Ongoing and new physics developments in COSMO

– **Mainly associated to the ICON model**

– **With particular focus on sub-km model resolution**

- **Clouds and Aerosols Improvements in ICON Radiation scheme**
- **Actions around Aerosols and Reactive Trace gases**

- **Treating the dynamical impact of SGS condensation**
- **Investigation of signal-to-noise ratio at simulating the land-see breeze**
- **3D-extensions for the turbulence scheme TURBDIFF**
- **Tackling missing impacts of the (SGS) topographic surface structure**

- **Some other ongoing development**

בס"ד

Clouds and Aerosols Improvements in ICON Radiation scheme - CAIIR PP

Participants:

Harel Muskatel (IMS)
Pavel Khain (IMS)
Alon Shtivelman (IMS)
Yoav Levi (IMS)
Ulrich Blahak (DWD)
Daniel Rieger (DWD)

Alexey Poliukhov (RHM)
Julia Khlestova (RHM)
Gdaly Rivin (RHM)
Natalia Chubarova (RHM)
Marina Shatunova (RHM)

- Improved parameterizations of **optical cloud properties**
  - Treatment of larger and multi-shape particles (including such from precipitation)
  - Now integrated into ecRAD in IFS -> ecRAD in ICON
- Implementing of new ice-nucleation according to deMott (2015) into ICON
- Implementing more-realistic information about aerosols:
  - CAMS (climatology and forecast), prognostic 2D AOD, direct prognostic ICON-ART
- Implementing of sophisticated spectral-bin microphysics as a reference tool

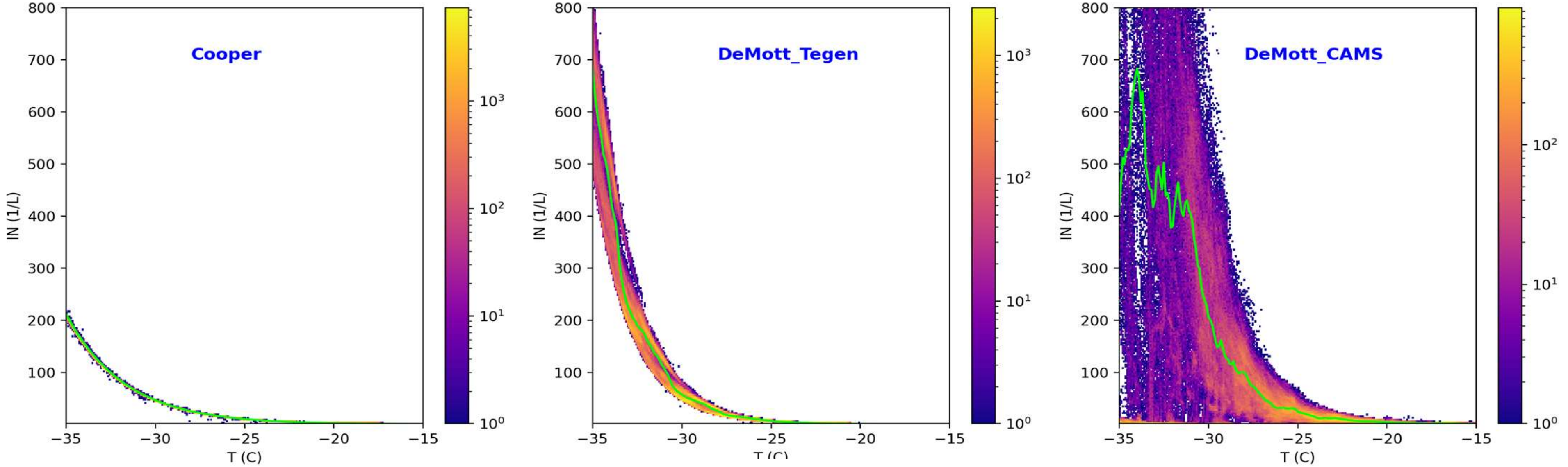
ICON Ice nucleation with DeMott (2015) scheme

Harel Muskatel (IMS)

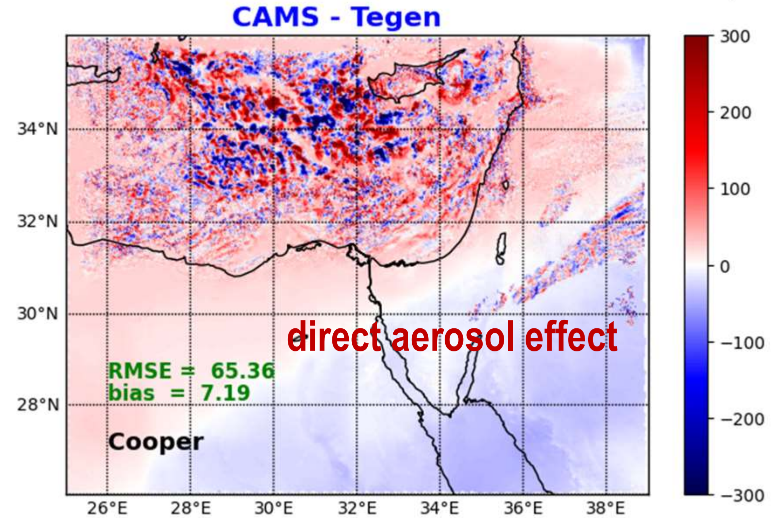
IN(T) for April 5, 2020

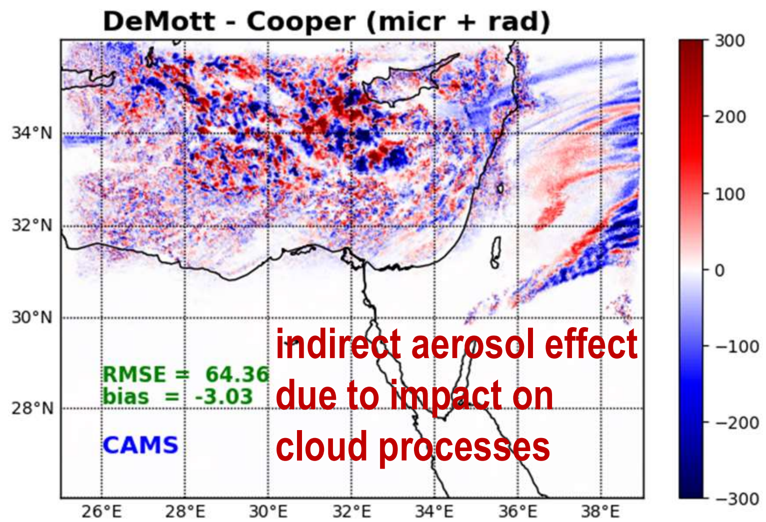
$\mathbf{IN(T)} = 5 \cdot exp^{0.304(T_0 - T)}$

$\mathbf{IN(T, n_{dust})} = 1000 \cdot n_{dust}{}^{1.25} exp^{0.46(T_0 - T) - 11.6}$



Impact on global radiation (Wm^{-2}) 2020-04-07 08:00:00 Z





Simplified 2D quasi-prognostic aerosol scheme based on input by AOD-climatology:

by **Günther Zängl** -> **Daniel Rieger (both DWD)**

$$\partial_t \psi_j(x,y) = \langle \underline{v}_h \rangle \cdot \nabla_h \psi_j + S_{e,j} + S_{w,j} + \underbrace{f_{diff} \Delta \psi_j}_{\text{artificial diffusion}} + \frac{f_{clim,j} \psi_{clim,j} - \psi_j}{\tau_{clim,j}}$$

relaxation towards climatological AOD

ψ_j 2D AOD for aerosol component j

$\langle \underline{v}_h \rangle$ 2D vertically averaged horizontal wind speed

$S_{e,j}$ 2D emission with some new implementations (by **Daniel Rieger**):

- **mineral dust (j=d)** emission according to Kok (2014), with the computational cheap assumption of size distributions being independent on wind speed
- **sea spray aerosol (j=ssa)** emission according to Grythe et al. (2014)
- **anthropogenic aerosol (j=anth)** to be parameterized by means of land-use fractions or an emission climatology

$S_{w,j}$ 2D wet deposition → related AOD through Mie-calculations

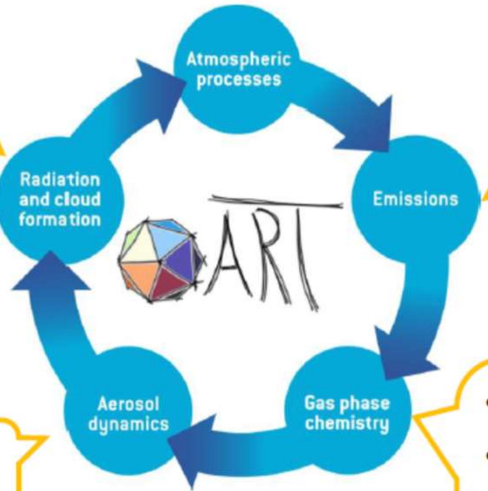
Seamless from local Air Quality to global Climate-Chemistry usable for operational NWP, climate and earth system modelling

Aerosols and Reactive Trace gases

ICON-ART: current features

- Optics of all natural aerosols
- Optics of internally mixed volcanic aerosols
- Coupling with ecRad

COSMO-PP CAIIR

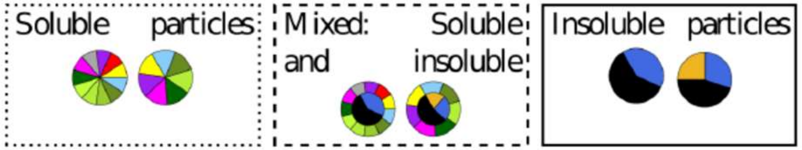


- All source types
- All natural aerosols
- Biomass-burning plumes
- Volcanic plumes
- Online emission module (EMPA)

AERODYN

- Lifetime based
- Linearized schemes (LINOZ, N_2O-NOy)
- Simplified OH chemistry
- "Complex" chemistry based on MECCA e.g. MOZART

SO_4 NH_4 NO_3 Na Cl POM SOA1 SOA2 SOA3 SOA4 H_2O BC DU VA



input by Heike Vogel (KIT)

- **(Quasi-)Operational forecast:**
  - Mineral dust (DWD)
  - Pollen (DWD, MeteoSwiss)
  - Emergency: Radionuclides, volcanic ash, accidental release (DWD)

