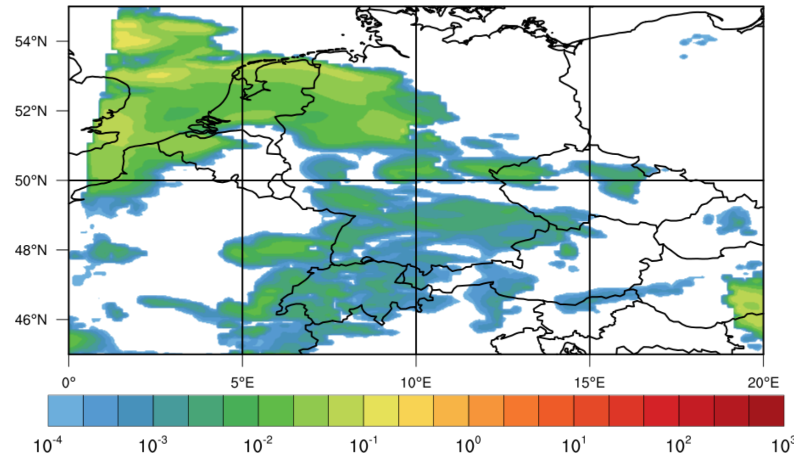


2mom: lower Troposphere, h = 3000 m

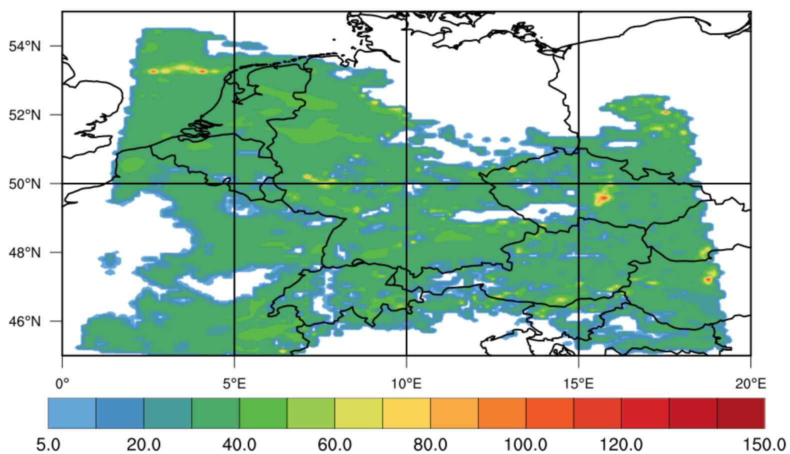
q_{ICE} in mg m^{-3}



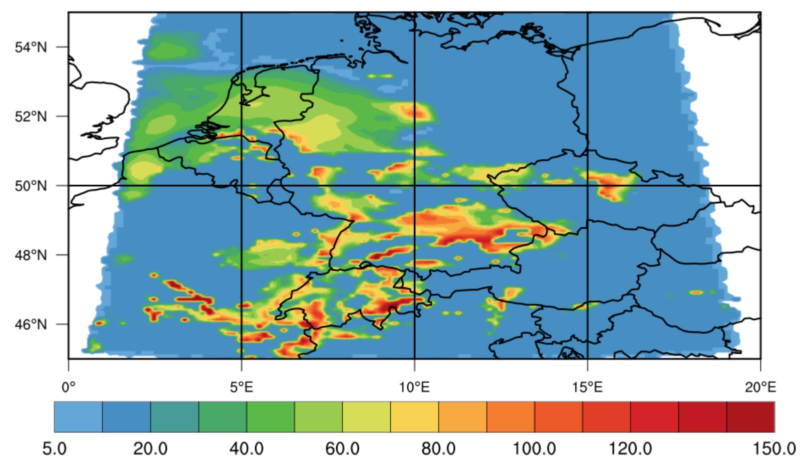
n_{ICE} in cm^{-3}



old re_{ICE} in µm



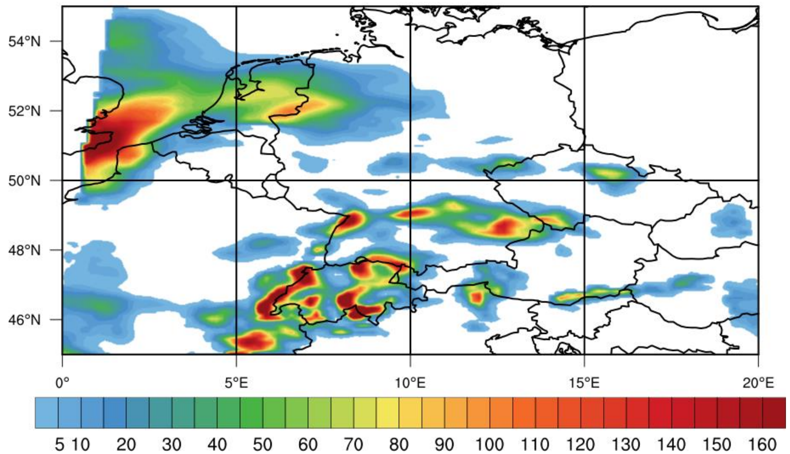
new re_{ICE} in µm



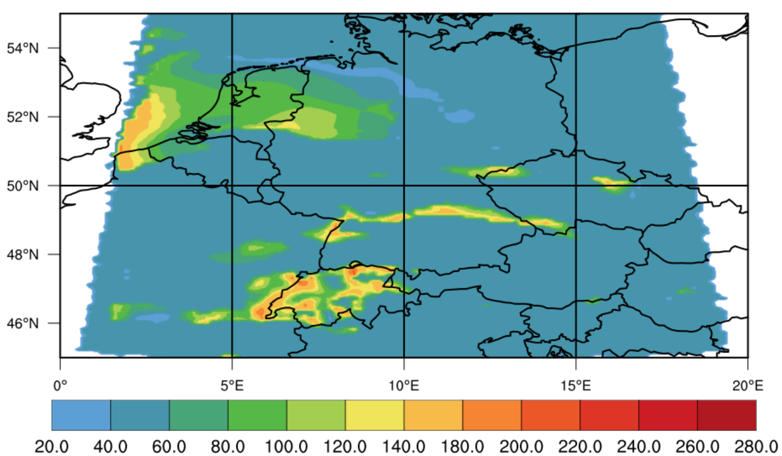
Snow, h = 3000 m

2mom

q_{SNOW} in mg m^{-3}

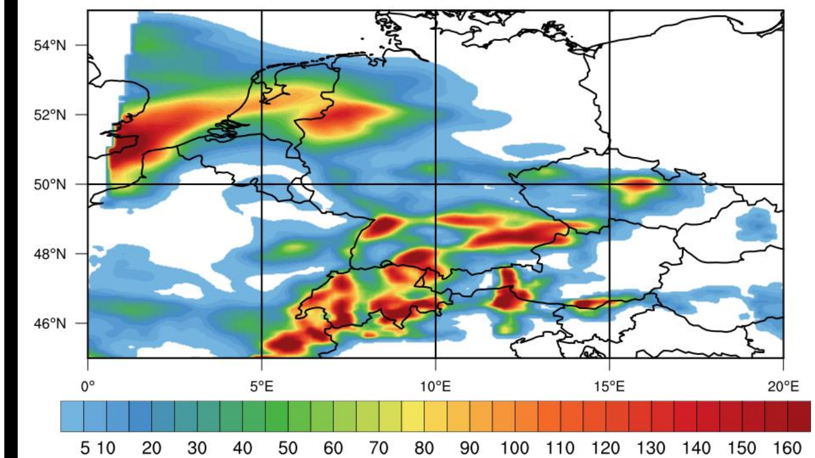


re_{SNOW} in µm

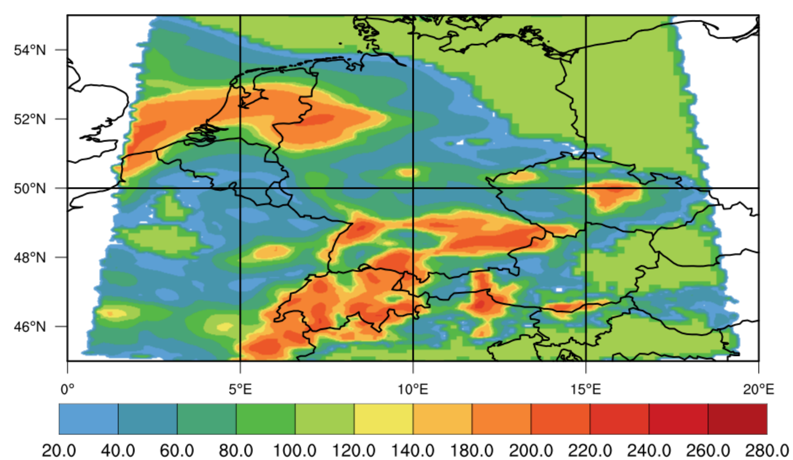


