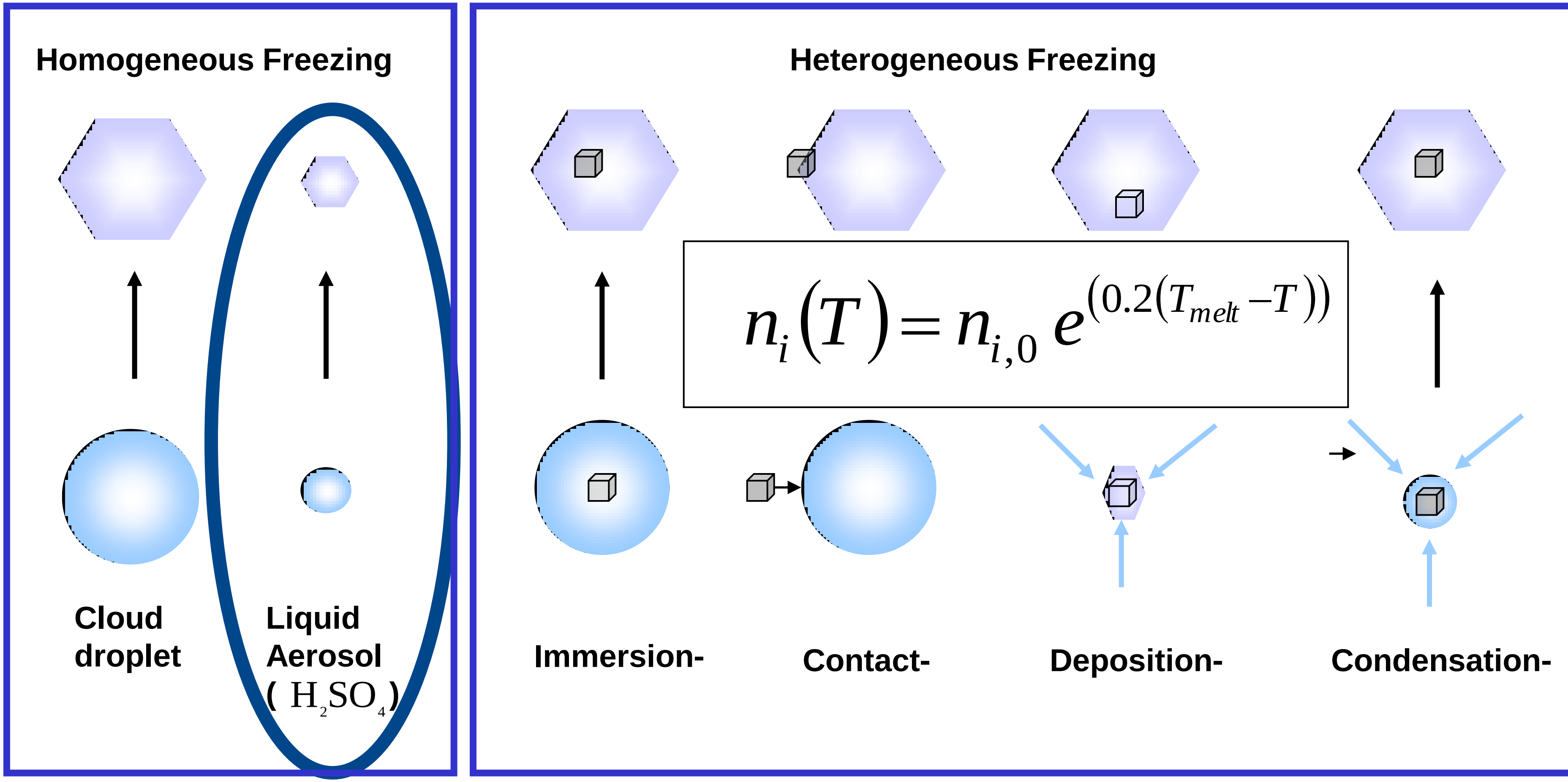
Recent developments in COSMO physics

- Cloud microphysics, Radiation
- Turbulence, SGS circulations (convection)

COSMO WG 3a

Work on icing processes in the 1-moment microphysics scheme:

Ice nucleation: status in current scheme (A. Seifert):



Missing

Thomas Leisner, Institut für Meteorologie und Klimaforschung FZ Karlsruhe und Institut für Umweltphysik, Uni Heidelberg (modified)

Slide by C. Köhler, DWD

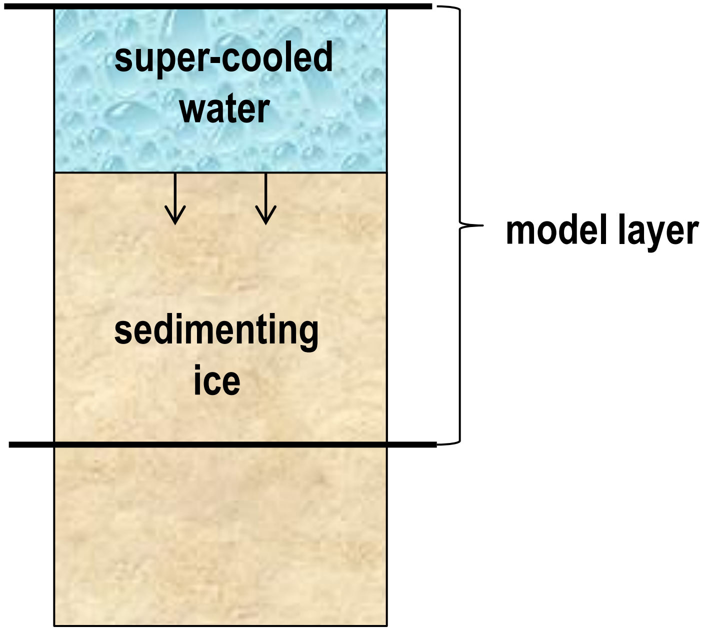
Work on icing processes the 1-moment microphysics scheme (1):

- Improved simulation of **super-cooled water** (mainly in order to improve forecast of **aircraft icing**, F. Rieper)

  - Much too less super-cooled LWC in **mixed phase clouds** in the **current scheme**

  → Reducing diagnosed number of ice particles N_i as a function of T leading to an **decreased Bergeron-Findeisen process** in mixed phase clouds

  → Parameterization of a **liquid water sub layer on top of ice cloud layers** due to **ice sedimentation**

