Current activity in atmospheric Physics in COSMO (for ICON-LAM)

- ✓ **Improving cloud-radiation interaction:**
  - Implementation of ecRAD into ICON
  - revised parameterizations of cloud optical properties: COSMO-> ICON
  - offline CAMS-aerosol data and prognostic 2D AOD approach
  - ICON-ART aerosols including operational mineral dust-forecast
- ✓ **Introduction of stochastic components into the shallow convection**
- ✓ **More about Separated Turbulence Interacting with non-turb. SGS Circulations:**
  - Operational CAT-forecast for aviation based on EDR from TURBDIFF
  - TKE production and buoyant heat flux by SGS sub-grid near surface kata- and anabatic circulations
  - Thinking about turbulence saturation adjustment embedded into convection
- ✓ **Revised Surface-to-Atmosphere Coupling and Roughness-layer treatment:**
  - Consideration Roughness by inter-tile variability
  - Implicit treatment of surface temperature
  - Consideration of a semi-transparent and mass-carrying R-layer (plant canopy) and about a vertically resolved atmospheric R-layer

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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**
  - Inclusion of larger and multi-shape particles (including precipitation)
  - Considering SGS variability of cloud properties
- Transfer of development from COSMO-model to ecRAD-implementation of ICON-model
- Implementing more-realistic information about aerosols

optical properties (as input for radiation): ext. coeff., single scat. alb., asymm. fact., delta-transm. fact.

Hu et Stamnes, 1993 (RG-COSMO, RRTM-ICON)

Hogan et Bozzo, 2018 (ecRAD-ICON: SOCRATES-package)

introduction into ecRAD delayed

extended particle size range (even snow-flakes included) and sub-grid effects

Ray-tracing for randomly hexagonal or ellipsoidal particles (visible bands, Fu 2007)

Mie-scattering (IR bands, Fu, 1998)

direct aerosol effect

effective radius of liquid clouds

SGS variability

cloud water content

number concentration of activated cloud droplets

SGS variability

effective updraft wind-speed

Segal/Khain, 2006

effective radius and aspect ratio of particles

particle-size distribution
mass-size relation

number concentration of activated ice particles

cloud-ice microphysics

not yet fully harmonized with microphysics

local aerosol number concentration (in m^{-3})

mean particle-radius and -density

assumed (exponent.) vertical decay

interpolation in space and time

offline prognostic CAMS aerosols (or related climatology): 4D-data

online prognostic ICON-ART-dust + …: 3D-data (for each time)

grid-column integrated mass per m^2

assumed extinction coefficient

2D AOD-550nm climatology (Tanre, Tegen, MACv2, CAMS)

online prognostic correction

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

by **Günther Zängl** -> **Daniel Rieger**

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

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**):

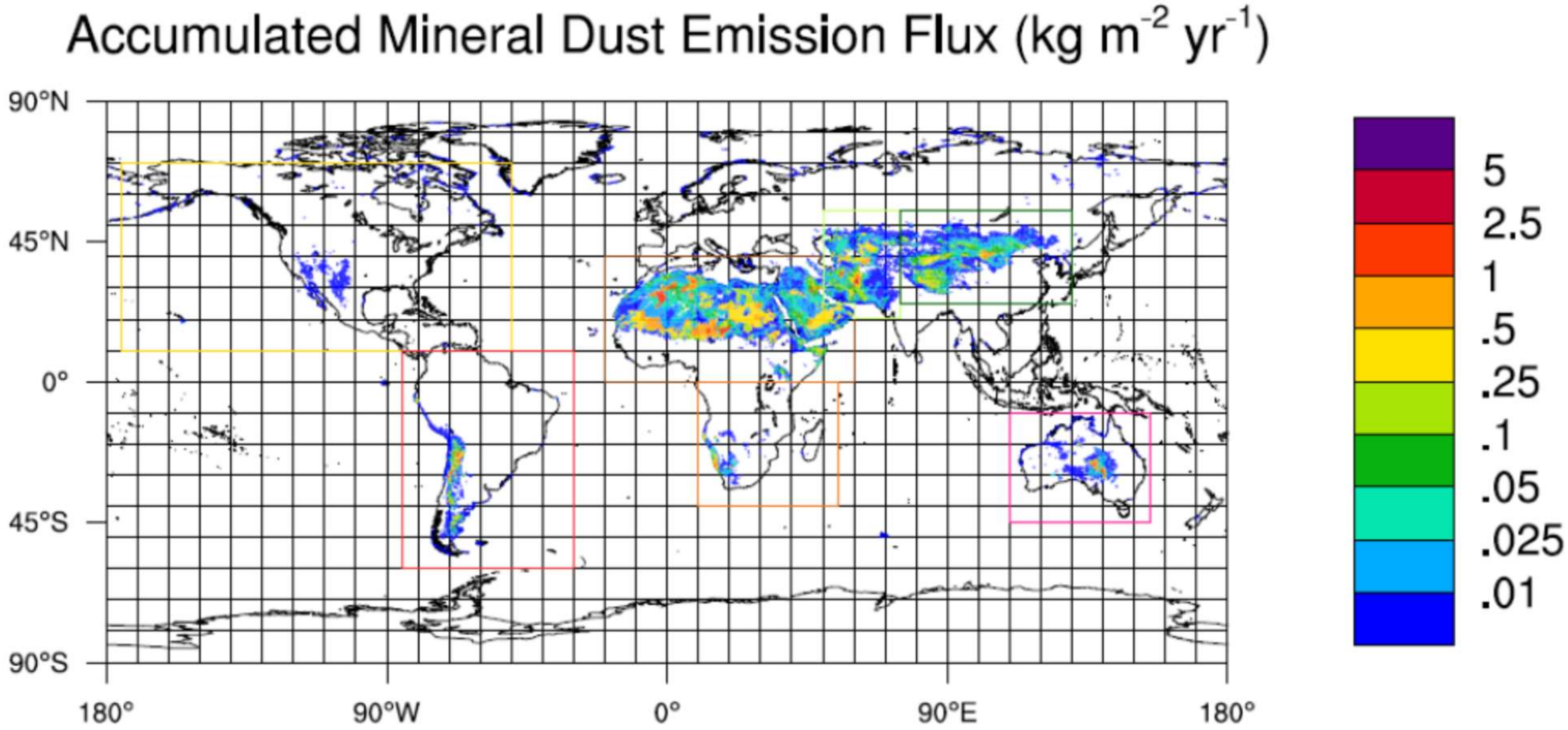
- mineral dust (j=d) emission according to Kok (2014), with the computational cheap assumption of size distributions being independent on wind speed
- sea spray aerosol (j=ssa) emission according to Grythe et al. (2014)
- anthropogenic aerosol (j=anth) to be parameterized by means of land-use fractions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

