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:	COSMO:		ICON:
Radiation scheme	Ritter/Geleyn	new optical properties →	RRTM
Convection scheme	Tiedke	← already implemented in COSMO, but not operational	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 optionally 2-moment version		Doms (2004) Seiffert (2010)
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** / **shallow**)	2-class (updraft-downdraft) mass-flux equations with moisture convergence closure and simplified microphysics		Tiedke (1989), update by Bechthold et al. (2008) optionally
	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	Raschendorfer (2001,->)
	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 COSMO	TURBTRAN	Raschendorfer (2001,->)
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 $R_{eff} = 5\mu m$
    - An additional effect of inhomogeneity in the expression of τ is taken into account by means of a constant reduction factor K_{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**

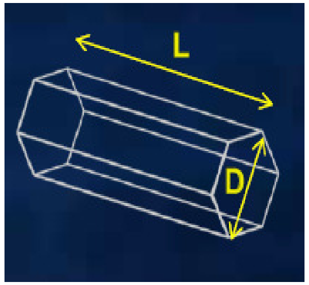
extinction coeff. β_{ext} , **single scattering albedo** ω, **asymmetry factor** **g** , **delta-transmission factor** f_d

    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 (5µm - 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 => grid-column-integrated aerosol-mass per m^{-2}
  - Assumed mean particle radius and density
  - Assumed exponential vertical decrease

  => aerosol number concentration $N_{CCN}(z)$ in m^{-3}
  - aerosol number concentration N_{CCN}
  - effective updraft wind speed:

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

convective velocity scale (w^*)

=> effective radius:

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

valid for cloud water q_c composed by all scales

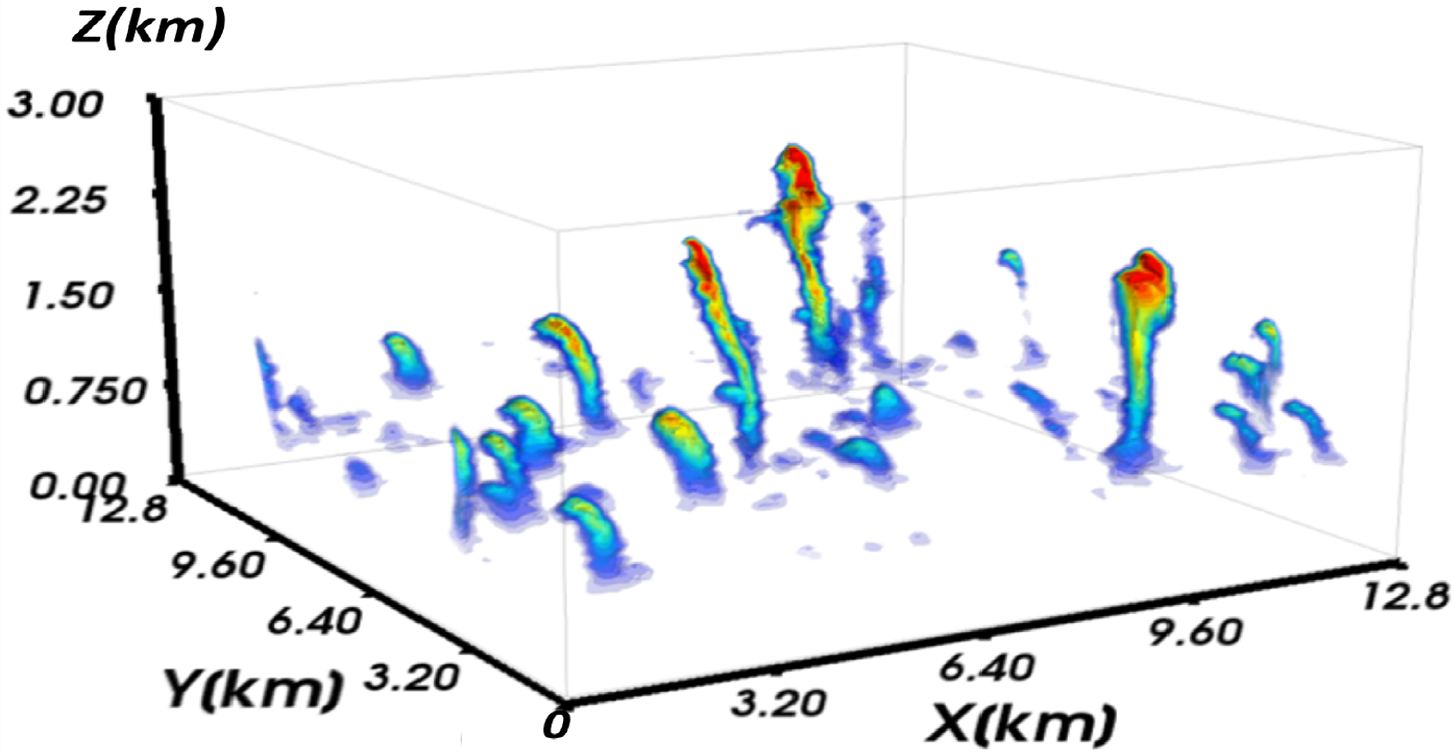
- z_{cb}: height of cloud base
- Δz_{cb}: characteristic cloud depth
- c_1 and c_2: tuning parameters
- N_{NC}: (activ.) cloud number concentration (**NC**) according to Segal/Khain (2006)