Aerosols and
Reactive
Trace gases

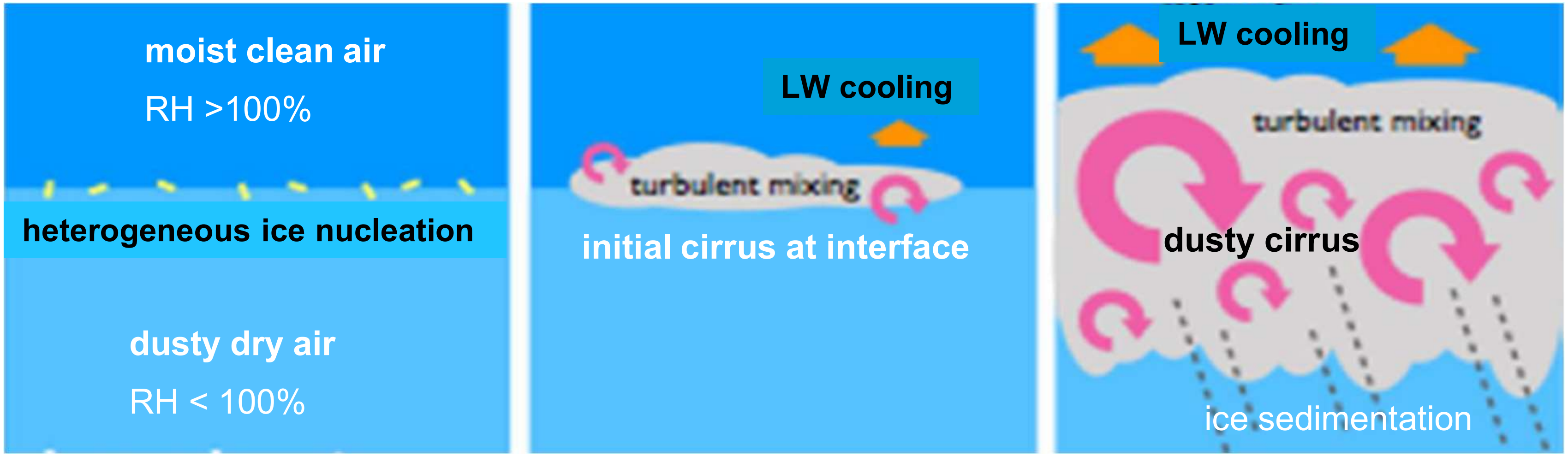
Karlsruhe Institute of Technology

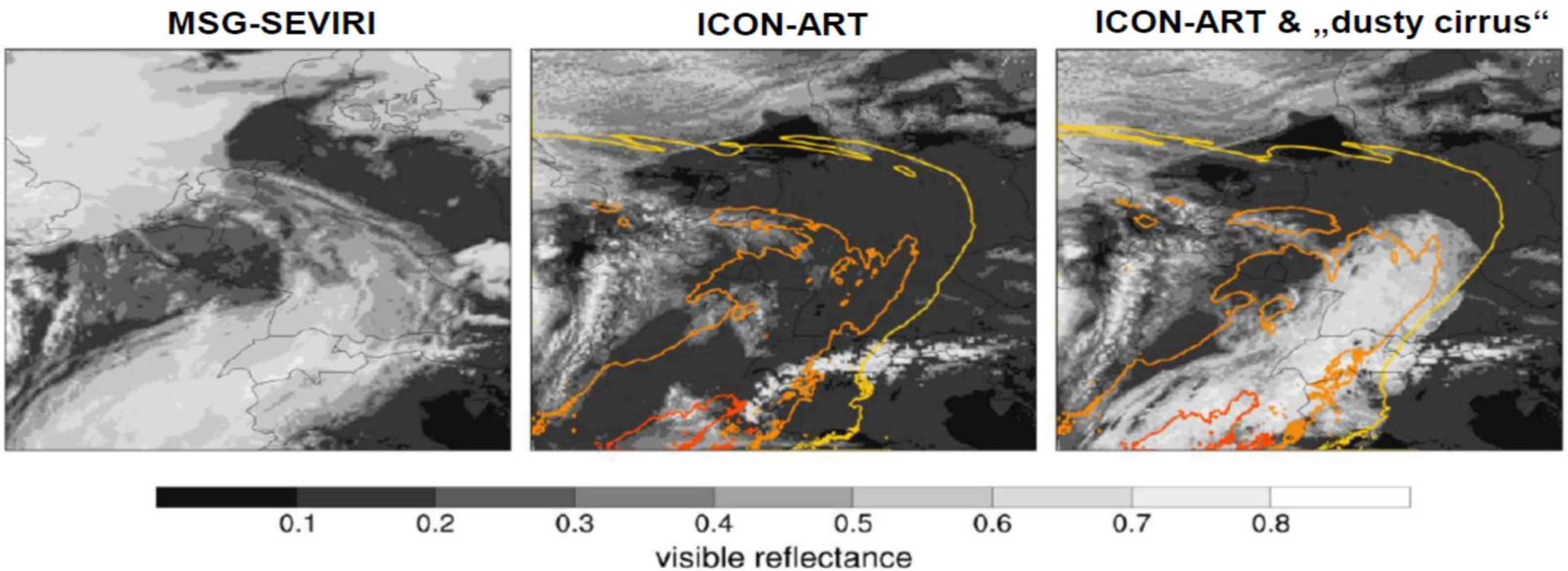
ICON-ART: Some current topics

- **Multiphase flow: aerosols contribute to air density:**
  - **First LES simulations; impact on convection around ash plumes**
- **New parameterization for aircraft icing**
- **GPU porting of ART code: first steps successful**
- **Dust forecast with improved representation of cirrus clouds**
  - **"dusty cirrus" developed by DWD project PermaStrom**

Axel Seifert (DWD), in preparation

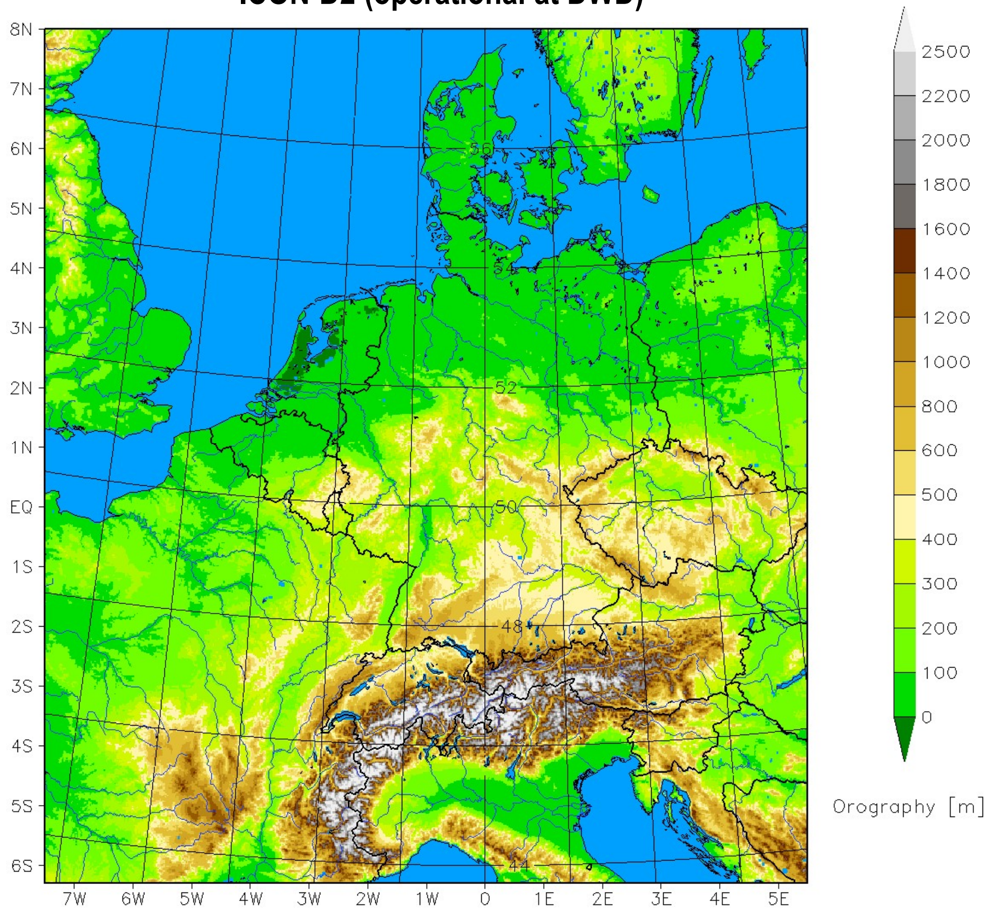
Dusty cirrus: conceptual model





Current activity in atmospheric Physics in COSMO (for ICON-LAM) with particular focus on sub-km model resolution:

ICON-D2 (operational at DWD)



- ➔ **Domain is defined as rectangle in rotated lat-lon coordinates in order to match coverage of previous COSMO-D2**
- ➔ **Horizontal mesh size 2.1 km**
- ➔ **65 levels with top at 22 km**
- ➔ **lead time 48 h, 8 forecasts per day for deterministic run plus 20 EPS members**
- ➔ **LETKF-based data assimilation scheme with 40 members**

- **Experiments with higher resolution had not yet been really successful!** **(*)**
  - ❖ **What can we expect from higher resolution and what are the challenges?**

Motivation for dealing with sub-km resolution, related challenges and strategies for model physics:

- GS representation of main convective activity
  - Scale-adaptive parameterization of remaining SGS convection lacking a spectral gap just at grid at GS (grey-zone)
- Better representation of surface topography or other kinds of horizontal heterogeneity (such as from change of surface properties)
  - Full treatment of GS orographic slopes or strong horizontal gradients as well as SGS surface struct. (Roughness) or inter-tile variability for:

GS SGS

- Soil water transport: Down-slope water fluxes (river- and groundwater-flows)
- Mech. pressure forces: Form drag and gravity wave drag also by Land-Use R
- Radiative transfer: Topographic correction of (solar) radiation
- SGS atmospheric transport and water-phase transitions by:
  - Turbulence:
    - 3D-shear, 3D-diffusion together with (**)
    - GBLA Generalized BL-Approx.: Tangent-to-Streamline-Approx. (TSA)
    - metric corrections from SGS topography in 1-st and 2-nd order equations
    - (*) STIC Separated Turbulence Interacting with NTCs: new TKE source terms by SGS shear!
  - Additional Non-Turbulent SGS Circulations (NTC), such as: kata- and ana-batic or land-see circulations

trigger for GS and SGS conv. (***)

<u>So far applied adaptations with regard to convection:</u>

Günther Zängl (DWD)

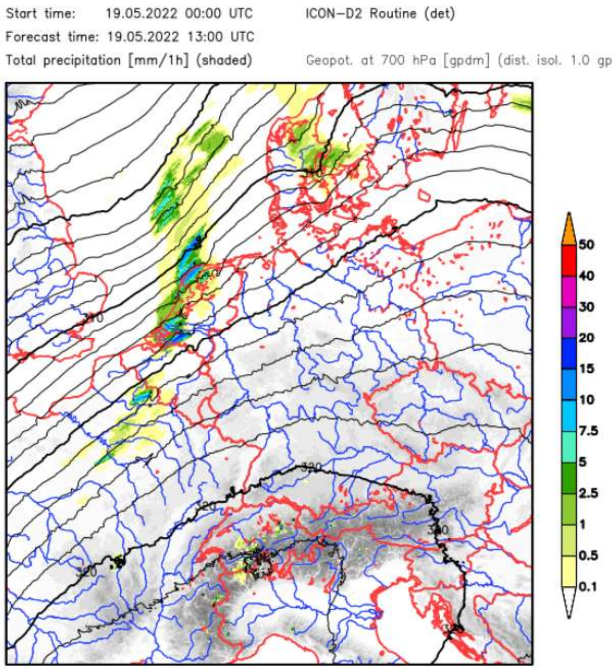
- **Tiedtke-Bechtold convection scheme in ‘grayzone deep convection’ mode**
  - **components for shallow and deep convection are active, but <u>not</u> mid-level convection**
  - **convective adjustment time scale, entrainment profile, and CAPE closure are strongly tuned in order to reduce the activity of the scheme**
  - **shallow convection depth and the cloud-base of entrainment rate are resolution-dependent for <u>dx < 5 km</u>**