1mom

q_{SNOW} in mg m^{-3}



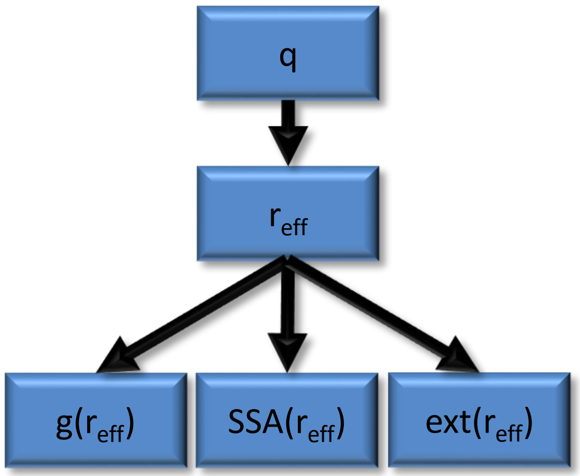
re_{SNOW} in µm



Simon Gruber DWD radiation talk 201709

Optical Properties of Hydrometeors

- old:
- interpolating tables of $r_{eff}(q)$
- cloud ice, cloud droplets



Issues

- general findings
  - new re_{ICE} smaller in upper layers → stronger cooling
  - new re_{ICE} larger in lower layers → stronger heating
- 1mom: re_{ICE} become very large in lower layers
  - tuning $n_{ICE}(T)$

