COSMO/ICON physics at DWD

Axel Seifert, Deutscher Wetterdienst

Outline

- Some information about the „COSMO/ICON physics library“
- Some examples of current work and projects at DWD

Note: This is not the usual WG3a overview, and I will not try to explain CONSAT.

COSMO vs ICON-NWP physics:

Scheme	COSMO	ICON-NWP
Microphysics	prognostic water vapour, cloud water, ice, rain, snow, graupel (Doms, 2004; Seifert, 2010)	
Radiation	Ritter-Geleyn δ two-stream	RRTM (ecRad coming)
Cloud Cover	EM/DM scheme	Köhler-Zängl
Subgrid scale orography	Lott and Miller (1997)	
Turbulence	prognostic TKE scheme (Raschendorfer)	
Surface schemes	TERRA (Heise and Schrodin, 2002) Flake (Mironov, 2008) Seaice (Mironov, 2004)	
Convection	Tiedtke or shallow	Tiedtke-Bechtold (includes shallow option)
	Tiedtke-Bechtold (optional)	

ICON uses a tile approach, COSMO does not!

Current status (in terms of source code)

Scheme	COSMO	ICON-NWP
Microphysics	gscp_hydor	
	gscp_kessler gscp_cloudice gscp_graupel	gscp_kessler gscp_cloudice gscp_graupel
		mo_2mom_[some files]
Subgrid scale orography	sso_lottmiller	mo_sso_cosmo mo_sso_ifs
Turbulence	turb_[data|diffusion|transfer|utilities|vertdiff]	
Surface Schemes	sfc_terra_data, sfc_terra_init, sfc_terra sfc_flake_data, sfc_flake, sfc_seaice	
Convection (Tiedtke-Bechtold)	conv_[many files]	mo_cu[many files]

Aim for end of this year (Uli S.):

Scheme	COSMO	ICON-NWP
Microphysics	gscp_hydor	
	gscp_kessler gscp_cloudice gscp_graupel	gscp_kessler gscp_cloudice gscp_graupel
		mo_2mom_[some files]
Subgrid scale orography	sso_lottmiller	
Turbulence	turb_[data|diffusion|transfer|utilities|vertdiff]	
Surface Schemes	**ICON uses a tile approach, COSMO does not!**	
Convection (Tiedtke-Bechtold)	conv_[many files]	

COSMO/ICON physics „note of caution“

- ➔ We will have identical Fortran files for most physics in COSMO and ICON
- ➔ Hence, we will achieve the original goal of the „COSMO/ICON physics library“

But …

- ➔ Often different parts of the Fortran codes are used for COSMO resp. ICON
- ➔ Physics in ICON behaves very different, for example and especially, due to the **tile approach** for the surface scheme.
- ➔ External parameters are handled differently in the models, etc. etc.

Therefore ...

- ➔ A streamlined synchronization of physics codes is not possible, but would require a lot of testing and evaluation, which DWD cannot do (SORRY!)
- ➔ A transfer of codes between COSMO and ICON is nevertheless rather simple and easy, but has to be done in individual or institutional branches.

Outline

- Some information about the „COSMO/ICON physics library“
- Some examples of current work and projects at DWD

TKESV scheme (Dmitrii and Ekaterina)

Basic formulation of TKESV:

$$\frac{\partial\langle\theta_l{}'q_t{}'\rangle}{\partial t} = -\langle u_3{}'q_t{}'\rangle\frac{\partial\langle\theta_l\rangle}{\partial x_3} - \langle u_3{}'\theta_l{}'\rangle\frac{\partial\langle q_t\rangle}{\partial x_3} - \frac{\partial\left\langle u_3{}'\theta_l{}'q_t{}'\right\rangle}{\partial x_3} - \varepsilon_{\theta q}$$

non-stationarity

non-homogeneity

Prognostic treatment of scalar (co)variances with due regard for third order transport (i.e. more intimate coupling with cloud scheme)

$$\langle u_3{}'u_1{}'\rangle = -F_M(\tau_\varepsilon{}^2S^2, Ri, P/e)\frac{\partial\langle u_1\rangle}{\partial x_3},$$

$$\langle u_3{}'q_t{}'\rangle = -F_{H1}(\tau_\varepsilon{}^2S^2, Ri, P/e)\tau_\varepsilon e\frac{\partial\langle q_t\rangle}{\partial x_3} + F_{H2}(\tau_\varepsilon{}^2S^2, Ri)\tau_\varepsilon\beta_3\langle q_t{}'\theta_v{}'\rangle$$

F_M, F_{H1} and F_{H2} are the so-called stability functions (Mellor and Yamada 1974) that account for the pressure-scrambling effects (fresh results: regularized well-behaved stability functions are developed).

TKESV scheme (Dmitrii and Ekaterina)

Ongoing work on TKESV at DWD:

- Baseline version of the TKESV scheme is implemented into ICON (some work still to be done, e.g. four-eye check)
- Testing within ICON has started
- Focus is initially on high-resolution applications (ICON-D2), testing within ICON global at later stage
- Detailed scientific documentation of the TKESV scheme is ready (Mironov and Machulskaya 2017), scientific papers are published or submitted (Machulskaya and Mironov 2013, 2018, 2019)
- Further work on the code and preparation of model documentation/papers: we try hard to make sure that what you see in the code is very similar to what has been described (hope we succeed ☺)

Machulskaya, E., and D. Mironov, 2013: Implementation of TKE - Scalar Variance mixing scheme into COSMO. *COSMO Newsletter*, No. 13, 25-33. (available from www.cosmo-model.org)

Mironov, D. V., and E. E. Machulskaya, 2017: A turbulence kinetic energy - scalar variance turbulence parameterization scheme. COSMO Technical Report, No. 30, Consortium for Small-Scale Modelling, 55 pp. (www.cosmo-model.org)