- **Activation of not yet considered latent heat conversion**
  - **Turbulent saturation adjustment from moist turbulence closure in TURBDIFF**
    - **Employed for overall cloud diagnostics**
    - **Related latent heat conversion squashed by gird-scale saturation adjustment in 1-mom. bulk microphysics**
    - **Diagnosed excess of cloud-water is treated as a sub-grid source term, and the associated latent heat release is ‘seen’ by the dynamic core now**

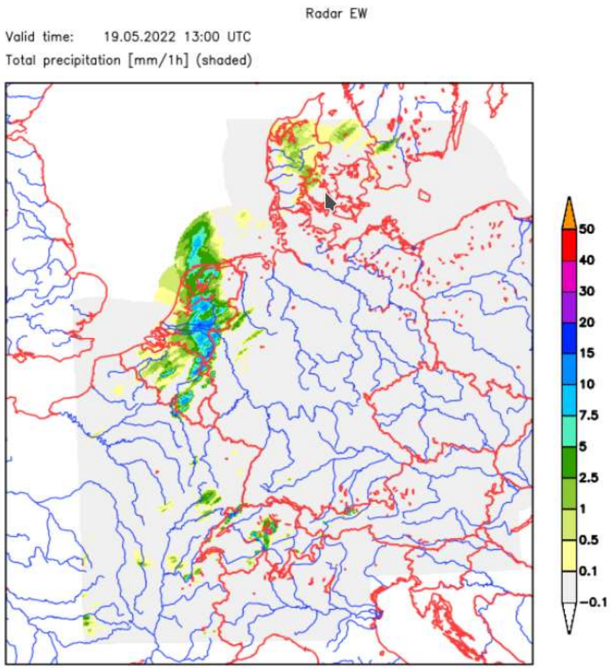
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

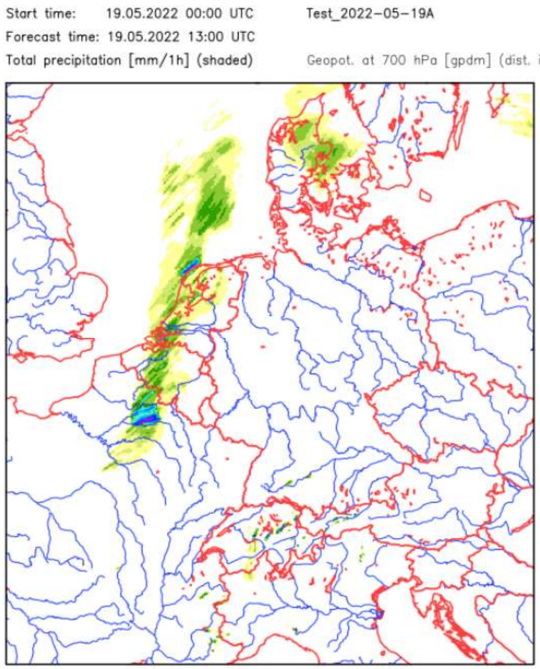
00-UTC forecast run, 1h-precipitation 12-13 UTC



Operational forecast



Radar

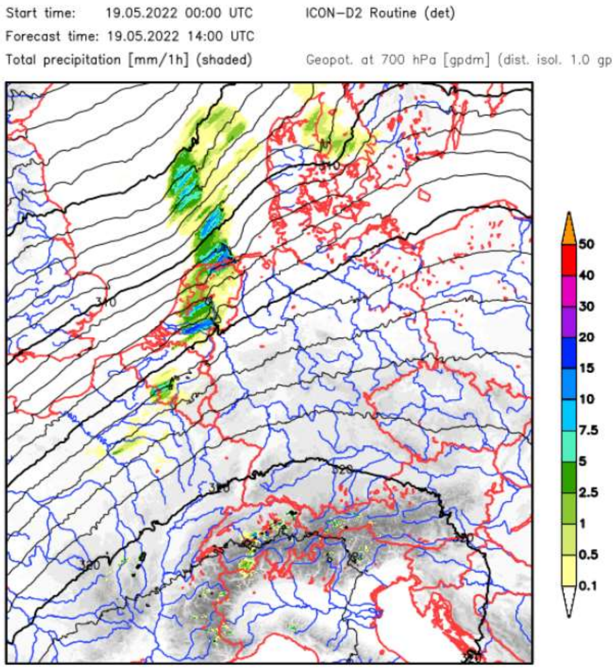


Exp. with SGS condens.

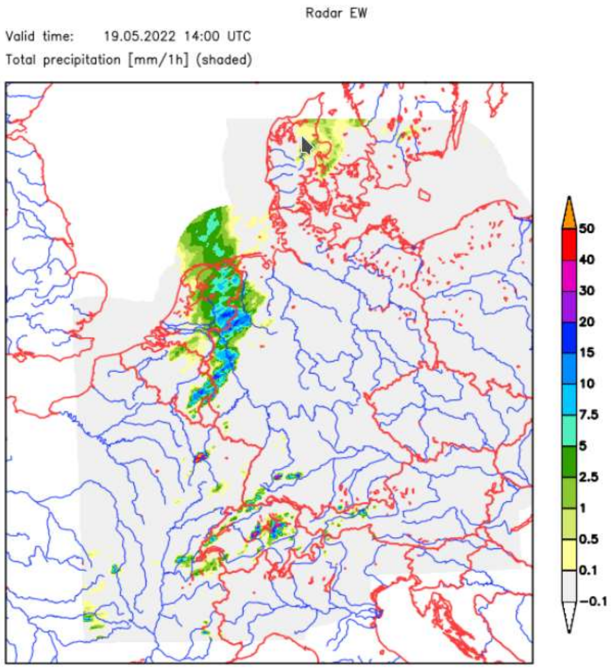
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

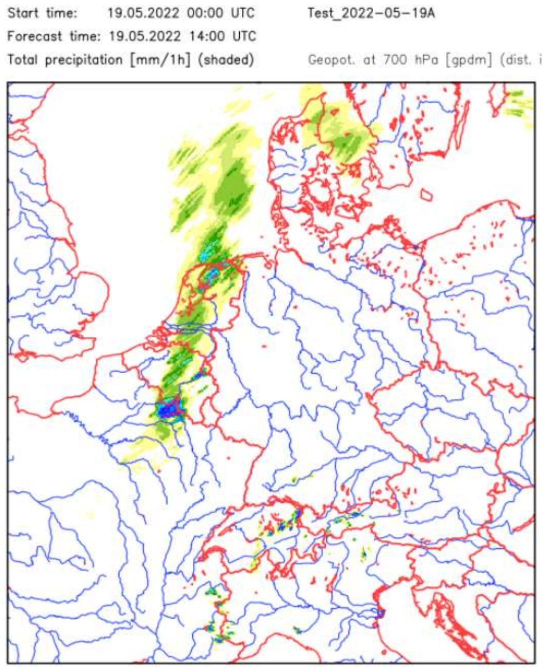
00-UTC forecast run, 1h-precipitation 13-14 UTC



Operational forecast



Radar

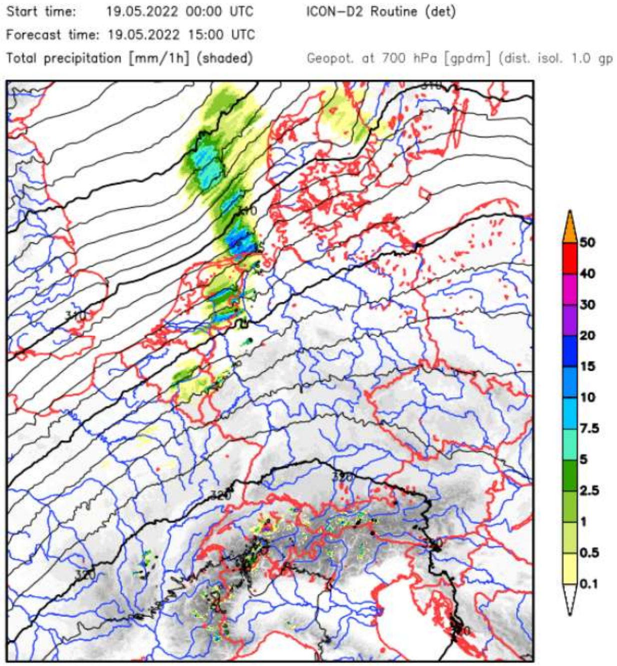


Exp. with SGS condens.

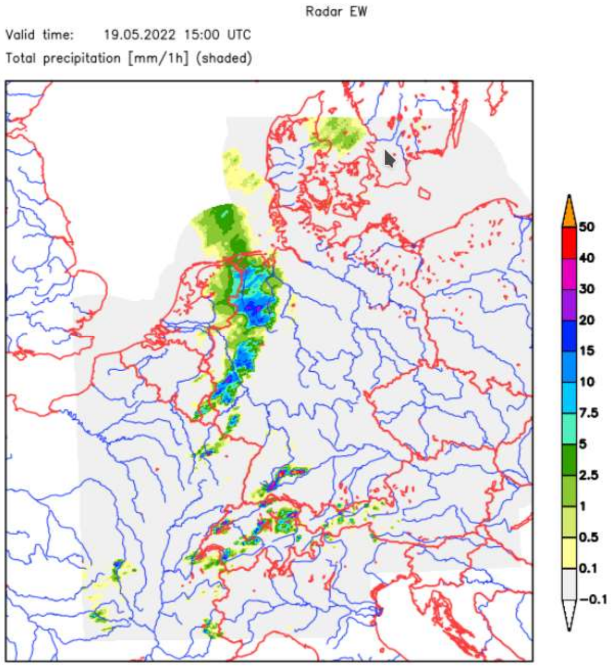
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

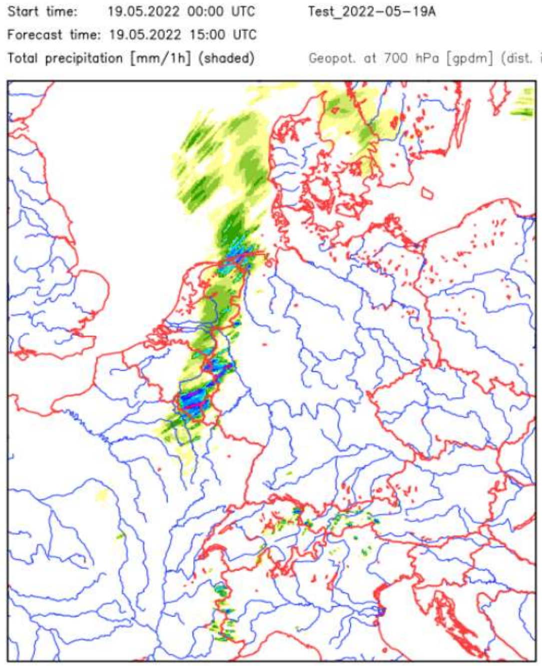
00-UTC forecast run, 1h-precipitation 14-15 UTC



