Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Current work on ecRad in ICON

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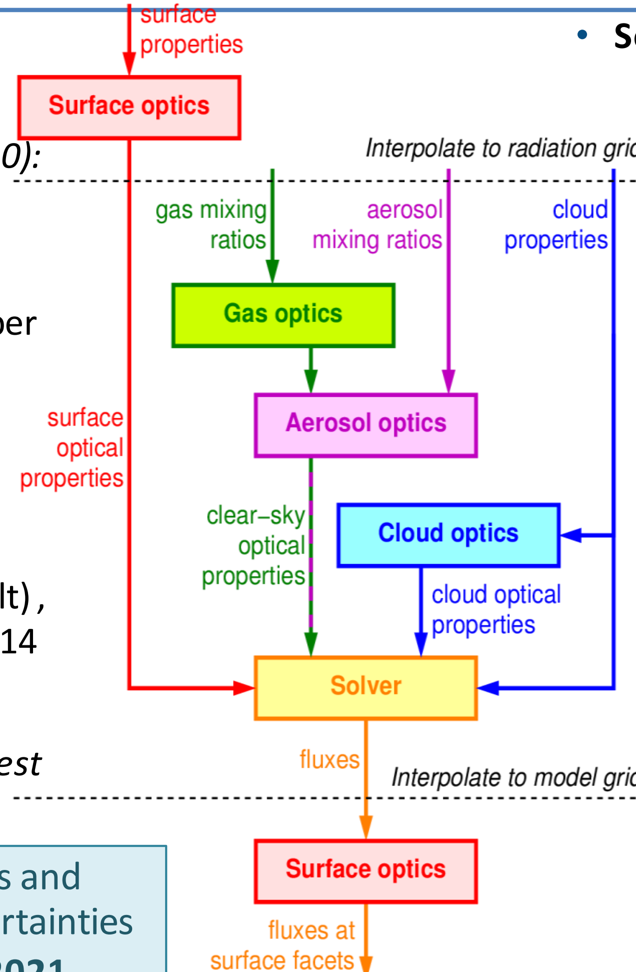
New modular radiation scheme: ecRad (Hogan & Bozzo 2018)

- **Gas optics:**
  - RRTMG (Iacono et al. 2008)
  - *ecCKD (Hogan & Matricardi 2020): Fewer spectral intervals but similar precision*
- **Aerosol optics:** variable species number and properties (set at run-time)
- **Cloud optics:**
  - **liquid:** SOCRATES (MetOffice), Slingo (1989)
  - **ice:** Fu 1996, 1997, 1998 (default) , Yi et al. 2013 or Baran et al. 2014
- *Surface (under development) Consistent treatment of urban and forest canopies*

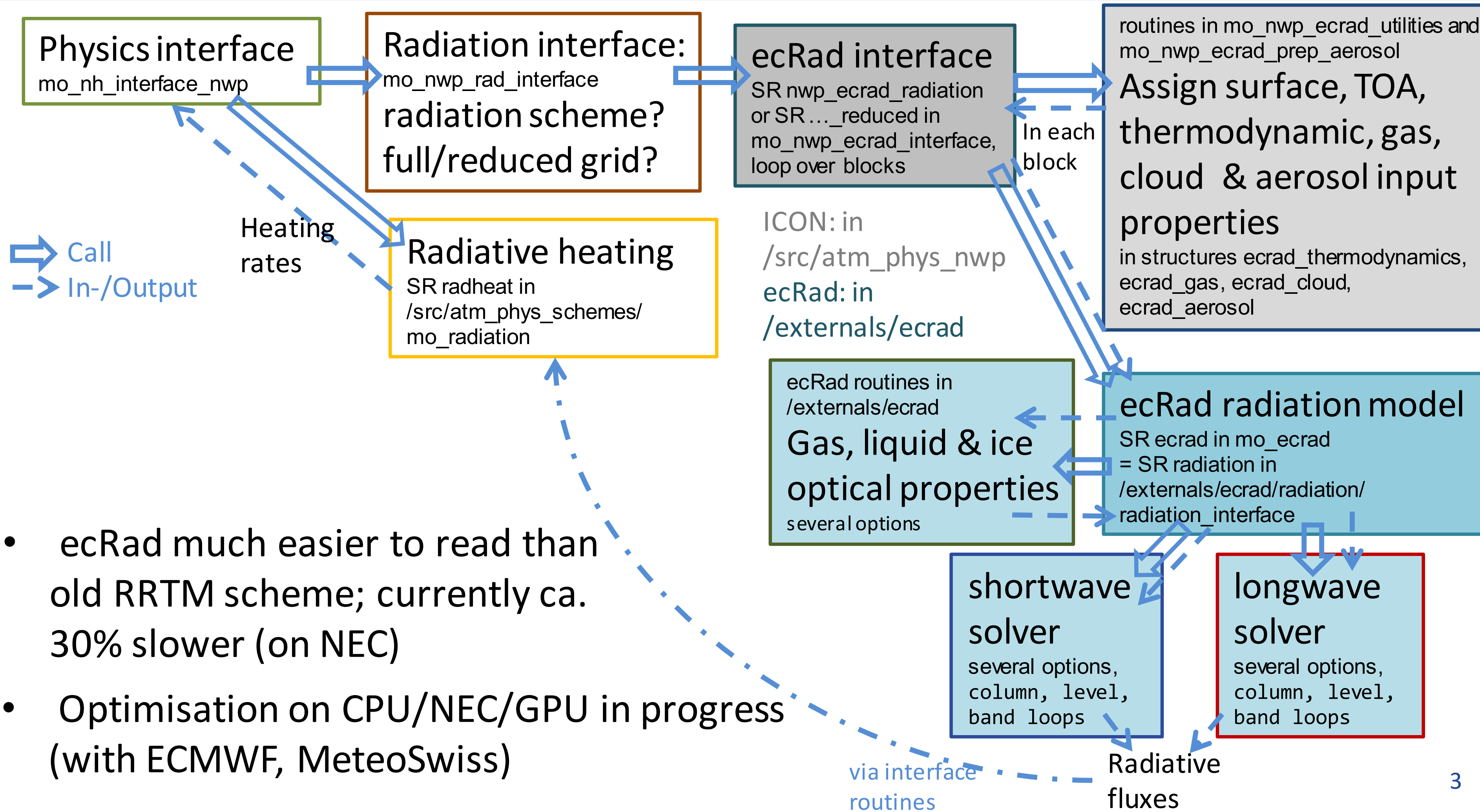
Modular: can vary optics components and solver individually to determine uncertainties
Operational in ICON since 14. April 2021



- **Solvers** for radiative transfer equations:
  - **McICA** (Pincus et al. 2003), **Tripleclouds** (Shonk & Hogan, 2008) or **SPARTACUS** (Schäfer et al. 2016, Hogan et al. 2016)
  - SPARTACUS makes ecRad the only global radiation scheme that can do sub-grid **3D** radiative effects
  - Longwave scattering optional
  - Can configure **cloud overlap**
  - **Cloud inhomogeneity**: can configure width and shape of PDF

Implementation in ICON:
D. Rieger, M. Köhler, R. J. Hogan, S. A. K. Schäfer, A. Seifert, A. de Lozar and G.Zängl (2019): *ecRad in ICON – Implementation Overview*, Reports on ICON

ecRad in ICON (implemented by D. Rieger)



- ecRad much easier to read than old RRTM scheme; currently ca. 30% slower (on NEC)
- Optimisation on CPU/NEC/GPU in progress (with ECMWF, MeteoSwiss)

Namelist parameters for radiation

```
 &grid_nml
radiation_grid_filename = 'icon_grid_0023_R02B05_R.nc',        !empty string if radiation on full grid
iredgrid_phys = .TRUE.                       !  .TRUE.: reduced radiation grid (one grid level higher)
...
&nwp_phy_nml
inwp_radiation = 1                           ! 0: no radiation, 1: RRTM, 2: RG, 3: PSRAD, 4: ecRad
dt_rad = 1800.                               ! in s;  Should be integer multiple of  dt_conv
...
 &radiation_nml
albedo_type = 2                              ! Surface albedo type; 1: dry soil table, 2: MODIS
icld_overlap=2                               ! Cloud overlap (in RRTM only changes sw); 1: maximum-random,
                                               2: exponential-random, 3: maximum, 4: random
irad_aero = 0                                ! Aerosols; 1: prognostic, 2: constant, 3:external file, 5:Tanre climatology,
                                               6: Tegen climatology, 9: ART
irad_h2o = 1                                 ! Tracer concentrations:  0: set to zero, 1: from tracer variable, 2: specified
irad_co2 = 2
vmr_co2  = 348.0e-6                          ! Specify globally constant volume mixing ratio
...
```

More details in icon-nwp/doc/Namelist_overview.pdf

Using ecRad in ICON

To use ecRad, **might need to specify** in configure: ./configure --enable-ecrad (depending on compiler settings)
+ need in **ICON namelist**:

&nwp_phy_nml
inwp_radiation = 4 ! 0: no radiation, 1: RRTM, 2: RG, 3: PSRAD, 4: ecRad
&radiation_nml
ecRad_data_path = '<ICON-directory>/externals/ecrad/data'