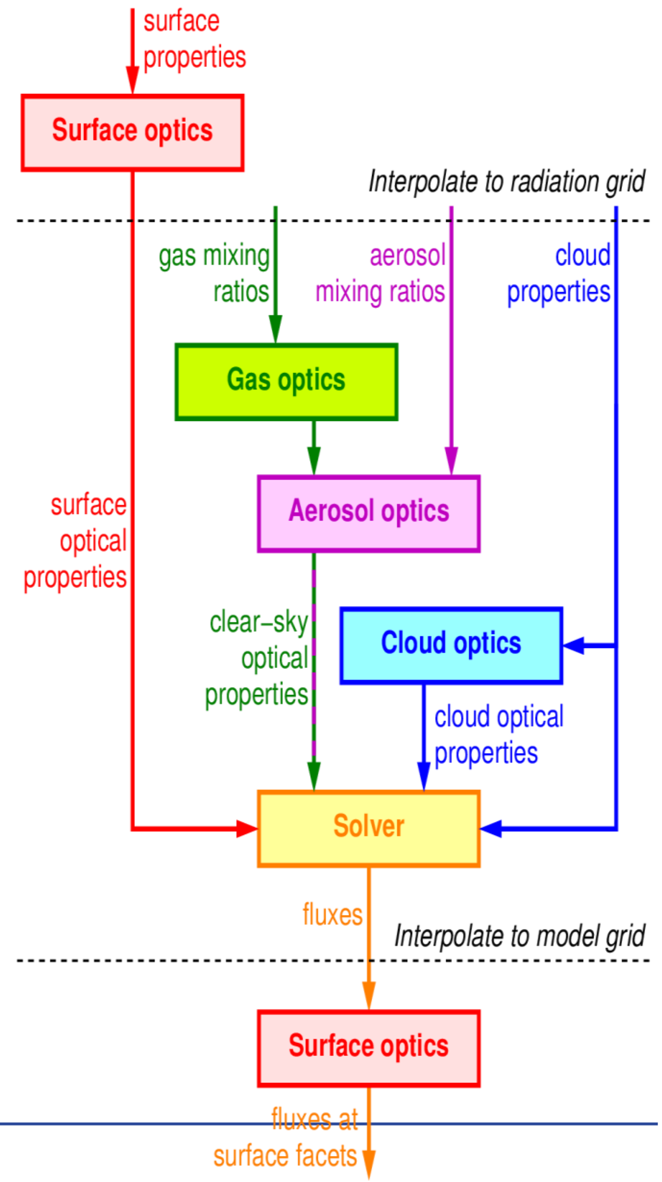
Machulskaya, E., and D. Mironov, 2018: Boundary conditions for scalar (co)variances over heterogeneous surfaces. *Boundary-Layer Meteorol.*, **169**, 139-150. doi: 10.1007/s10546-018-0354-6

Machulskaya, E., and D. Mironov, 2019: The so-called stability functions and realizability of the TKE - Scalar Variance closure for moist atmospheric boundary-layer turbulence. Submitted to *Boundary-Layer Meteorol.*

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

- **Gas optics:** RRTM-G (Iacono et al. 2008)
  - *Robin H. plans to develop new scheme with fewer spectral intervals*
- **Aerosol optics:** variable species number and properties (set at run-time)
- **Cloud optics included:**
  - **liquid:** SOCRATES (MetOffice)
  - **ice:** Fu 1996, 1998 (default) or Yi et al. 2013 or Baran et al. 2014
- **Longwave scattering**
- **Cloud solvers:**
  1. McICA (Pincus et al. 2003)
  2 .**Tripleclouds** (Shonk & Hogan, 2008)
  3. **SPARTACUS** (Schäfer et al. 2016, Hogan et al. 2016)

SPARTACUS makes ecRad the only global radiation scheme that can do 3D radiative effects



ecRad in ICON (Sophia, Daniel and Martin)

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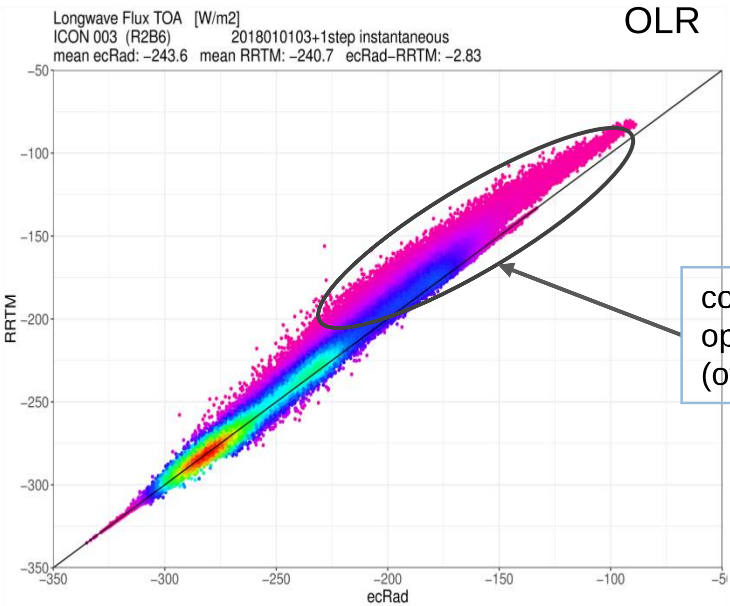
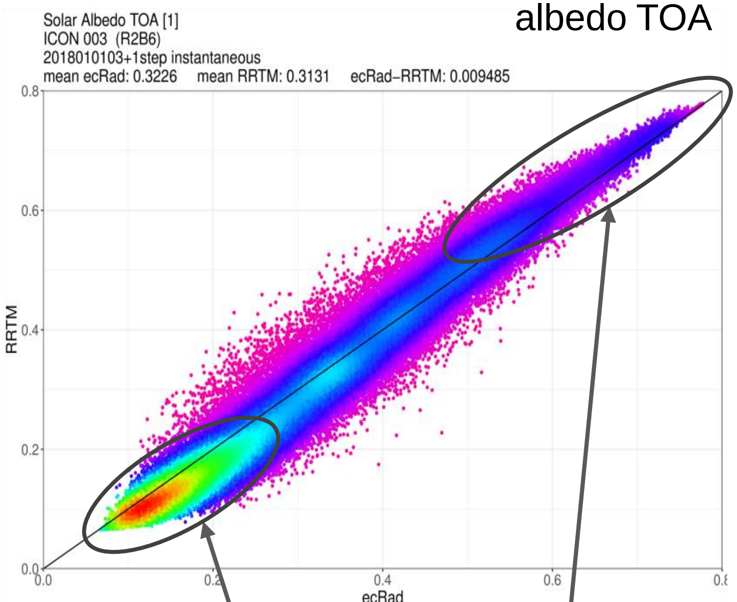
ecRad versus RRTM: same atmosphere input

OLR



cold high clouds:
optically thinner in LW
(offset = ~15Wm^{-2})

albedo TOA



thin clouds or surface:
more reflective (~2%)

thick clouds:
less reflective (~2%)

Why?