Operational forecast



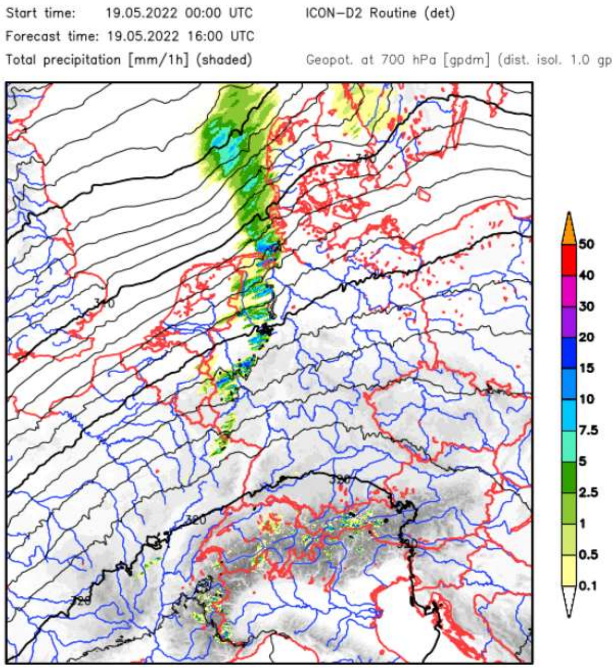
Radar



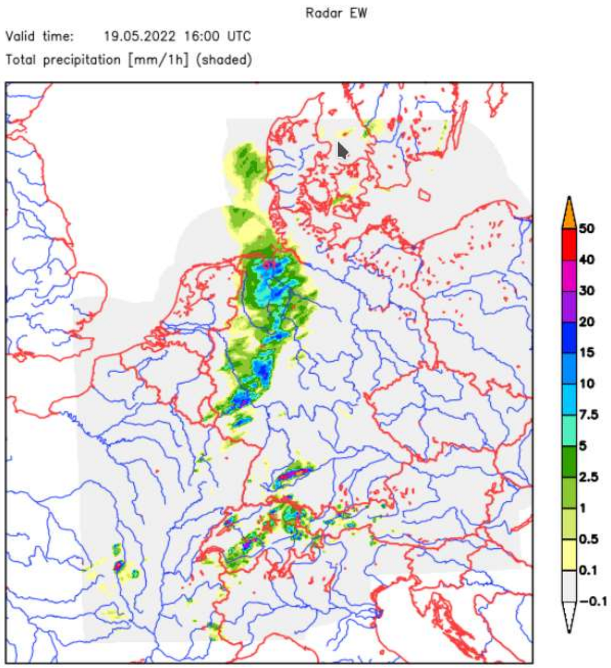
Exp. with SGS condens.

Showcase 19.05.2022

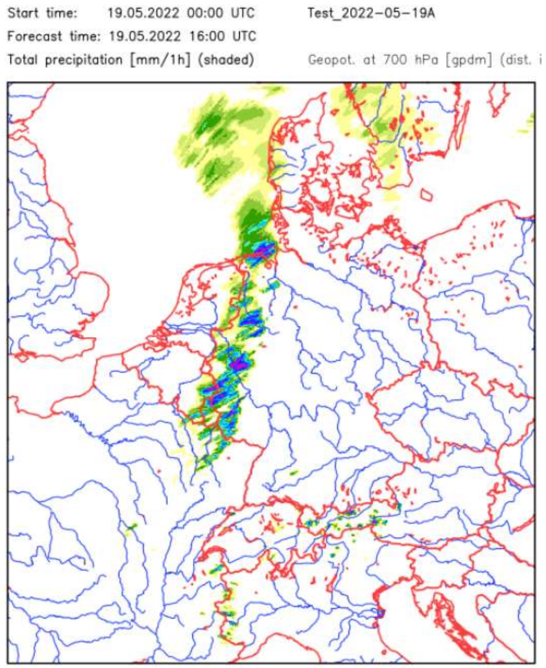
00-UTC forecast run, 1h-precipitation 15-16 UTC



Operational forecast



Radar

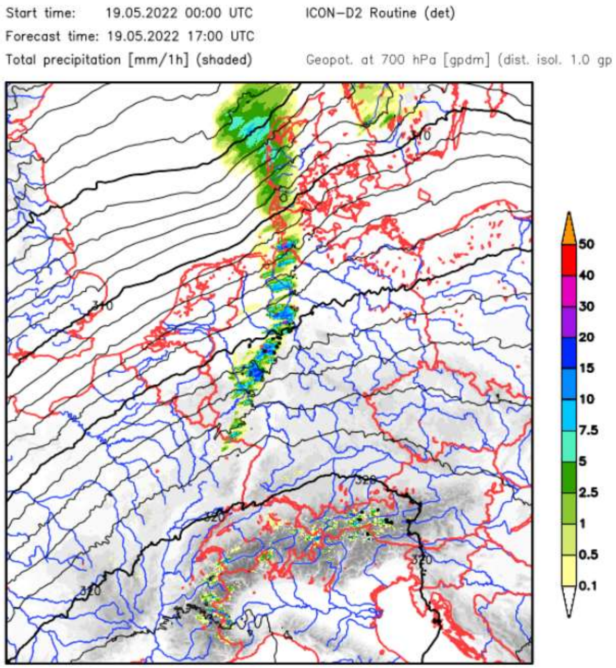


Exp. with SGS condens.

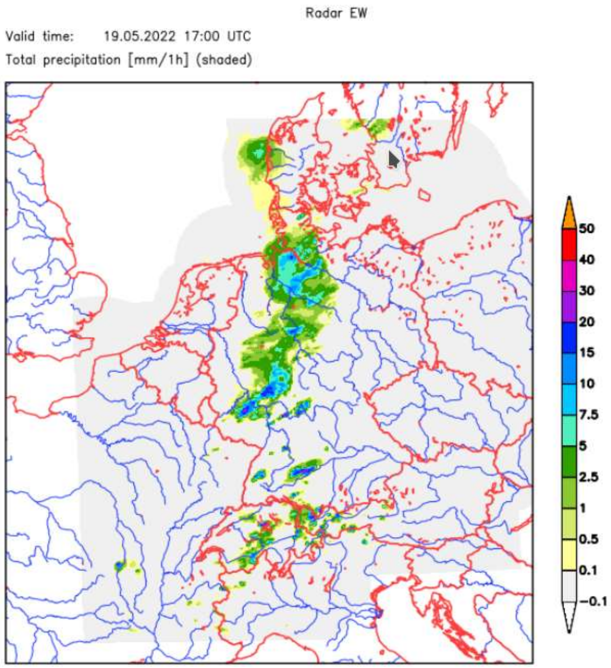
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

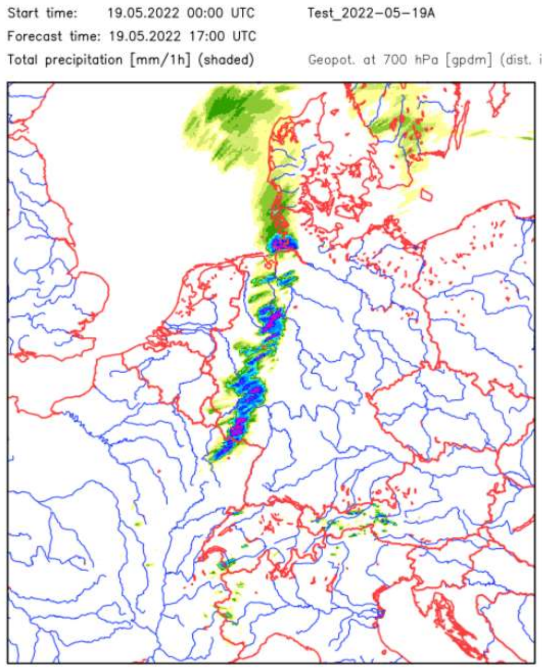
00-UTC forecast run, 1h-precipitation 16-17 UTC



Operational forecast



Radar

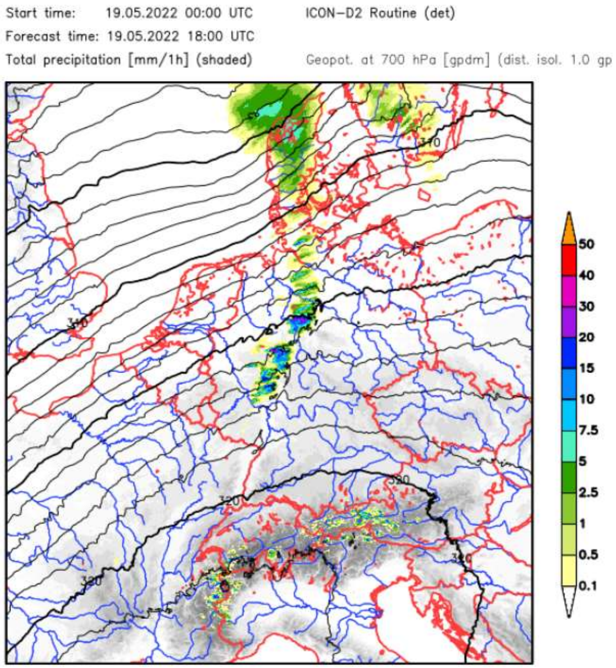


Exp. with SGS condens.