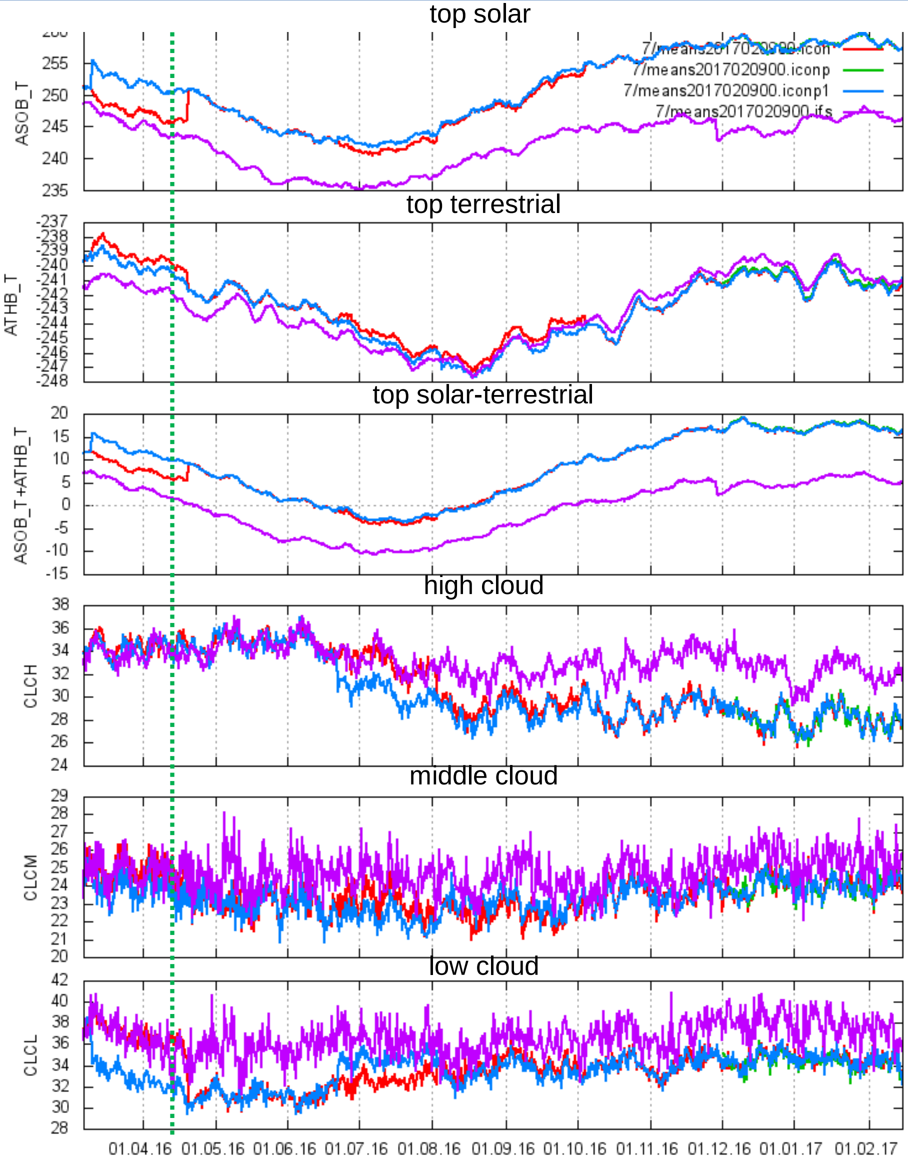
- 2mom: partly very low n_{ICE} → very large re_{ICE}
  - seamless ICON: using 2mom globally (40km) and nested (5km) ?

- using qi from microphyics or from cloud cover parameterization?

Martin DWD radiation talk 201709

ICON radiation bias

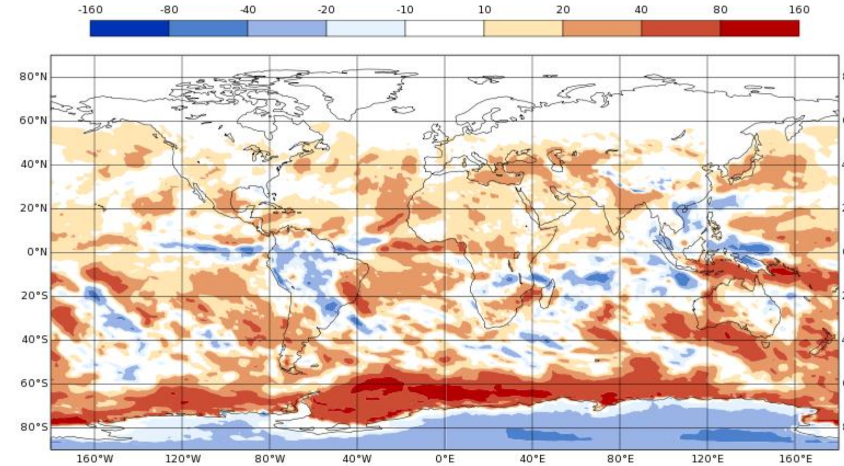
ICONoper ICONparallel IFS



Helmut Frank: 168h forecasts, global mean

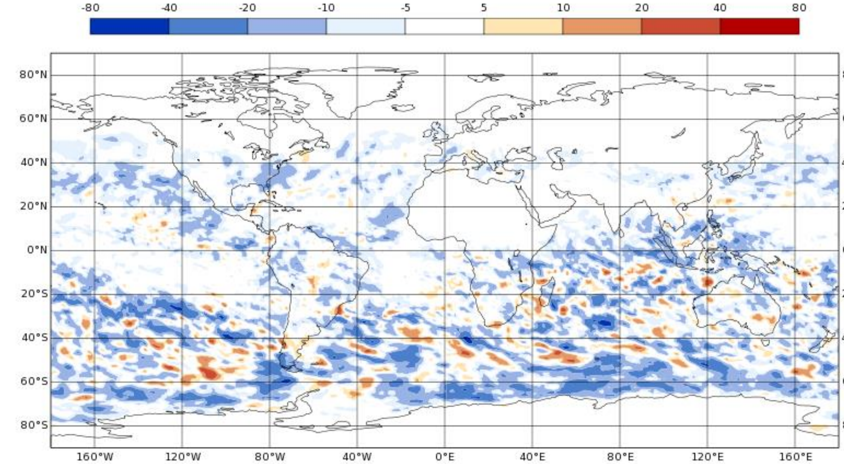
net top solar ICON - CERES

bias:
12.12 W/m²



TKE cloud input - default

difference:
4.81 W/m²



ICON R2B6 from IFS 240h forecasts from 201201

scores

dei2_296 vs. dei2_292 -- climate mean errors -- 31 forecasts from 20120101 + 24h sfc