Probably cloud geometry treatment

ecRad vs RRTM in ICON: 1-day simulations

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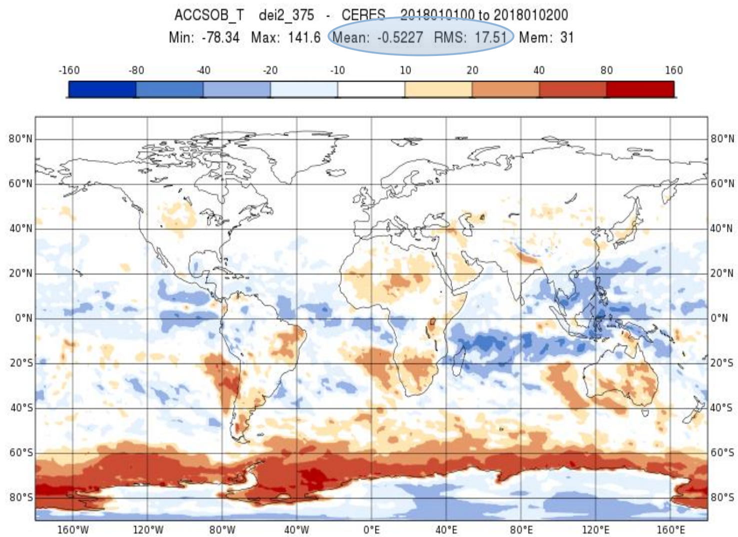
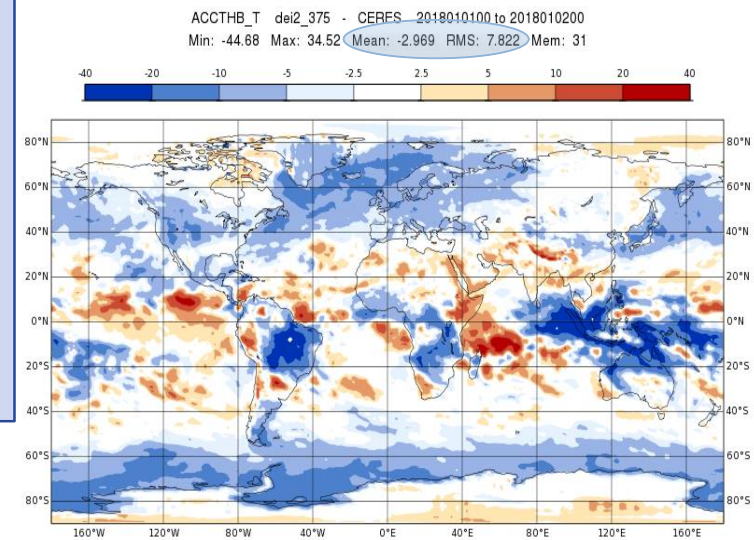
TOA solar vs. CERES

TOA thermal vs. CERES

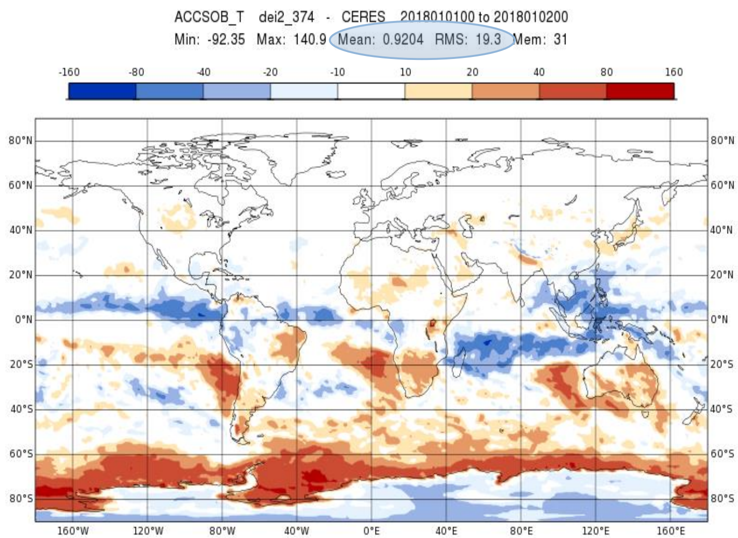
ecRad reduces errors in shortwave fluxes, longwave bias changes sign → colder troposphere, weaker meridional temperature gradient and circulation

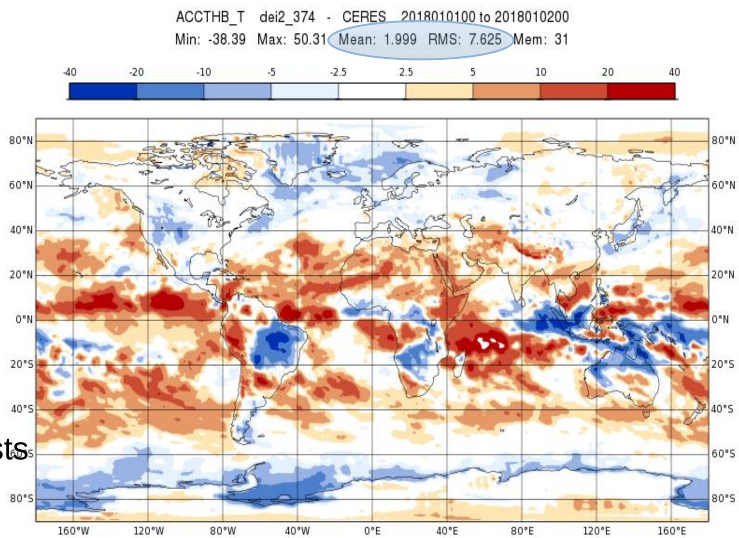
ecRad





RRTM





January 2018, 24h forecasts

ecRad in ICON

- ➔ ecRad has been successfully implemented in ICON by Daniel Rieger
- ➔ some significant and mostly positive changes in cloud-radiative effects compared to old RRTM scheme

Next steps:

- Extend ecRad to include snow or graupel in radiation
- Implement revised optical properties for snow and graupel: “Extended Fu” (with Uli B. and Harel and Pavel of IMS)
- Coupling to 2-moment microphysics
- Extensive tests in global ICON and ICON-D2
- Revise subgrid cloud scheme and microphysics for ecRad

New DWD project on stochastic shallow convection

- Started 1. September with Maike Ahlgrimm as project scientist.
- The project aims at testing the stochastic shallow convection of Mirjana Sakradzija et al.
- The goal is to make the scheme operational in ICON-D2 by end of 2021.
- We will start with the classic mass flux Tiedtke-Bechtold scheme, but plan to work on the higher-order closure (TKESV) later in the project.
- We will also make use of the stochastic SDEs, which Ekaterina derived recently

Published papers related to the project:

Sakradzija, M., Seifert, A., & Heus, T. (2015). Fluctuations in a quasi-stationary shallow cumulus cloud ensemble. Nonlinear Processes in Geophysics, 22(1), 65-85.

Sakradzija, M., Seifert, A., & Dipankar, A. (2016). A stochastic scale-aware parameterization of shallow cumulus convection across the convective gray zone. Journal of Advances in Modeling Earth Systems, 8(2), 786-812.

Sakradzija, M., & Hohenegger, C. (2017). What determines the distribution of shallow convective mass flux through a cloud base?. Journal of the Atmospheric Sciences, 74(8), 2615-2632.

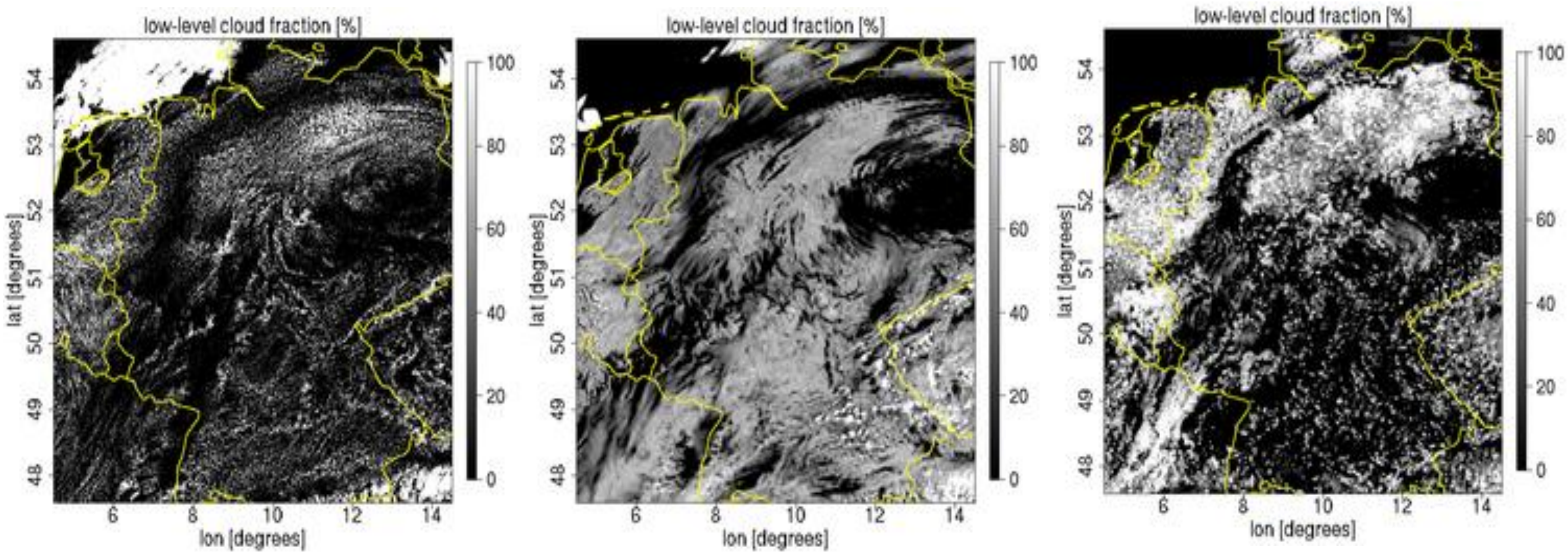
Sakradzija, M., & Klocke, D. (2018). Physically Constrained Stochastic Shallow Convection in Realistic Kilometer-Scale Simulations. Journal of Advances in Modeling Earth Systems, 10(11), 2755-2776.

Machulskaya, E., & Seifert, A. (2018). Stochastic differential equations for the variability of atmospheric convection fluctuating around the equilibrium. Journal of Advances in Modeling Earth Systems.

New DWD project on stochastic shallow convection

➔ Results in individual case studies are quite promising

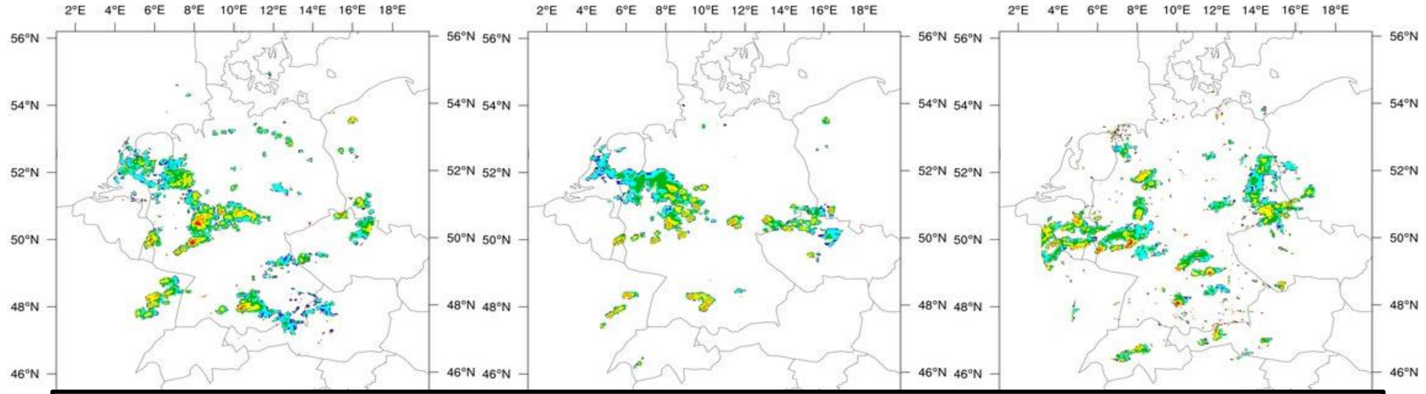
ICON-LES | deterministic scheme | stochastic scheme



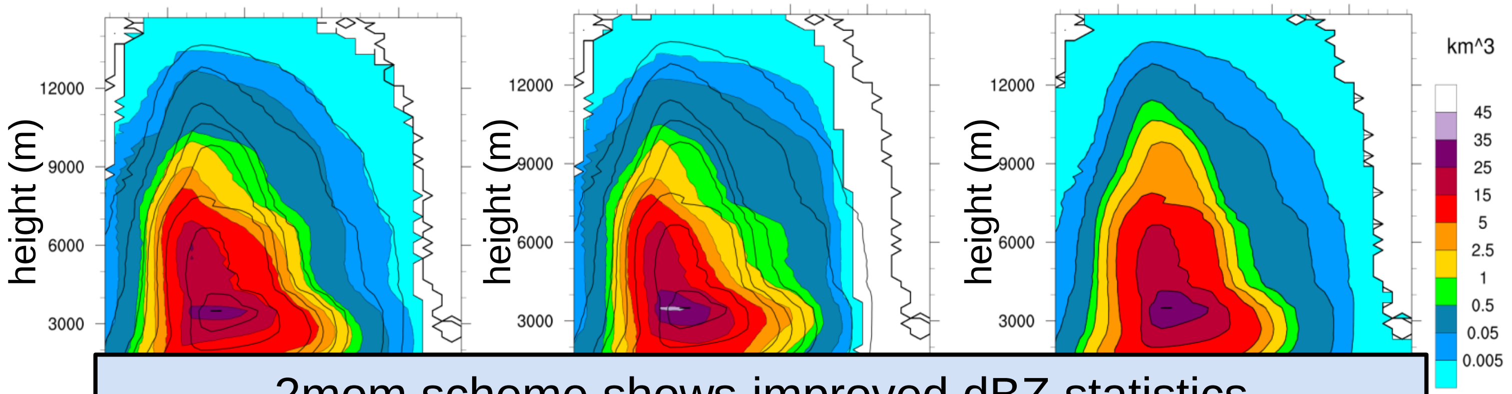
Sakradzija, M., & Klocke, D. (2018). Physically Constrained Stochastic Shallow Convection in Realistic Kilometer-Scale Simulations. Journal of Advances in Modeling Earth Systems, 10(11), 2755-2776.