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 ad Randell, 2003): dx=100m, dt=1s, 40 levels, domain of 12.8X12.8X5.1 Km^3
  - **Spectral-bin microphysics** (Khain et al. 2013) with 33 mass bins for droplets (radii from 2μm 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 ~ R_{eff} horizontally almost constant
    - But horizontally varying NC and (with it) LWC

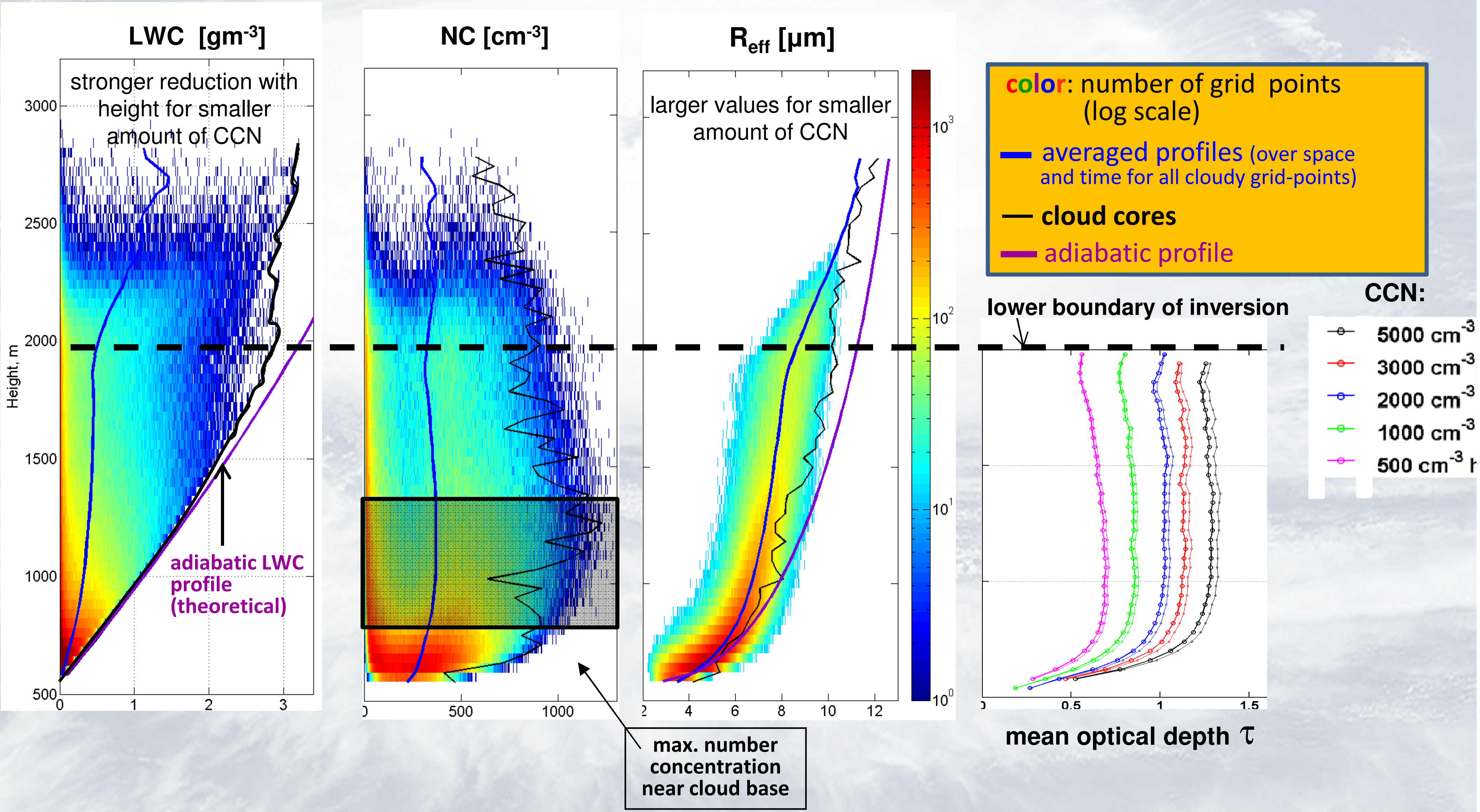
  - Using: $\mathbf{LWC \sim NC \cdot R_{eff}^3}$ and **LES-results** as **foundation of parameterizations**:
    - Expressing virtual vertical profiles of LWC and R_{eff} related to adiabatic lifting of air at cloud base (with invariant NC)
    - **Parameterizing** reduction of mean NC with height due 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