variable	bias new,ref	rms new,ref
TOT_PREC	-0.169500 -0.173900	0.942200 0.912400
TCC	-0.0486400 -0.0514400	0.105300 0.105600
HCC	-0.0315800 -0.0286300	0.103700 0.0977800
MCC	-0.0187700 -0.0153300	0.0791100 0.0778900
LCC	-0.0359000 -0.0430300	0.116100 0.118800
TQV	0.0795000 0.0884200	0.559800 0.546600
TQC	-0.00549400 -0.00638600	0.0393500 0.0375800
TQI	-0.00771700 -0.00547900	0.0131400 0.0106600
ACCLHFL_S	0.780500 0.457100	11.1400 11.0300
ACCSHFL_S	-4.69000 -5.05400	14.0700 14.0600
ACCSOB_S	7.26200 13.2000	18.6000 18.8300
ACCTHB_S	-8.08200 -5.84100	10.2100 7.95100
ACCSOB_T	7.14200 13.4300	17.8600 18.3500
ACCTHB_T	-8.64300 1.44700	13.4200 4.20700
PS	-5.98500 -5.92000	535.400 535.400
T_2M	-0.270200 -0.102700	1.13700 0.964000
T_G	0.0630100 0.247200	1.64400 1.56300
U_10M	-0.0162600 -0.0360400	0.541500 0.536400
V_10M	0.0211100 -0.00161900	0.468800 0.461000

variable	bias new,ref	rms new,ref
W_SO L 1	-0.0151400 -0.0152200	0.140000 0.139700
W_SO L 2	-0.0299100 -0.0299800	0.257600 0.257100
W_SO L 3	-0.105200 -0.105400	0.662900 0.661400
W_SO L 4	-0.304500 -0.304900	1.55900 1.55600
W_SO L 5	-0.313100 -0.314200	2.36600 2.36600
W_SO L 6	-0.0906900 -0.0907600	1.13300 1.13300
W_SO L 7	-0.270500 -0.270600	3.39000 3.39000
W_SO L 8	-0.811800 -0.812300	10.1700 10.1700
T_SO L 1	0.0205400 0.0589800	0.908000 0.924800
T_SO L 2	0.0171800 0.0572200	1.02700 1.04000
T_SO L 3	-0.0137000 0.0228600	0.857800 0.864100
T_SO L 4	-0.0346400 -0.00607100	0.768500 0.765300
T_SO L 5	-0.0444800 -0.0288000	0.380700 0.370600
T_SO L 6	-0.0262600 -0.0245700	0.108400 0.107500
T_SO L 7	-0.00566600 -0.00565300	0.0550200 0.0550300
T_SO L 8	-0.000574100 -0.000585000	0.0461500 0.0461700
ACCSOB_T - CERES	9.88800 16.1700	22.7300 25.4500
ACCTHB_T - CERES	-13.8000 -3.70600	18.6000 6.78600
ACCLHFL_S - WHOI	-11.1500 -11.1400	18.7600 18.8300
ACCSHFL_S - WHOI	-6.03400 -5.83000	10.9300 10.7800
T_2M - WHOI	-0.658400 -0.622300	0.911600 0.882400
T_G - WHOI	-0.122100 -0.119800	0.605400 0.589000
SP_10M - WHOI	-0.473600 -0.441000	0.827900 0.805300

