

Current activity in upper-air COSMO Physics

- ✓ Revision of cloud optical properties:
 - Sub-grid cloud effects and CAMS-aerosol climatology
- ✓ Towards an operational dust-forecast
- ✓ About applications of the STIC-approach in ICON:
 - Operational CAT-forecast for aviation based on EDR from TURBDIFF

Note:

- We are compiling a common physics package for the quadrilateral LAM COSMO and the new icosahedral global model ICON (also applicable as a LAM):

Still different are:

Radiation scheme

Convection scheme

COSMO:

Ritter/Geleyn $\xrightarrow{\text{new optical properties}}$

Tiedke $\xleftarrow{\text{already implemented in COSMO, but not operational}}$

ICON:

RRTM

Tiedke/Bechthold

Physical Process in COSMO			Method	Name	Authors
Local Parameteriz. of atmospheric source terms	Radiation Transport		δ two-stream; revised optical cloud properties		Ritter and Geleyn (1992) Blahak (->)
	Microphysics		1-moment; 3 prognostic ice phases; prognostic rain and snow		Doms (2004) Seiffert (2010)
			optionally 2-moment version		
Grid-scale Parameteriz. of sub-grid scale atmospheric processes (dependent on horizontal resolution)	any other not yet (completely) considered process (e.g. SSO driven thermal circulations or horizontally propagating GW)				
	Convection	deep	2-class (updraft-downdraft) mass-flux equations with moisture convergence closure and simplified microphysics		Tiedke (1989), update by Bechthold et al. (2008) optionally
		shallow			
	Sub-grid Scale Orography (SSO) effects		orographic blocking and breaking of vertically propagating Gravity Waves (GW)		Lott and Miller (1997)
	Quasi-Isotropic Turbulence		2-nd order closure; progn. TKE with addit. scale-interaction terms (STIC); horizont. BL-approx. with opt. 3D- extensions; turb. sat.- adjustm.		TURBDIFF
	Surface-to- Atmosphere Transfer and Roughness Layer effects		transfer resistances based on vertically constant turbulent/laminar near-surface fluxes normal to roughness-covering surfaces; separate heat budget of roughness elements (shading)	not yet tiled in C O S M O	TURBTRAN
Modelling the Non- atmospheric part below the surface	----		---	TERRA	---

- effect of single-precision
radiation calculations
on results

Testing & Tuning of (Revised Cloud Radiation Coupling) $T^2(RC)^2$:

Harel Muskatel, Pavel Khain (IMS)

Uli Blahak (DWD)

Natalia Chubarova (RHM)

and others

Operational state of cloud-treatment for radiation :

■ Operational cloud-treatment in radiation scheme (Ritter & Geleyn 1992) of COSMO:

– Concentrations of cloud-water are a low-sophisticated combination of grid scale micro-physics

○ grid-scale saturation adjustment for liquid water content (**LWC**) $\rho_c = q_c \cdot \rho$

○ grid scale 1-moment box-scheme for ice water content (**IWC**) $\rho_i = q_i \cdot \rho$

and additional diagnostics considering also sub-grid scale generation of cloud-water using a temperature dependent ice/liquid-ratio, separately for

○ grid-box fraction occupied by convective clouds (derived from convection scheme)

■ with a fixed cloud-water concentration

○ (more stratiform) grid-box complement where only turbulence causes heterogeneity, either

■ based on relative humidity (operational) or

■ based on turbulent saturation adjustment (statistical scheme, also used in moist turbulence)

– Optical depth τ of liquid-clouds is calculated based on constant effective radius $R_{\text{eff}} = 5\mu\text{m}$

○ An additional effect of inhomogeneity in the expression of τ is taken into account by means of a constant reduction factor $K_{\text{het}}=0.5$ applied to the mass fraction q_c .

– Optical depth of aerosols (AOD) is taken from old Tanre (1983) climatology.

– Optical properties of ice-clouds

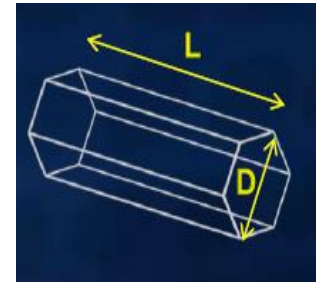
extinction coeff. β_{ext} , single scattering albedo ω asymmetry factor g , delta-transmission factor f_d
--

are described only crudely and don't include precipitation products.

Revised parameterization of optical ice-cloud properties (already from last year):

Already from last year:

- New parameterizations of ice cloud **optical properties** based on idealized calculations according to Fu
 - **Visible-bands:** Ray-tracing for randomly orientated hexagonal ice particles (Fu 2007)
 - **IR-bands:** weighted average of Mie-scattering and related methods (Fu et al. 1998)
 - **Optical properties** are treated as functions of **effective arguments**
 - **effective radius** R_{eff} and wave-length
 - **aspect ratio** AR
 - **Arguments** deduced from inherent assumptions in terms of **particle size distribution** $N(L)$, **mass size relation** $m(L)$ and **particle shapes** (expressed by **L** and **D**):
 - Suitable also for **complicated ice particles** (bullet rosettes, aggregates with rough surfaces, fractional crystals)
 - **Extending particle size range** (5 μm - 300 μm) by using 7000 size-modified **Generalized Gamma-Distributions** $N(L)$
 - **Fitting** the calculated relations between **optical properties** and **effective arguments**
 - In terms of **rational functions** using **spectral averaging** for **8 distinctive spectral bands**