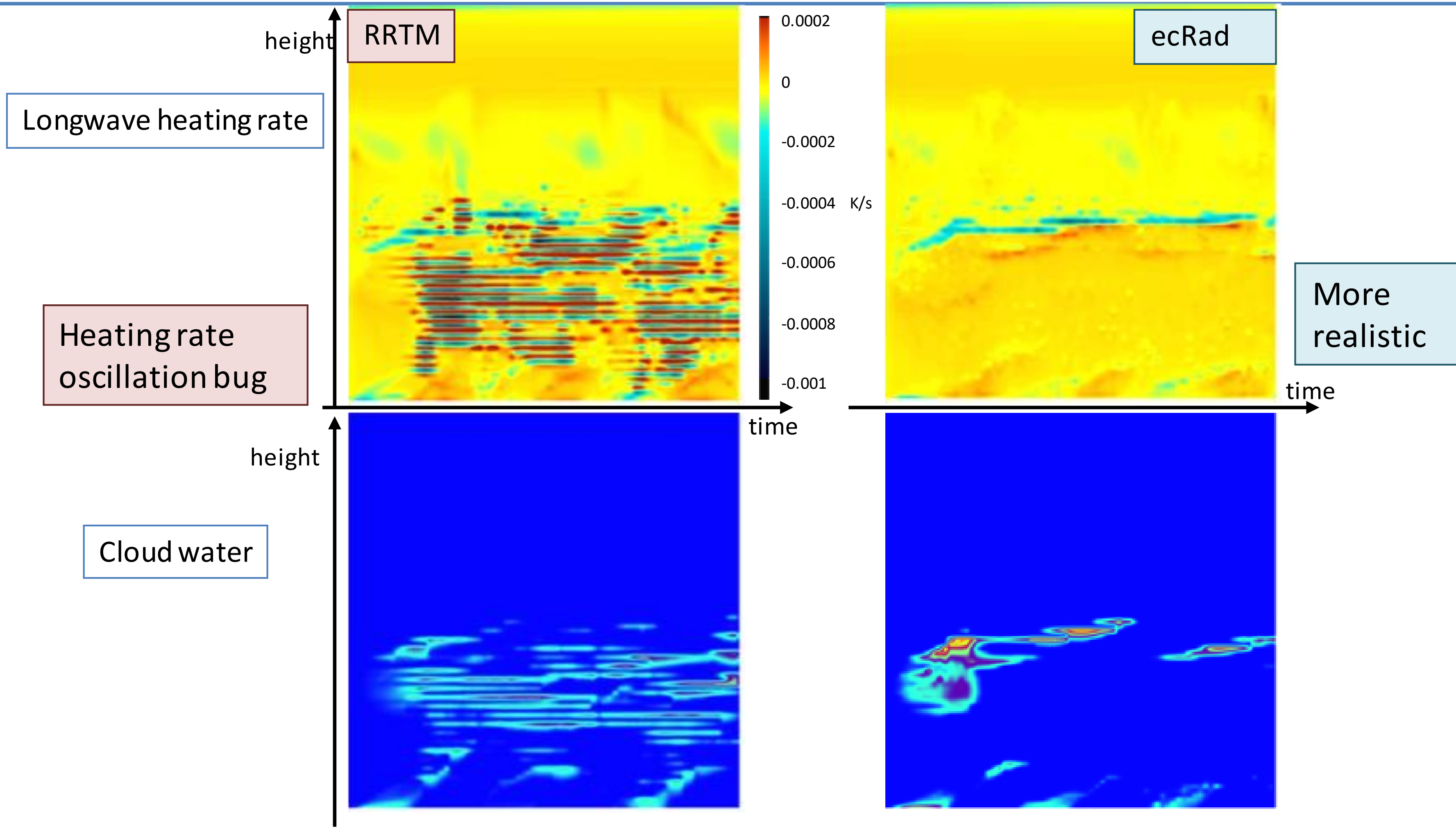
Can configure model behaviour:

&radiation_nml
icld_overlap=2 ! Cloud overlap (in RRTM only changes sw); 1: maximum-random, 2: exponential-random, 3: maximum, 4: random
irad_aero = 0 ! Aerosols; 0: no aerosol, 2: constant, 5:Tanre climatology, 6: Tegen climatology
iliquid_scat = 0 ! Liquid optics scheme: 0: SOCRATES, 1: Slingo (1989)
iice_scat = 0 ! Ice optics scheme: 0: Fu et al. (1996), 1: Baran et al. (2016)
llw_cloud_scat = .true. ! Do longwave cloud scattering? etc.

Additional ecRad namelist parameters set in SR setup_ecrad in atm_phys_nwp/mo_nwp_ecrad_init
ecrad_conf%i_solver_sw = ISolverMcICA ! Short-wave solver
ecrad_conf%i_solver_lw = ISolverMcICA ! Long-wave solver
ecrad_conf%do_3d_effect = .false. ! Do we include 3D effects?
ecrad_conf%do_lw_aerosol_scattering = .false. ! LW scattering due to aerosol etc.
Not all combinations possible. ecRad documentation at https://confluence.ecmwf.int/display/ECRAD

Impact of ecRad in ICON

ecRad versus RRTM : ICON single column model (Bašták Ďurán et al. 2021)



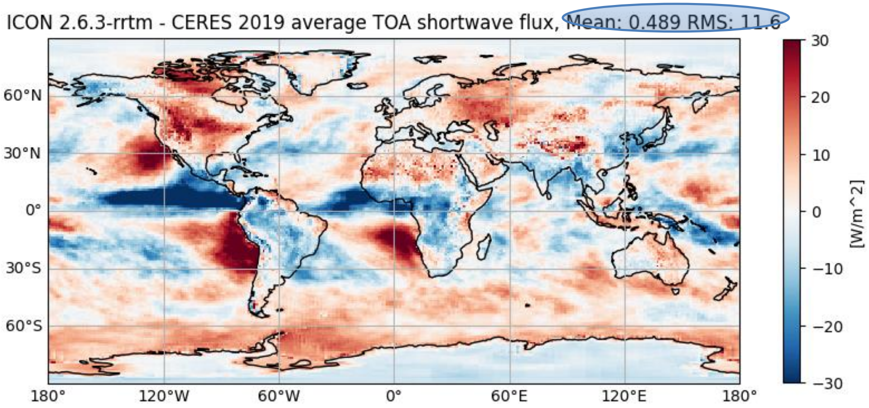
Impact of ecRad, ice fall speed tuning : Biases vs. CERES-EBAF 2019

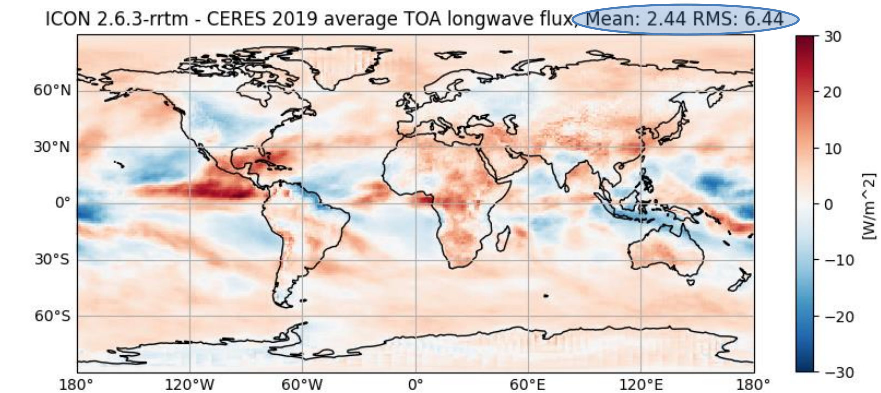
ICON 2.6.3, **RRTM** + ice fall speed tuning

ICON 2.6.3, **RRTM** + ice fall speed tuning

Resolution R2B6, $\Delta x \approx 40$ km

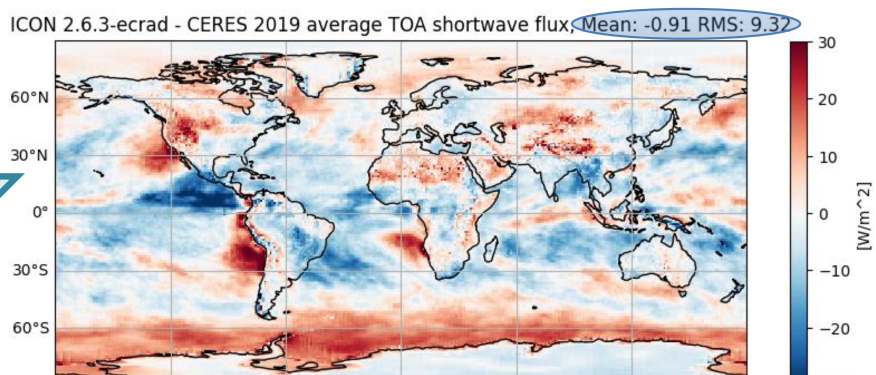
ecRad, fall speed tuning

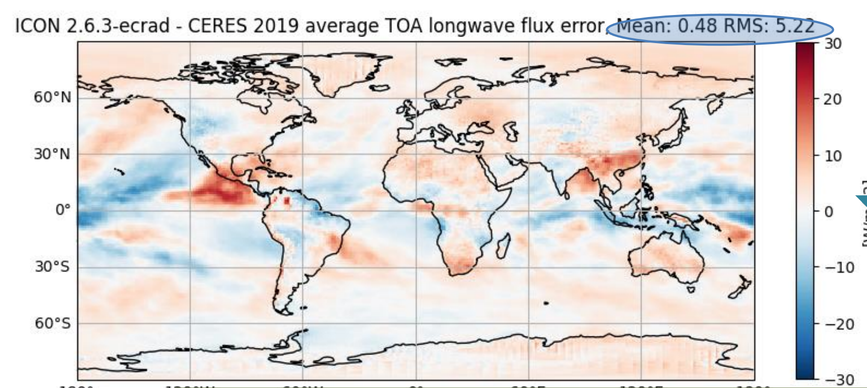




Shortwave (SW) TOA flux biases vs. CERES

Longwave (LW) TOA flux biases vs. CERES





ecRad, fall speed tuning

ICON 2.6.3, **ecRad** + LW scat., no ice fall speed tuning

ICON 2.6.3, **ecRad** + LW scat., no ice fall speed tuning

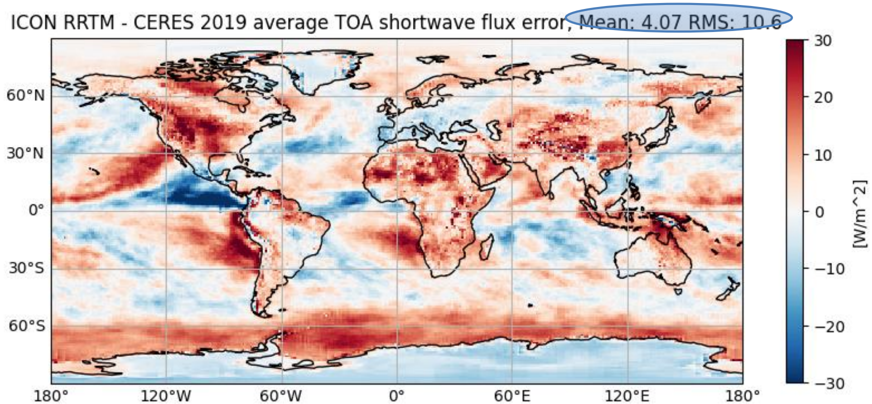
CERES-EBAF: Loeb et al. (2018)

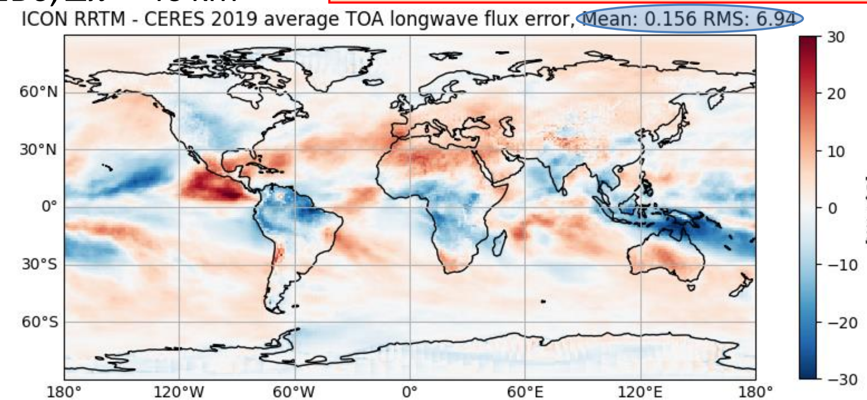
Impact of ecRad, c_p/c_v-Bugfix, tuning : Biases vs. CERES-EBAF 2019