Harel Muskatel, IMS

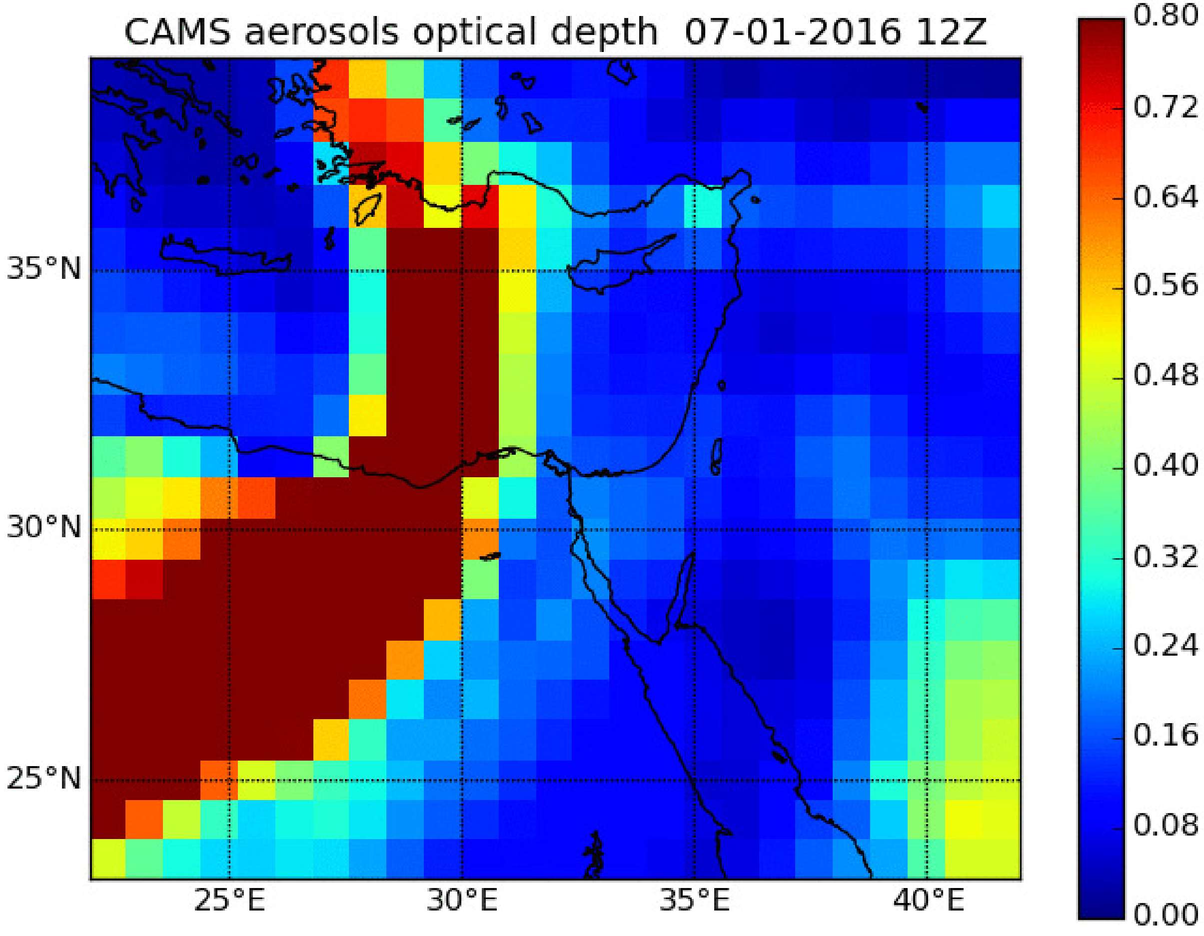
CAMS prognostic aerosols

Atmosphere Monitoring Service

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)