ICON-D2 SINFONY (Alberto de Lozar)

ICON 2mom | ICON 1mom | Observation



2mom scheme can simulate high dBZ convective cores, which are missing with 1mom scheme



2mom scheme shows improved dBZ statistics

dBZ dBZ dBZ

ICON-D2 SINFONY (Alberto, Leonhard)

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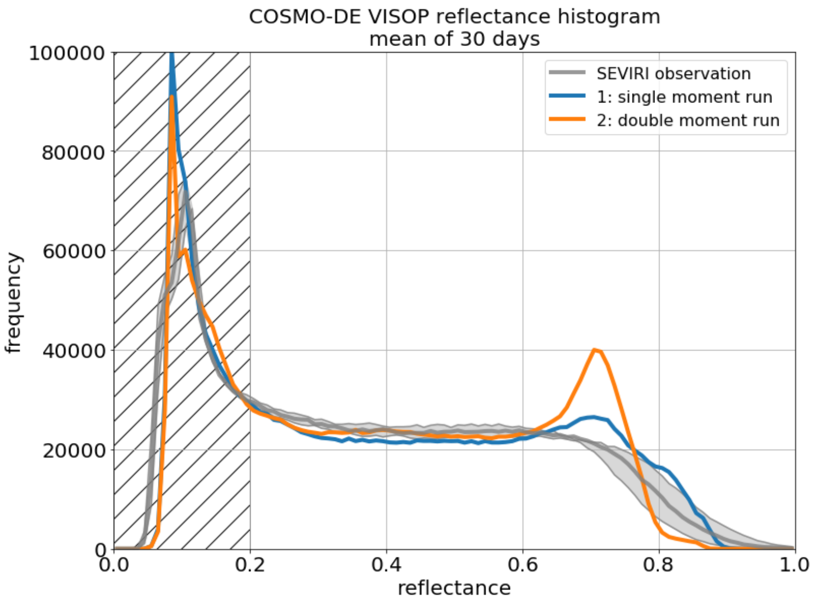
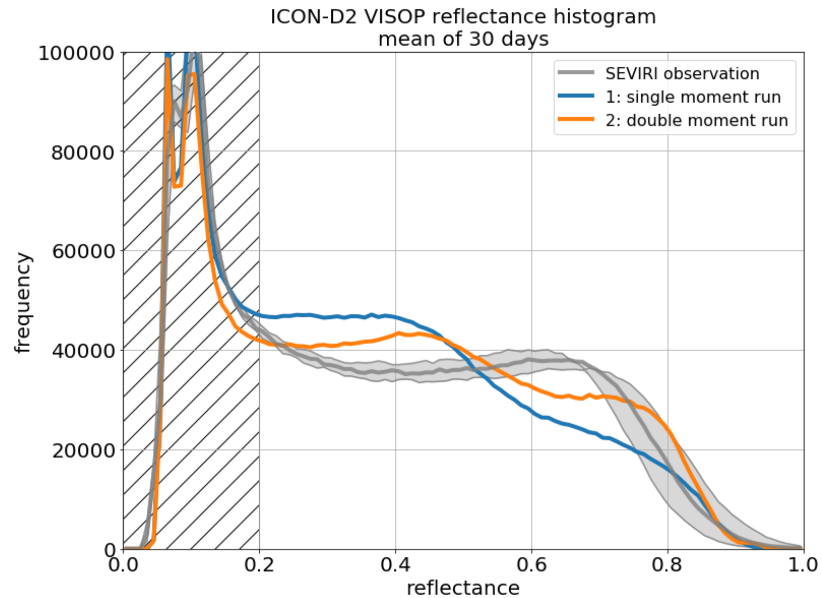
Comparison of simulated and observed visible reflectance:





- ➔ Difference between models is larger than difference between 1mom vs 2mom
- ➔ COSMO-DE is better, but ICON-D2 has more room for improvement ☺
- ➔ 2mom is clearly better in ICON-D2, but not necessarily in COSMO-DE

Particle-based microphysics „McSnow“

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➔ Developing a benchmark model to understand microphysical processes

Operational microphysics:

Many simplifications to cope with complexity:

- fixed form of size distribution

$$f(x) = A\,x^{\nu}\,e^{-\lambda x^{\mu}}$$

- categorization

  cloud water, rain
  cloud ice, snow, graupel

Particle-based benchmark model

Will be much more expensive but

- avoids both simplification
- allows a direct more validation with measurement

→ use benchmark model to learn how to improve operational parametrizations.

Processes

nucleation
vapor diffusion
sedimentation
coalescence
riming
rime splintering
riming
melting & shedding
hydrodynamic breakup
collision breakup

Locatelli & Hobbs 74

ice mass m_i
Monomer count N_m
rime mass m_r
rime density ρ_r
liquid mass m_w

Diagnose
→ geometry
→ fall velocity
→ anything else

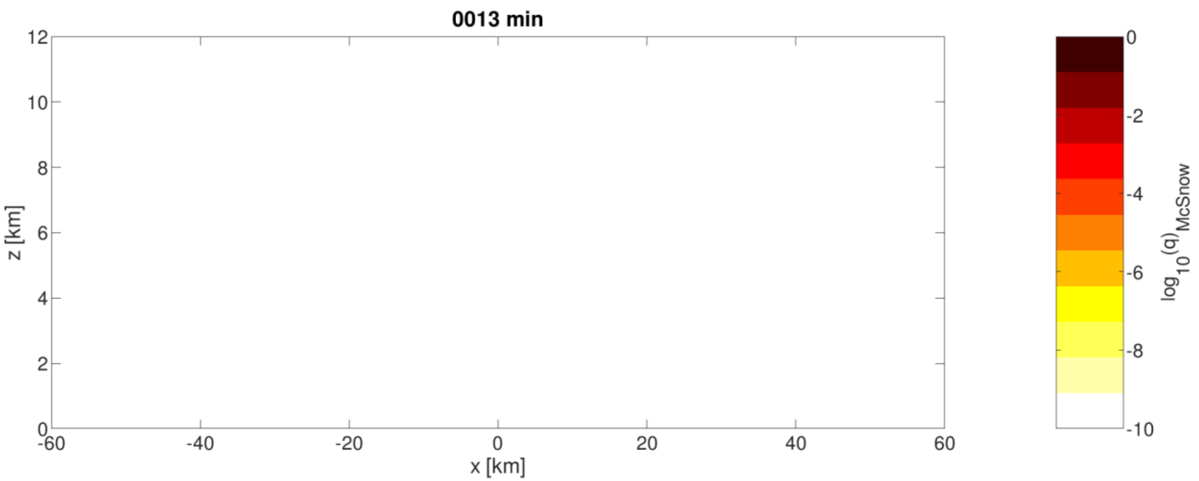
Brdar, S., & Seifert, A. (2018). McSnow: A Monte-Carlo Particle Model for Riming and Aggregation of Ice Particles in a Multidimensional Microphysical Phase Space. Journal of Advances in Modeling Earth Systems, 10(1), 187-206.