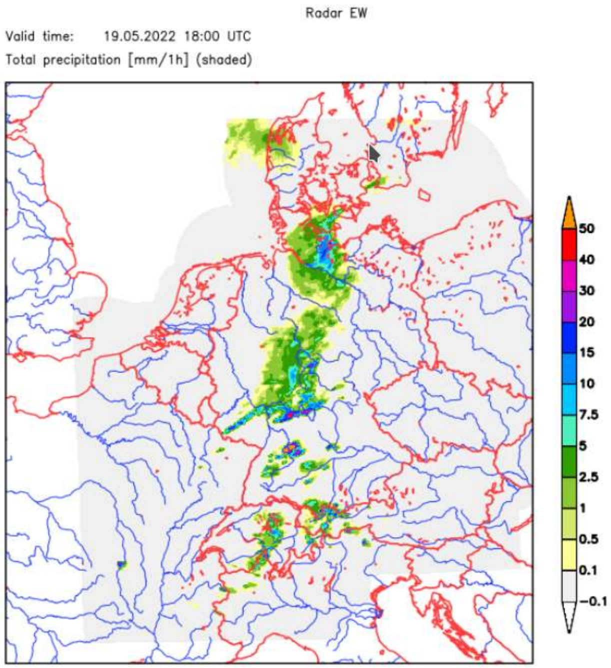
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

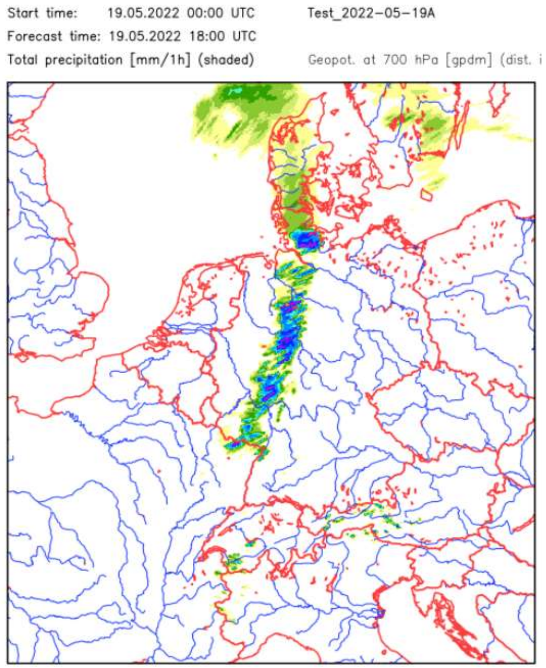
00-UTC forecast run, 1h-precipitation 17-18 UTC



Operational forecast



Radar

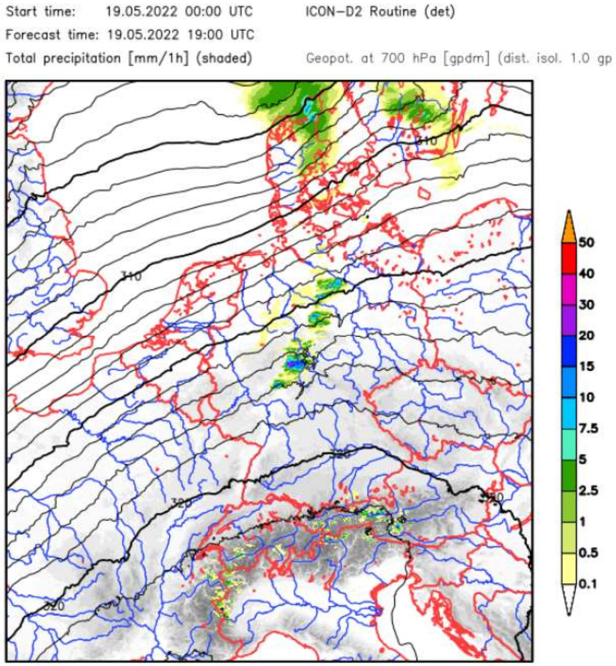


Exp. with SGS condens.

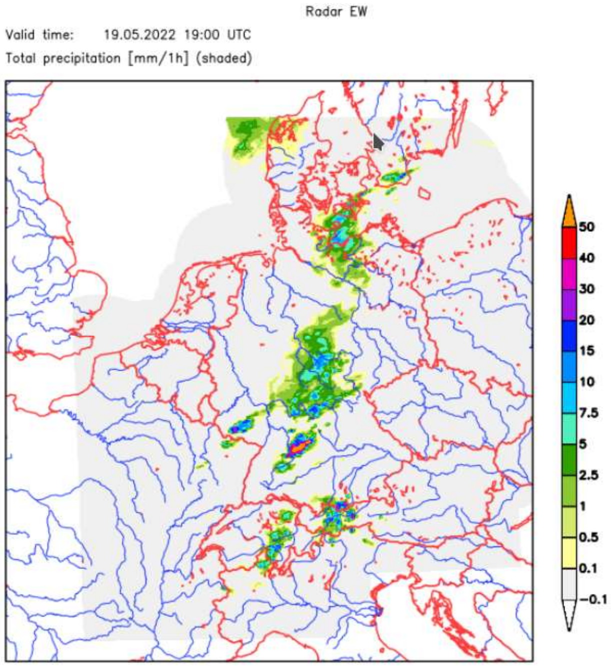
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

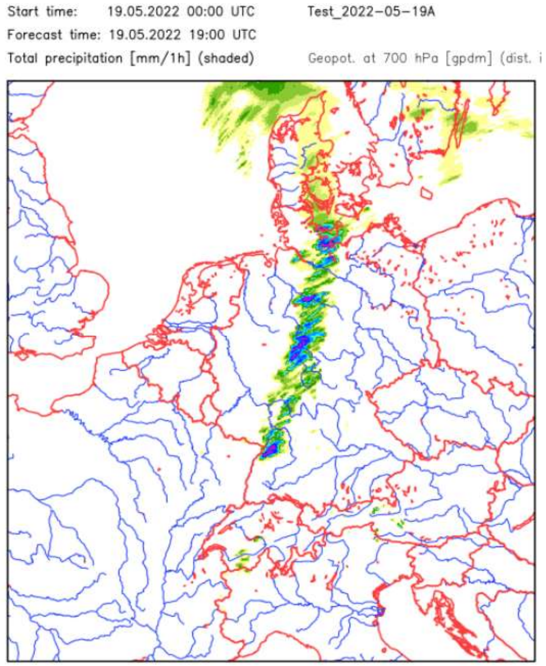
00-UTC forecast run, 1h-precipitation 18-19 UTC



Operational forecast



Radar

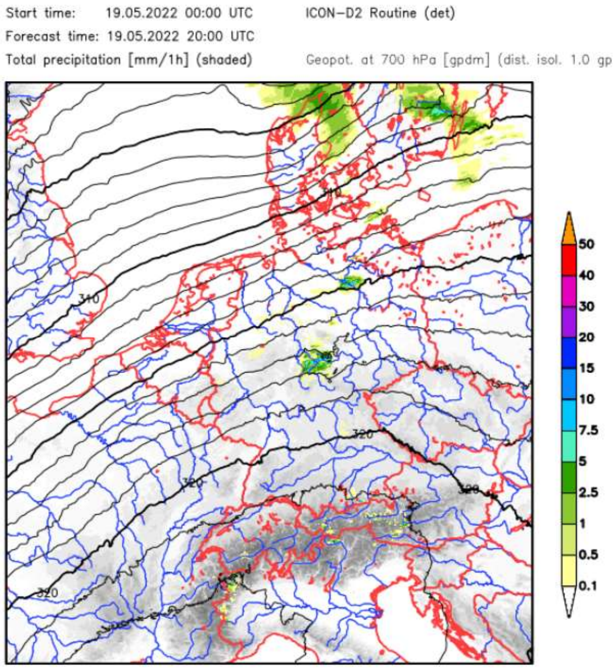


Exp. with SGS condens.

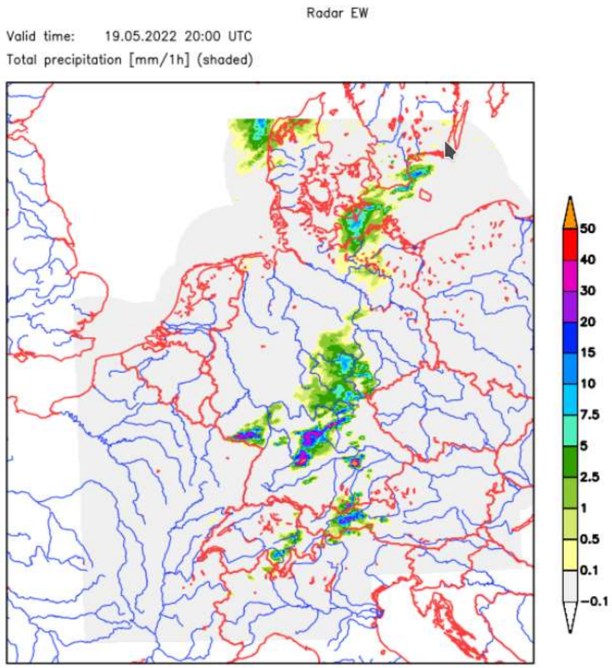
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

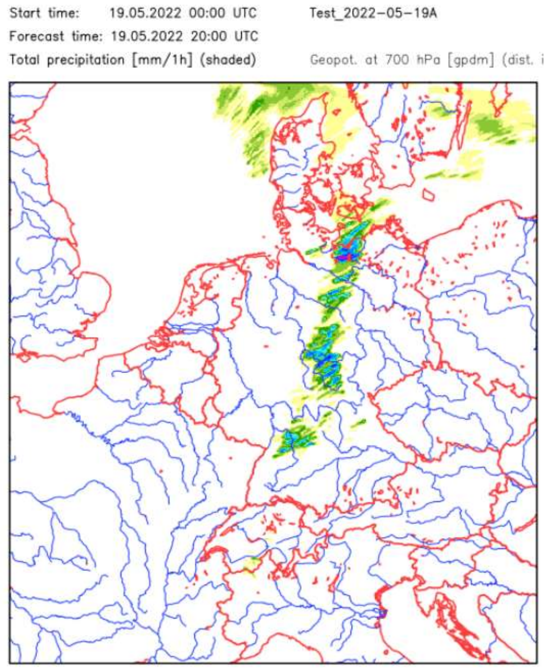
00-UTC forecast run, 1h-precipitation 19-20 UTC



Operational forecast



Radar

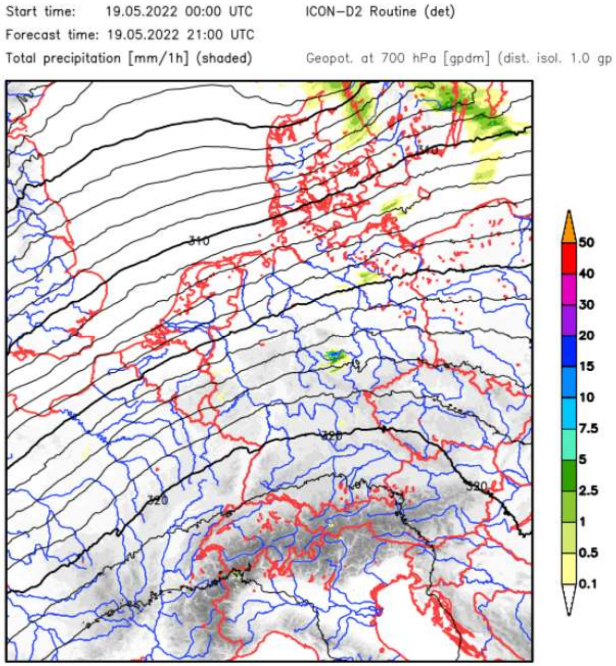


Exp. with SGS condens.