CONSORTIUM FOR SMALL SCALE MODELING COSMO

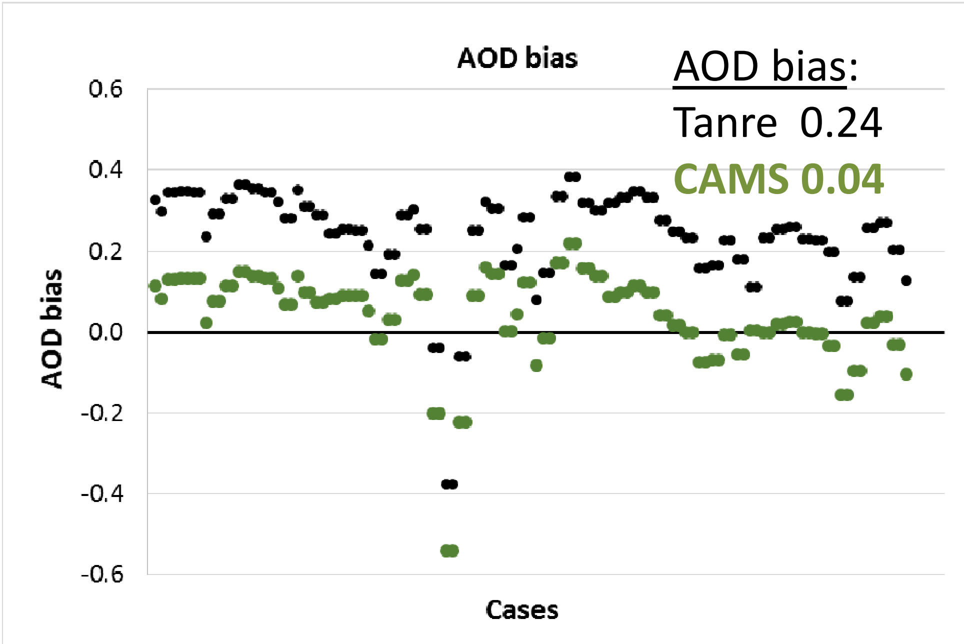
IMS

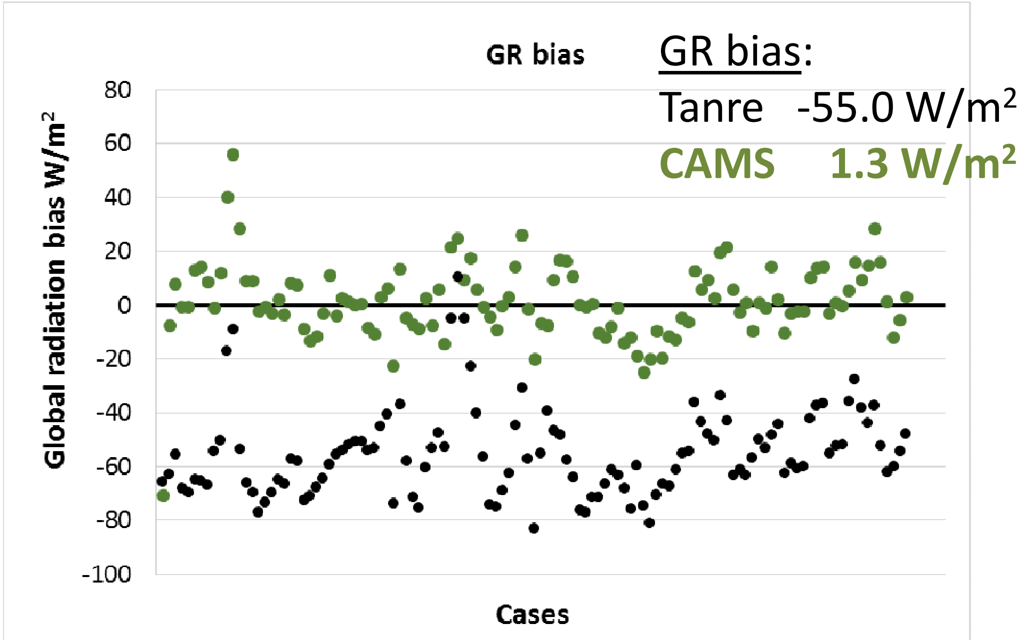
Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

Global radiation and AOD – model vs. Observations

AERONET
AEROSOL ROBOTIC NETWORK

- **2 months** in summer Jun-Aug 2017 twice a day