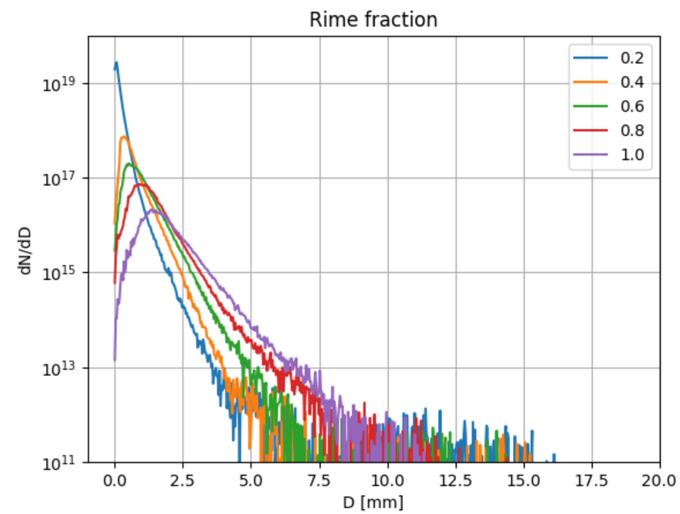
Particle-based microphysics „McSnow“

by Christoph Siewert (DWD) as part of the HD(CP)2 project:

Idealized 2D warm bubble

size distribution = f(rime fraction)

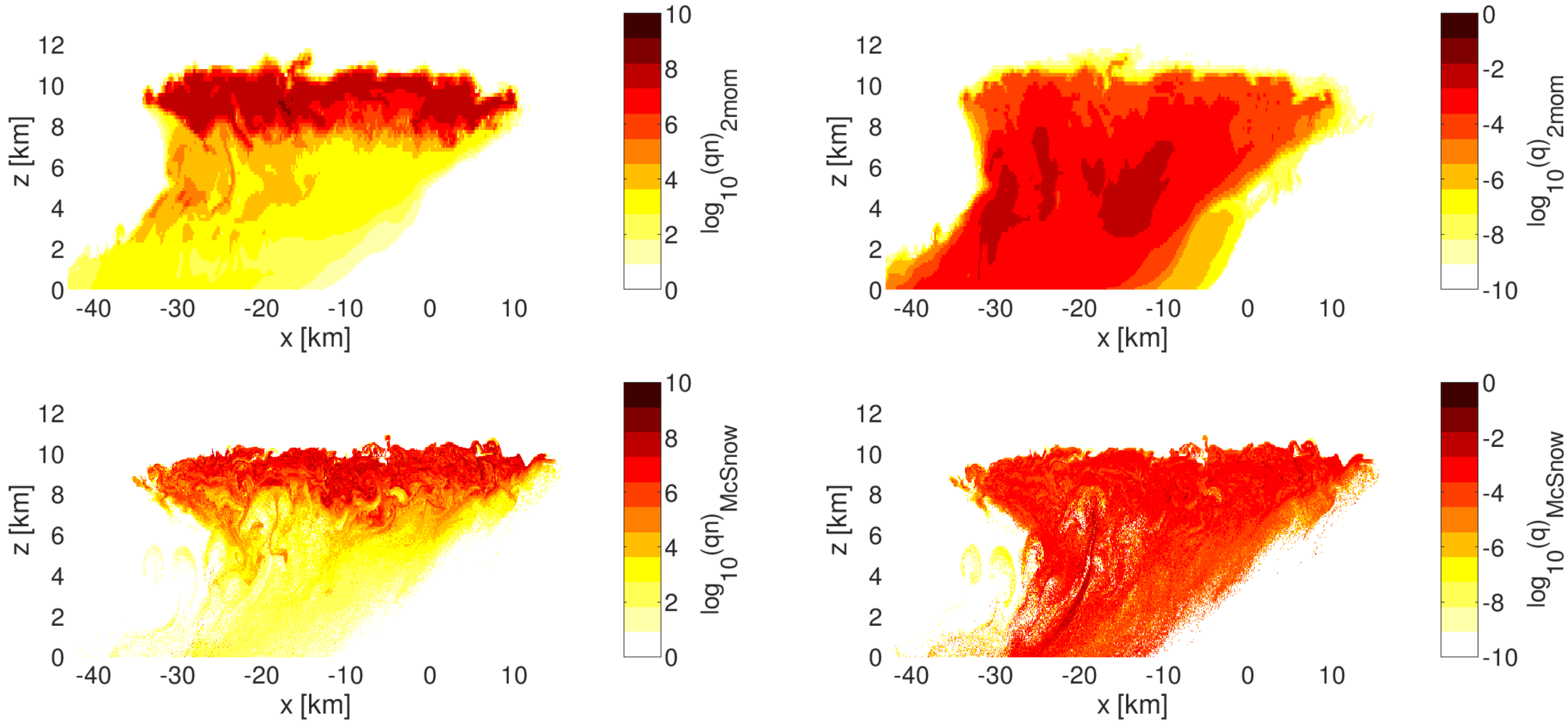




ICON-LEM (Δx ~ 150 m) + McSnow (N_{part} ~ 15 Mio.)

- ➔ We have an implementation in ICON that works and gives reasonable results.
- ➔ A detailed evaluation against observations will be done in the next project.
- ➔ We will also extent the model to include a habit prediction of ice crystals

Comparison with 2-moment bulk scheme



➔ Fairly good agreement, but understanding the differences will be a challenge.

PerduS (Vanessa B. et al.)