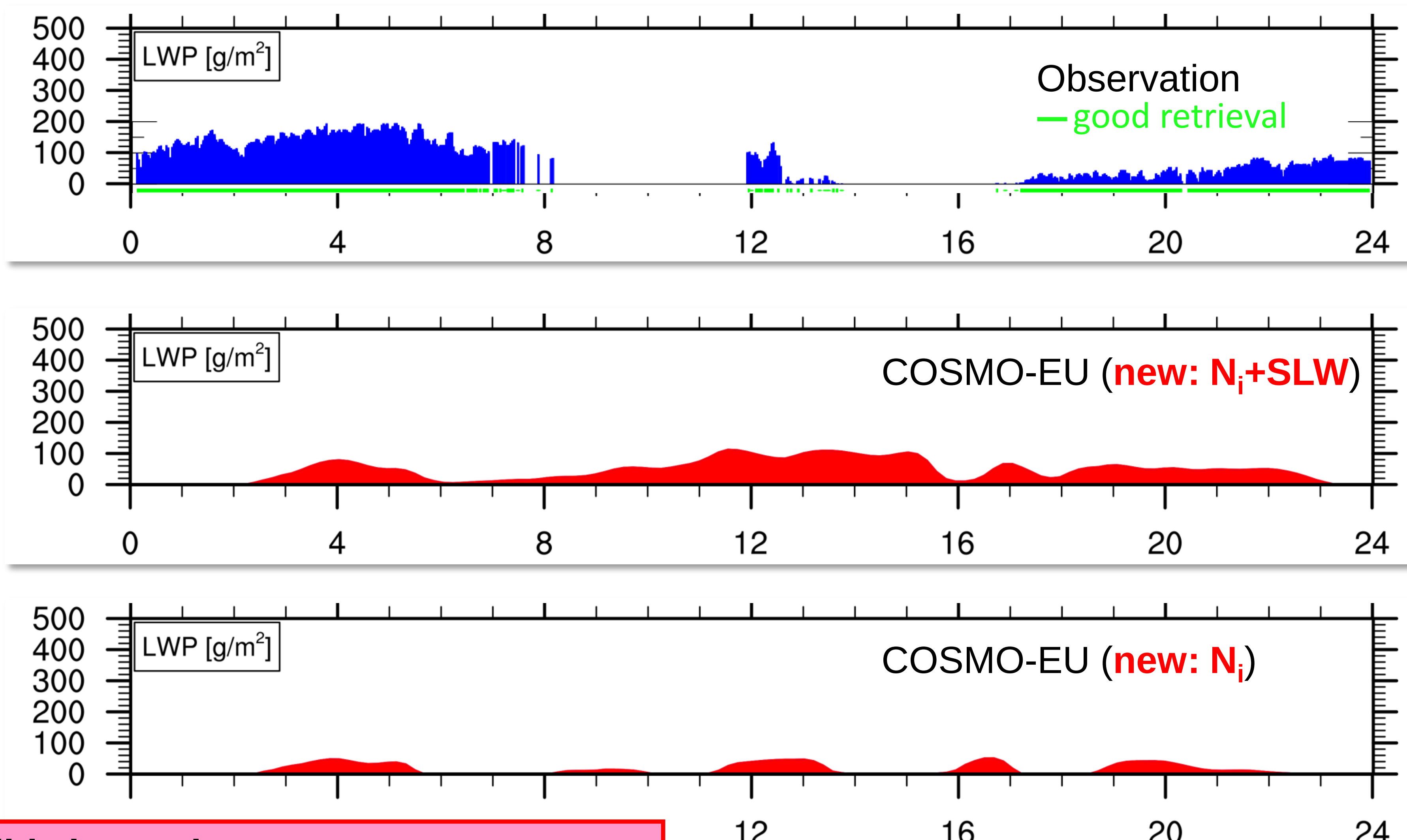


- Implemented in COSMO and ICON

  (big impact to forecast of aircraft icing)

Result: impact on supercooled LWP

January 18, 2013 Lindenberg



Slide by F. Rieper, DWD

Work on icing processes in the 1-moment microphysics scheme (2):

- **Development of improved treatment of cirrus clouds** (PhD of C. Köhler DWD)
  - Implementation of state-of-the-art parameterizations for **homogeneous and heterogeneous nucleation**
  - New **prognostic model variables (number concentration of activated ice nuclei** $n_{i,nuc}$

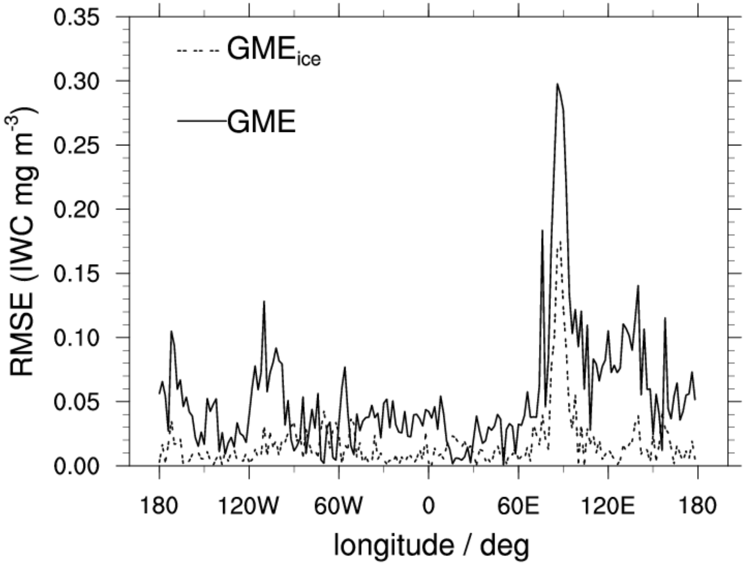
$$\frac{\partial n_{i,nuc}}{\partial t} + \nabla \cdot (\underline{\mathbf{v}}\, n_{i,nuc}) = \left.\frac{\partial n_{i,nuc}}{\partial t}\right|_{het} - \frac{n_{i,nuc}}{\tau_{mix}}$$

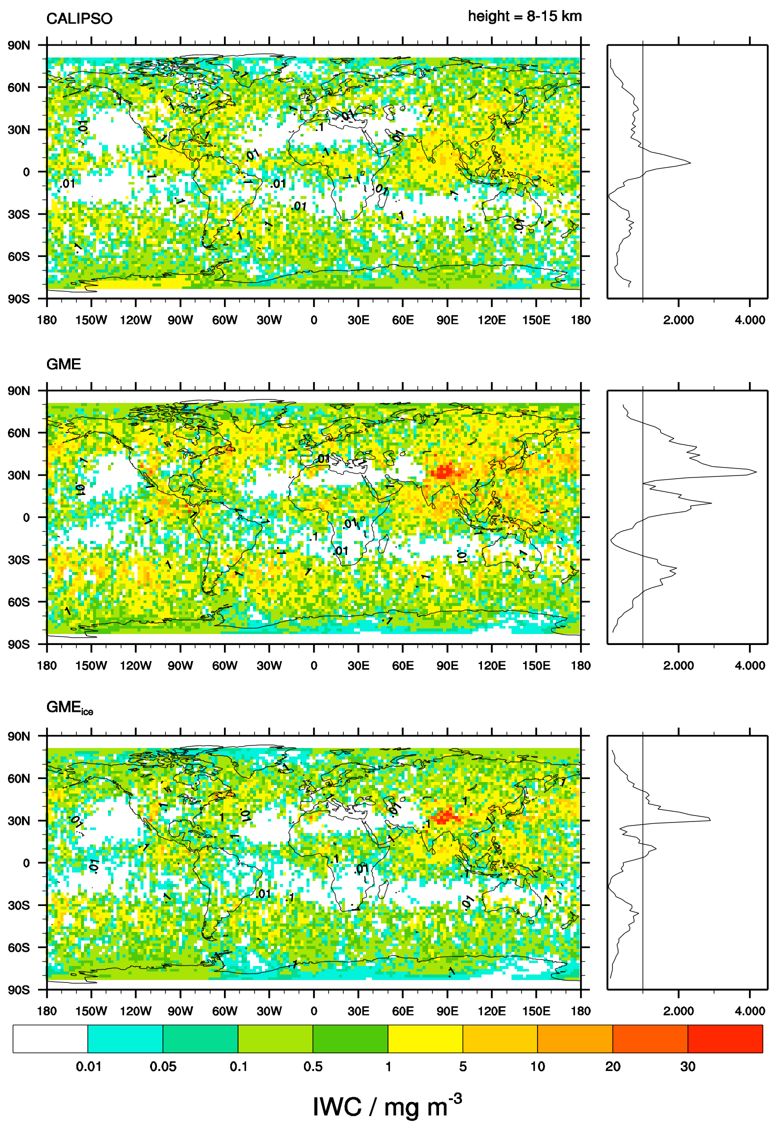
  ➔ **2-moment cloud ice scheme (still mono-disperse size distribution)**