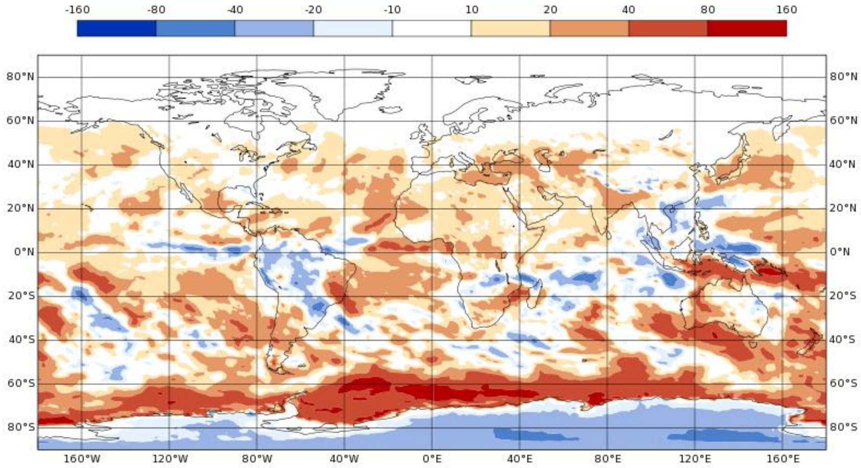
1.00 Percent bias

1.00 Percent rms

ICON radiation bias

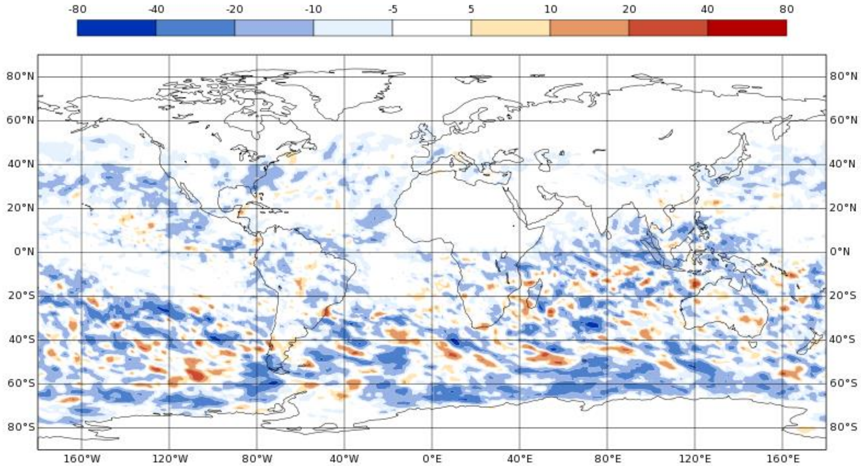
net top solar ICON - CERES

bias:
12.12 W/m²



TKE cloud input - default

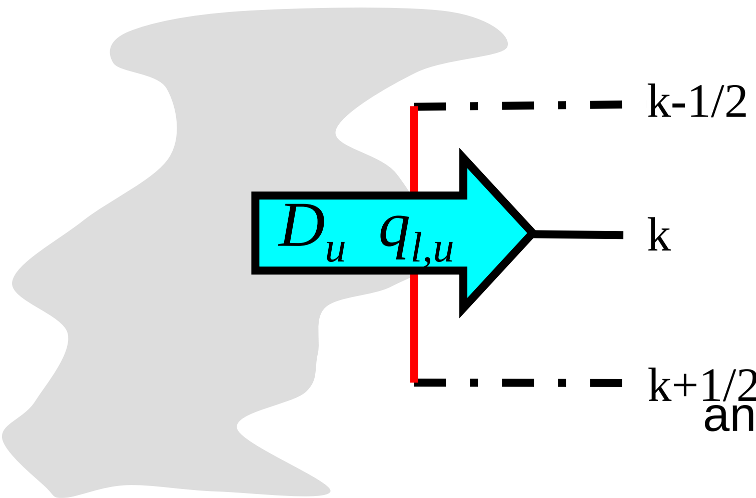
difference:
4.81 W/m²



ICON R2B6 from IFS 240h forecasts from 201201

diagnostic clouds with convective anvil and TKE variance

➔ convective source to cloud cover and condensate in equilibrium

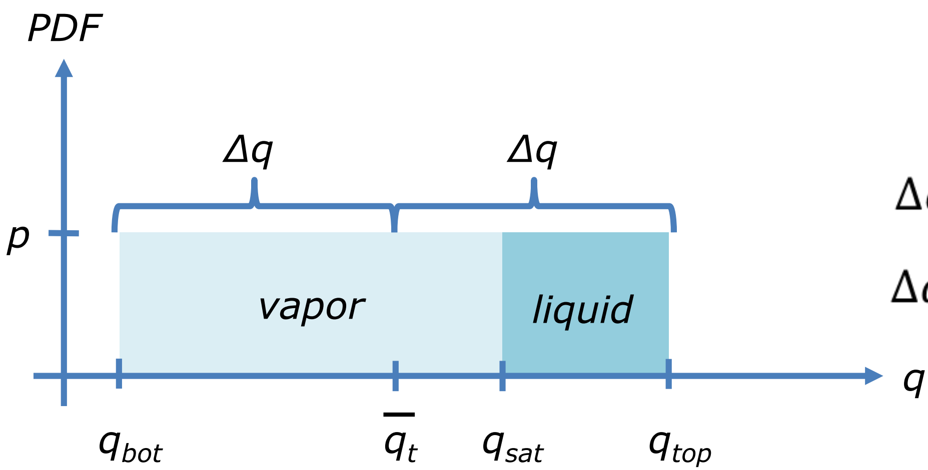


$$\cancel{\frac{\partial CC}{\partial t}} = \frac{D_u}{\rho} - \frac{CC}{\tau_{diss}}$$

τ_{diss} anvil decay time-scale

observational estimate:	1-2 hours
ICON:	1500s

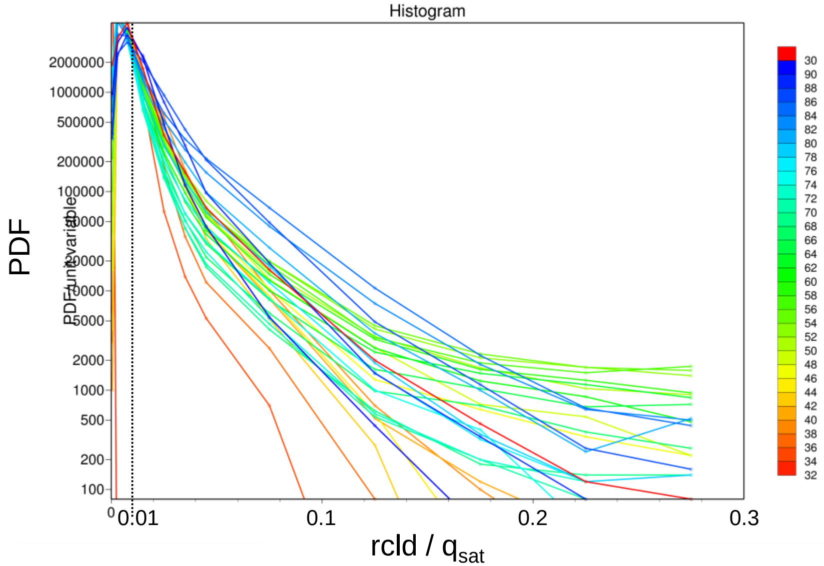
➔ non-convective total water variability

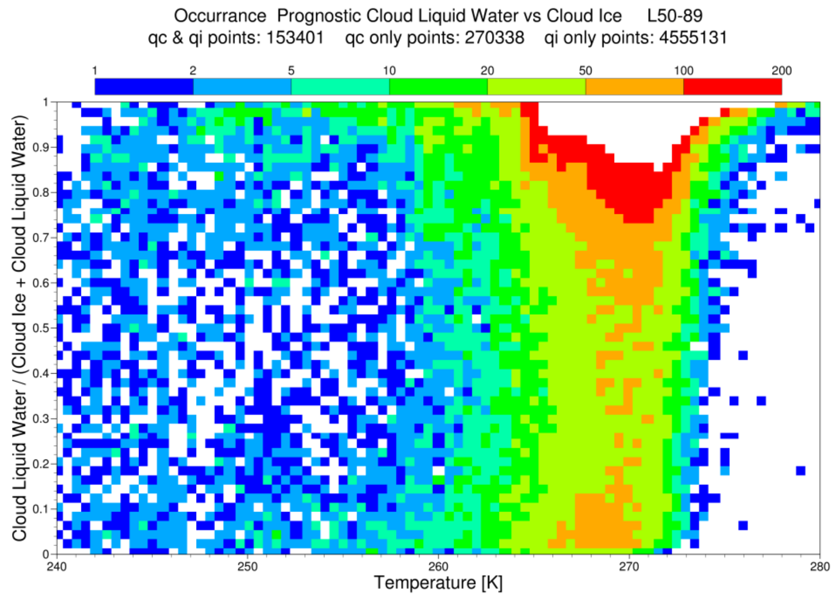


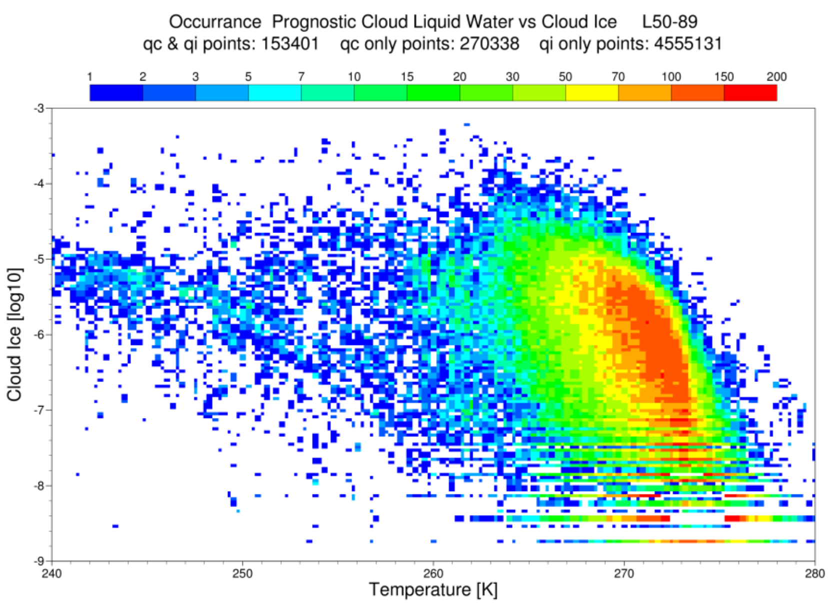
$\Delta q_{liq} \approx \sigma_{qt}$ taken from TKE scheme (RCLD)

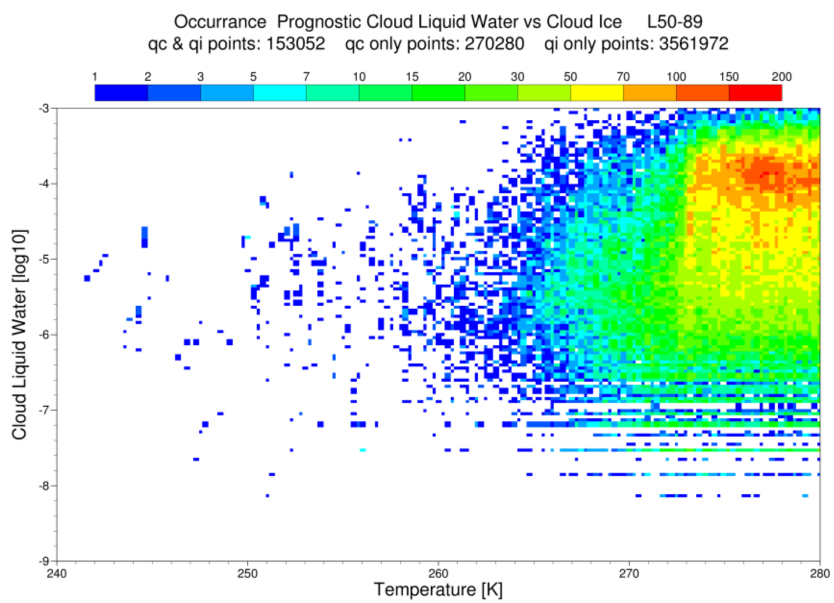
$\Delta q_{ice} = 0.05 q_{sat}$

RCLD and qi/ql from ICON



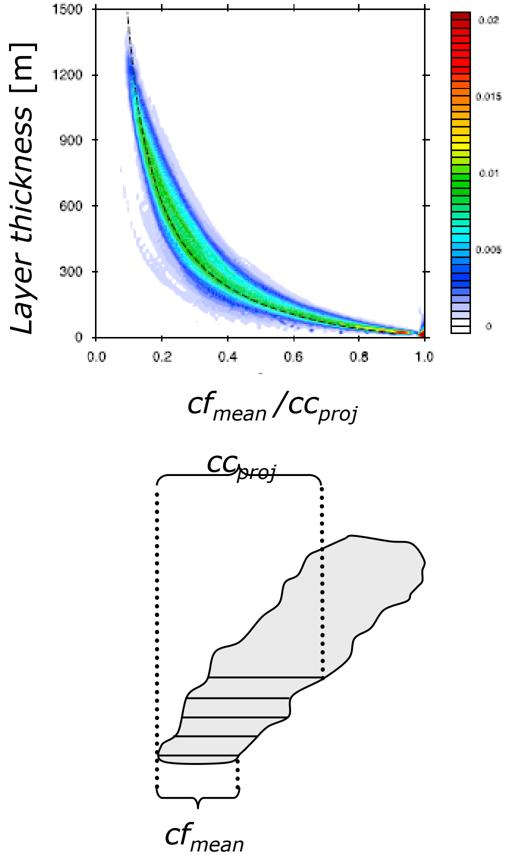






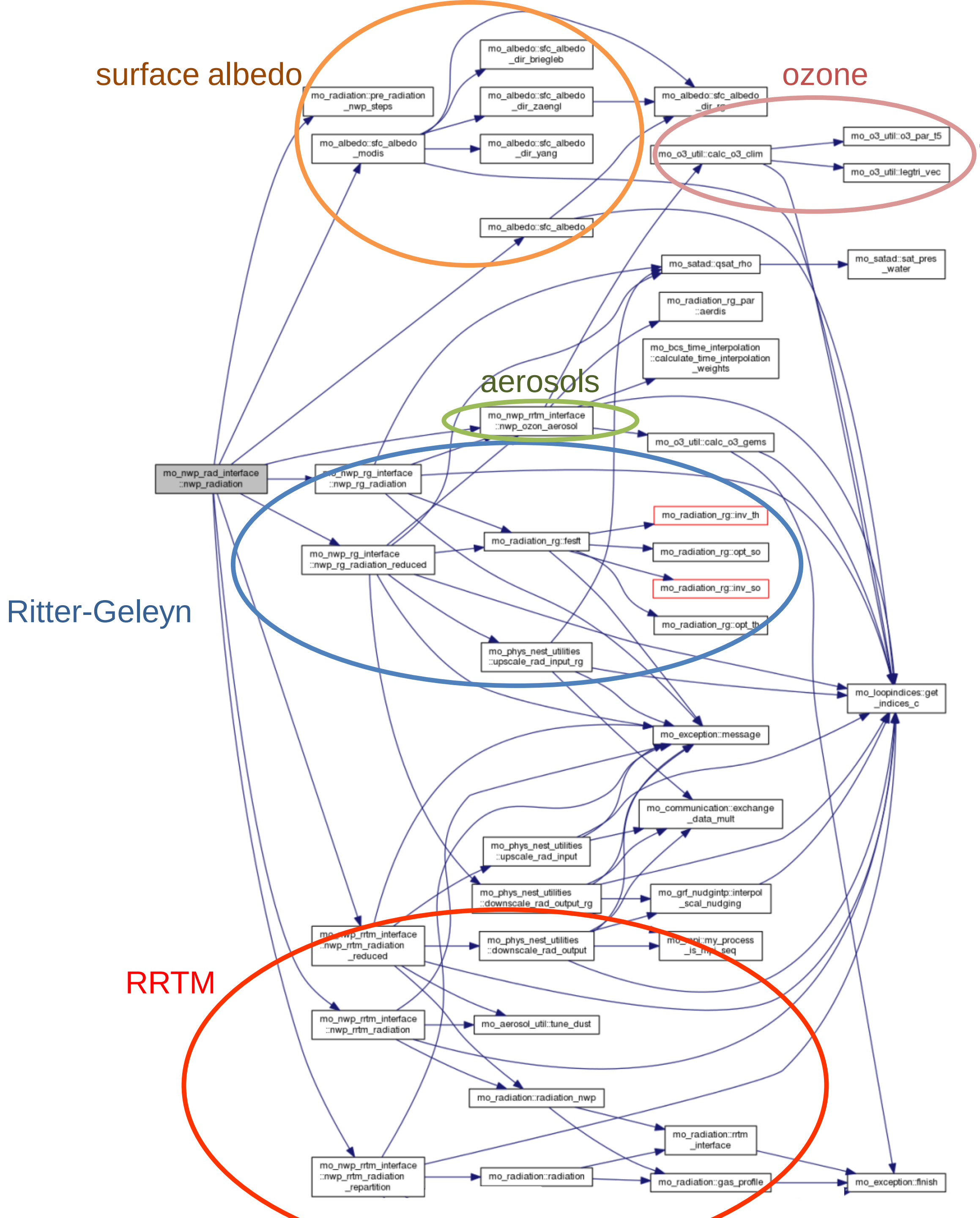
ICON radiation bias – solution ideas

- TKE input to cloud diagnostic
  - Saturation standard deviation
- Convective input to cloud diagnostic
  - Detrainment mass flux
  - Updraft condensate
  - Cloud wake
  - Cloud overlap
  - Qc tendency
- TKE/shallow convection: stratocumulus
- Cloud albedo (aerosols, zalbvisdir)
- Snow radiative properties