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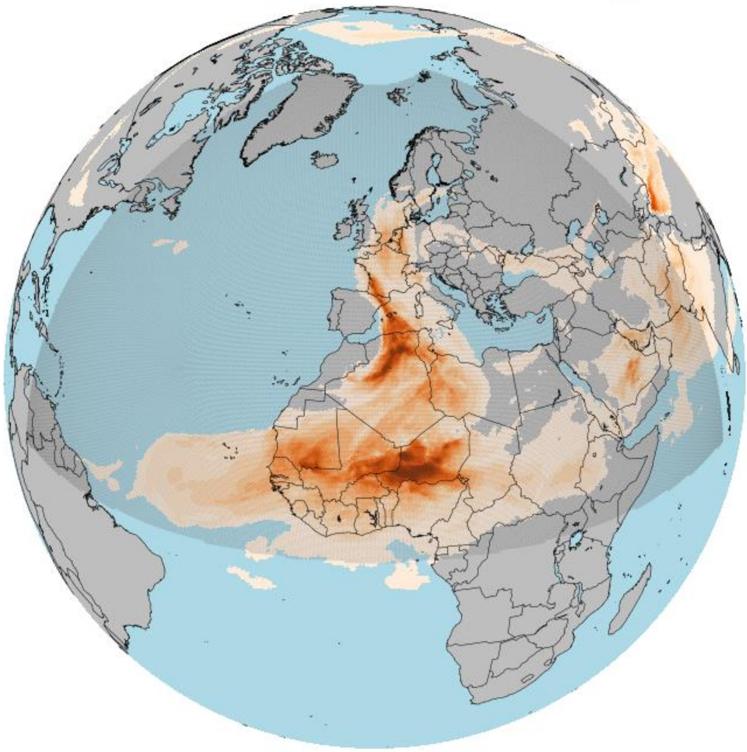
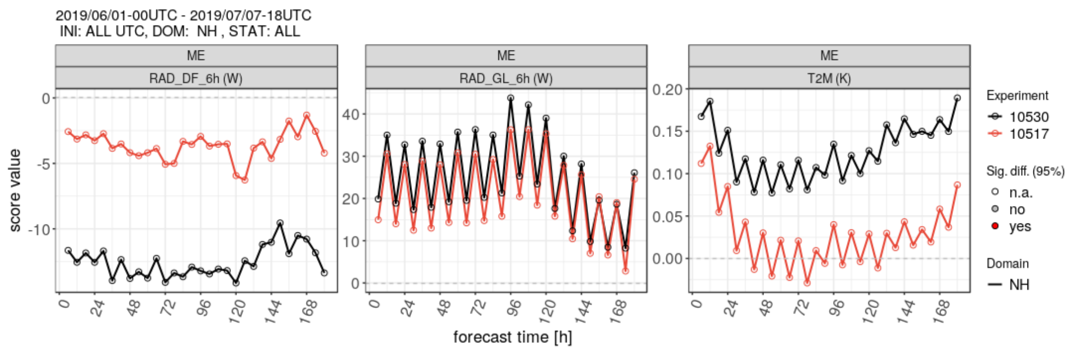
Quasi-operational Mineral Dust Forecast

2018040800, vv: 003, ICON-ART, AOD_DUST



- ➔ Daily 00/12 UTC forecasts up to +180 h (Nest: +120 h)
- ➔ Including dust in radiation
- ➔ Global: 40 km, Nest: 20 km



Verification for **10517** with prognostic Dust comparison to reference **10530** with Tegen climatology (June 2019, Northern Hemisphere)

- ➔ Improves mean error of radiation and T2m

ICON-ART @ WMO SDS-WAS

(WMO Sand and Dust Storm Warning Advisory and Assessment System)

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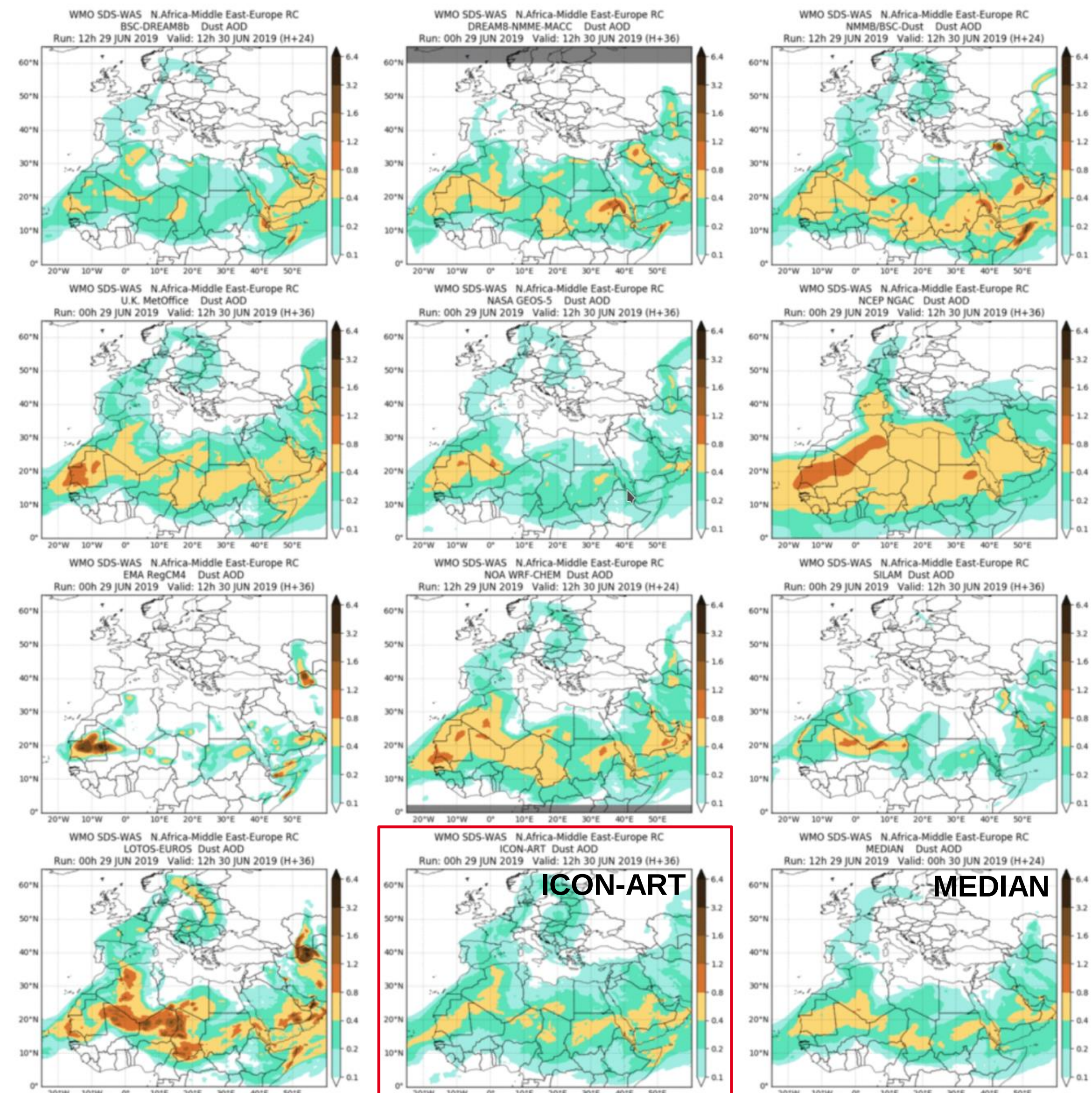
Online model forecast comparison of operational dust models:

- ➔ ICON-ART forecasts online since 29.06.2019
- ➔ dust aerosol optical depth and dust near surface mass concentration
- ➔ https://sds-was.aemet.es/
- ➔ ICON-ART compares quite well with other forecasts, even without an assimilation of AOD.

Dust optical depth:



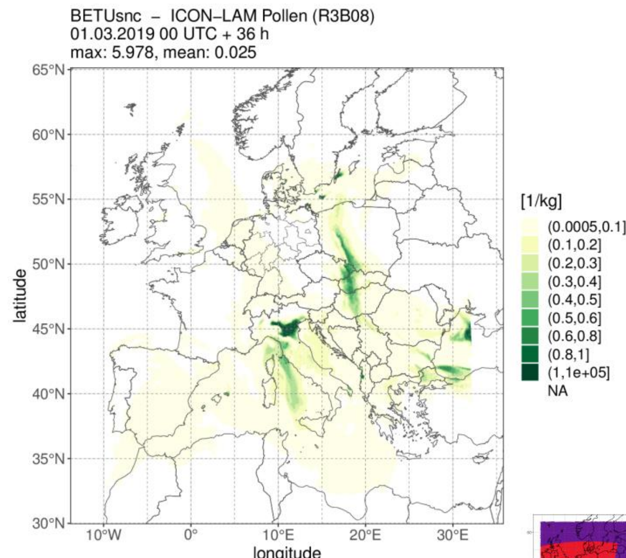
Pollen with ICON-ART (Jochen F. et al.)