  - Changes in treatment of **depositional growth for cloud ice and snow**
  - **Limitation of heterogeneous nucleation** by number of **activated ice nuclei**.
  - Introduction of **cloud ice sedimentation**

- Implemented in GME and ICON

Verification in GME Model:





- Overestimation of ice water content (IWC) of the GME is reduced
- RMSE reduced with the new cloud ice nucleation scheme

Slide by C. Köhler, DWD

Work on icing processes in the 1-moment microphysics scheme (3):

- **Development of an improved snow melting parameterization** (PhD of C.Frick, DWD)
  - New prognostic snowflake water content
    - ➔ **Enebles better parameterization of melting process**
    - ➔ **Leads to solwer melting**

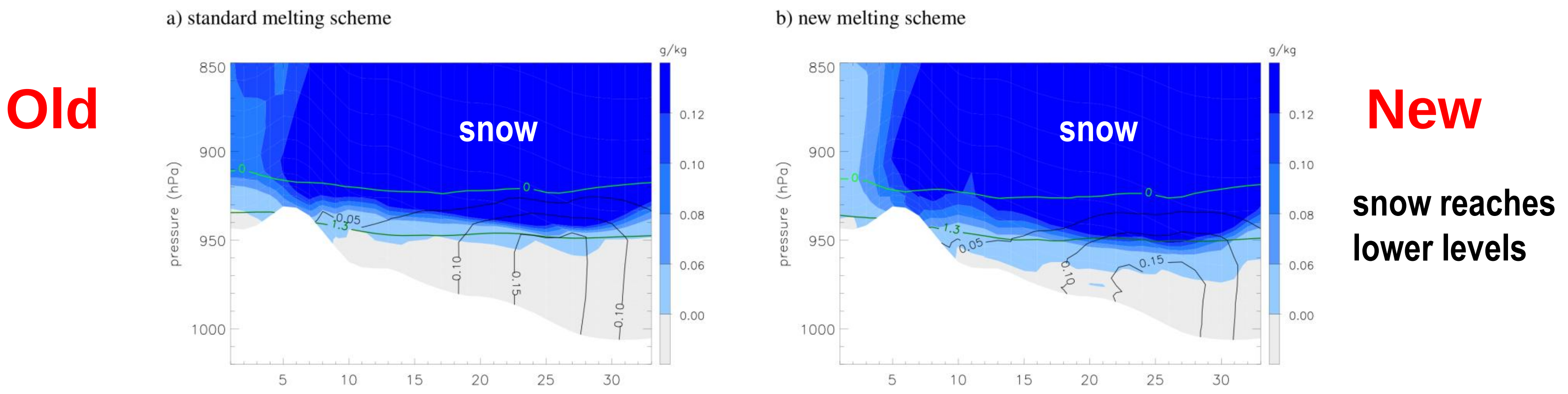


Fig. 6. Vertical section across the snowfall region in eastern Germany at 14:00 UTC, 16 November 2010 **(along an arbitrary horizontal line).** Shown are snow mixing ratio (colors, in $\mathrm{g\,kg^{-1}}$), rain mixing ratio (black lines, in $\mathrm{g\,kg^{-1}}$), the 0 °C isoline (green), and the isoline of 1.3 °C wet bulb temperature (dark green) for the simulations with **(a)** the standard and **(b)** the new snow melting scheme.

- Implemented in test version

Slide by C. Frick, DWD

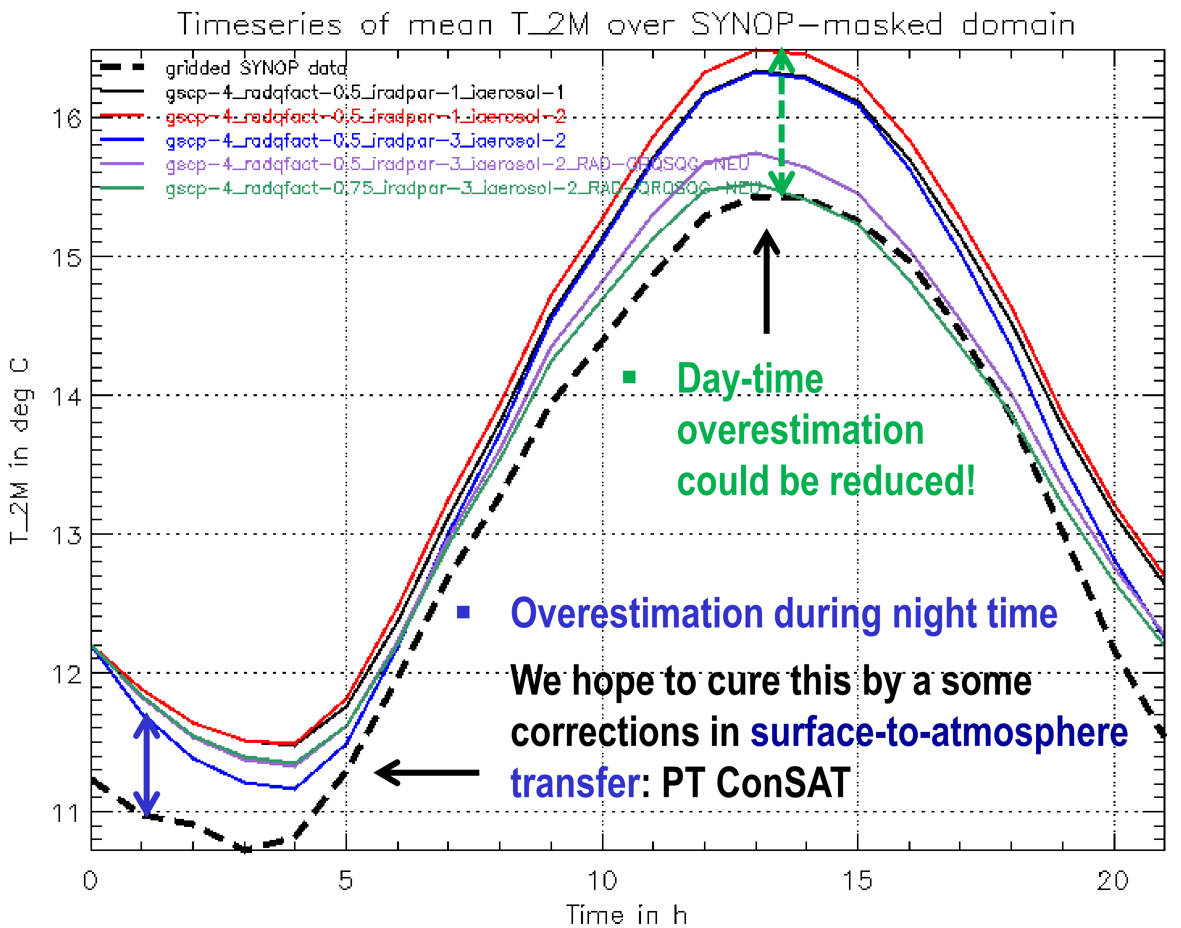
Current work on radiation:

- **Providing better external parameters**
  - New **MODIS derived „total“ albedo**
  - **External parameters for orographic radiation corrections** now available

- **Revision of cloud radiation feedback** (U. Blahak)
  - In **current radiation scheme** (B. Ritter, F. Geleyn) all **optical properties** (extinction coefff, …) depend only on **grid scale values** of **qc** and **qi**. **SGS variability** of this properties is roughly taken into account by an **effective reduction factor k=0.5**.
  - Optical properties are now dependent on
    - ➔ **Effective radii** R_{eff} **,** which can be derived form **particle scale distributions** and **particle shapes** in microphysics
    - ➔ **Precipitation (snow)**
  - Larger values of the **effective reduction factor** have been tested

Revision of cloud-radiation feedback

Case study COSMO-DE, 13.6.2012, 00UTC run, domain average T_2M



Control

+ Tegen aerosols

+ hydrometeor radiative properties depending on R_{eff}

+ qg, qs

+ radqfact 0.5 -> 0.75

- - - - Synop Obs.

Result from U. Blahak, DWD

Work on operational turbulence scheme:

- **We use a 2-nd order scheme** (M. Raschendorfer) **based to Mellor/Yamda level 2.5**
  - **using a prognostic TKE-equation**
    - **vertical TKE-diffusion; (TKE-advection switched off)**
  - **and a linear diagnostic system in horizontal boundary layer approximation for reduced 2-nd order moments from** $\{\theta_w, q_w, u, v, w\}$ → **single column solution**
    - **Turbulent condensation and evaporation: using quasi conservative scalar variables and a statistical saturation adjustment assuming Gaussian distribution functions (according to Sommeria and Deardorff) in order to solve for buoyant heat flux** $\overline{\rho\theta_v'' w''}$

→ **Flux gradient representation** of the only relevant 2-nd order moments (**vertical** flux densities):

$$\boxed{\overline{\rho\phi'' w''} \approx \bar{\rho}\,\overline{\phi' w'} \approx -\bar{\rho} K^{\phi}\, \partial_z \hat{\phi}}$$

$$K^{\phi} := \ell\, S^{\phi} \cdot q$$

turbulent diffusion coefficient

- ℓ: turbulent master length scale
- S^{ϕ}: stability function
- q: turbulent velocity scale $\left(\frac{1}{\bar{\rho}} \underbrace{\sum_{i=1}^{3} \overline{\rho v_i''^2}}_{2 \cdot TKE}\right)^{1/2}$

$$\zeta'(\mathbf{s}) := \zeta(\mathbf{s}) - \bar{\zeta}(\mathbf{r}) \qquad \zeta''(\mathbf{s}) := \zeta(\mathbf{s}) - \hat{\zeta}(\mathbf{r})$$

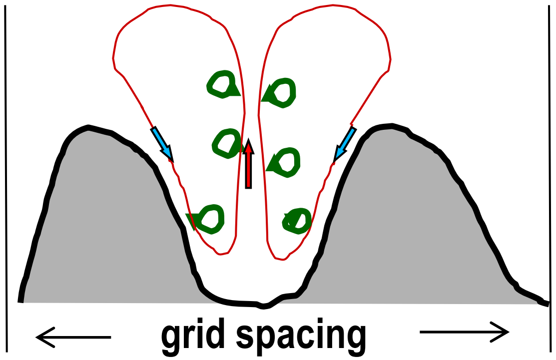
$$\hat{\varsigma} := \frac{\overline{\rho\varsigma}}{\bar{\rho}}$$ **weighted average**

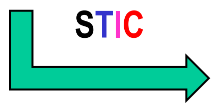
S^M and S^{ϕ} are the **final solution** of the **reduced linear system** and **q** is calculated by a **prognostic equation.**

ℓ is for each horizontal point a pure **function of vertical height** z.

Separated TKE equation including scale interaction sources (M. Raschendorfer) :

Formal scale separation automatically produces interaction between GS parameterizations of turbulence and circulations



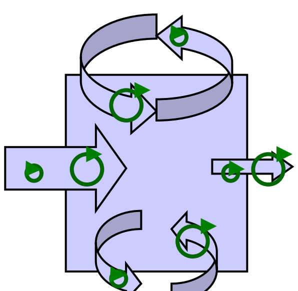


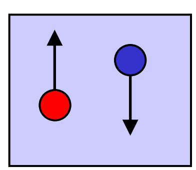
Additional Shear -Production of TKE by:
- SSO wakes
- Horizontal shear eddies
- Vertical thermal driven currents

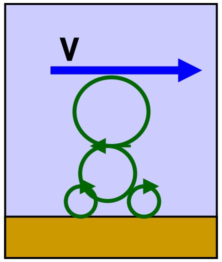
- Missing link:
  - Ri_crit less likely exceeded
  - Main source for turbulence above the BL
- Computationally cheap, but clear impact

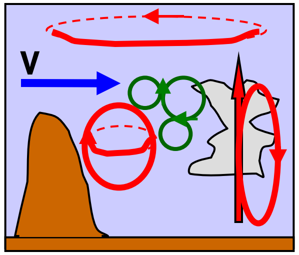
More physically based mixing even for stable stratification

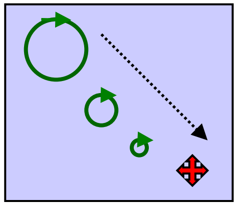
time tendency of TKE	transport (advection + diffusion)	buoyancy production	shear production by the mean flow	shear production by sub grid scale circulations	eddy-dissipation rate (**EDR**)
		labil: > 0 neutral: $= 0$ stabil: < 0	≥ 0	≥ 0	< 0