- **10** measurement stations (GR, T, Tmax)
- **2 AEORNET** 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

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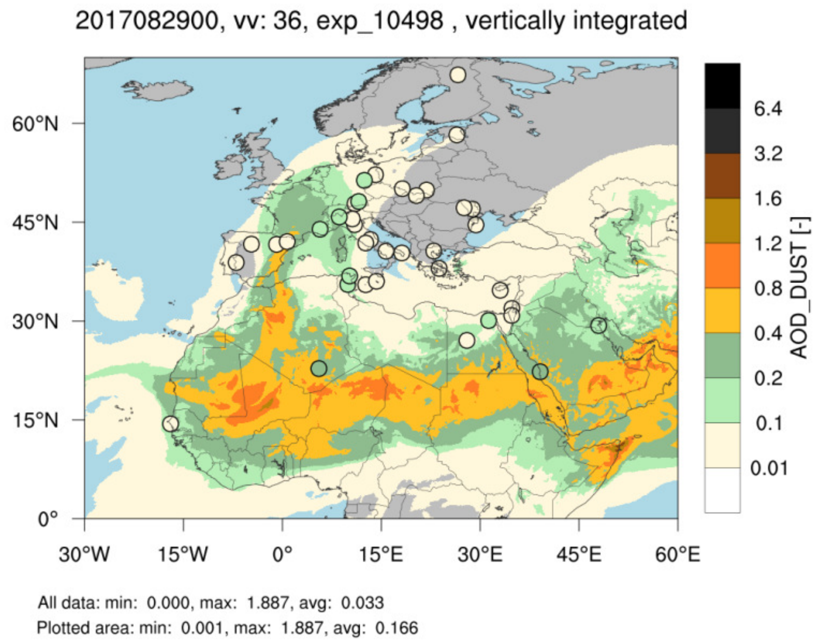
- ➔ Improvement of the photovoltaic power forecast during Saharan dust outbreaks on a regional and national scale