Old routine: c_p/c_v-Bug, tuned RRTM

Resolution R2B6, $\Delta x \approx$40 km

Old routine: c_p/c_v-Bug, tuned RRTM



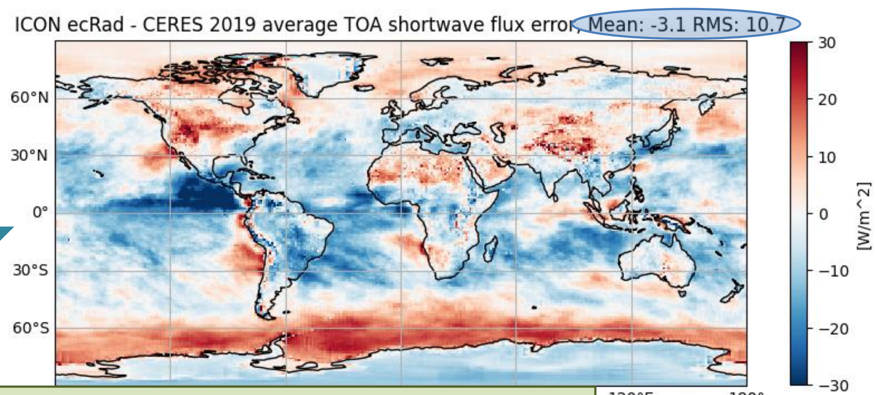


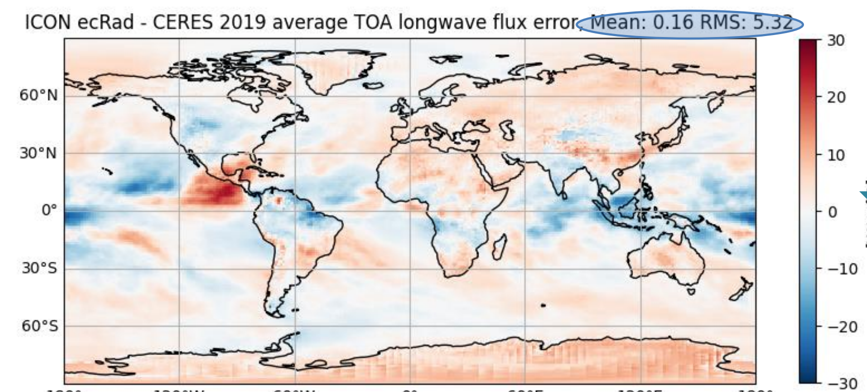
c_p/c_v-Bugfix, ecRad, tuning

Shortwave (SW) TOA flux biases vs. CERES

Longwave (LW) TOA flux biases vs. CERES

c_p/c_v-Bugfix, ecRad, tuning





New routine: c_p/c_v-Bugfix, ecRad + LW scat., new CAMEL emissivity

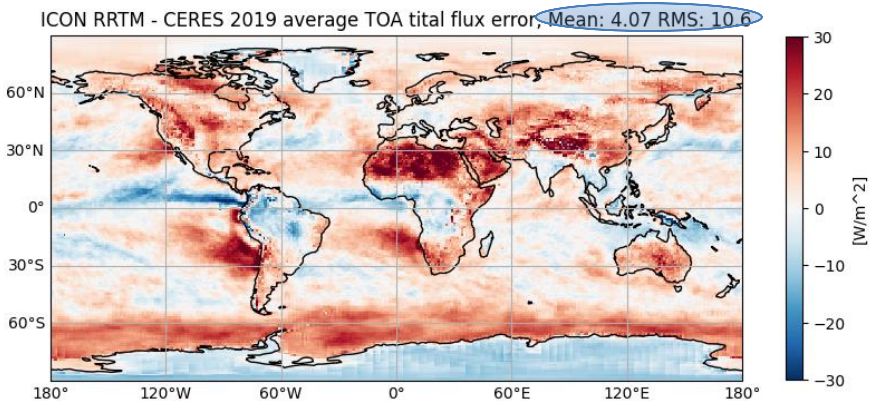
CERES-EBAF: Loeb et al. (2018)

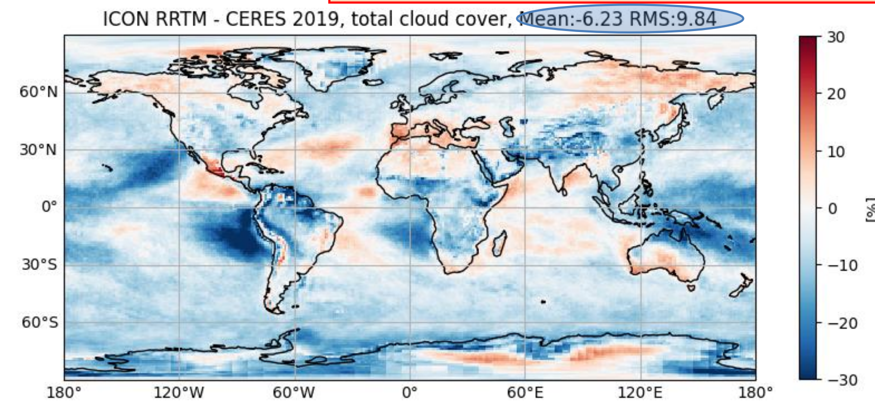
New routine: c_p/c_v-Bugfix, ecRad + LW scat., new CAMEL emissivity

Impact of ecRad: Biases vs. CERES all 2019: R2B6, $\Delta x \approx 40$km

Routine: c_p/c_v-Bug, tuned RRTM

Routine: c_p/c_v-Bug, tuned RRTM



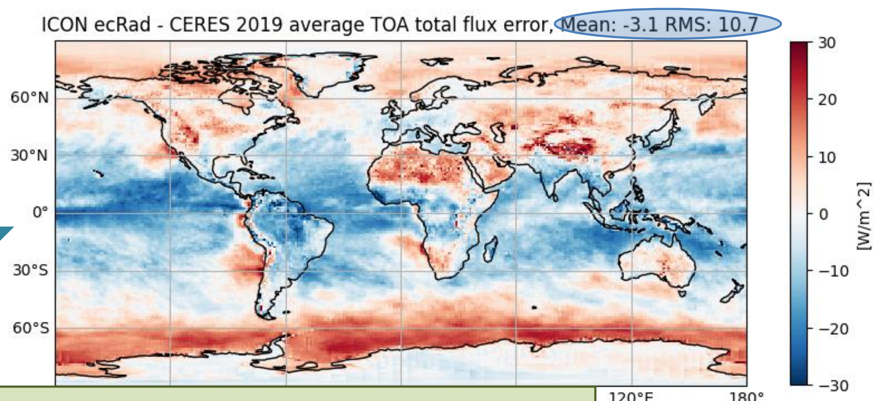


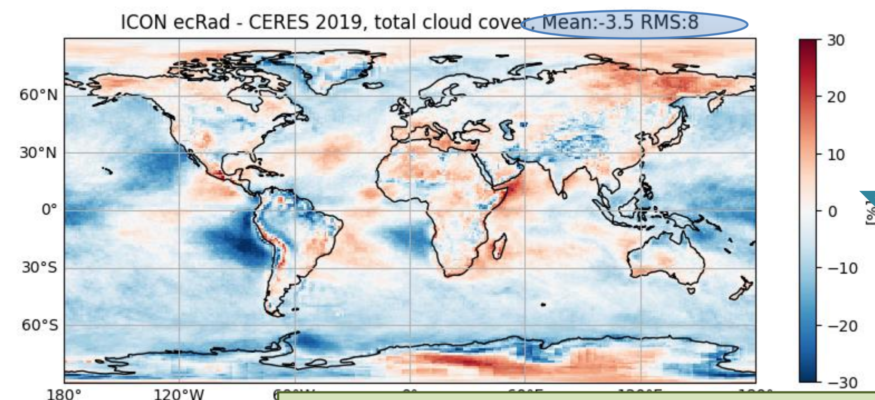
Total TOA flux biases vs. CERES

Total **cloud cover** biases vs. CERES

c_p/c_v-Bugfix, ecRad, tuning

c_p/c_v-Bugfix, ecRad, tuning



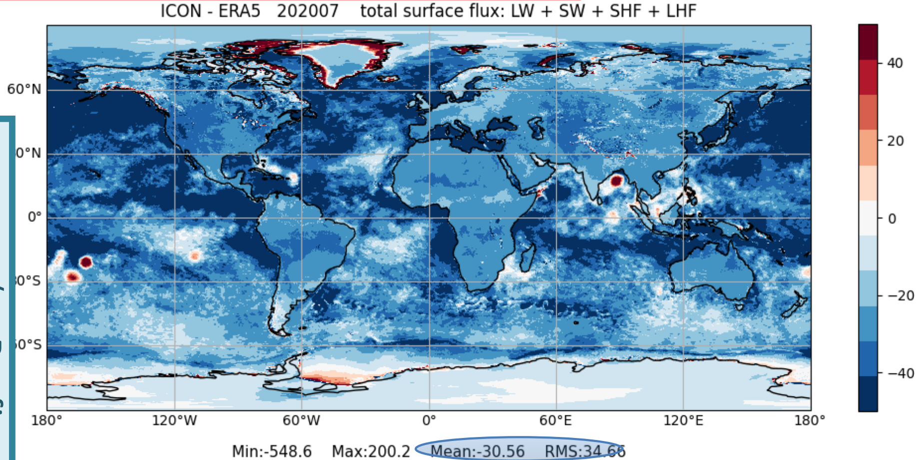


Parallel routine: c_p/c_v-Bugfix, ecRad+LW scat., new emissivity

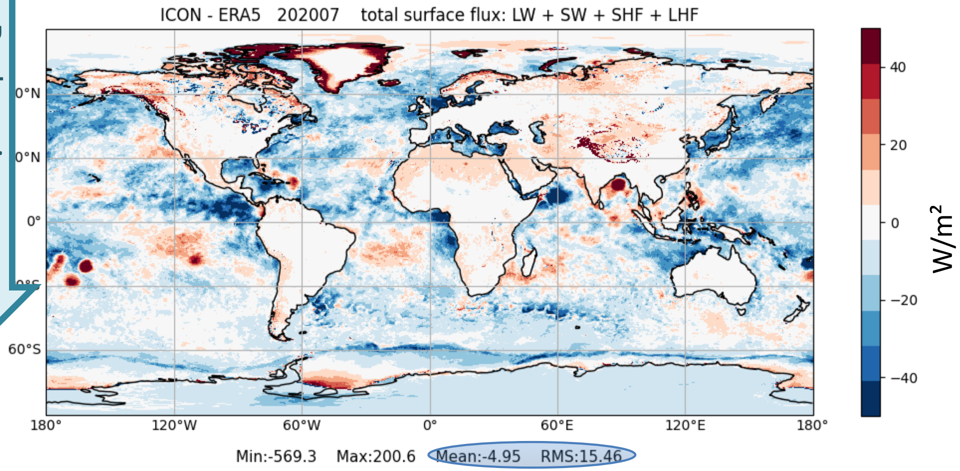
Parallel routine: c_p/c_v-Bugfix, ecRad+LW scat., new emissivity