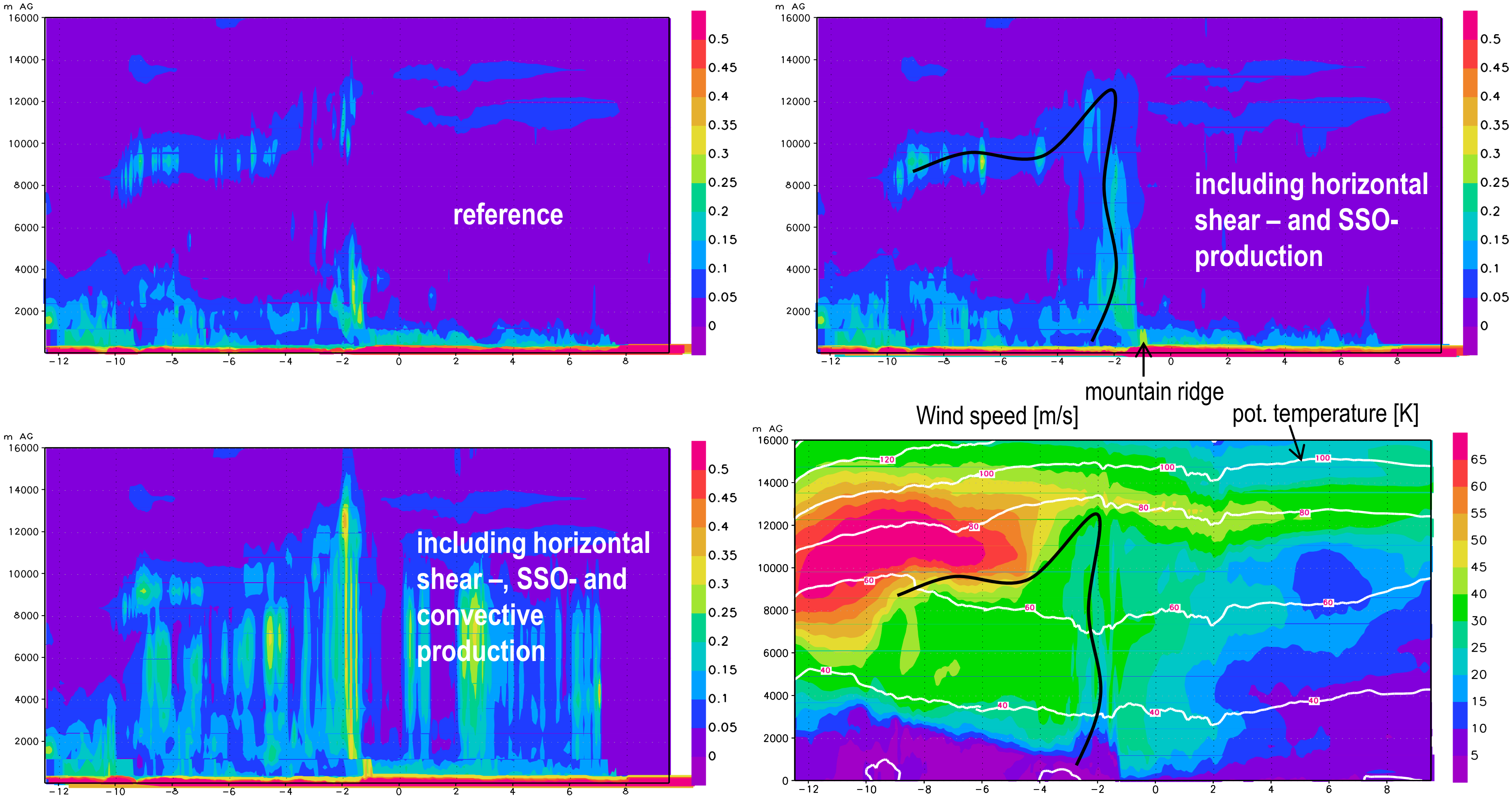








pow_1/3 (eddy dissipation rate (EDR) [m^2/s^3])



COSMO-US: cross section across frontal line and Appalachian mountains

st_time=00z01may2010 pr_hour=18hr – 19hr

Work on operational turbulence scheme (1):

- **STIC: Adding scale interaction terms in TKE-equation**:
  - Production due to **SSO-wakes**, **horizontal shear eddies** and **convection,** dependent on **specific non-turbulent length scales**:
    - **SSO-wake term:** (horiz. dim. of roughness elements) — **- operational** at DWD (already last year: **significant improvement**)
    - Production by **convection:** (vert. conv. scale) — - needs **to be verified, but model output still used for EDR-forecast**
    - **Horizontal shear term:** (horiz. grid scale) — **- tuning parameter only estimated, but still used for EDR-forecast**

Medium term outlook for STIC approach:

- **Introduction/completion of SGS transport due to the interacting circulations**
  - **Horizontal diffusion by separated horizontal shear eddies (3D-turbulence)**
  - **vertical TKE-diffusion by convection**

Consequences of scale interaction terms and general model improvment:

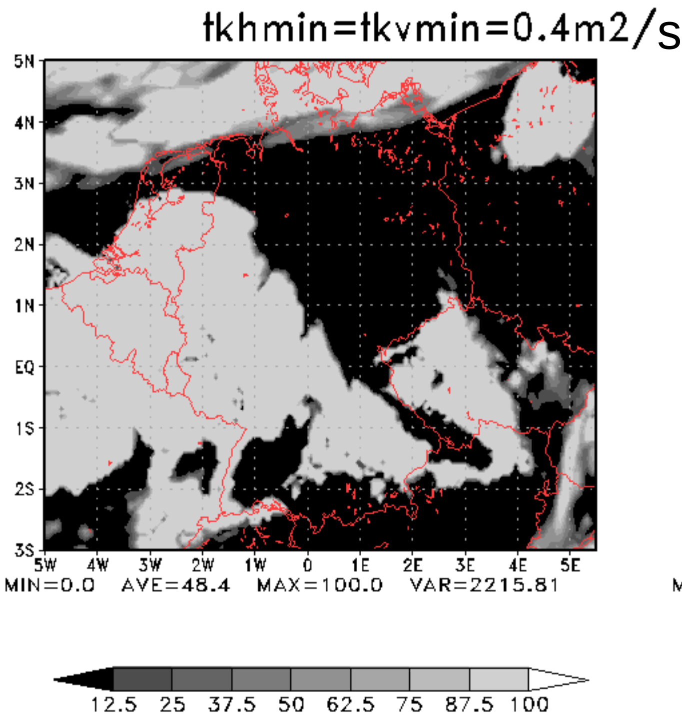
- **More physical based TKE and mixing in the stable BL**
  - Is already beneficial for **CAT-forecast** needed for **aviation** (s. previous reports)
  - Should be beneficial also for near surface **SBL**.
  - **Previous artificial security measures needs to be adopted!**

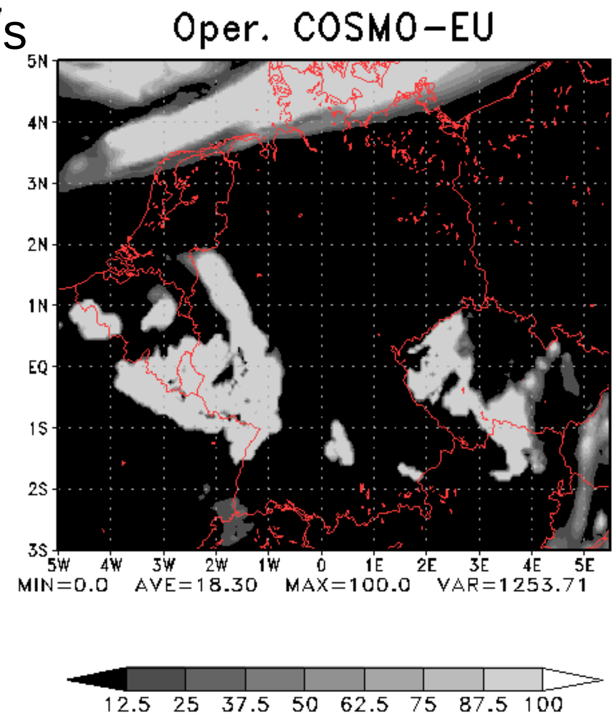
- **First candidate: the minimal diffusion coefficient**
  - Previous value: **tkv[h,m]min = 1.0 m²/s** (same for scalars and momentum)
  - Seems to **dissolve BL clouds much to early** now (and was presumably always a bit too large)
  - Previous attempts to decrease it has **not** been successful
  - After lots of **general numerical improvement** of the model and the introduction of at least the **SSO-source term,** a further attempt has now been tried
  - New value: **tkv[h,m]min = 0.4 m²/s**

Extremely cheap tuning measure; large impact in particular for T_2m_Min (RV=-13.33% for a 2-month exp.) !!