- ➔ 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

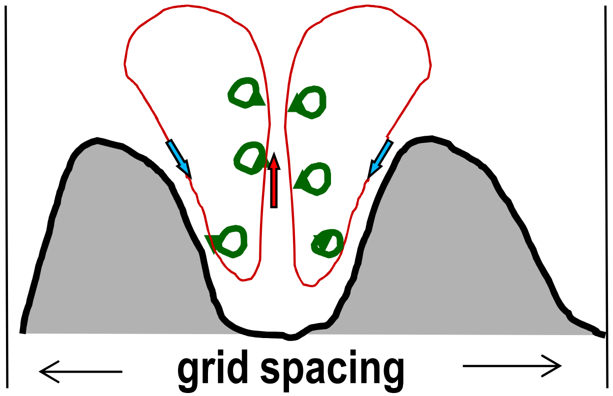
- ➔ Quasi-operational forecasting system for mineral dust dispersion



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)
Crculations

STIC

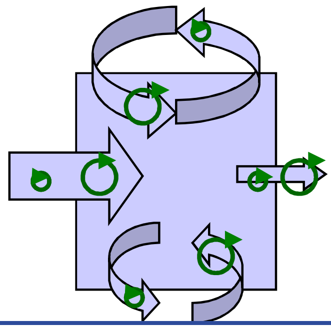
additional Shear -Production of TKE by:

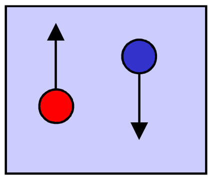
- near surface density circul. dTKEcrc
- SSO wake-eddies dTKEsso
- separated horiz. shear eddies dTKEshs
- vertical convective currents dTKEcon

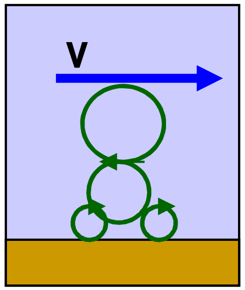
- missing link to gain realizability
- avoids singularities in solution of TKE-scheme
- clear adittional physical impact

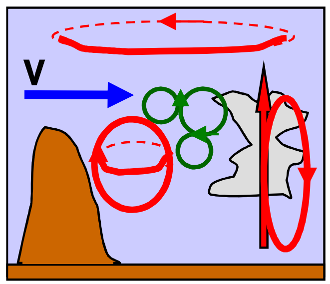
more physically based mixing even for stable stratification

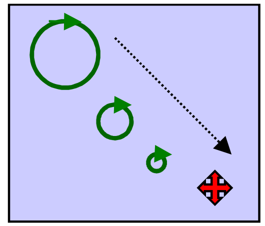
time tendency of **TKE**	transport (advection + diffusion)	buoyancy production	shear production by the mean flow	shear production by sub grid scale circulations	eddy-dissipation rate (**EDR**)
		labil: >0 neutral: $=0$ stabil: <0	≥ 0	≥ 0	< 0