Impact of ecRad + c_p/c_v-Bugfix: Surface fluxes

Old routine: c_p/c_v-Bug, tuned RRTM



c_p/c_v-Bugfix, ecRad, tuning



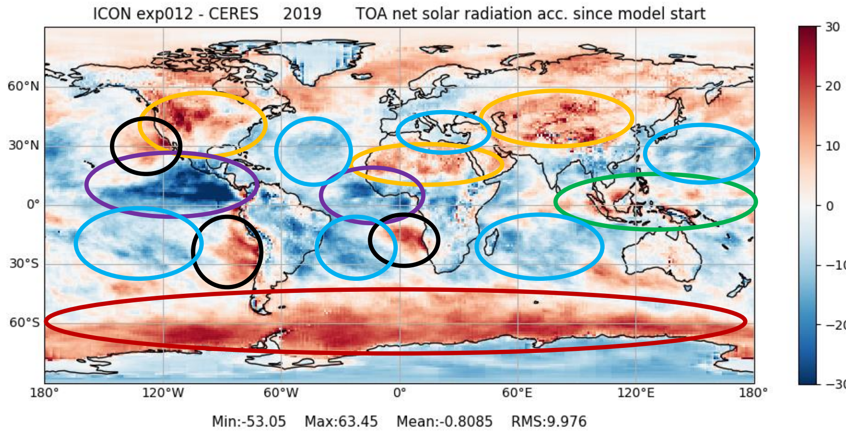
New routine: c_p/c_v-Bugfix, ecRad + LW scat., new CAMEL emissivity

Bias of ICON total surface flux July 2020 vs. Era5, $\Delta x \approx 13$ km, plots by M. Köhler

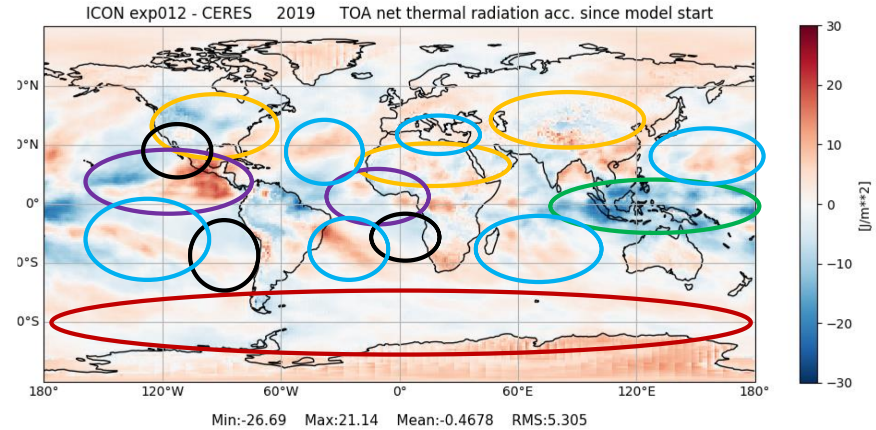
- Surface flux bias reduces from 31 W/m² to 5 W/m²
- Mainly due to bias reductions of 9 W/m² in SW, 11 W/m² in LW surface flux
- Also improves sensible heat flux

Remaining regional biases – clouds major source of uncertainty

TOA SW bias vs. CERES

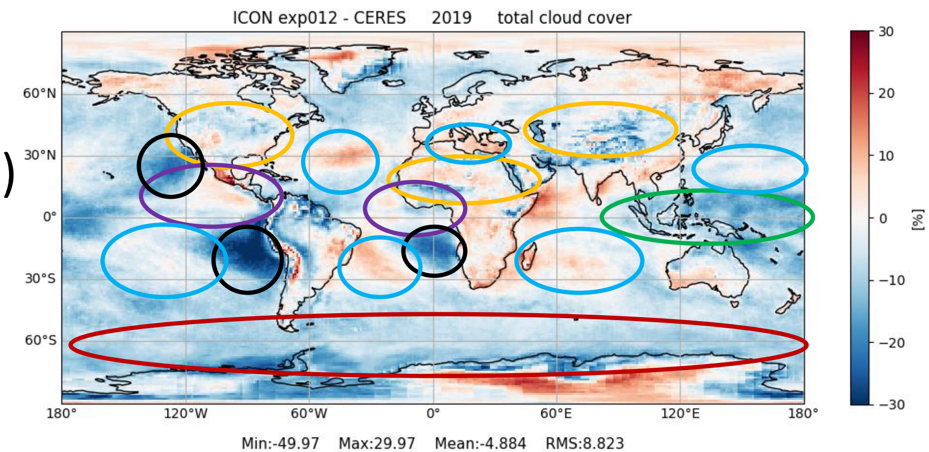


TOA LW bias vs. CERES



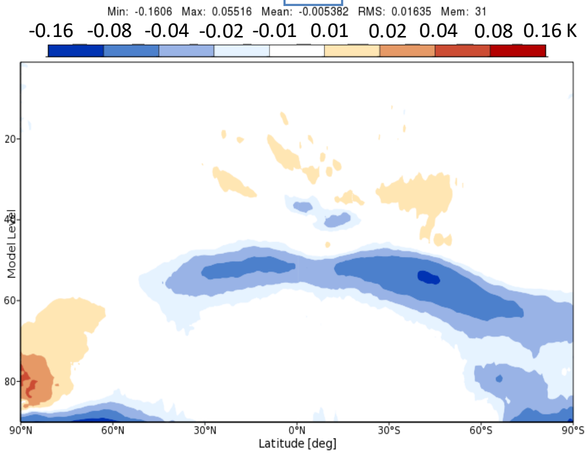
1. Deserts too little reflection – LW OK, little cloud
2. ITCZ eastern oceans too optically thick
3. West Pacific too little cloud
4. Too little stratocumulus (low cloud, LW OK)
5. Southern Ocean too little reflection
6. Extratropical oceans too much cloud (incl. Mediterranean)

Cloud cover bias vs. CERES

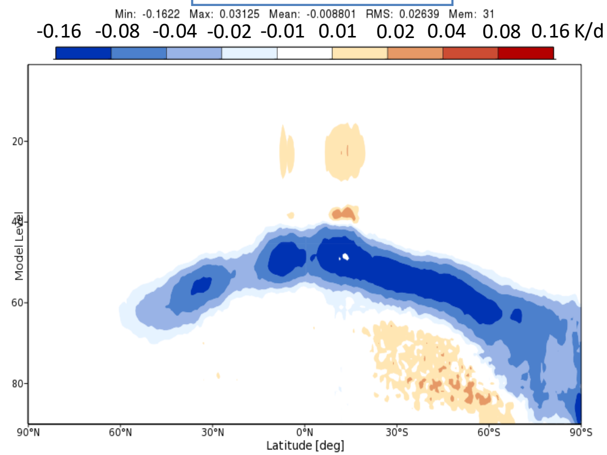


Ice optics uncertainty in ICON-ecRad: Baran – Fu (Jan 2018, 24h runs)

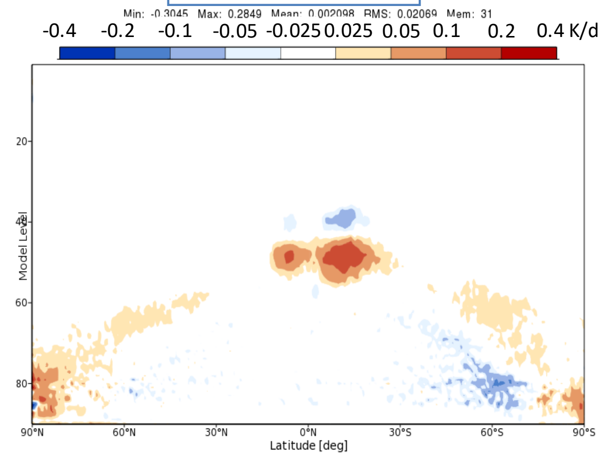
T



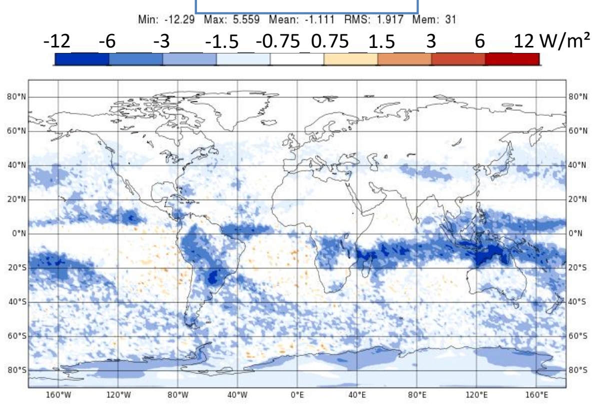
T SW tendency



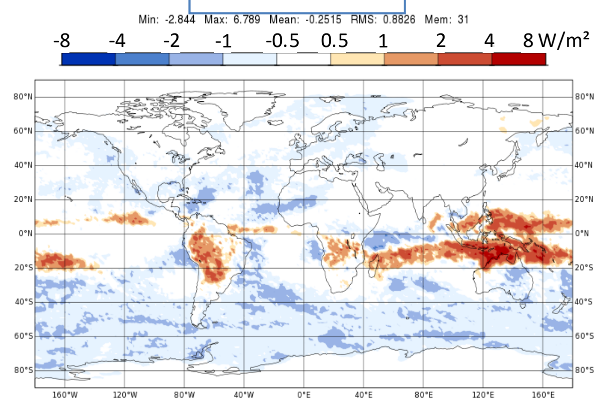
T LW tendency



SW TOA flux



LW TOA flux



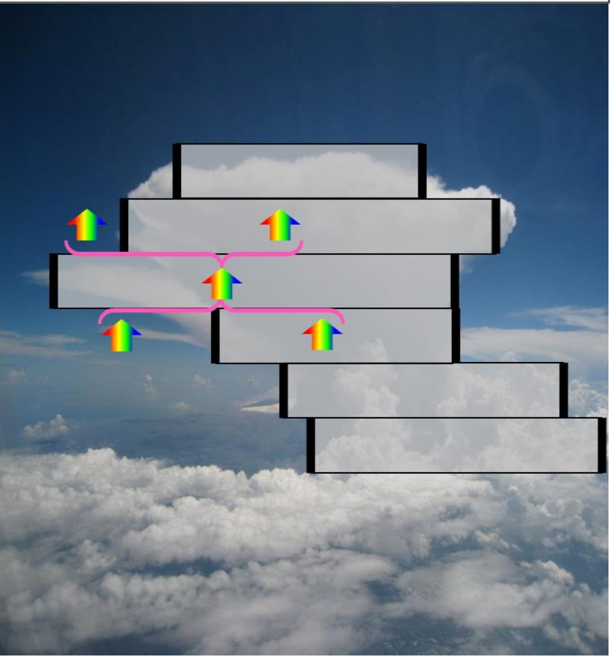
- Uncertainty 1.5 W/m² globally
- Liquid optics uncertainty 0.5W/m² (spheres)