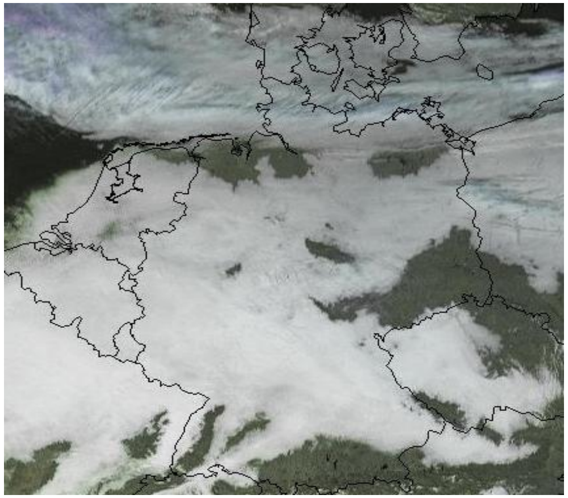
Low level cloud cover CLCL

Ini. 2012111400, Verf. 2012111506: CLCL [%]



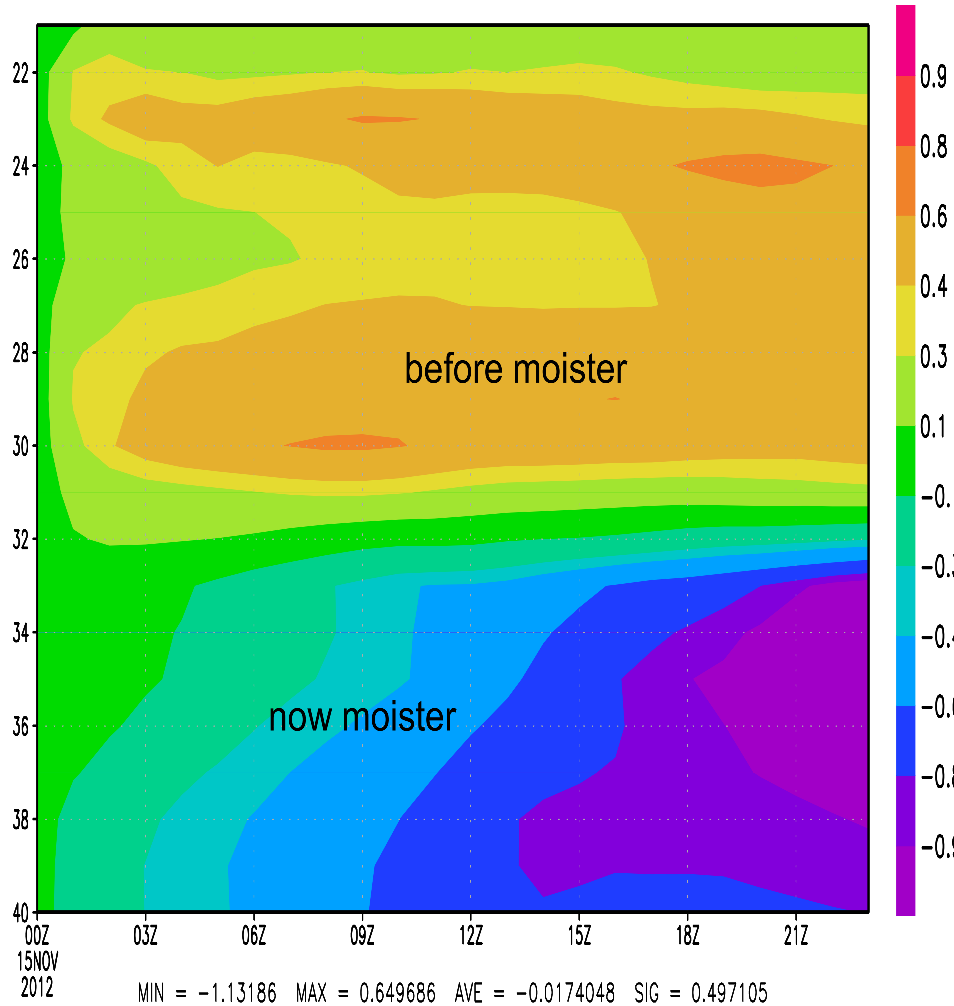


Satellite



Experiment | **Routine** | **Reality**

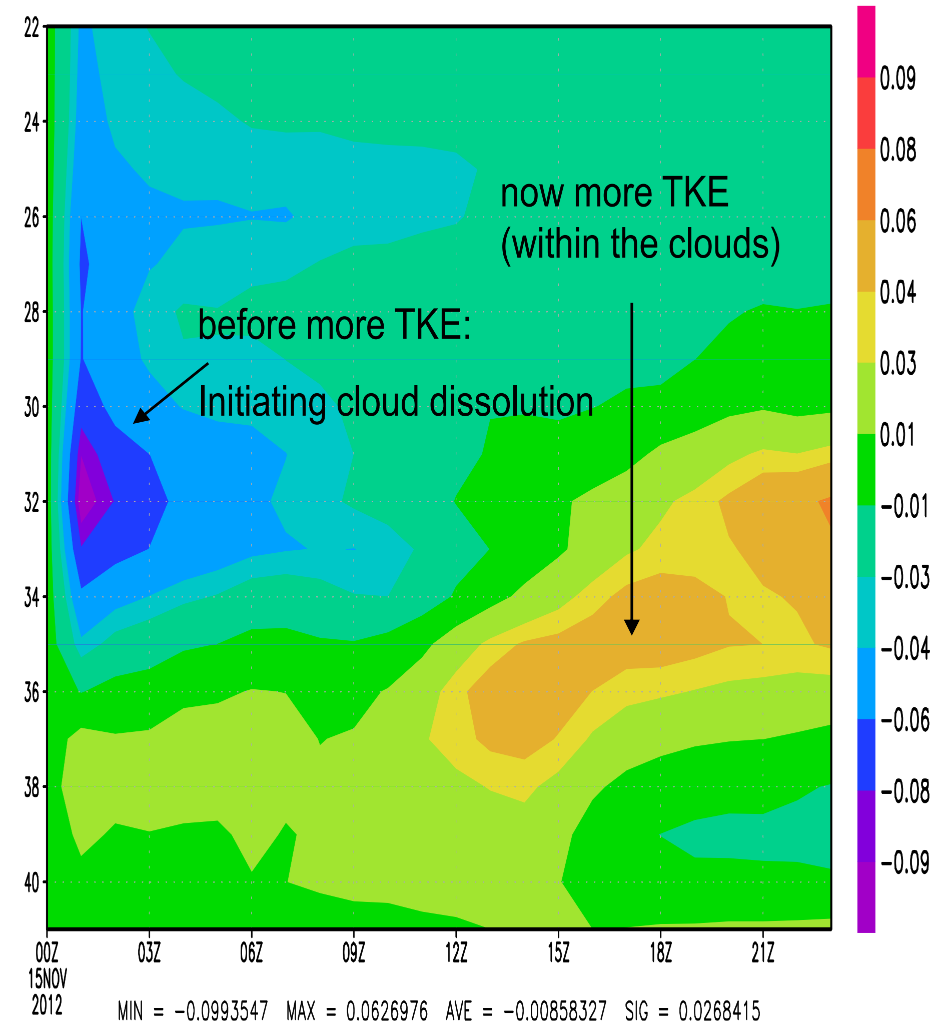
dif (Spread [C])
Experiment - Routine
out_lm2_rlme_4.24-rlme-tkmin=0.4