- **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:**

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

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

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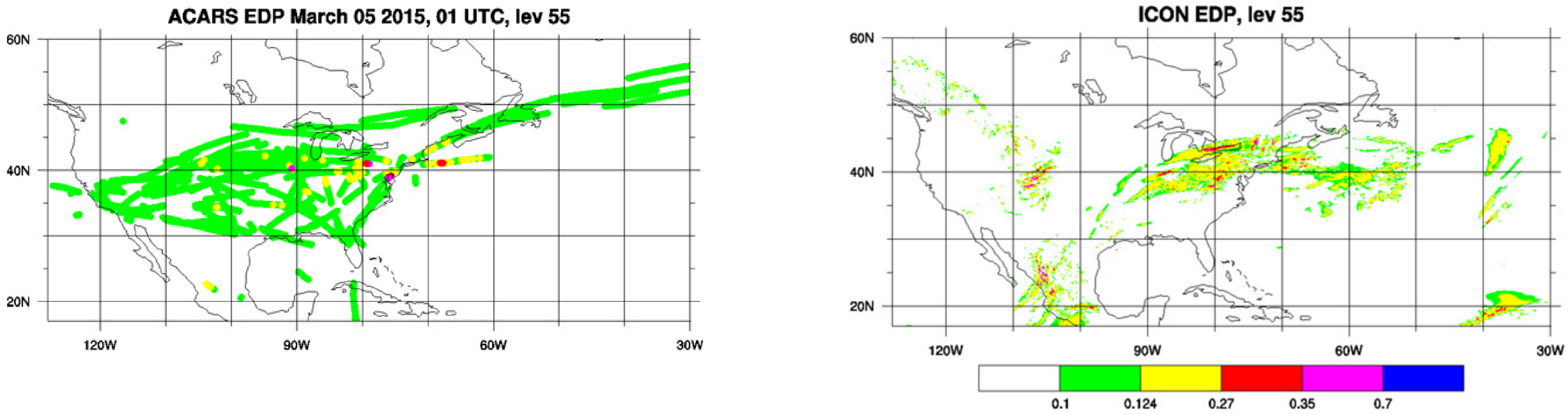
Wetter und Klima aus einer Hand

- Verification data from <u>hourly</u> 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)

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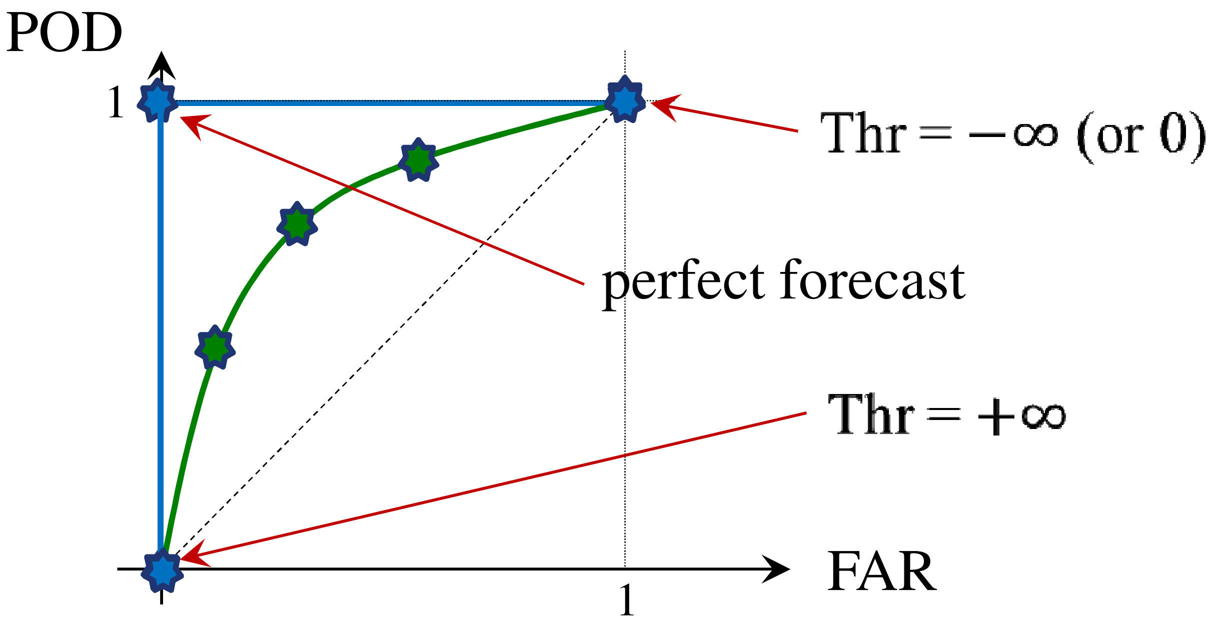
The Receiver Operating Characteristic (ROC) Curve is widely used for the evaluation of quantities for which it makes sense to use thresholds.