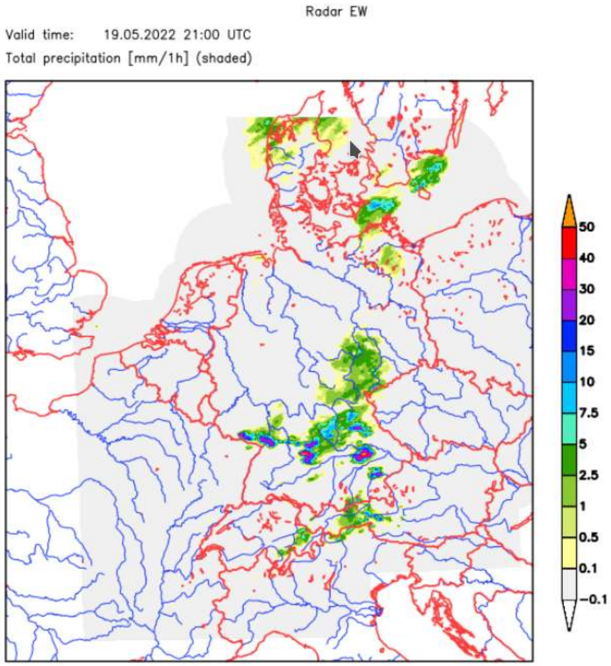
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

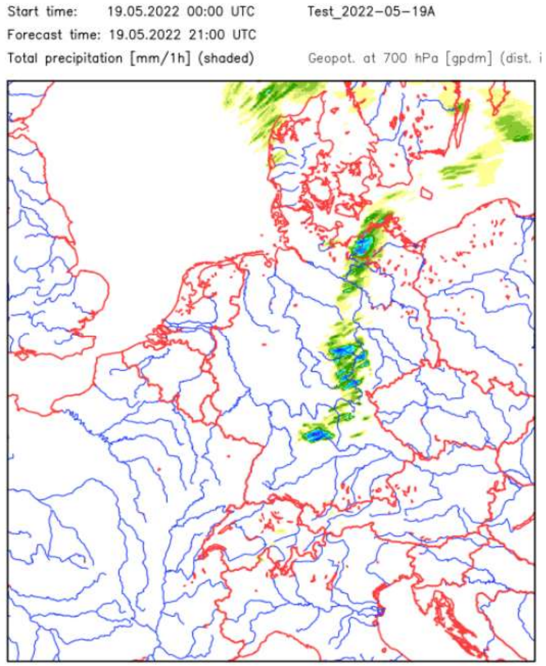
00-UTC forecast run, 1h-precipitation 20-21 UTC



Operational forecast



Radar

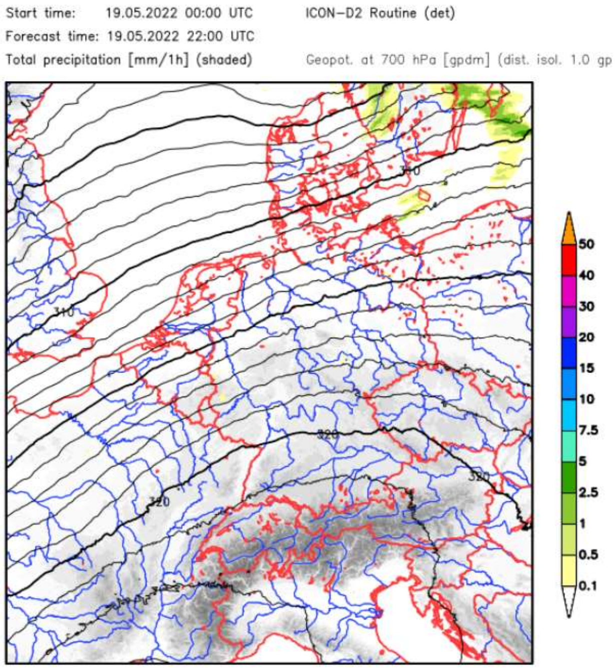


Exp. with SGS condens.

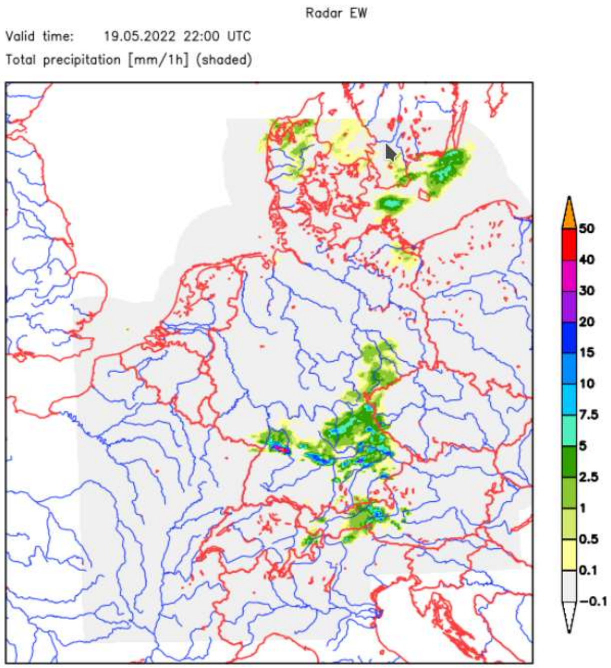
Showcase 19.05.2022

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

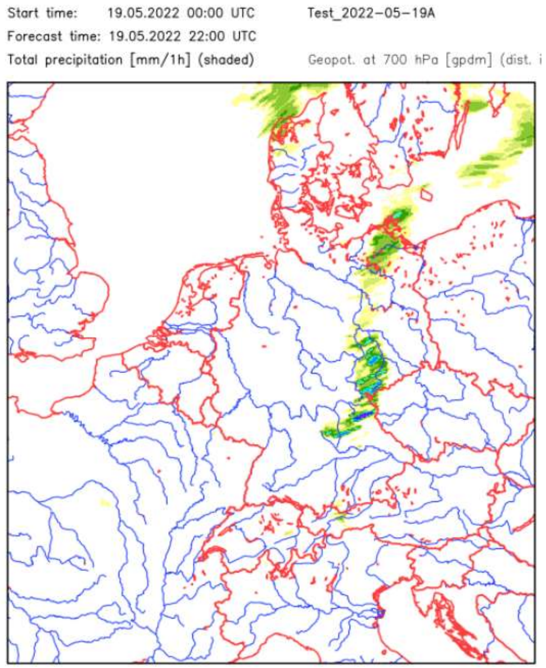
00-UTC forecast run, 1h-precipitation 21-22 UTC



Operational forecast



Radar



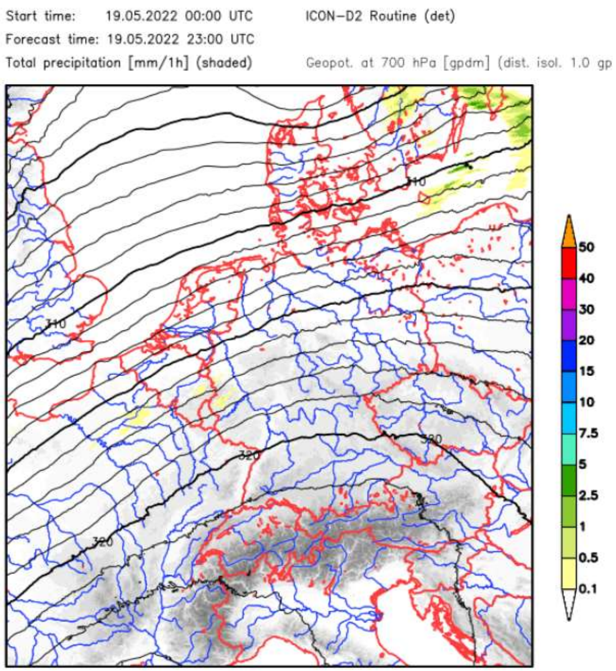
Exp. with SGS condens.

Showcase 19.05.2022

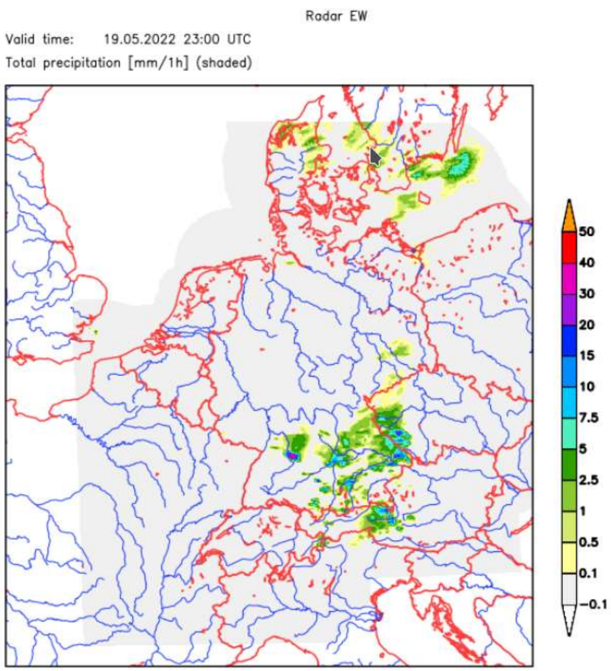
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

00-UTC forecast run, 1h-precipitation 22-23 UTC

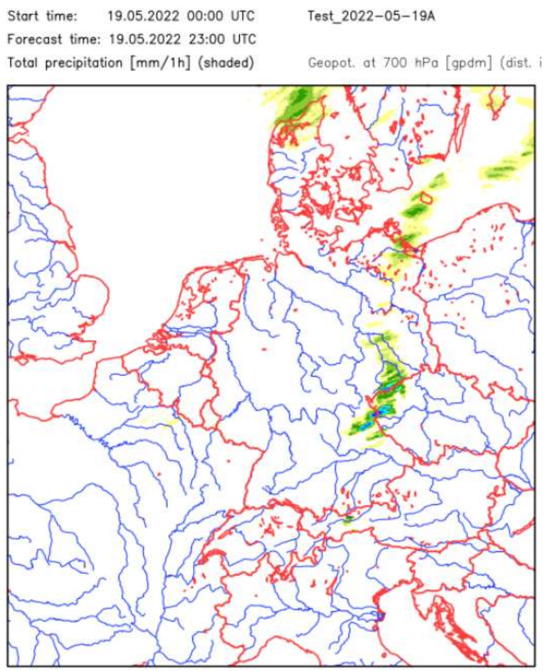
end of simulation



Operational forecast



Radar



Exp. with SGS condens.

Lake Breeze and Land-Lake Wind

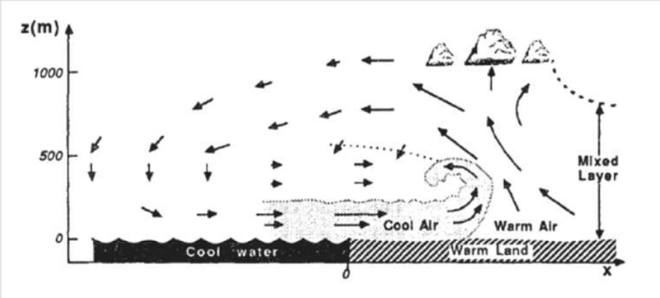


Image: Vertical cross section of Land Sea wind. Source : Lyons (1975) and Ogawa, et al., 1986

- Phenomenon
  - intermittent meso-scale stabilization of the atmosphere in the PBL
  - Physical mechanism: Different heat capacity of land and lake → differential heating of air → pressure gradient at the surface → convection over land → pressure gradient at top of the PBL → reversal flow → Land-Lake Wind
- Typical Scale:
  - Big Lakes/Sea (D > 100 km) due to balance of friction and forcing
  - Small Lakes (D < 20 km): limited by lake size

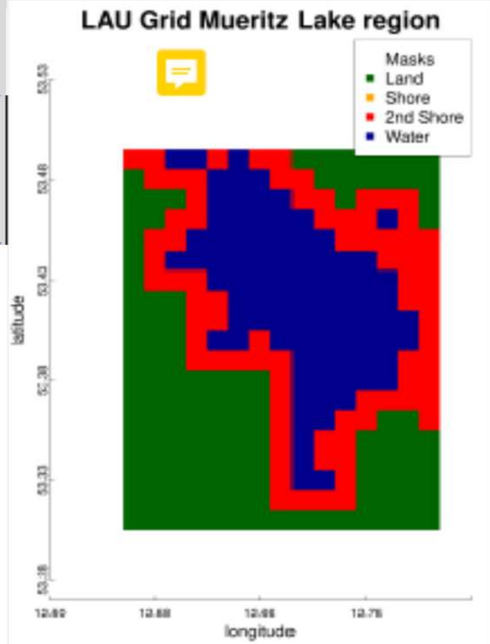
2

IMPACT OF NUMERICAL DIFFUSION, CONVECTION AND TURBULENCE PARAMETERISATION ON LAKE BREEZE OF SMALL LAKES IN 1 KM SIMULATIONS IN NORTH-EAST GERMANY

b-tu Brandenburg University of Technology Cottbus - Senftenberg

Andreas Will and Palash Gupta
Department of Atmospheric Sciences
BTU Cottbus-Senftenberg

Name of Lake	Lake shape	Surface area (km^2)	Horizontal grid resolution in model (km)
Lake Mueritz		117	2.8 and 1



Domain:
COSMO-DE:
421 x 461x50 Grid points – CDE (0.025 °)
COSMO-LAU:
301 x 401x80 Grid points - LAU (0.01 °)

h_{max} = 22 km

Müritz Region: 271 qkm lake surface

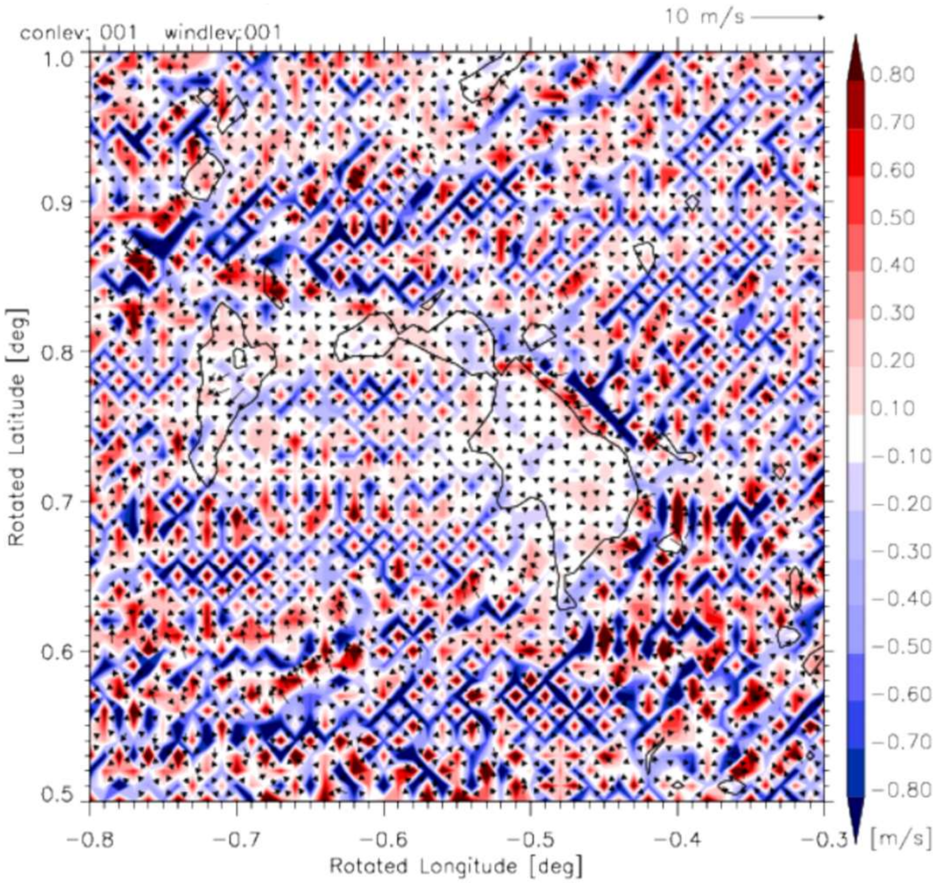
Impact of turbulence and numerical diffusion:

(by Andreas Will and Palash Gupta)

Brandenburg University of Technology Cottbus - Senftenberg

Difference of vertical wind-speed at 500 m a. NN (colors) and of horizontal wind speed at 10 m a. ground (arrows):

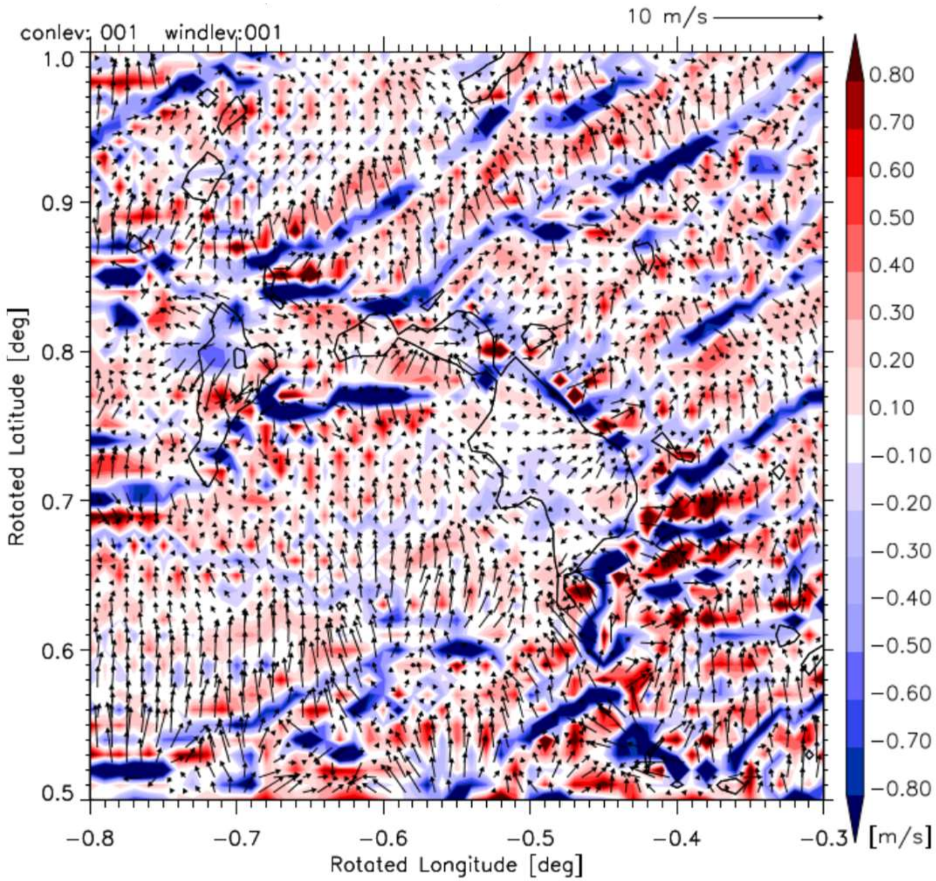
For runs with large and small turbulent length-scale



Turbulent length-scale needs to be **close to horizontal grid-scale**

in order to get rid of noisy grid-cell convection

For runs with different implicit numerical schemes



Only the symmetric 4-th order discretization of Euler equations (S4p4d0.0) with conservation of kinetic energy, implicit removal of alias errors and no numerical diffusion

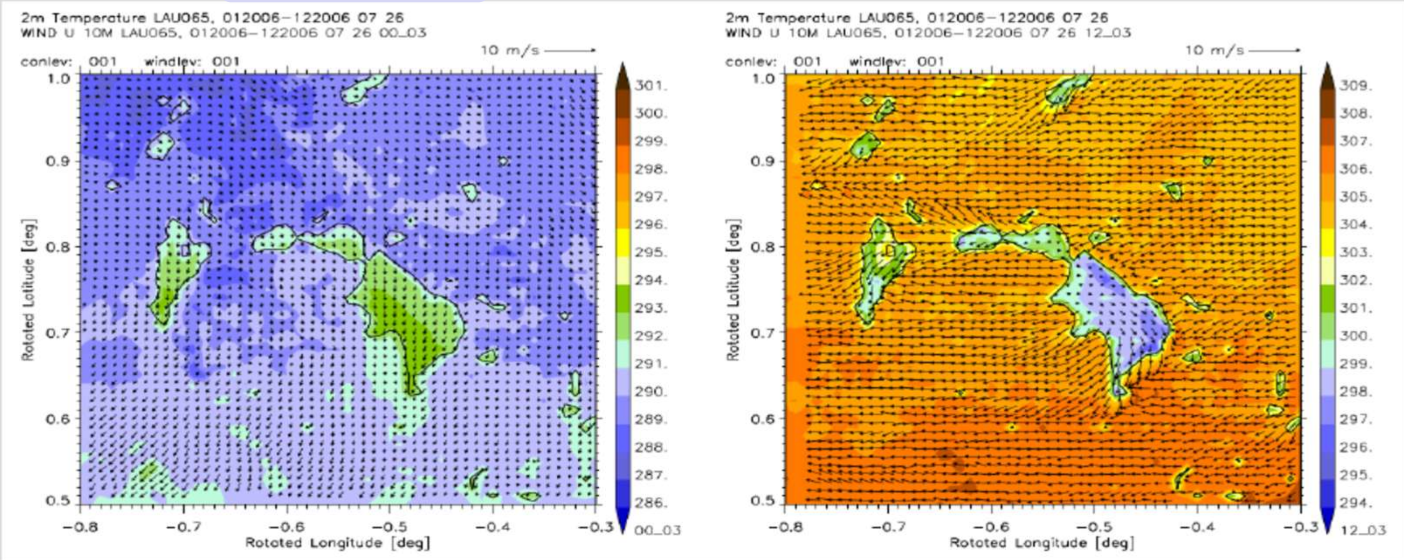
removes (probably) unphysical streak-patterns

Simulation with optimal configuration

(by Andreas Will and Palash Gupta)

Lake Müritz, T2M/V10M, 26. July 2006

00 h 12h



Lake Breeze phenomenon: v_g=3.2 m/s, dT=6.9 K, d Theta=100°. No Lake Breeze during night, radial wind over lake during the day, Cooling in shore region

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- **No convection parameterization**
- **Non-dissipative dynamics**
- **Adapted surface-to-atmosphere transfer**
- **Adapted vertical diffusion**
- **Additional horizontal Smagorinsky-diffusion**

➔ **small-scale physical signal becomes dominant compared to numerical noise**

❖ **Physically based 3D diffusion seems to be essential!**

Generalizations of turbulence scheme TURBDIFF by Tangent-to-Stream-Approximation (TSA) and Separated Turbulence Interacting with non-turbulent Circulations (STIC): (M. Raschendorfer, DWD)

- Optional 3D GS shear forcing, based on pre-calculated:
  - Deformation and divergence of GS horizontal wind field
  - Horizontal gradients of GS vertical wind (as from resolved convection)
  - So far generally switched off

❖ Already part of ICON-master

- TSA for closure scheme -> isotropic diff.-coeffs. from "tilted SC-solution"
- Additional TKE production according to STIC by SGS shear from NTCs:
  - Mechanical SSO wakes
  - Thermal vertical SSO circulations
  - Separated horizontal shear circulations
  - Thermal vertical convective circulations

  being, altogether, the foundation of DWDs CAT-forecast

❖ To be tested now!