Extended effective Radius R_{eff} calculation for liquid-water clouds based on an aerosol-climatology:

New:

- Aerosol-climatology from Tegen (et al., 1997), Kinne (2013), or CAMS-ECMWF (later: prognostic aerosols: **COSMO-ART** and **ICON-ART**)
 - Optical thickness for 5 aerosol categories:
 - sea-salt, mineral dust, black carbon, organics

Already from last year (Uli Blahak, DWD):

- Vertical profiles of mean effective radius:
 - Assumed specific extinction coefficients
 - Assumed mean particle radius and density
 - Assumed exponential vertical decrease
 - aerosol number concentration
 - effective updraft wind speed:

=> grid-column-integrated aerosol-mass per m^{-2}

=> aerosol number concentration $N_{\text{CCN}}(z)$ in m^{-3}

convective velocity scale

$$w_{\text{eff}} = \max \left\{ w_{\text{grid-scale}} + 0.7 \sqrt{\frac{TKE}{3}} - \frac{c_{\text{pd}}}{g} \partial_t T|_{\text{radiation}}, w^* \right\}$$

=> effective radius:

valid for cloud water
 q_c composed by all scales

$$R_{\text{eff}} = c_1 \cdot \left(\frac{q_c \cdot \exp\left(-\frac{z - z_{\text{cb}}}{\Delta z_{\text{cb}}}\right)}{N_{\text{NC}}(N_{\text{CCN}}, w_{\text{eff}})} \right)^{c_2}$$

height of cloud base

characteristic cloud depth

c_1 and c_2 : tuning parameters

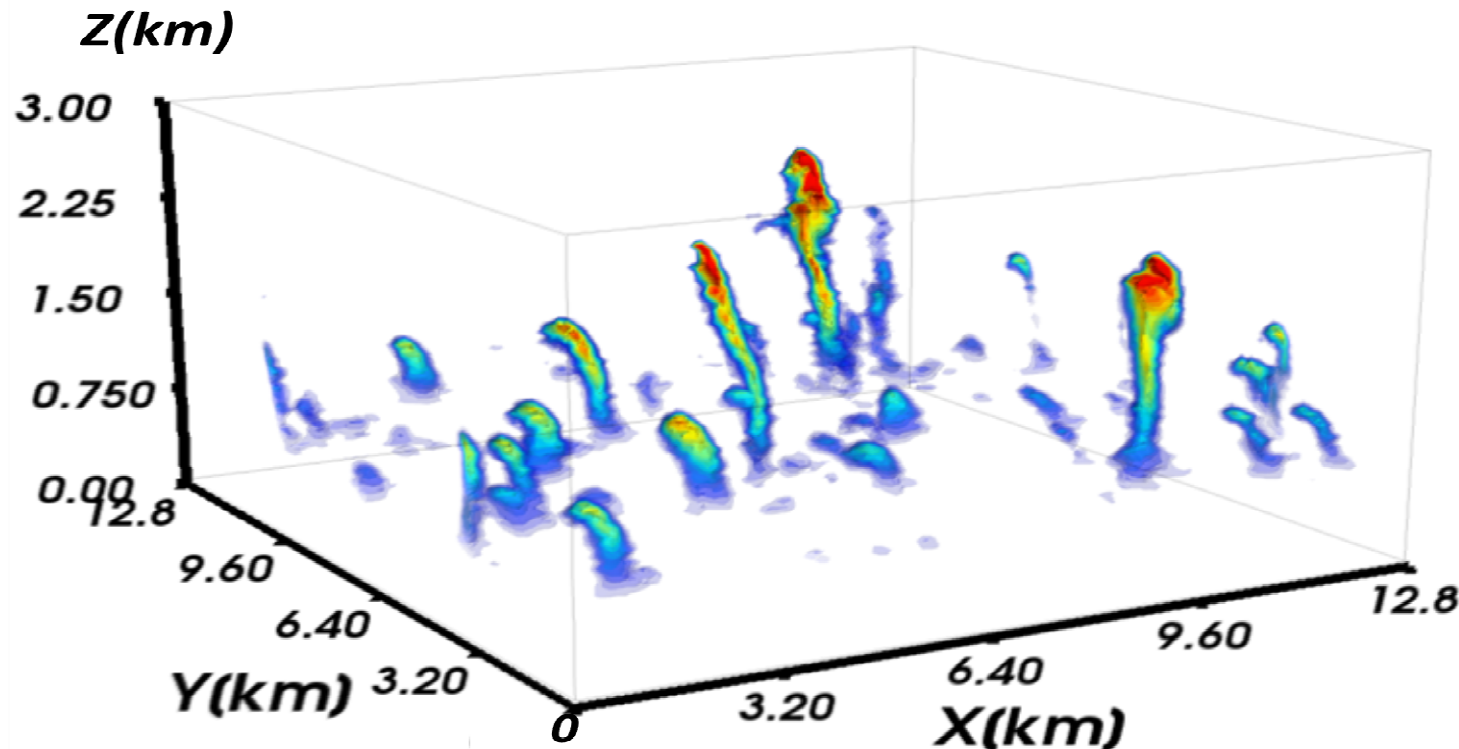
(activ.) cloud number concentration (**NC**) according to Segal/Khain (2006)

Combined parameterization of LWC, R_{eff} and K_{het} for convective clouds:

Pavel Khain, IMS

New:

- Parameterized vertical profiles derived from **LES-simulations** with **System of Atmospheric Modelling (SAM)**, Khairoutinov and Randell, 2003): $dx=100m$, $dt=1s$, 40 levels, domain of $12.8 \times 12.8 \times 5.1 \text{ km}^3$
 - Spectral-bin microphysics** (Khain et al. 2013) with 33 mass bins for droplets (radii from $2\mu m$ to $3.2mm$) to simulate warm processes
 - Different size distributions of aerosols** (100 to 5000 CCN cm^{-3})
 - Applied to **BOMEX case** (trade wind cumulus cloud field) with different inversion heights



■ Parameterization strategy:

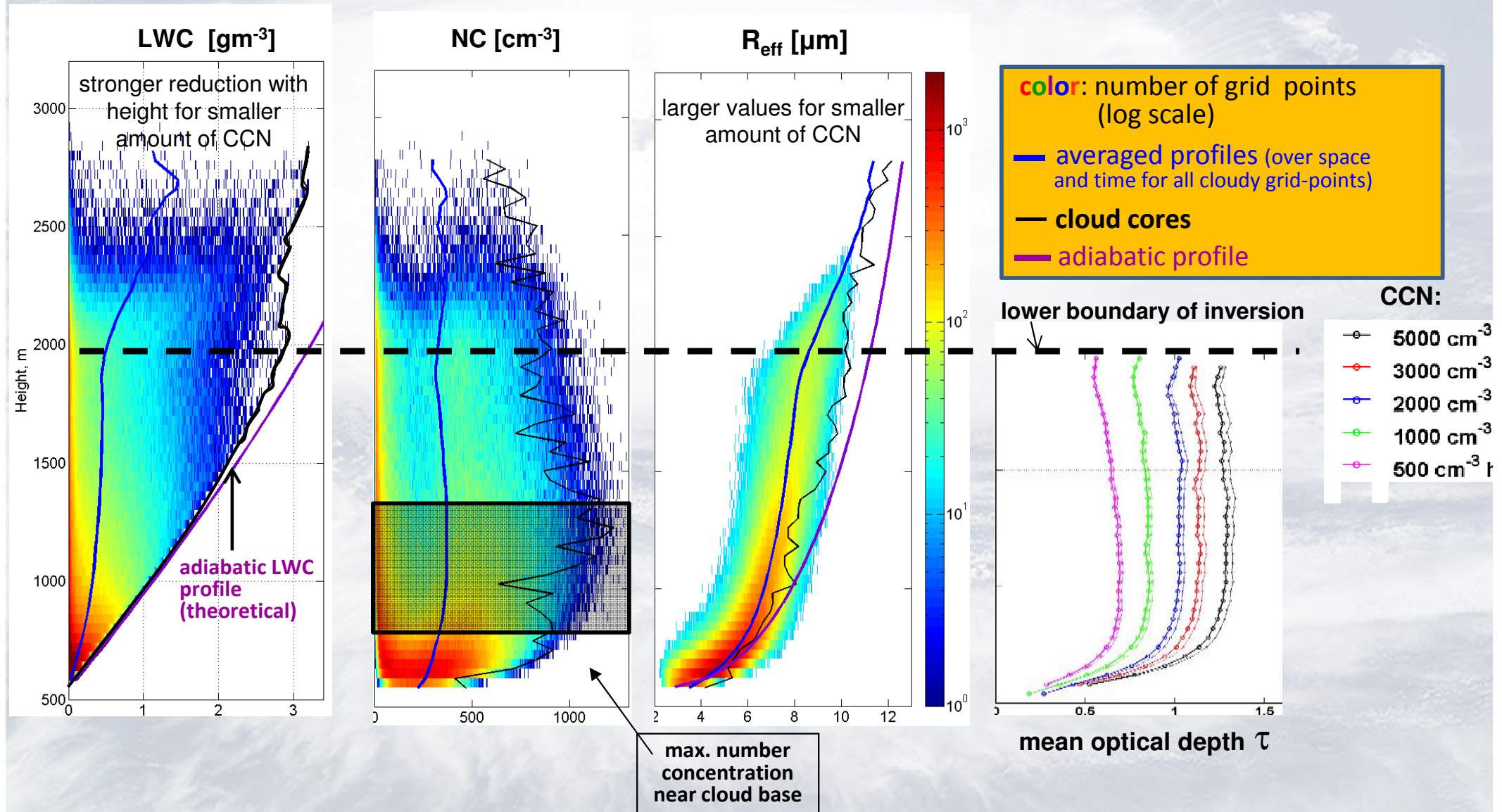
- Assuming **homogeneous mixing** (de- and entrainment):
 - Droplet size $\sim R_{\text{eff}}$ horizontally almost constant
 - But horizontally varying NC and (with it) LWC
- Using: **LWC** $\sim$ **NC** $\cdot$ **R_{eff}^3** and **LES-results** as **foundation of parameterizations**:
 - Expressing virtual vertical profiles of LWC and R_{eff} **related to adiabatic lifting** of air at cloud base (with invariant NC)
 - **Parameterizing** reduction of mean NC with height due to **wash-out by rain**
 - **Parameterizing** reduction of R_{eff} with height compared to adiabatic profile due to **mixing**
 - ❖ Calculating vertical profiles of R_{eff} , mean NC and hence also of mean LWC
 - **Parameterizing** vertical profiles of K_{het}

❖ Calculating vertical profiles of mean optical depth τ according to definition

▪ **Example of simulation results for 5000 CCN cm^{-3} :**

taken from Pavel Khain, IMS

scatter over all grid points and output times:



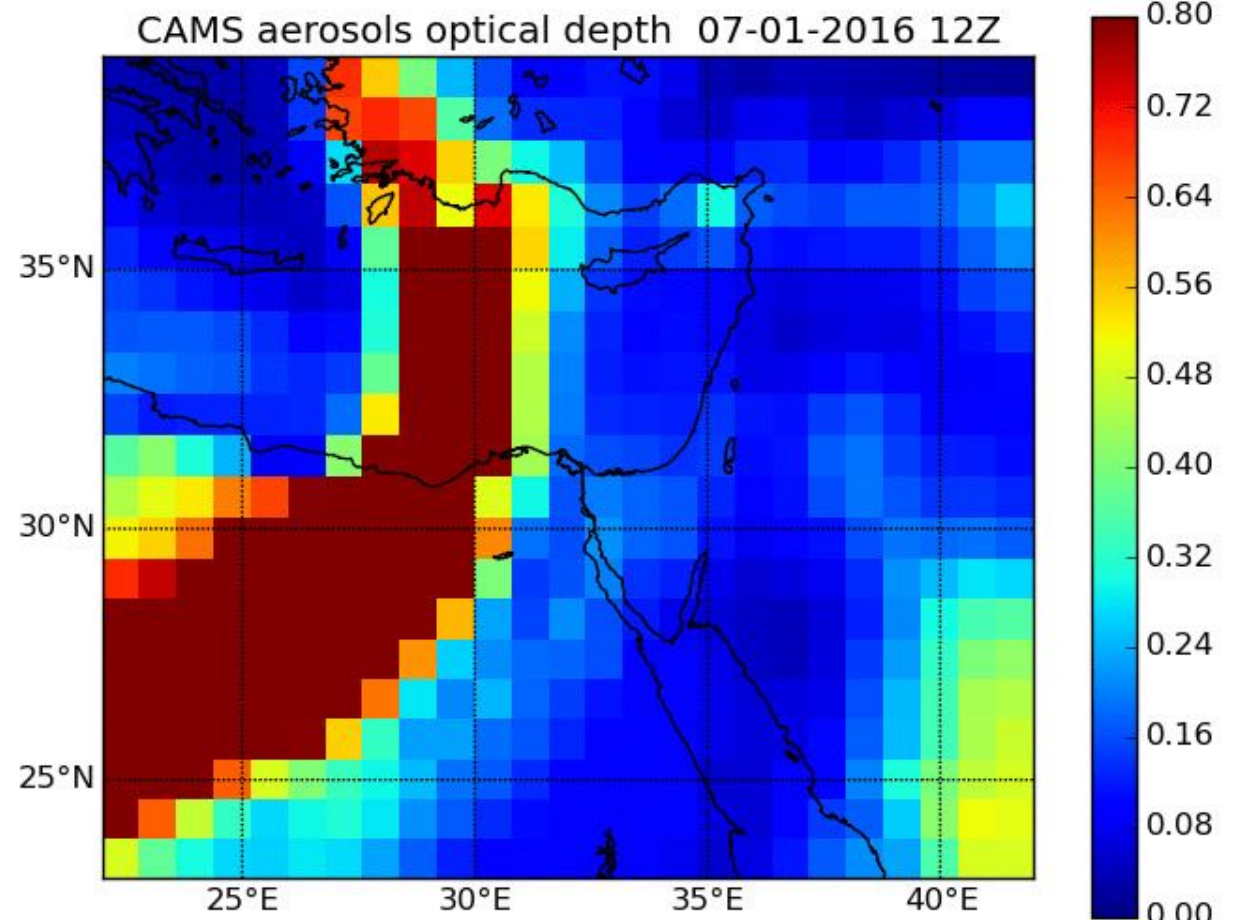
- **Still missing so far:**

- Improved combination with turbulent cloud generation
- Improved consideration of ice-clouds generated by sub-grid scale processes
- Improved estimation of convective cloud-cover
- Parameterization of cloud overlap
- Consistency with corresponding microphysics in (shallow) convection scheme

CAMS prognostic aerosols

itype_aerosol = 4

- Built on the ECMWF NWP system with additional prognostic aerosol variables
- Input aerosols analysis:
 - NASA/MODIS Terra and Aqua Aerosol Optical Depth at 550 nm
 - NASA/CALIOP CALIPSO Aerosol Backscatter
 - AATSR, PMAP, SEVIRI, VIIRS
- Verification based on AERONET
(text adapted from Benedetti CUS2016)



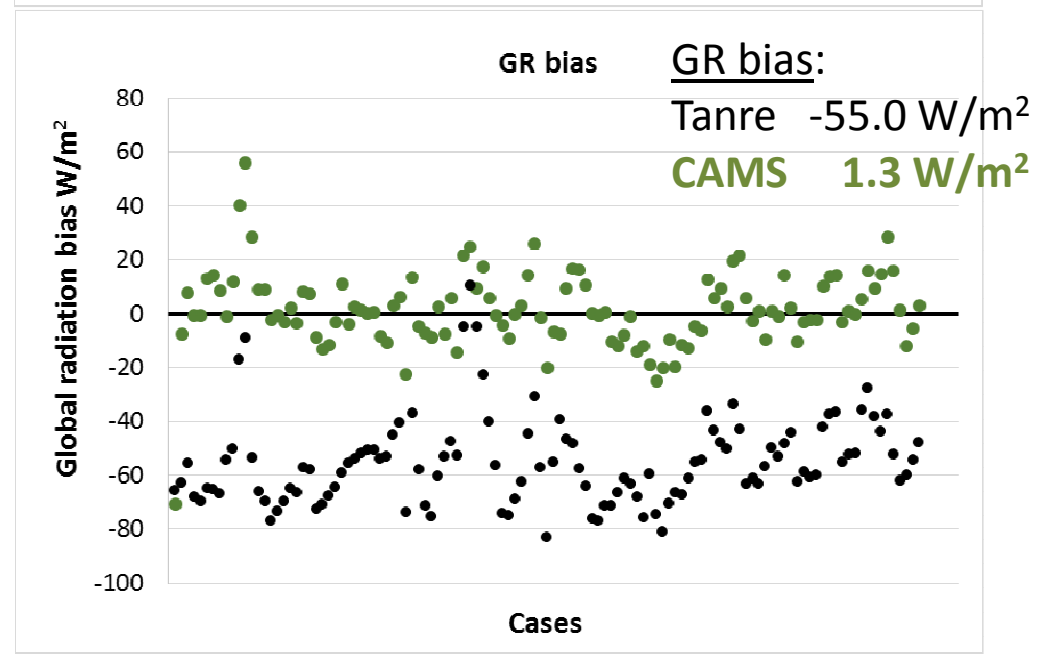
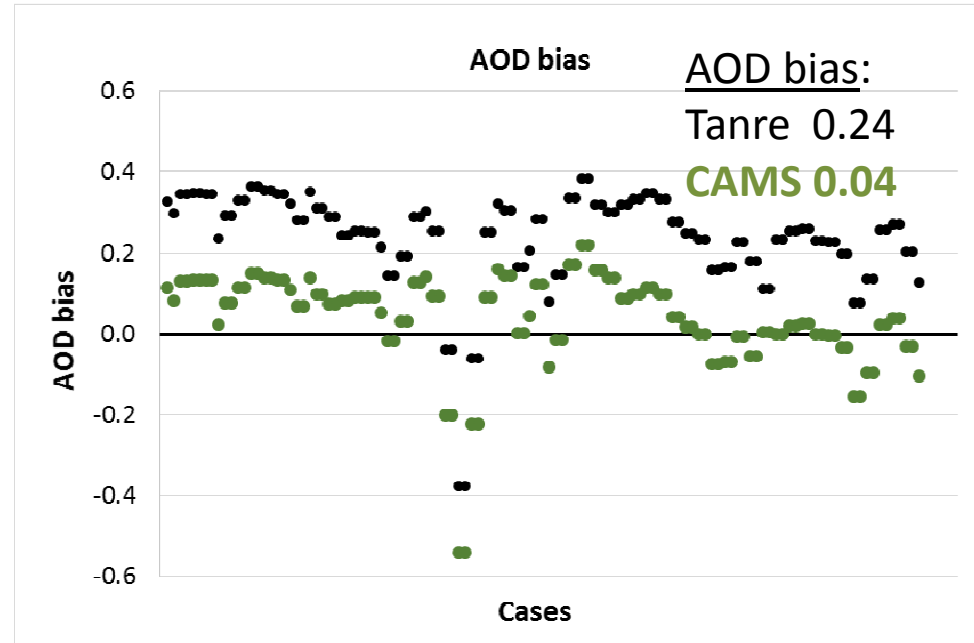
Global radiation and AOD – model vs. Observations



- **2 months** in summer Jun-Aug 2017 twice a day
- **10** measurement stations (GR, T, Tmax)
- **2 AERONET** station in **Sede-Boker & Technion** (AOD)
- **2 models**: **COSMO 2.8km 5.0** (driven by IFS):
 - Oper. rad. scheme + **Tanre**
 - New rad. Scheme + **CAMS**
- **CAMS** data taken from 12h before



- RMSE for AOD and GR better with CAMS as well
- T2m slightly better



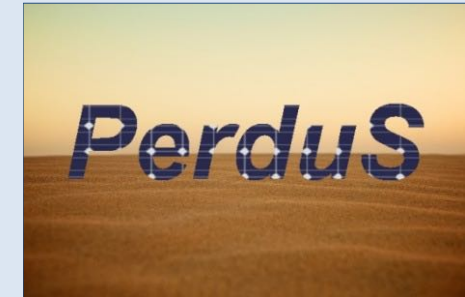
PerduS: Aims of the Project

Vanessa Bachmann, Andrea Steiner, Jochen Förstner (DWD)
& the PerduS-Team

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



➔ Improvement of the photovoltaic power forecast during Saharan dust outbreaks on a regional and national scale

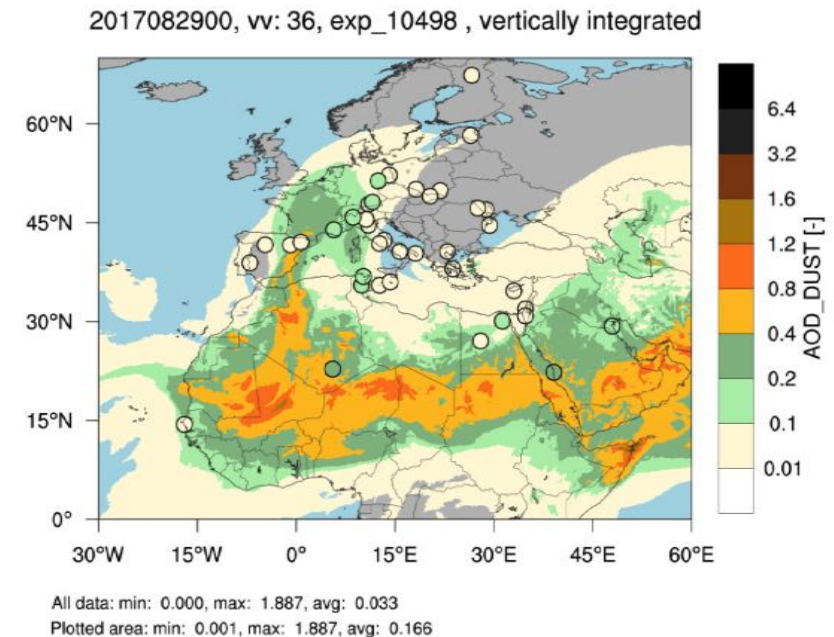


➔ Application and further development of the model system ICON-ART

- Dust emission
- Optical properties of mineral dust
- Washout of mineral dust

➔ Parameterization for the soiling of PV panels

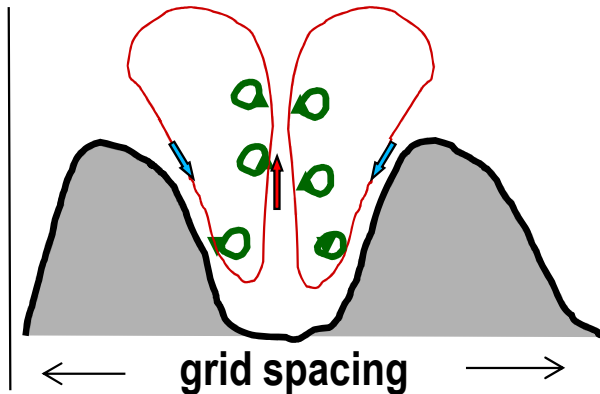
➔ Quasi-operational forecasting system for mineral dust dispersion



DUST AOD - Comparison with
AERONET Stations (Level 1.5)

Separated TKE-equation with Scale-Interaction sources (M. Raschendorfer) :

Formal scale separation automatically produces **Scale-Interaction (SI)** between GS parameterization of **turbulence** (TURBDIFF) and non-turbulent circulations



Separated
Turbulence
Interacting with
(non-turbulent)
Circulations



more physically based mixing
even for stable stratification

additional Shear -Production of TKE by:

- **near surface density circul.** $dTKE_{crc}$
- **SSO wake-eddies** $dTKE_{sso}$
- **separated horiz. shear eddies** $dTKE_{shs}$
- **vertical convective currents** $dTKE_{con}$

- missing link to gain realizability
- avoids singularities in solution of TKE-scheme
- clear additional physical impact

time
tendency
of **TKE**

transport
(advection
+ diffusion)

buoyancy
production

labil: > 0
neutral: $= 0$
stabil: < 0

shear production
by the mean flow

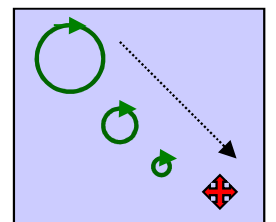
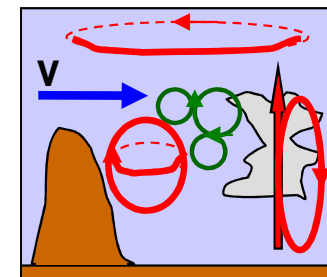
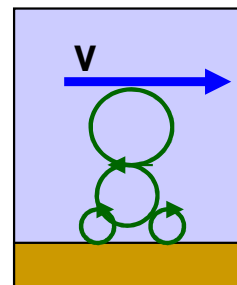
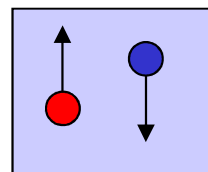
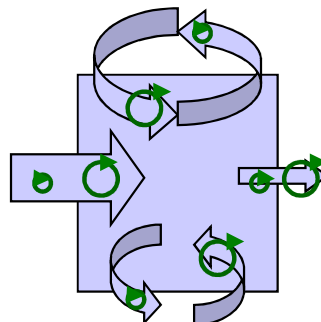
≥ 0

**shear production
by sub grid scale
circulations**

≥ 0

eddy-
dissipation
rate (**EDR**)

< 0



- **STIC-terms** allow for a physical based solution of the turbulence scheme, where **direct grid-scale** TKE-production is **negligible**, due to impact of **non-turbulent SGS circulations**:

○ SBL with vanishing vertical wind shear:	dTKEcrc	
○ Above the BL and within the stable stratosphere:	dTKEshs	↔ CAT
○ Above the BL close to convective plumes:	dTKEcon	↔ CAT, CIT
○ Within the BL close to SSO-wakes:	dTKEsso	↔ CAT

- **Still to be done:**

- Testing direct physically based horizontal diffusion by **SHS** (probably missing when running numerical schemes with small implicit diffusion) and addit. direct vertical diffusion by **CRC**
- Introducing a more sophisticated formulation of **SSO-induced CRC**
- Scale adaptive (shallow) **CON** with SI-terms from turbulence (describing de- and entrainment)

➤ **Operational turbulence forecast based on EDR:**

$$EDP = \sqrt[3]{EDR + \alpha_{ss0} \cdot dTKEsso + \alpha_{shs} \cdot dTKEshs + \alpha_{con} \cdot dTKEcon}$$

direct model output from
prognostic TKE-equation
with **some STIC-terms**

but no dTKEcon so far

extra amount
by **optional**
post-processing

Eddy-Dissipation Parameter



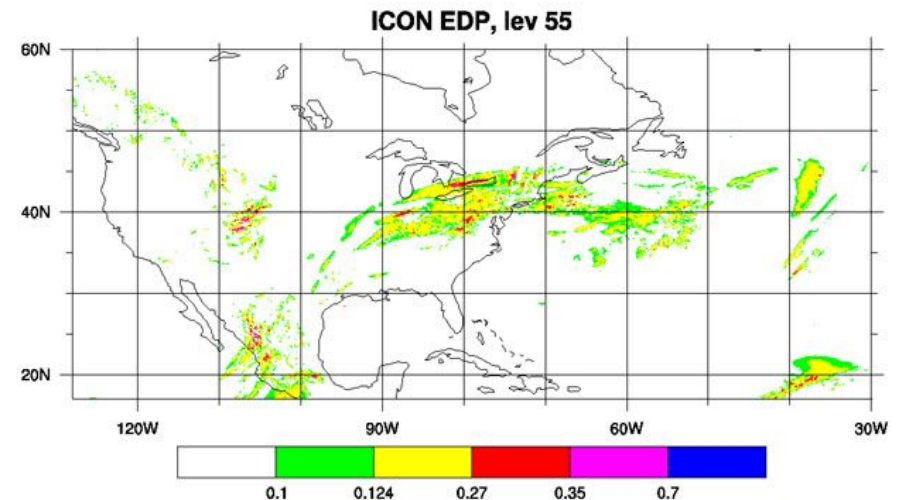
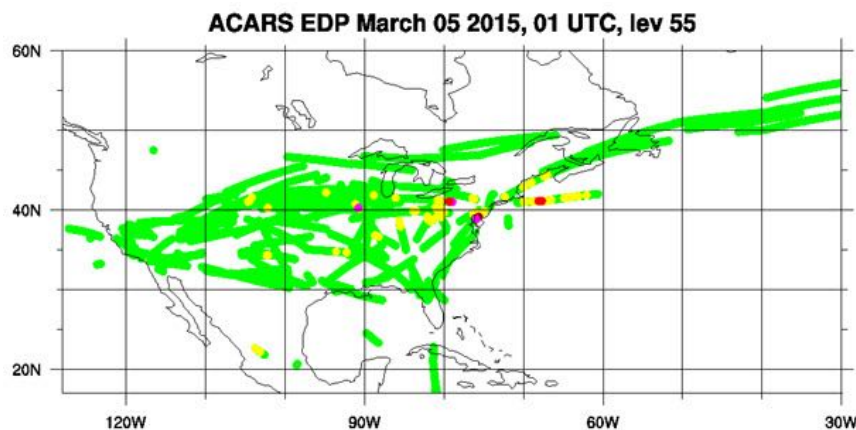
Local property scaling
inertial sub-range turbulence



Derivable from energy-spectra
of vertical aircraft motion

Tuning and verification of EDP

- Verification data from hourly EDP measurements have been collected by airliners over the USA in 2015 (whole year).
- Each record includes: observation time, geographical coordinates, flight level, and Eddy Dissipation Rate.
- All together there are ca. 2.5 Mio records.



Ekaterina Machulskaya & Tobias Göcke

German Weather Service



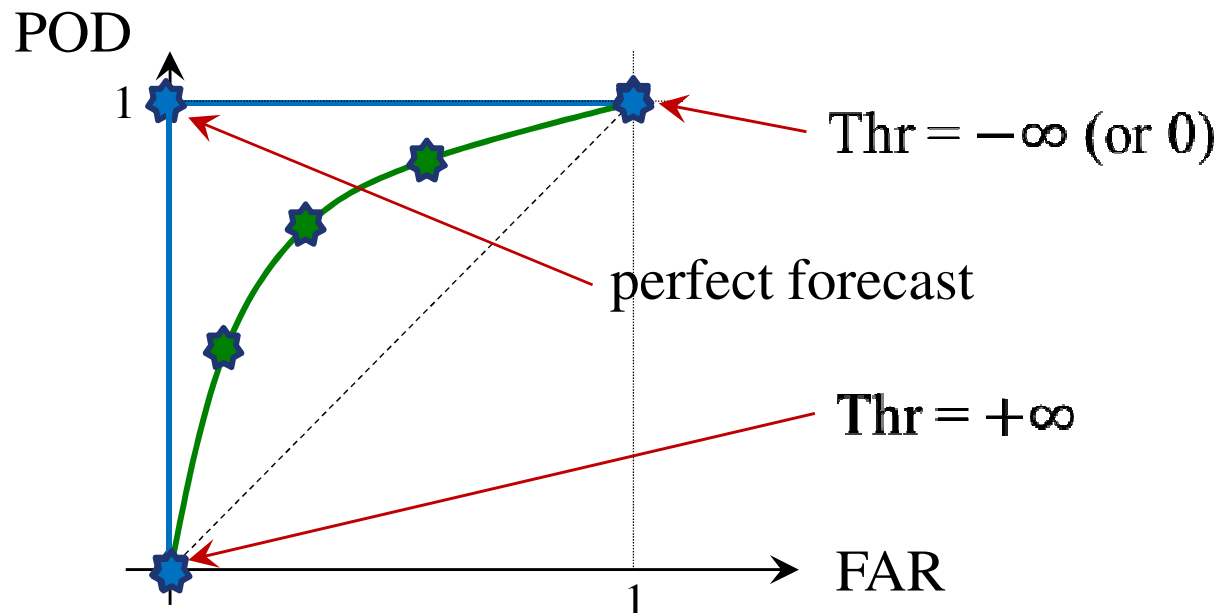
Verification results (ROC)

The Receiver Operating Characteristic (ROC) Curve is widely used for the evaluation of quantities for which it makes sense to use thresholds.