For each threshold

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

Probability of Detection (POD) $= \frac{a}{a+b}$ False Alarm Rate (FAR) $= \frac{c}{a+c}$



The more convex the curve, the better the forecast

Verification results (ROC)

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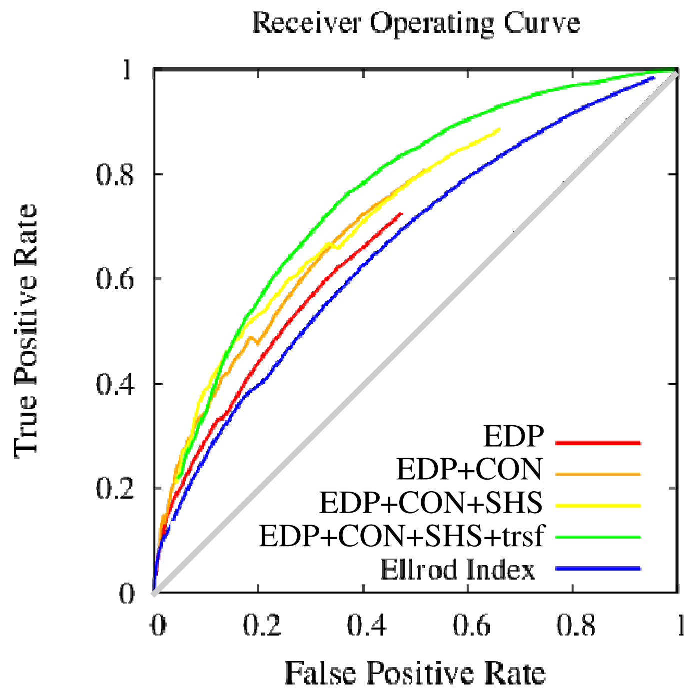
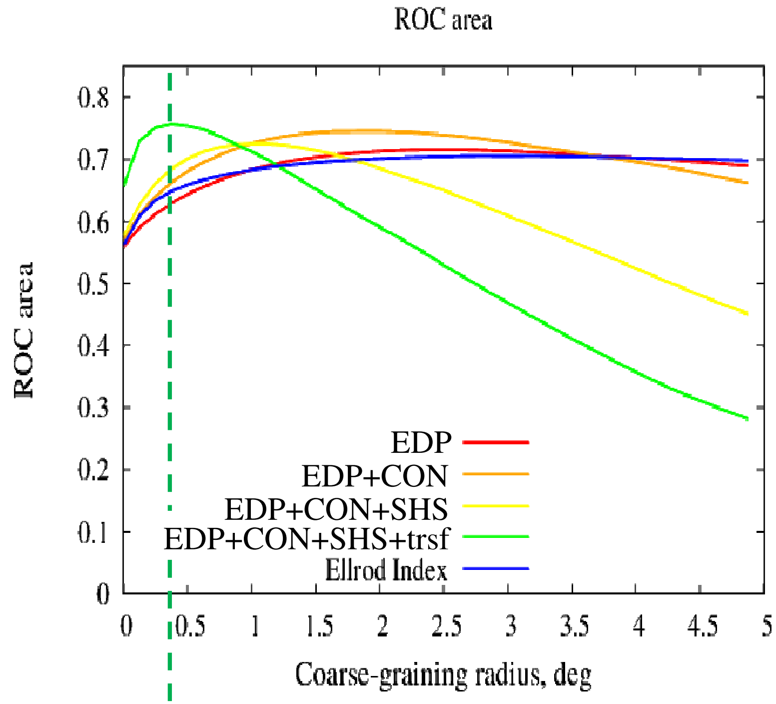


EDP: prognostic EDP **without any post-processing**, in particular without dTKEcon

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



radius of uncertainty: ≈ 0.5 deg ≈ 40 Km

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)