- Application of isotropic turbulent diffusion coefficients for 3D-diffusion:

$$\overline{\left(\rho\phi''\underline{v}''\right)}_{L_p} = -\bar{\rho}K^H\,\nabla(\hat{\phi})_{L_p} \qquad \overline{\left(\rho v_i'' v_j''\right)}_{L_p} - \delta_{ij}\,\bar{\rho}\frac{q^2}{3} = -\bar{\rho}K^M\cdot\left[\nabla_i(\hat{v}_j)_{L_p} + \nabla_j(\hat{v}_i)_{L_p}\right]$$

$\phi \in H$ scalar property

with respect to maximal turbulent wave-length

kinematic contribution to mean pressure

$$\bar{\rho}\frac{q^2}{2} = \frac{1}{2}\sum_{i=1,2,3}\overline{\left(\rho v_i'' v_i''\right)}_{L_p} \qquad \text{TKE}$$

❖ To be adapted from LES-version in ICON

- Metric SAI-corrections of turbulence parameters in closed 2-nd order equations:
  - Due to SGS slopes of model surfaces within the vertical resolved R-layer of SSO

❖ Being implemented

TKE-production and additional NTC-diffusion by separated horizontal shear modes:

(M. Raschendorfer, DWD)

→ A foundation of CAT-forecast for more than 10 years

- **Horizontal shear production term for separated non-turbulent shear circulations:**

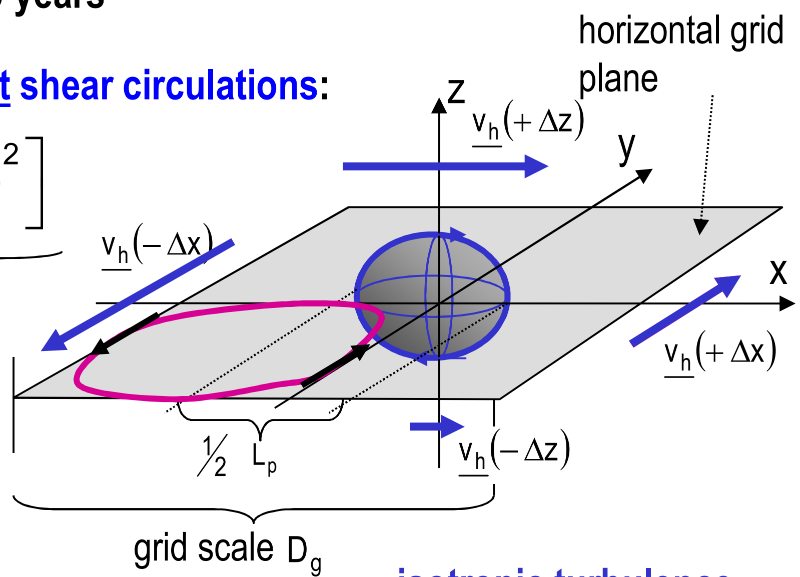
$$Q^{v\cdot v}_{C\_SHS} := q_H \cdot \underbrace{\beta_H D_g}_{} \cdot \underbrace{\left[\left(\partial_1 \overline{v}_2 + \partial_2 \overline{v}_1\right)^2 + 2\left(\partial_1 \overline{v}_1\right)^2 + \left(\partial_2 \overline{v}_2\right)^2\right]}_{=: F_H^M}$$

separated horizontal shear ($Q^{v\cdot v}_{C\_SHS}$)

effective mixing length of diffusion by horizontal shear eddies ($\beta_H D_g$)

velocity scale of the separated horizontal shear mode (q_H)

$\beta_H < 1$ **scaling parameter**



isotropic turbulence

horizontal shear eddy

- **Equilibrium of production and scale transfer towards turbulence:**

$$q_H \cdot \beta_H D_g \cdot F_H^M = \frac{q_H^3}{\alpha_H D_g} \qquad \alpha_H < 1 \qquad \textbf{scaling parameter}$$

$$\Rightarrow \quad Q^{v\cdot v}_{C\_SHS} = \underbrace{q_H \beta_H D_g}_{K_H^{M,H}} \cdot F_H^M = \underbrace{\alpha_H^{\frac{1}{2}} \beta_H^{\frac{3}{2}}}_{=: \alpha_S^2} D_g^2 \cdot F_H^{M\frac{3}{2}}$$

additional TKE source term by SGS shear
<-> spectral transfer from NTCs towards Turbulece

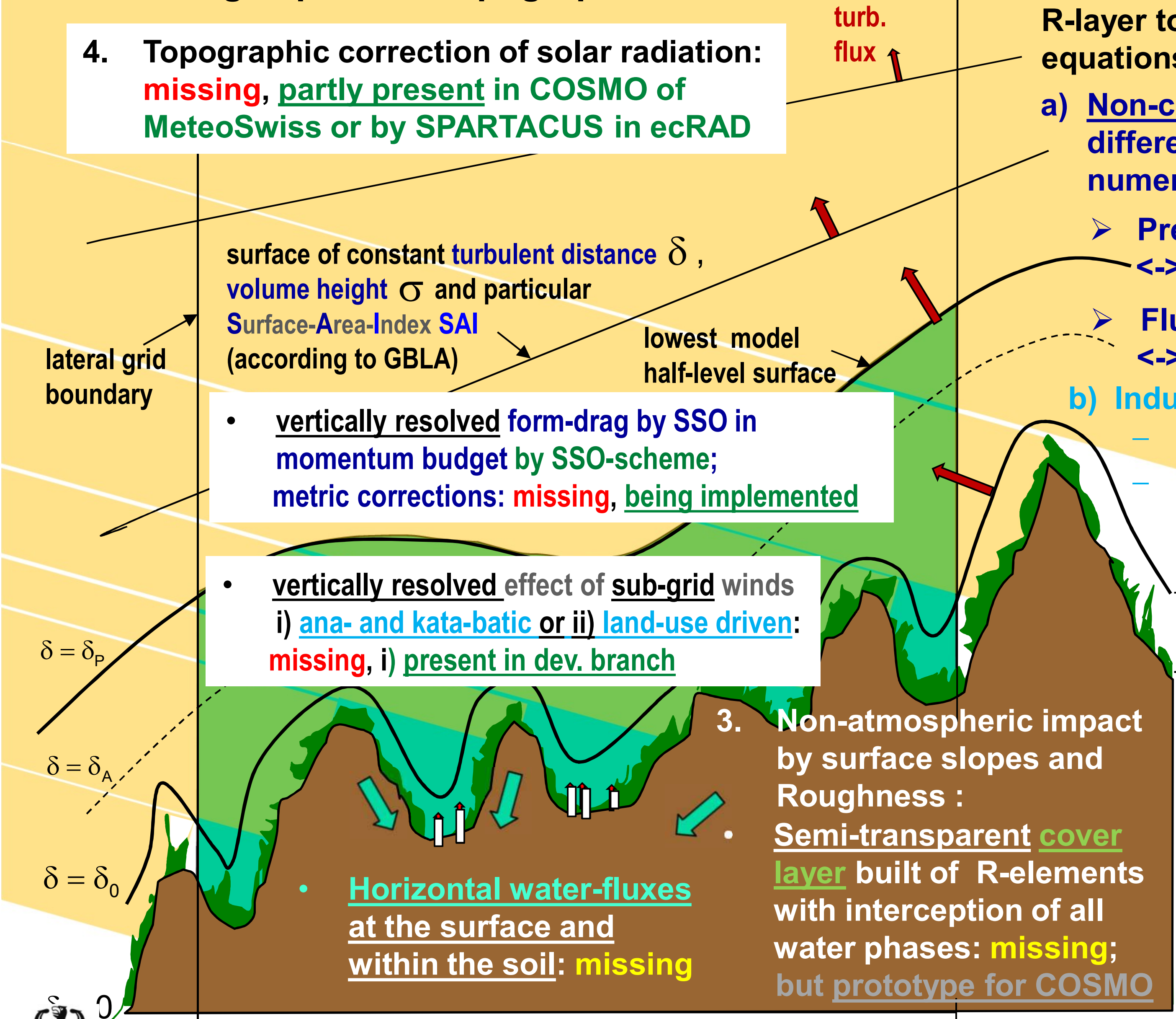
$=: \alpha_S^2$ ....effective scaling parameter

$K_H^{M,H}$ particular **circulation-scale diffusion-coefficient for additional horizontal diffusion**

- **Now, modified by empirical extensions** (G. Zängl, DWD) ⇒ **revised formulation of scale transfer is being implemented**

Consolidation of Surface-to-Atmosphere Transfer (ConSAT): (M. Raschendorfer, DWD)

- **Missing impacts of topographic structure:**



4. **Topographic correction of solar radiation: missing, partly present in COSMO of MeteoSwiss or by SPARTACUS in ecRAD**

- vertically resolved form-drag by SSO in momentum budget by SSO-scheme; metric corrections: missing, being implemented

- vertically resolved effect of sub-grid winds i) ana- and kata-batic or ii) land-use driven: missing, i) present in dev. branch

- **Horizontal water-fluxes at the surface and within the soil: missing**

3. **Non-atmospheric impact by surface slopes and Roughness :**
   - **Semi-transparent cover layer built of R-elements with interception of all water phases: missing; but prototype for COSMO**

1. **Direct impact of vertically resolved R-layer to atmospheric model equations: <-> SGS layer structure**
   a) **Non-commutativity of spatial differentiation and inherent numerical averaging**
      - **Pressure gradient <-> Form drag by blocking**
      - **Flux divergence <-> Larger surface area (SAI)**

   b) **Induced sub-grid heterogeneity:**
      - **Heating or cooling of slopes**
      - **Differential heating of surface tiles**

2. Impact of vertically not resolved R-layer by small-scale Land-Use:
   - Part of CF transfer-layer
   - Increased R-length by inter-tile variation of Land Use: missing; now in dev. branch
   - Shear by non-turbulent sub-grid wind induced by NTCs: missing ; now in dev. branch

Some other related promising general activity:

(partly still rather basic research)

- Turbulence-Interaction with **M**icro-**P**hysics beyond pure Satur.-Adjustm.:
  - Consideration of turbulent statistics in MP
  - 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

- Consistent treatment of sub-grid cloud processes
  - SGS Convection based on conditional domain closure and STIC
  - Turbulent **S**aturation **A**djustment embedded in convective sub-domains

Matthias Raschendorfer, Martin Köhler

Thanks for your attention!