For each threshold		OBS = Yes	OBS = No
	MOD = Yes	a (hits)	c (false alarms)
	MOD = No	b (misses)	d (correct rejections)

$$\text{Probability of Detection (POD)} = \frac{a}{a+b}$$

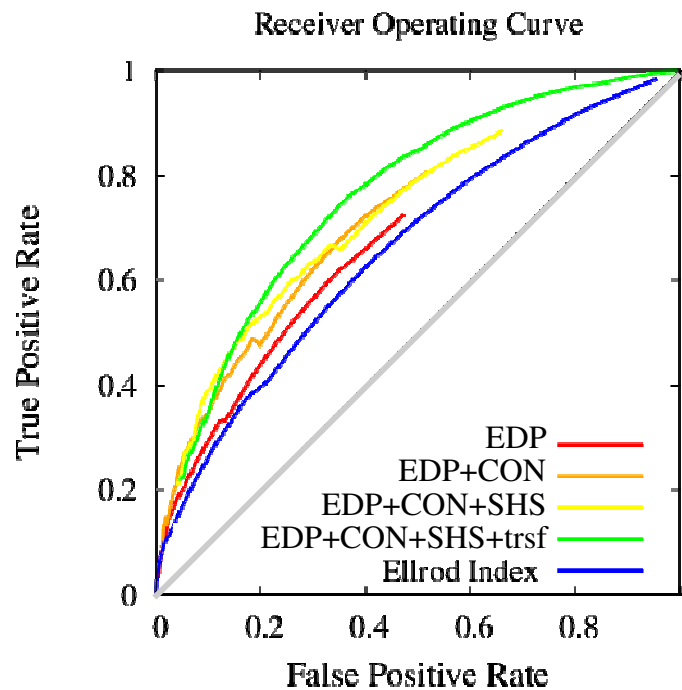
$$\text{False Alarm Rate (FAR)} = \frac{c}{a+c}$$



The more convex the curve,
the better the forecast

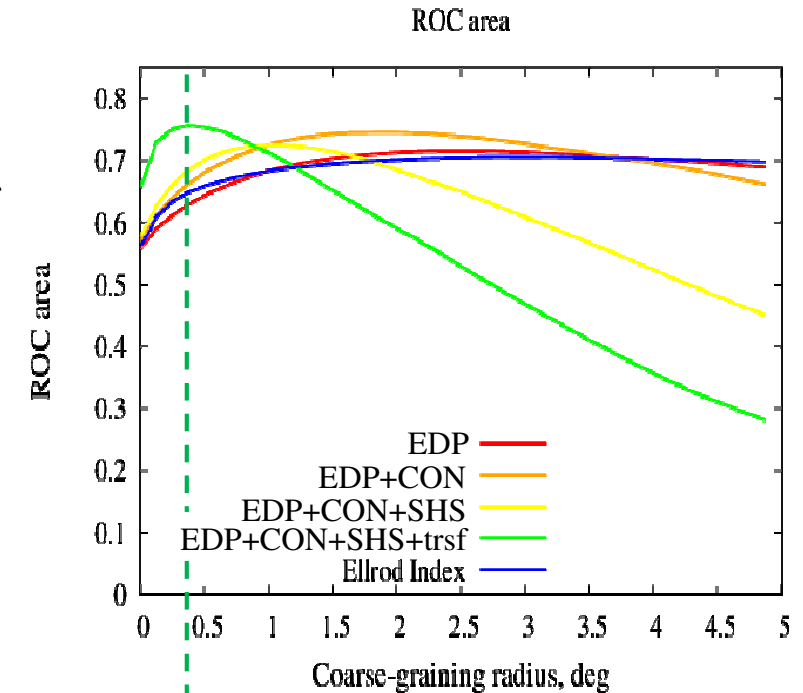


Verification results (ROC)



EDP: prognostic EDP
without any post-
processing, in particular
without dTKEcon

trsf: transformation of
EDP-results in order to
adapt to measured
frequency distribution



Pure prognostic EDP already performs better than traditional **Ellrod Index** (mainly based on HSH)

Consideration of post-processed **dTKEcon** and an **transformation** provides significant improvement

The **transformed** EDP with post-processed **dTKEcon** and an **additional post-processed dTKEshs** performs best and shows a clear and reasonable **optimal uncertainty radius of about 40Km!**

This configuration is **operational in ICON since July 2017!**



Some other promising general activity:

(still basic research, not yet implemented, partly not even really started)

■ Turbulence-Interaction with Micro-Phys. beyond pure saturation adjustment:

- Consideration of turbulent statistics in MP

Axel Seifert

- Deriving missing correlations between model variables and MP-source-terms in 2-nd order budgets for turbulence

Dimitrii Mironov, Axel Seifert

■ Increasing the range of scales included to turbulence closure:

- coherent structures with skewed distributions, TKESV

Dimitrii Mironov, Ekatarina Maschulskaya

■ Dealing with statistical parameterizations

- substituting intended model-parameters to reduce systematic model errors

staff from ICON or special projects at DWD (renewable energy)

■ Developing stochastic BL perturbations

- simulating the not closed remaining stochastic discretization error

Kirstin Kober George Craig (Uni Munich)