Lon -6 6, Lat -6 6

time-height cut

dif (turbulent kinetic energy (TKE) [m^2/s^2])
Experiment - Routine
out_lm2_rlme_4.24-rlme-tkmin=0.4



Lon -6 6, Lat -6 6

all values are area averages

Work on operational turbulence scheme (2):

- **Decreasing the minimal diffusion coefficients**
    - **operational**

- **Reformulation of TKE scheme**
    - **Changing positive definite solution of prognostic TKE-equation**
    - **Weakening numerical security limits and stronger modularization**
    - **Diffusion of applied to conserved scalar variables**
    - **Same implicit diffusion solver for 1-st order variables and TKE with options for better coupling**
        - implemented in **private test-version** and ICON; **not yet verified; common version in work**)

- **Deardorff-restriction of turbulent master length scale**
    - Implemented since more than a year in **current version, needs to be verified**

- **Validation of reformulated scheme**
    - Work for **next future** (DWD + ARPA-SIMC Bologna)

Work on SGC cloud processes:

- In a **2-nd order framework** (related to **turbulence**):
  - So far only **equilibrium cloud processes** (**statistical saturation adjustment**).

statistical cloud scheme → **CLC and qc according to SGS fluctuations**, but **neither turbulent icing nor precipitation**

- In current **(separated) TKE scheme**: based on a **pure Gaussian PDF** of **saturation deficit** Δq_s
- related **SGC qc-tendencies are ignored** yet due to **GS saturation adjustment applied in microphysics**)

- **In a mass flux framework** (related to **convection**):

adapted full microphysics → **all cloud species including precipitation,** but **not (yet) CLC due to convection**

- **Scale separation (STIC)**:
  - **Overlap of turbulent and convective cloud processes**

- **Alternative (at least for models with LES resolution):**
  - **SGS cloud processes only within an extended turbulence framework**

- We try this in the framework of an **extended TKE-scheme** with additional **3 prognostic equations** for the **2 scalar variances** and the corresponding **covariance**

  (TKESV, D. Mironov, E. Maschulskaya)

- An **extended statistical cloud scheme** has been implemented based on a **double-Gaussian PDF** of **linearized** Δq_s, dependent on the **3 moments**: **mean**, **variance**, and **skewness** S_s (Naumann et al. 2013), where a **further prognostic equation** has been introduced for S_s

TKESV: 3 additional prognostic equations for conservative scalar (co-)variances ↔

1 further prognostic equation for skewness S_s ↔

double-Gaussian statistical saturation adjustment using S_s

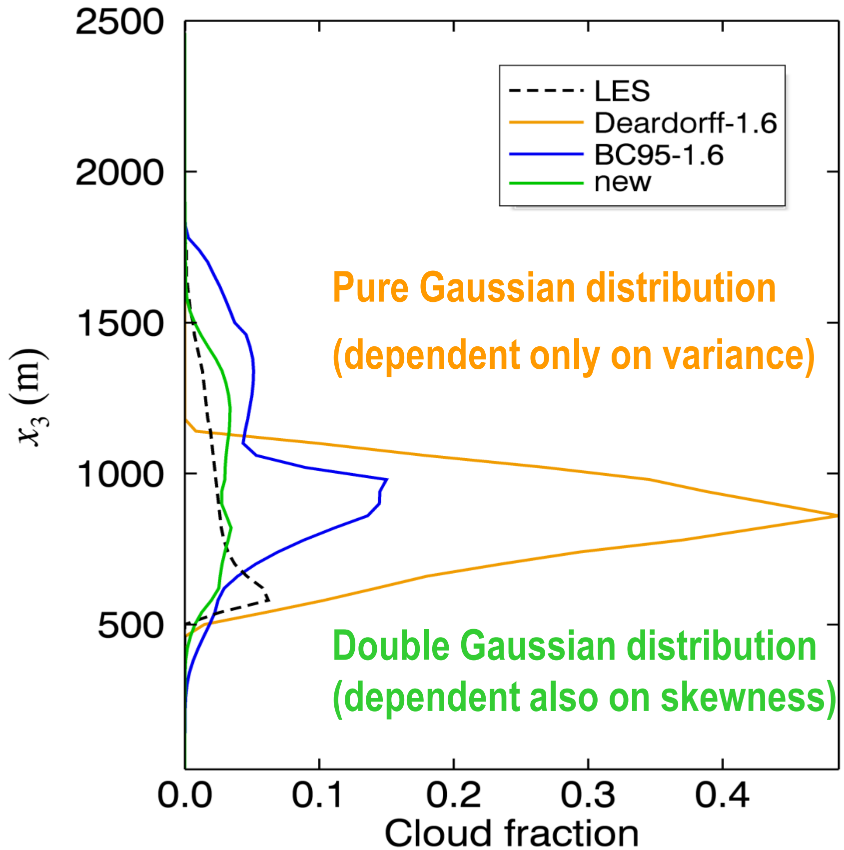
---

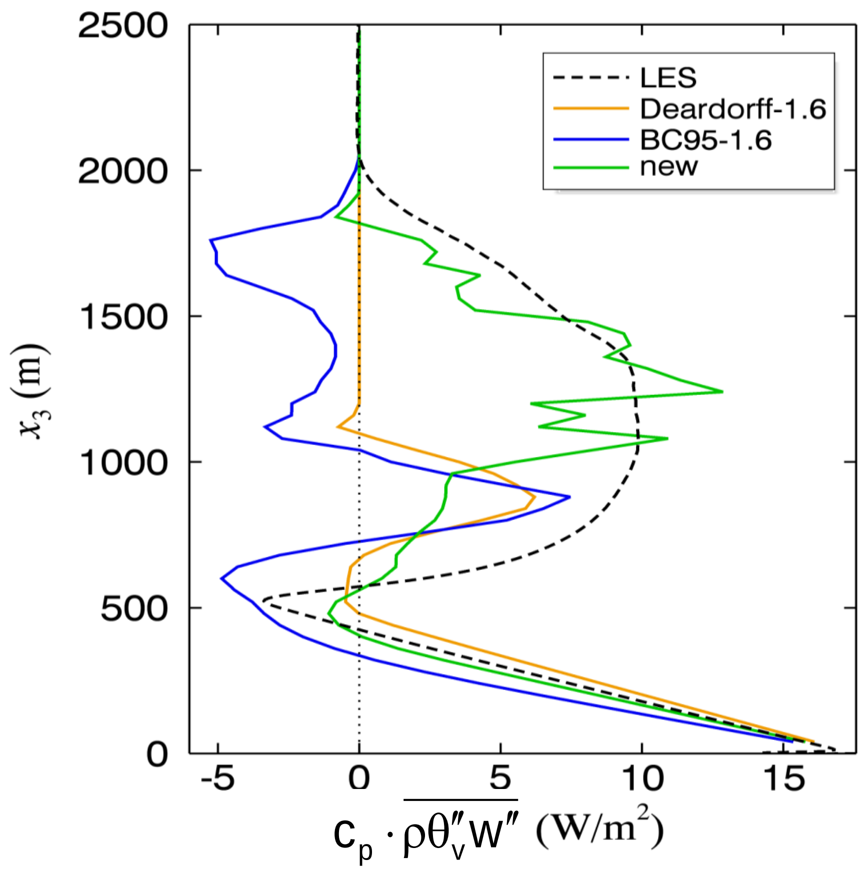
4 additional prognostic equations!