Sub-grid clouds in radiation solvers

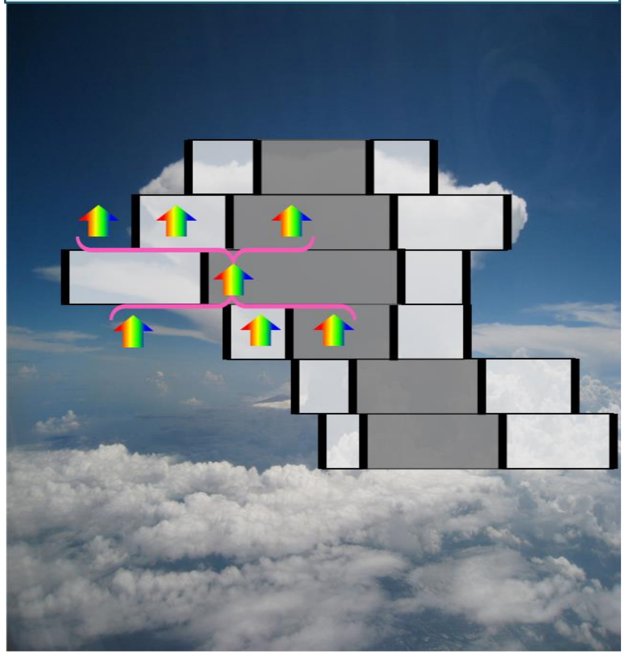
Simplify by treating **only vertical** dimension explicitly.

Deterministic:

Two-stream solver (e.g. RRTM in ICON)**:** solve in **cloudy / clear regions**, partition at layer boundaries according to **overlap**

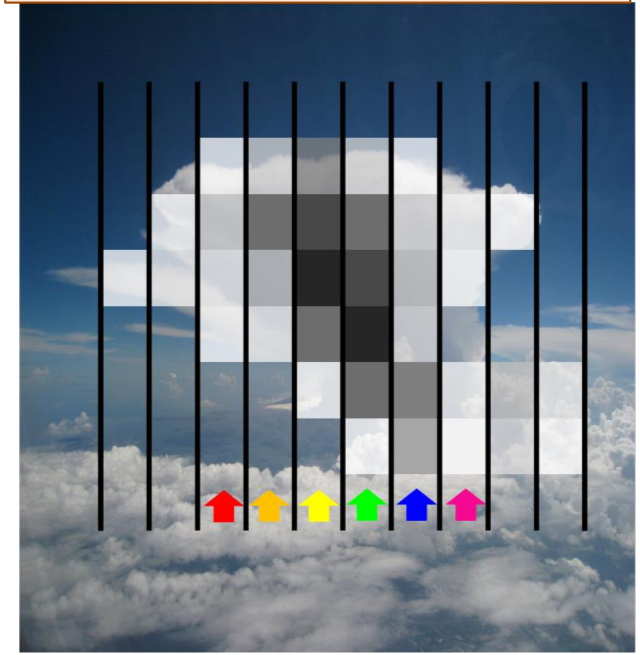


Tripleclouds/SPARTACUS (ecRad)**:** similar; 3 regions: **clear, thin cloud, thick cloud** → cloud **inhomogeneity**



Stochastic:

McICA (ecRad)**:** draw **random clouds in sub-columns** for overlap + inhomogeneity; **distribute spectral intervals** in 1 sub-column each → **fast, random noise**



Plots adapted from R. Hogan

Solver uncertainty in ICON+ecRad: Tripleclouds-McICA (Jan 2018, 24h runs)

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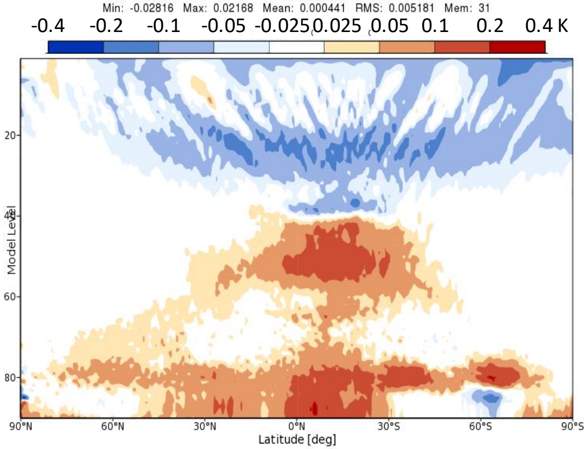
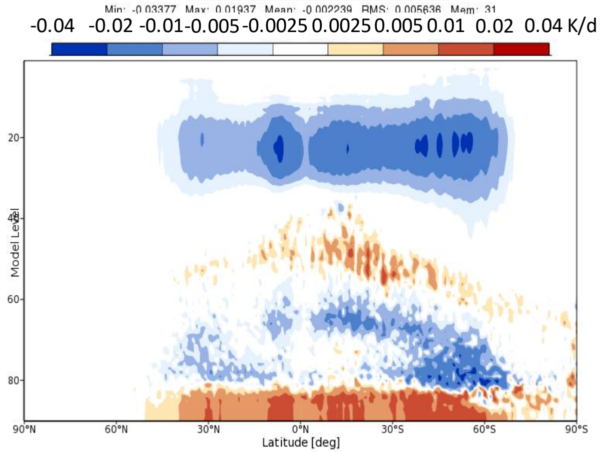
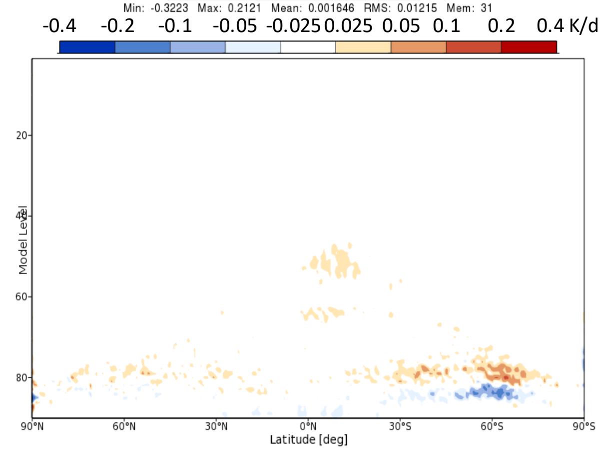


T SW tendency

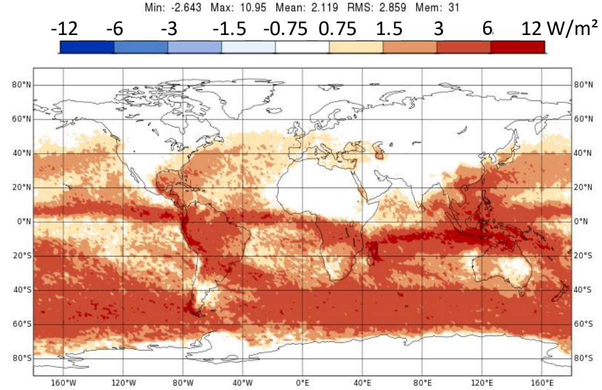


T LW tendency

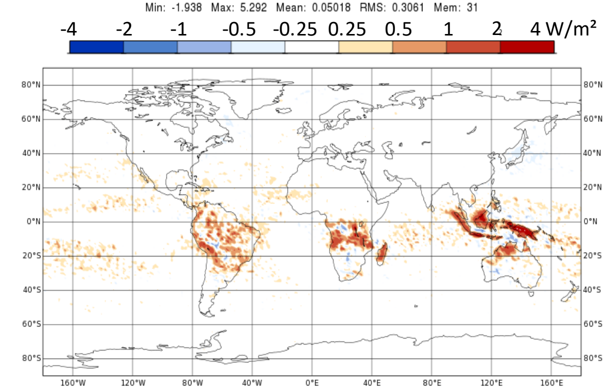


Uncertainty: 2 W/m² systematic difference in global flux (similar settings available) + random variability in McICA

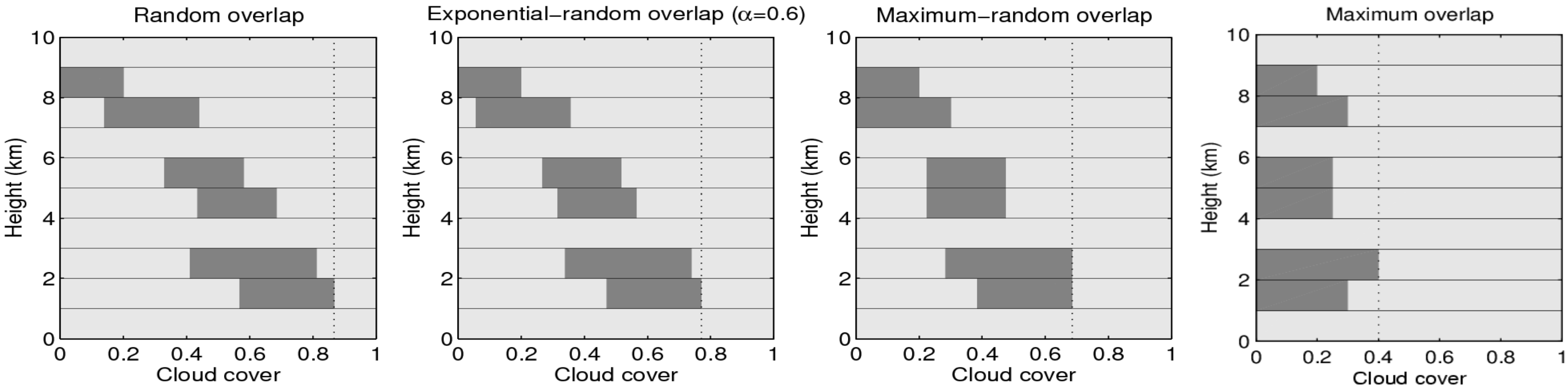
SW TOA flux



LW TOA flux

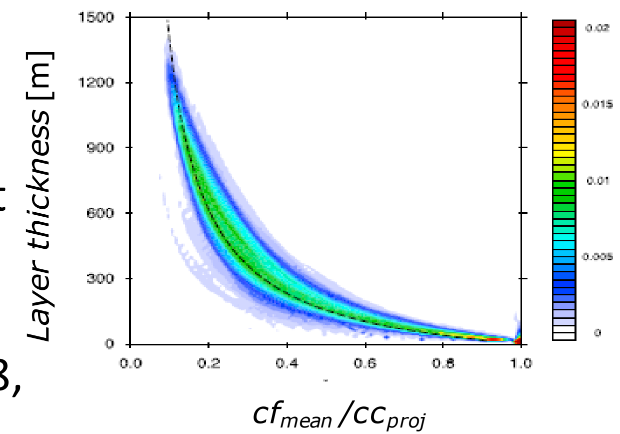


Cloud vertical overlap



Adapted from Hogan & Illingworth 2000

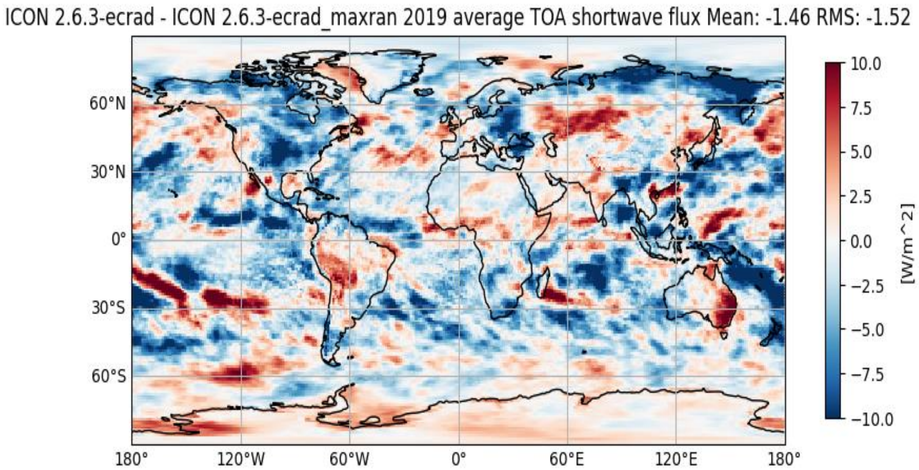
- For given layer cloud fraction, **cloud overlap** decides total cloud cover
- Based on observations: **exponential-random overlap,** decorrelation length ca. 2 km (Hogan & Illingworth 2000); small cumulus: 100-600m (Neggers et al. 2011, Corbetta et al. 2015)
- Decorrelation length 1 km in ICON: global flux +5.2 W/m^2
- **Should depend** on situation and cloud type (Jing et al 2018, Sulak et al 2020) – will include in ecRad



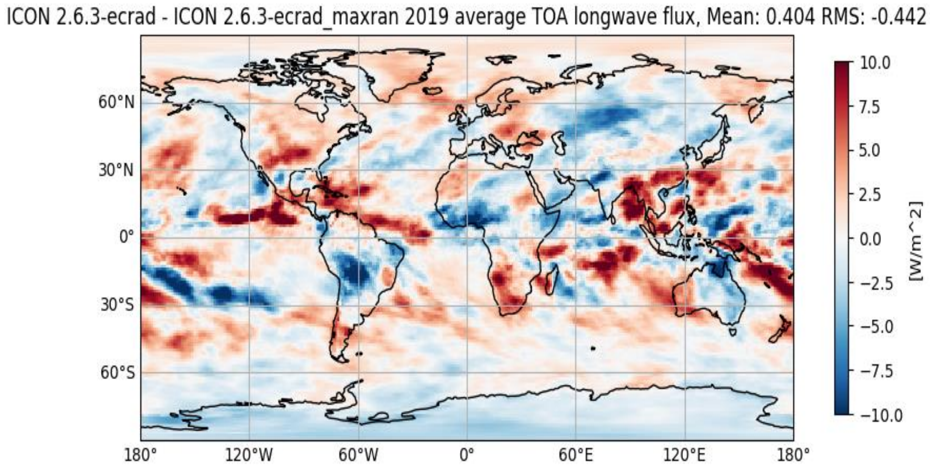
Neggers et al. 2011

Overlap uncertainty in ICON+ecRad: Exp-ran – Max-ran (2019, 1y-run)

SW TOA flux



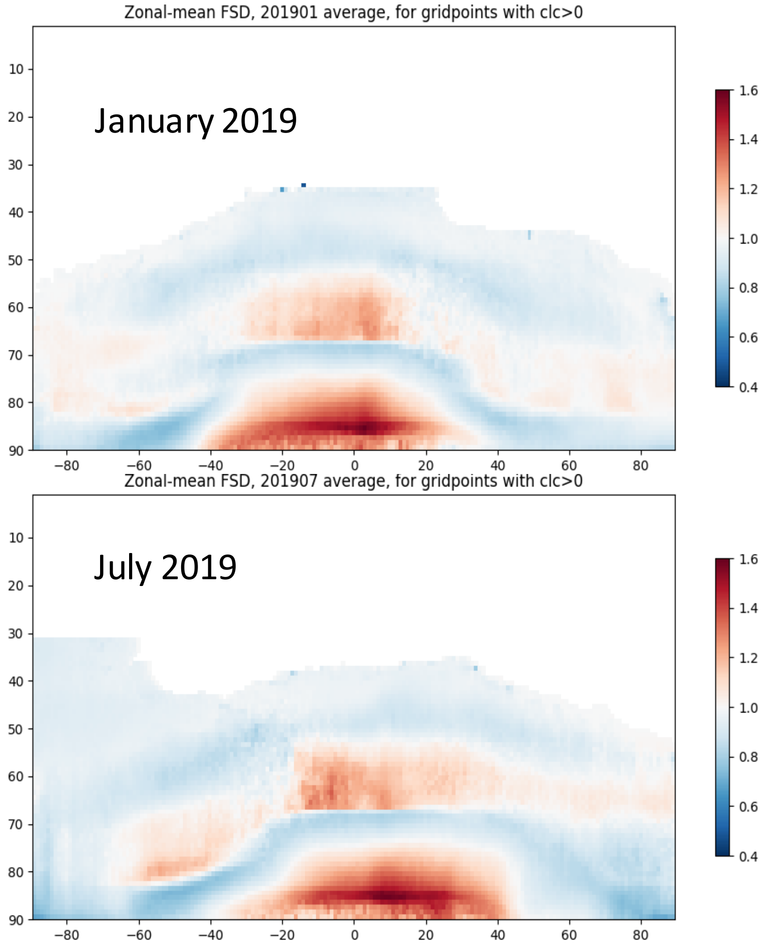
LW TOA flux



- Maximum-random used e.g. in RTTOV – ongoing work to get cloud geometry + particle treatment consistent between ecRad and RTTOV
- **Uncertainty:** 1.5 W/m² systematic difference in global flux
- Analysis ongoing

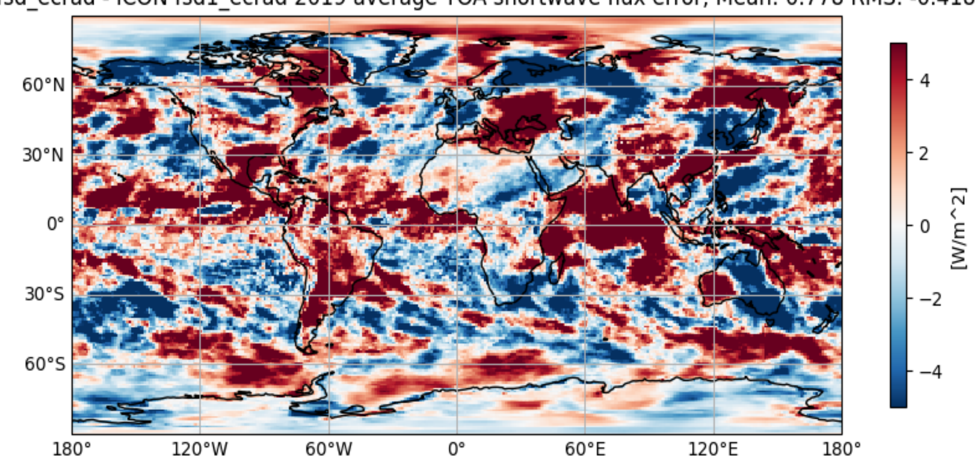
Cloud horizontal inhomogeneity

Zonal mean parametrised in-cloud FSD

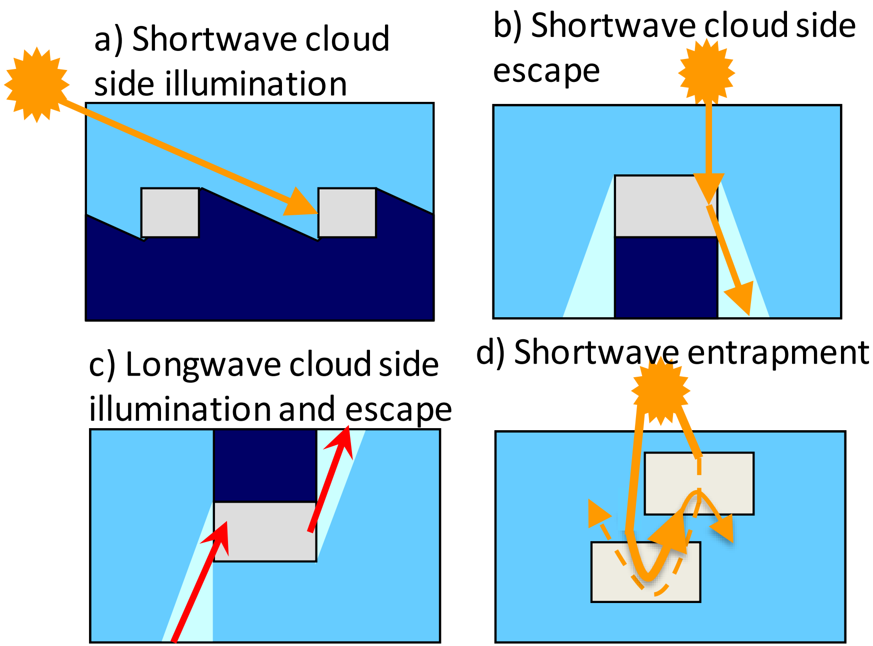


- Default: fractional standard deviation of cloud PDF FSD=1
- FSD parametrised by cloud type (Ahlgrimm and Forbes 2016, 2017): global flux +0.9 W/m²
- Can help with cumulus – stratocumulus distinction

Change in SW TOA flux 2019: parametrised FSD vs FSD=1

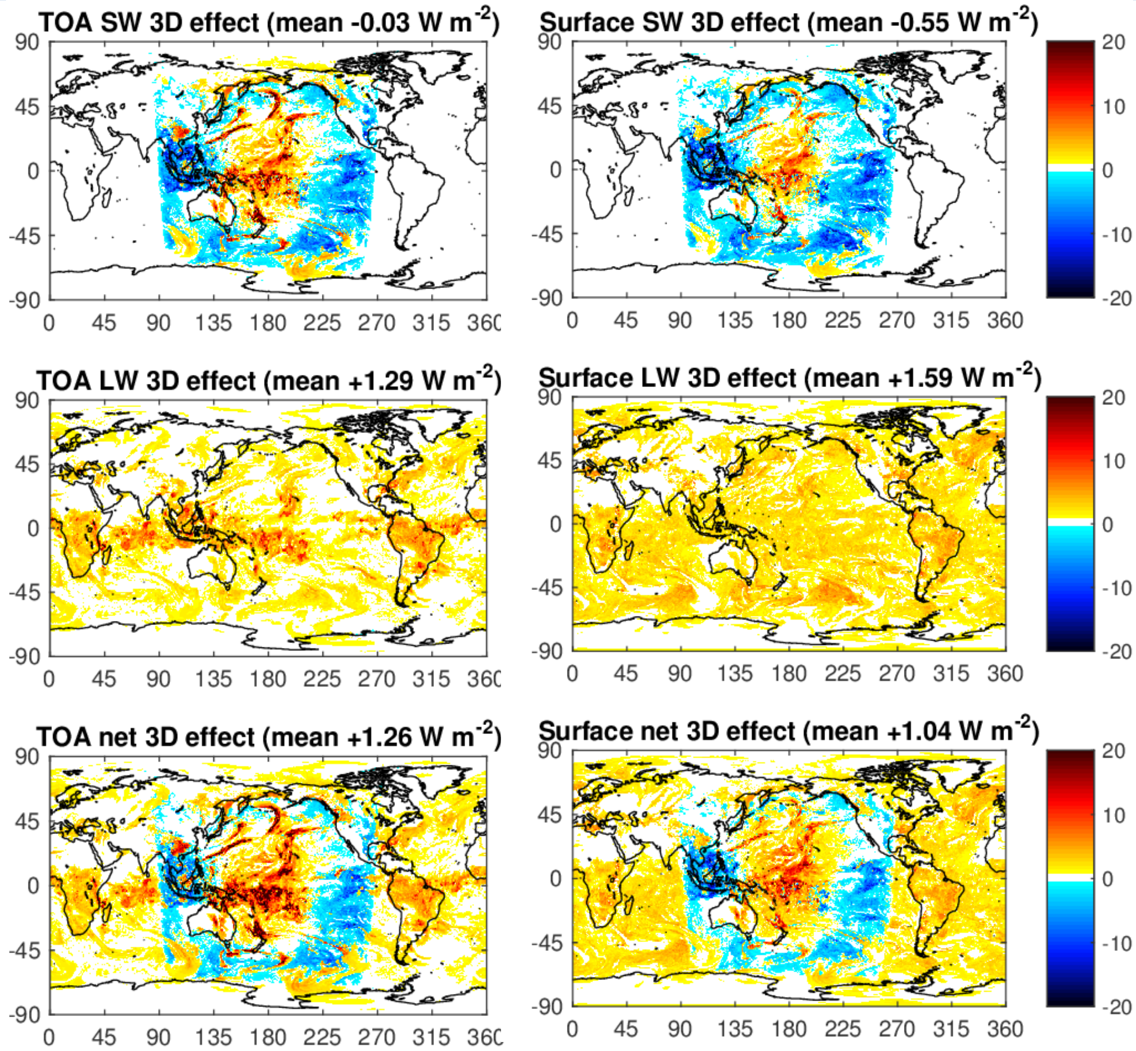


3D cloud effects



- **Shortwave cloud side illumination** increases cloud reflectivity, **cloud side escape** decreases cloud reflectivity
- **Longwave cloud side illumination and escape** increase cloud warming effect
- **Shortwave entrapment** decreases cloud reflectivity
- Similar effects at complex surfaces (trees / mountains / buildings)
- **Usually neglected, SPARTACUS** solver in ecRad can treat them (Schäfer et al. 2016, Hogan et al. 2016, 2019), cost ×4

Global 3D cloud effects



Total 3D effect on climate

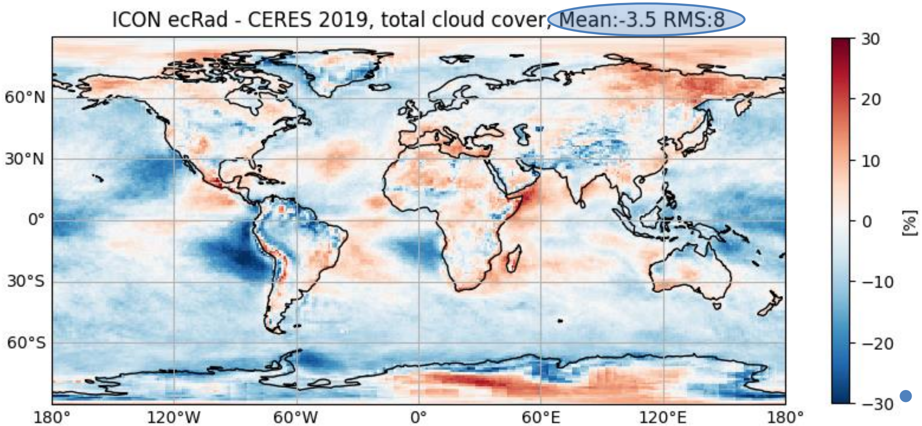
- **Global 3D effects, surface:** Longwave +1.6 $\mathrm{Wm^{-2}}$, Shortwave -0.6 $\mathrm{Wm^{-2}}$ (cancel)
- **Long-term total** +1.4 $\mathrm{Wm^{-2}}$, **warms** by ~1K (more at poles)
- Depends on entrapment and cloud geometry (Hogan et al. 2019)
- Longwave evaluation and improvement ongoing

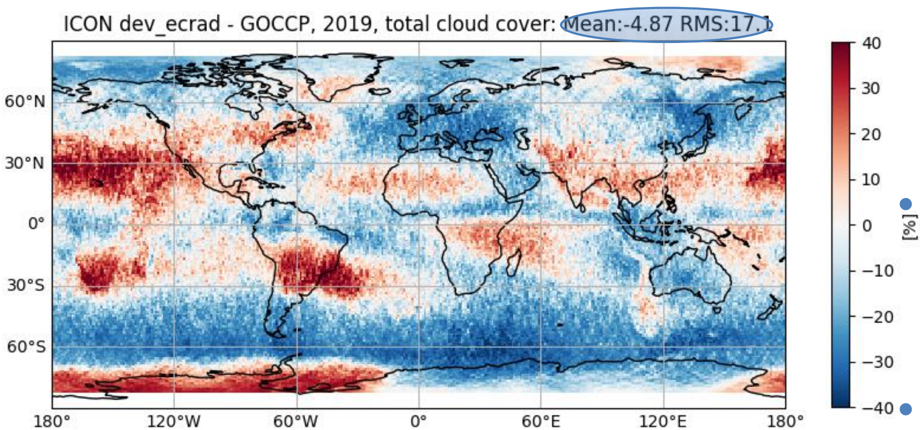
Instantaneous 3D cloud effects in Era5 cloud field, 01.04.2000 0UTC, at TOA and surface. Plots by R. Hogan

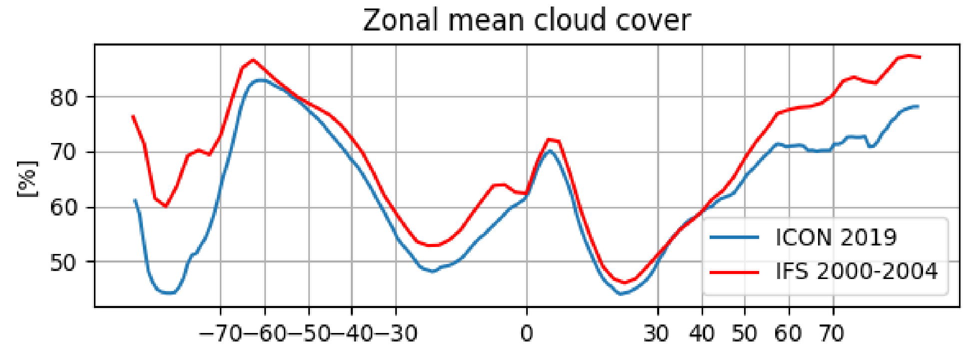
Cloud uncertainty

Cloud cover uncertainty

Total **cloud cover** bias vs. CERES and GOCCP, 2019



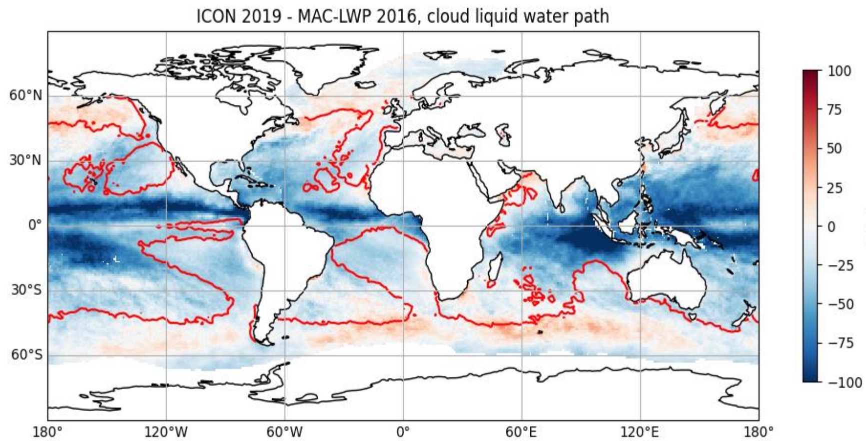


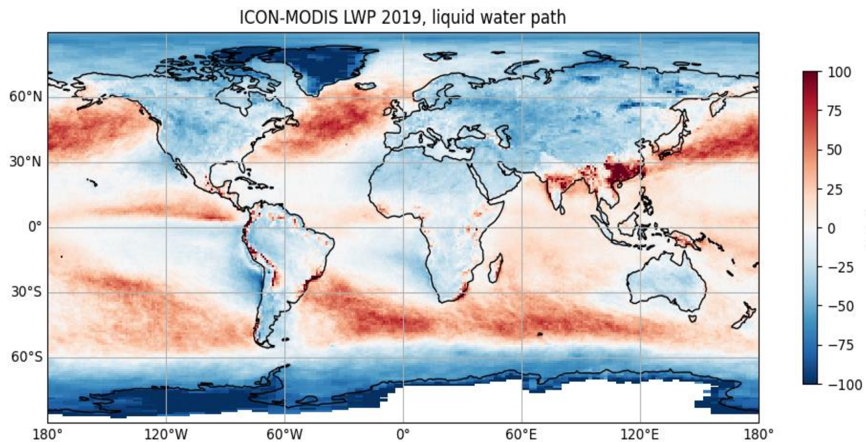


Zonal cloud cover in ICON 2019 and IFS 2000-2004,
IFS data courtesy of P. Bechtold