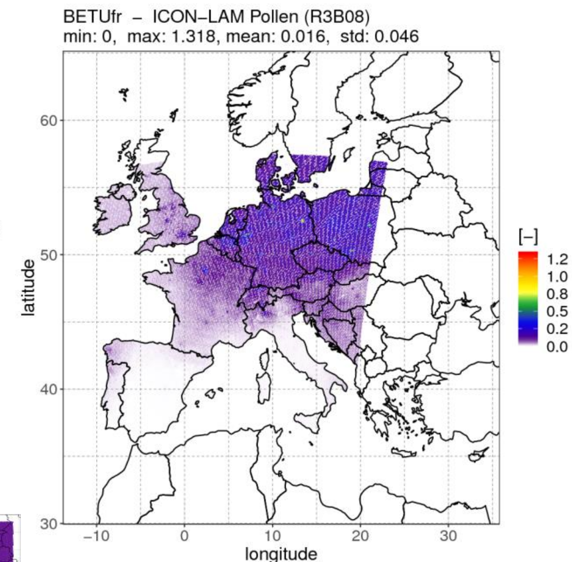
- Pollen code was ported from COSMO-ART to ICON-ART (KIT and DWD).
- Currently external parameter dataset from COSMO7 (MeteoSwiss), which is only available on the respective subdomain, is used.
- To-Do until end of Sep. 2019: Extend operational model script for ICON-LAM to run pollen forecast in experimenting system (NUMEX) and operational environment.
  - Run pollen seasons of this and possibly also last year in NUMEX.
  - Should become operational early 2020.

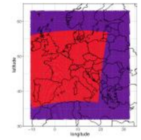
Pollen with ICON-ART (Jochen F. et al.)

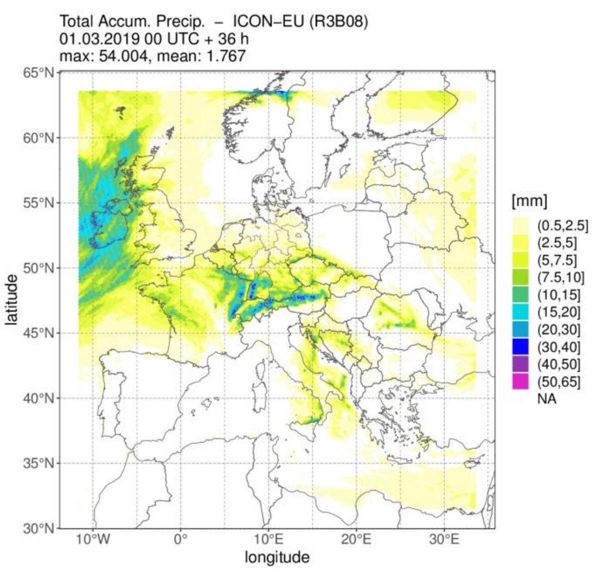
Test of pollen forecast with ICON-ART-LAM 01.03.2019 00 UTC + 36 h

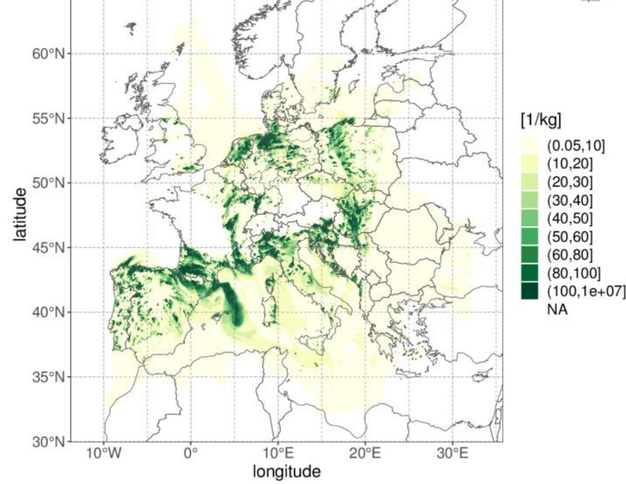
- Specific number conc. of birch and alder pollen (left)
- Fraction of land covered by birch and alder pollen (right)
- Total accumulated precipitation (below, ICON-EU)

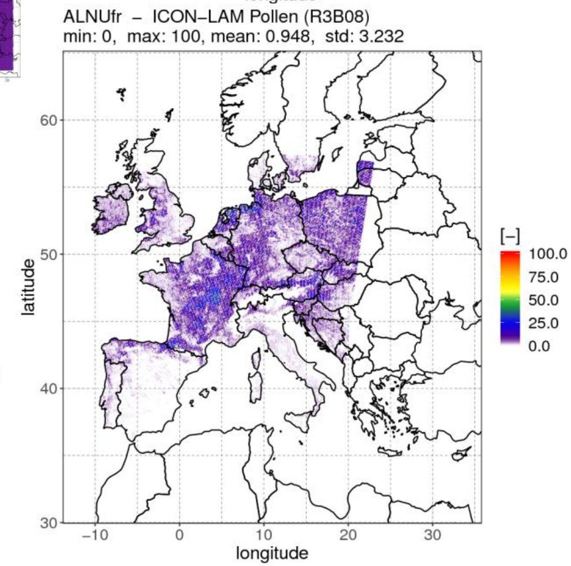












Pollen with ICON-ART (Jochen F. et al.)

- Pollen code was ported from COSMO-ART to ICON-ART (KIT and DWD).
  - Creation (Extpar) and input of external parameters (NetCDF / GRIB2) as well as handling of “ATAB” files (ASCII) in ICON-ART.
  - Offline calculation of pollen specific cumulated 12 UTC 2m-temperatures (from T_{2m} surface analysis of previous day)
  - GRIB2 definitions for pollen tracers and diagnostics (ecCodes 2.12.5)
  - Interface (ICON-branch: icon-nwp/icon-nwp-pollen) to, and the emission routines (ART-branch: pollen) themselves got cleaned-up and prepared for operational use.
  - Code is up-to-date with current ICON-NWP branch as well as current ART master.
- Currently external parameter dataset from COSMO7 (MeteoSwiss), which is only available on the respective subdomain, is used.
  - Task for DWD’s biometeorology group (KU12, Freiburg) to provide complete and improved datasets in the future.
- To-Do until end of Sep. 2019: Extend operational model script for ICON-LAM to run pollen forecast in experimenting system (NUMEX) and operational environment.
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