- The new scheme is being tested against **LES data** (Heinze 2013) of the **BOMEX** test case (http://www.knmi.nl/~siebesma/BLCWG/#case5); by **SC runs**

  first results look promising

TKESV + New Cloud Scheme: cloud cover and buoyancy Flux





- SC-runs of shallow cumulus case over a sea point: no mass-flux scheme active, but TKESV
- Averaged profiles 3 hours of integration (hours 4 – 6); LES data from Heinze (2013)
- Statistical cloud scheme is only affecting the calculation of buoyant heat flux in TKE-equation
  - ➢ Cloud – turbulence feed back can be improved, if considering a skewed distribution of saturation deficit

Result from D. Mironov, E: Maschulskaya, DWD

Outlook for SGS cloud processes

Within the extended TKESV turbulence framework: 4 additional prognostic equations

- ➔ Comprehensive testing of the new scheme (stratus and stratocumulus regimes, etc.)
- ➔ Consideration of numerical issues
- ➔ Implementation into COSMO an ICON as an option of the TKE scheme
- ➔ Further development of the scheme, e.g. consideration of the effect of microphysical processes on the scalar variance and skewness

(in co-operation with the HErZ-CC team)

Within a STIC framework (separated turbulence interacting with circulations):

- ➔ Turbulence remains Gaussian distributed
- ➔ Skewness is generated by mass flux parameterizations of (shallow) convection
- ➔ Total cloud cover form overlap of turbulent and convective processes
- ➔ Would be applicable to deep convection as well

General work on turbulence/convection/SGC cloud processes:

- **TKESV: treating scalar (co-)variances in prognostic equations (test version)**
  - **statistical cloud scheme now based on double Gaussian distribution**
    - Implemented in test version

- **Turb-i-Sim:** (J. Schmidli, O. Fuhrer, …)
  - Evaluation and improvement of COSMO turbulence for **1-km resolution** over **Alpine topography**
    - Project at ETH and MeteoSwiss, just started

General urgent tasks for next future:

- Interchangeable modules with physical parameterizations between COSMO and ICON
  - Common interfaces for COSMO and ICON
- Unification and validation of independent development
  - Present in test versions of COSMO or ICON
- 3D-effects
  - In turbulence and radiation

New future perspectives:

- Closer coupling between different parameterizations
- Stochastic parameterization extensions, such as
  - Monte-Carlo spectral integration for radiation
  - Stochastic variations of start conditions for vertical mass flux integration

Thank you for attention

Stochastic Physics

Motivations

- to improve the model stochastically if it is not possible to do it deterministically
- to estimate the background (model) error for the data assimilations purposes
- to provide the users with an estimation of the forecast reliability and uncertainty

Possible steps

- to determine the entire model error and to approximate it with a random process with the same time and space correlations
- to go further into the determination of different types of the model error
- to develop a more consistent approach: noise structure should not be arbitrary, but should be determined by the governing equations

Work on microphysics:

- **Implementation of 2-moment scheme** (A.Seifert)
  - **Runtime 60-100% increased**! Only as an **reference or for special purpose** (COSMO-ART)
  - Further work on **hail-microphysics and optimization**
    - Adopted as an **extra code** to 4.25 and tested: slightly better over all verification

- **Prognostic treatment of melted water fraction within solid water parcels** (A.Seifert)
    - Ready for testing in case of **snow**
    - Further work for graupel and hail planned only **as an extension of the 2-moment scheme**

- **Almost ready improvement of the 1-moment scheme** (F.Rieper)
  - **Changing exponential distribution** function to a more general **gamma-function**
  - Implementation of an **improved sedimentation formulation for snow and rain**
  - Some **bug fixes**
    - All to gather **implemented** in current version and **being tested**

- **Running improvement of 1-moment scheme**
  - Consideration of **homogeneous ice nucleation in cirrus clouds** allowing higher oversaturation (C.Köhler)
  - Improved simulation of **super-cooled water** to improve forecast of **aircraft icing** (F.Rieper)

Microphysics: plans

- **Short term (2013 – 2017):**
  - Common COSMO / ICON physics library
  - Investigate dry precipitation bias in summer time
  - Further testing of the works of C. Köhler and C. Frick
  - Continuing work of F. Rieper regarding supercooled LWC, demand of aviation forecasters (aircraft icing)
  - 2-moment scheme: further studies to evaluate benefit in operational NWP; consistent data assimilation, otherwise we will most likely not see the full benefit
  - Towards explicit hail forecasting with 2-moment scheme:
    - improvement of hail melting / shedding following methodology of C. Frick (Postdoc work of V. Sant in HD(CP)2 , Hamburg)
    - Resolution requirements?
- **Longer term (2018 – 2020):**
  - Keep an eye on scientific developments regarding subgrid scale processes in cloud microphysics parameterization (effects of turbulence and spatial inhomogeneity)

Work on radiation:

- **Using an improved aerosol climatology** (J.Helmert)
    - Test runs performed: currently **too transparent clouds**

- Slightly **modifying cloud cover diagnostics for ice clouds in radiation scheme** (A.Seifert)
    - Already in current code

- **Considering precipitating hydrometeors in radiation calculation** (U.Blahak)
    - In particular **slowly falling snow** should be considered
        - Work just started

- **Adaptive sampling of grid points used for radiation calculation** (V.Venema, Uni Bonn)
    - Running radiation **only once for all grid points with similar properties related to radiation**
        - **Promising**, only research version prepared

- **Monte Carlo spectral integration** (MPI Hamburg; B. Ritter)
    - Varying stochastically the absorption coefficients of a reduced number of spectral bands
        - **Promising**, only research version prepared

Radiation: plans

- **Short Term (2013 – 2017):**
  - Common COSMO / ICON physics library
  - Test parameterization of 3D radiation effects (work from Uni Munich within Extramural Research program), TICA, McICA
  - Test McSI – Monte Carlo Spectral Integration methods (B. Ritter)
  - Revision of cloud - radiation feedback (U. Blahak)
  - Test alternative scheme RRTM for COSMO (available via common physics library):
    - Consistent coupling with ICON
    - RG92 has problems for domain heights >~ 25 km
- **Longer Term (2015 – 2017):**
  - Likely: Revision of cloud - radiation feedback cont.

cloud-water-content/[Kg/Kg]: