Optical properties of atmospheric snow
in ICON

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Optical Properties of Hydrometeors

- old:
  - interpolating tables of $r_{\text{eff}}(q)$
  - 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

\[
\begin{align*}
&g(r_{\text{eff}}) & \quad & \text{g(AR)} \\
&\text{SSA}(r_{\text{eff}}) & \quad & \text{SSA}(r_{\text{eff}}) \\
&\text{ext}(r_{\text{eff}}) & \quad & \text{ext}(r_{\text{eff}}) \\
\end{align*}
\]
Optical Properties of Hydrometeors

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

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

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

\[ n(D) = N_0 D^v \text{ext}[-\lambda D^\mu] \]

\[ D = ax^b \]

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

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

\[ ext = \frac{c_0 + c_1 r_e + c_2 r_e^2}{c_3 + c_4 r_e + c_5 r_e^2 + c_6 r_e^3} \]
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
    • irad_use_2mom=1: qv,qc,qi,qr,qs
    • irad_use_2mom=2: … & qnc…

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_largsizeapprox = .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**

**Occurence in %**

**new**

**Occurence in %**
1mom: reff and ddt

old $r_{\text{ICE}}$ in $\mu$m

new $r_{\text{ICE}}$ in $\mu$m

diff ddt lw in K h$^{-1}$

diff ddt sw in K h$^{-1}$
2mom: reff and ddt

old $r_{\text{ICE}}$ in µm

new $r_{\text{ICE}}$ 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
diff: -6.3 W/m²
outgoing long-wave

**new-optic - CERES**
- bias: -13.8 W/m²

**ICONdefault - CERES**
- bias: -3.7 W/m²

**new-optic - ICONdefault**
- diff: -10.1 W/m²
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: 0.1748  Mean: -0.001768  RMS: 0.05299  Mem: 31

diag. ice water content [kg/kg]

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 $r_{e,\text{ice}} (\Rightarrow N_{\text{eff}}$)

• debugging (calc_n0_snow)

• code cleaning:
  • 6 radiation calls with different argument lists
  • logicals as integers

• turn off old $q_{i,\text{adj}} = q_i + 0.1q_s$

• $n(T,\text{snow})$ from Fields et al (2005)
  • mid-latitude
  • tropics (data needed)

• $n_{\text{ice}}(T)$ separately for
  • microphysics (for sedimentation)
  • radiation
Extra slides
work to do

• results:
  • optically thicker in SW (6.3 W/m^2) good
  • warmer OLR (10.1 W/m^2) 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

2mom, with snow

1mom, without snow

1mom, with snow
cloud and snow optics: ICON physics

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

\[ r_e = \text{5um or } r_e = f(w^*, \ldots) \quad \text{or} \quad r_e = \alpha \left( \frac{q_I}{CNC} \right)^\beta \]

- 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 $\text{re}(\xi)$
    • 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
  Occurrence in %

• new
  Occurrence in %
Case Study

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

$q_{\text{ICE}}$ in mg m$^{-3}$

old $r_{\text{ICE}}$ in µm

new $r_{\text{ICE}}$ in µm
mom: lower Troposphere, h = 3000 m

$q_{\text{ICE}}$ in mg m$^{-3}$

old $r_{\text{ICE}}$ in µm

new $r_{\text{ICE}}$ in µm
2mom: upper Troposphere, $h = 8000$ m

$q_{\text{ICE}}$ in mg m$^{-3}$

$n_{\text{ICE}}$ in cm$^{-3}$

old $r_{\text{ICE}}$ in µm

new $r_{\text{ICE}}$ in µm
2mom: lower Troposphere, h = 3000 m

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

$n_{ICE}$ in cm$^{-3}$

old $r_{ICE}$ in µm

new $r_{ICE}$ in µm
Snow, $h = 3000$ m

2mom
$q_{\text{SNOW}}$ in mg m$^{-3}$

1mom
$q_{\text{SNOW}}$ in mg m$^{-3}$

$\text{re}_{\text{SNOW}}$ in µm
Simon Gruber DWD radiation talk 201709
Optical Properties of Hydrometeors

- old:
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- cloud ice, cloud droplets
Issues

• general findings
  – new $r_{ICE}$ smaller in upper layers $\rightarrow$ stronger cooling
  – new $r_{ICE}$ larger in lower layers $\rightarrow$ stronger heating

• 1mom: $r_{ICE}$ become very large in lower layers
  – tuning $n_{ICE}(T)$

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

• using qi from microphysics or from cloud cover parameterization?
Martin DWD radiation talk 201709
ICON radiation bias

Helmut Frank: 168h forecasts, global mean

ICON R2B6 from IFS 240h forecasts from 201201
### scores

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Bias (New, Ref)</th>
<th>RMS (New, Ref)</th>
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<tbody>
<tr>
<td>TOT_PREC</td>
<td>-0.169500, -0.173500</td>
<td>0.342200, 0.392400</td>
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<td>ACCTHB_T</td>
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<td>V_10M</td>
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<td>T_SO L8</td>
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<td>0.0461300, 0.04617000</td>
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<td>9.89800, 16.17900</td>
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<td>AGCTHB_T - CERES</td>
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<td>AGCLHFL_S - WHCI</td>
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<td>T_G - WHCI</td>
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<td>SP_10M - WHCI</td>
<td>-0.473600, -0.4410000</td>
<td>0.827900, 0.8053000</td>
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</tbody>
</table>

- 1.00 Percent bias
- 1.00 Percent rms
ICON radiation bias

**net top solar**

ICON - CERES

bias: 12.12 W/m²

difference: 4.81 W/m²

**TKE cloud input - default**

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

\[ \frac{\partial CC}{\partial t} = \frac{D_u}{\rho} - \frac{CC}{\tau_{diss}} \]

Anvil decay time-scale

Observational estimate: 1-2 hours
ICON: 1500s

Non-convective total water variability

\[ \Delta q_{liq} \approx \sigma_{qt} \text{ taken from TKE scheme (RCLD)} \]
\[ \Delta q_{ice} = 0.05 q_{sat} \]
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 radiation code

- nwp_radiation
  - mo_nwp_rad_interface
    - nwp_rrtm_radiation
      - mo_nwp_rrtm_interface
        - radiation_nwp
          - mo_radiation
            - rttm_interface
              - mo_radiation
                - newcld_optics
                  - mo_newcld_optics

- dimensions:
  - nbnds_lw = 16 longwave bands
  - nbnds_sw = 14 shortwave bands

- input:
  - ktype: type of convection
  - zland: land fraction
  - zglnac: glacier fraction
  - zcdnc: cloud drop number concentr.
  - zlwc: liquid water content
  - ziwc: ice water content

- output:
  - tau_lw: LW optical depth
  - tau_sw: SW optical depth
  - omg: cloud single scatt. albedo
  - asy: cloud asymmetry factor

- • pre_radiation_nwp_steps
  - • sfc_albedo_modis
  - • sfc_albedo
  - • nwp_ozon_aerosol
  - • nwp_rrtm_radiation_repartition
  - • nwp_rrtm_radiation
  - • nwp_rrtm_radiation_reduced
  - • nwp_rg_radiation
  - • nwp_rg_radiation_reduced

- • tune_dust
  - • radiation_nwp

- • gas_profile
  - • rrtm_interface

- • art_rad_aero_interface
  - • set_bc_aeropt_kinne
  - • add_bc_aeropt_stechnikov
  - • set_bc_aeropt_kinne
  - • add_bc_aeropt_stechnikov
  - • rad_aero_diag
    - • newcld_optics
    - • lrtm
    - • srtm_srtm_224gp
    - • psrad_cloud_optics
    - • psrad_lrtm
    - • psrad_srtm
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

\[ r_{e}^{liq} = f(lnd, gl, oc) \left( \frac{q_{liq}}{CNC} \right)^{1/3} \]
\[ r_{e}^{ice} = 83.8q_{i}^{0.216} \]

\[ \tau_{liq} = 0.77 f(band, r_{e}^{liq}) \text{ LWP} \]
\[ \tau_{ice} = 0.85 f(band, r_{e}^{ice}) \text{ IWP} \]

inhomogeneity factor