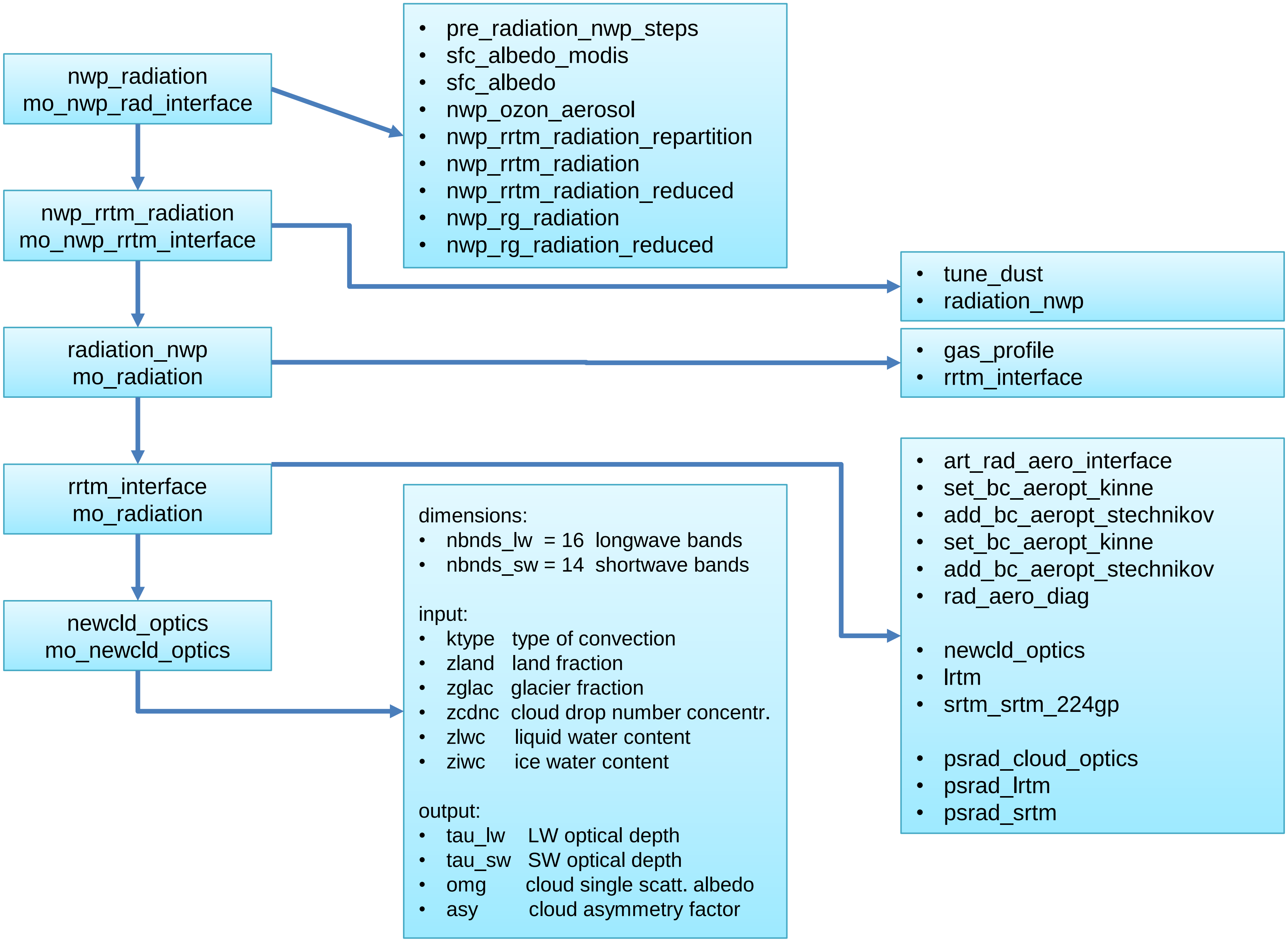


Neggers,Heus,Siebesma,2011

ICON RRTM code



ICON RRTM radiation code



ICON RRTM radiation code

- cloud diagnostic
  - cloud fraction
  - cloud liquid water
  - cloud ice water
- cloud overlap
- McICA
- snow
  - cloud ice + 0.2 * snow (of cloud ice)
- effective radius
  - liq and ice: Roeckner, ECHAM5 docu
  - IFS:
    - liq: Martin et al. 1994
    - ice: Ou and Liou, 1995 (fct(T))
- optical thickness
- single scattering albedo
- asymmetry factor

$$r_e^{liq} = f(lnd, gl, oc) \left(\frac{q_{liq}}{CNC}\right)^{1/3}$$

$$r_e^{ice} = 83.8 q_i^{0.216}$$

$$\tau_{liq} = 0.77\, f(band, r_e^{liq})\ \mathrm{LWP}$$

$$\tau_{ice} = 0.85\, f(band, r_e^{ice})\ \mathrm{IWP}$$

inhomogeneity factor