- Globally: 3.5% too little cloud cover vs. CERES (Loeb at al. 2018), 4.87 % too little vs. GOCCP (GCM Oriented CALIPSO Cloud Product; Guzman et al., 2017 - noisy); less cloud cover than IFS
- Need to consider retrievals, sensitivity and cloud cover definition, potentially evaluate in observation space
- New cloud parametrisation in ICON planned

Cloud liquid water path (LWP) uncertainty



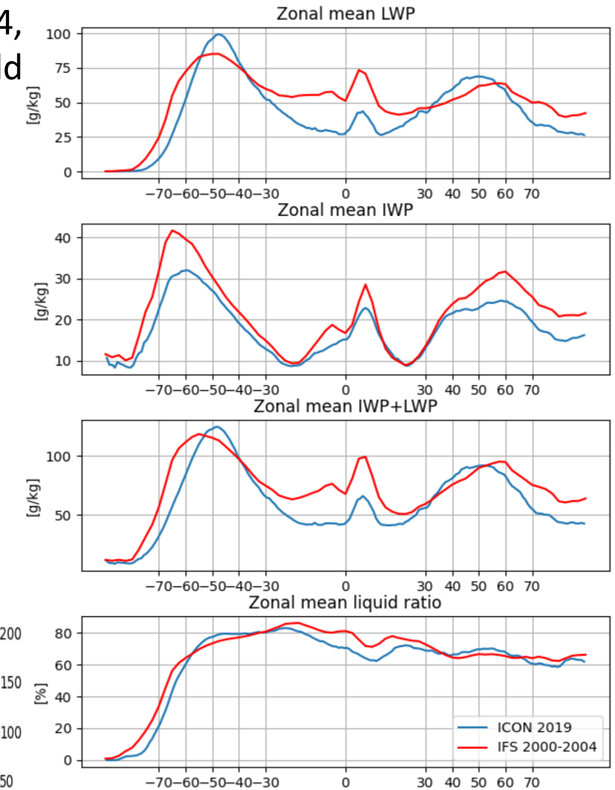


Cloud liquid water path bias in ICON 2019 compared to MAC-LWP (top, 2016-2019) and MODIS (base, 2019), plots by M. Ahlgrimm

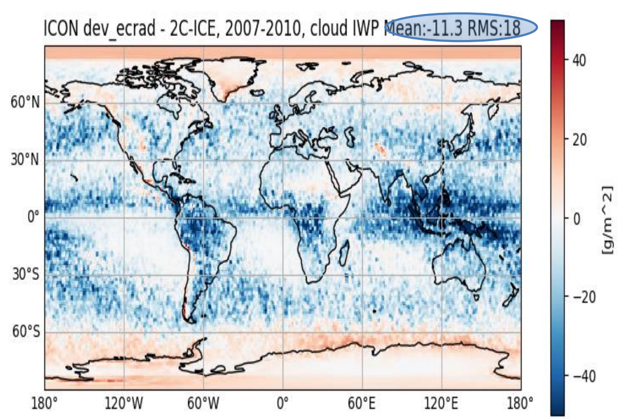
- Multi-Sensor Advanced Climatology of LWP (MAC-LWP, microwave, Elsaesser et al., 2017) reliable in extratropics (poleward of red contours), MODIS (CERES-MODIS SSF visible/infrared retrieval, Loeb et al., 2018) reliable for subtropical low cloud
- Lack of LWP in stratocumulus, trade cumulus regions all right
- Too much LWP 45°S-55°S, no good data south of 60°S

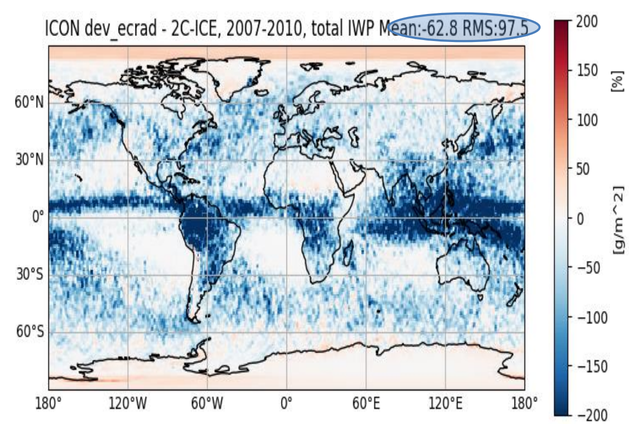
Cloud ice water path (IWP) uncertainty

Zonal mean LWP and IWP in ICON 2019 and IFS 2000-2004,
plots by M. Ahlgrimm, IFS data courtesy of P. Bechtold



- ICON radiation sees maximum of cloud ice and 10% of snow + cloud ice, cloud ice 25% of total (Li et al. 2012); Most models: cloud ice higher to compensate (Li et al. 2020)
- ICON: **lower** cloud and total **IWP** than 2C-ICE and IFS, but too reflective – why?! Phase ratio similar to IFS.
- Uncertainties in retrivals, microphysics,…especially at poles

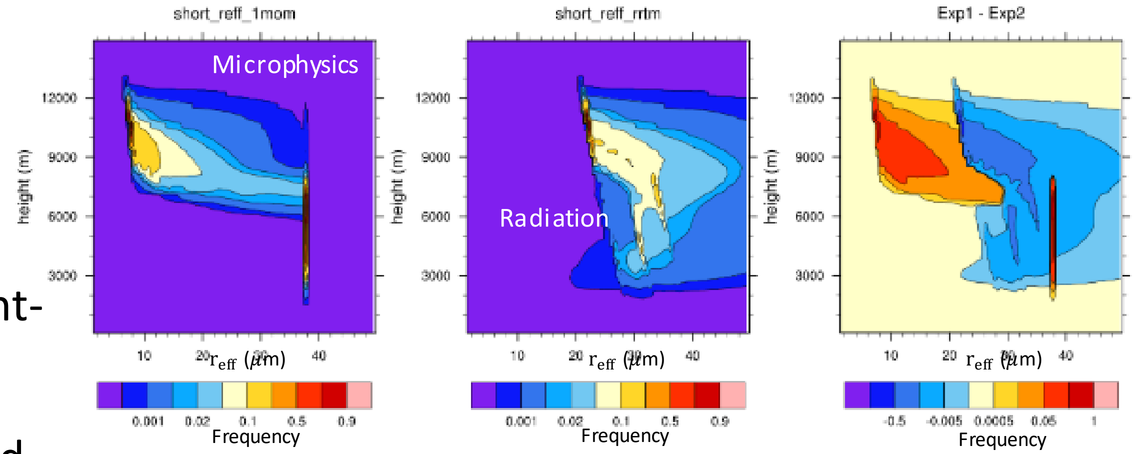




Cloud (left) and total (right) ice water path bias in ICON 2007-2010 vs. 2C-ICE dataset by J. Li
https://zenodo.org/record/3879566

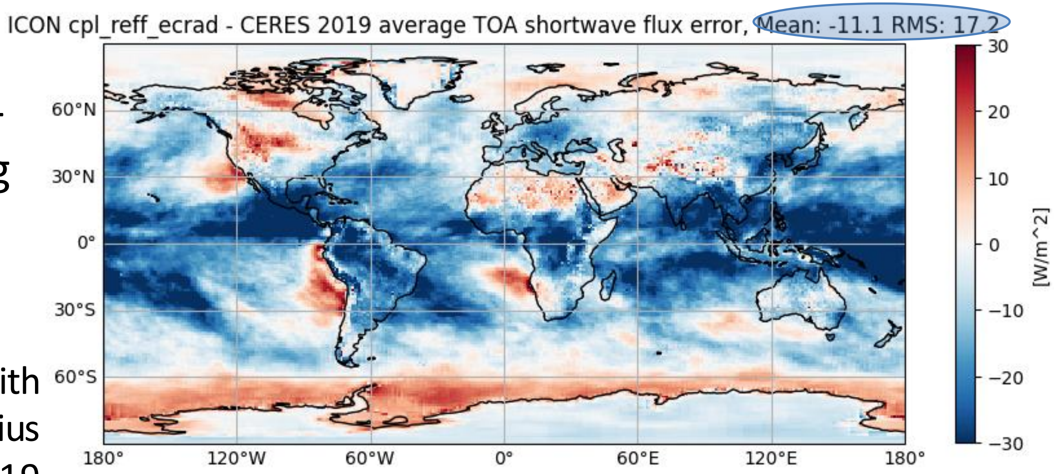
Cloud particle size parametrisation

- **Currently**: ice **effective radius** in radiation **inconsistent** with microphysics
- A. de Lozar: effective radius for radiation consistent with 1-moment- or 2-moment-microphysics



Plots by A. de Lozar

- Precipitation water content included + coupled effective radius smaller → stronger cloud effect (ongoing work)
- **Include** general particle species + large-particle optics → **precipitation** (ongoing work with R. Hogan, A. de Lozar, COSMO project CAIIR)



SW TOA flux bias with coupled effective radius vs. CERES, 2019

Summary

- **ICON: ecRad operational** since April 2021: fast and flexible, can represent **cloud inhomogeneity** and sub-grid **3D** effects; parametrisation **choices** → uncertainty estimation
- **ecRad improves** cloud and radiation in ICON and global flux balance
- Old schemes psrad (in ICON-NWP) and Ritter-Geleyn have been removed
- Main **uncertainties**: **cloud-radiation interaction** (up to 5 W/m^2) and **cloud input** (~10 W/m^2)
- **Why** has ICON **less cloud**, **ice** and **liquid water** than observations / IFS, **more cloud-radiation** effect?

Ongoing and future work:

- Further **code optimisation** and **evaluation and improvement of radiation together with clouds**: cloud condensate, cloud geometry, particle size and shape etc. (with colleagues at DWD, ECMWF, MeteoSwiss, COSMO project CAIIR, KIT, DLR, TROPOS,…), additional data sources
- User-defined cloud particle species → include precipitation (with R. Hogan, project CAIIR, A. de Lozar)
- Aerosol evaluation, ecRad in ICON-ART (with colleagues at KIT, CAIIR and project Permastrom)
- Interactions between clouds, radiation and dynamics, cloud feedbacks (with H. Joos and group, ETH)

Thank you for your attention!

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