$S_{w,j}$ 2D wet deposition

→ related AOD through Mie-calculations

CAIIR Task 6, 2D-Aerosol

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



- Cheap approximation of a full 3D aerosol model
- Is able to add a significant benefit compared to a pure climatology
- Improves radiation output of the model
- Impact to 2m temperature mainly neutral (possibly due to previous tuning)

Picture by **Daniel Rieger**, DWD

ICON-ART dust forecast

Aerosols and
Reactive
Trace gases

Karlsruhe Institute of Technology

KIT Dust dashboard:

https://www.imk-tro.kit.edu/english/10581.php

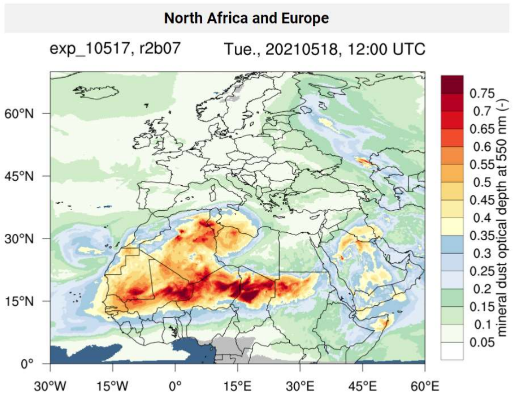
Dust Forecast

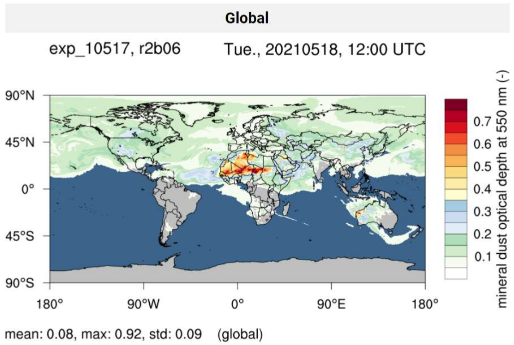
The German Weather Service (DWD) performs quasi-operational forecasts of mineral dust concentration using the ICON-ART forecast system developed jointly with KIT. From these predictions, the Aerosol Optical Thickness of Mineral Dust (AOD) can be calculated. This quantity is a measure of the attenuation of solar irradiation at the earth's surface.

Select date

18.05.2021

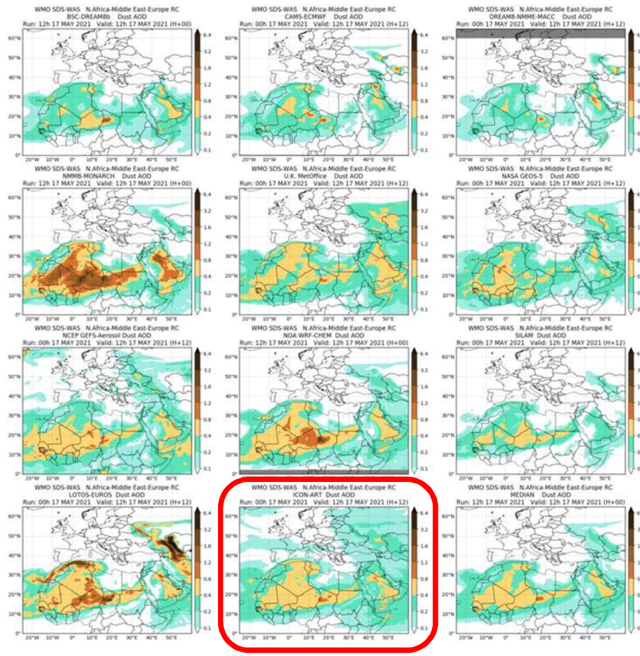
00:00 UTC 06:00 UTC 12:00 UTC 18:00 UTC Animation ▶





WMO Dust forecast:

https://sds-was.aemet.es



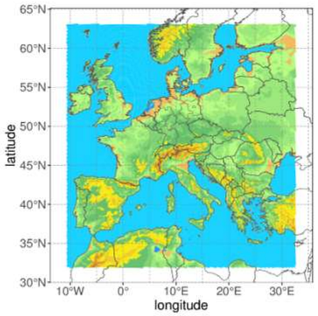
Slide by **Bernhard Vogel**, KIT

Aerosols and
Reactive
Trace gases

Karlsruhe Institute of Technology

Pollen forecast using ICON-ART

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

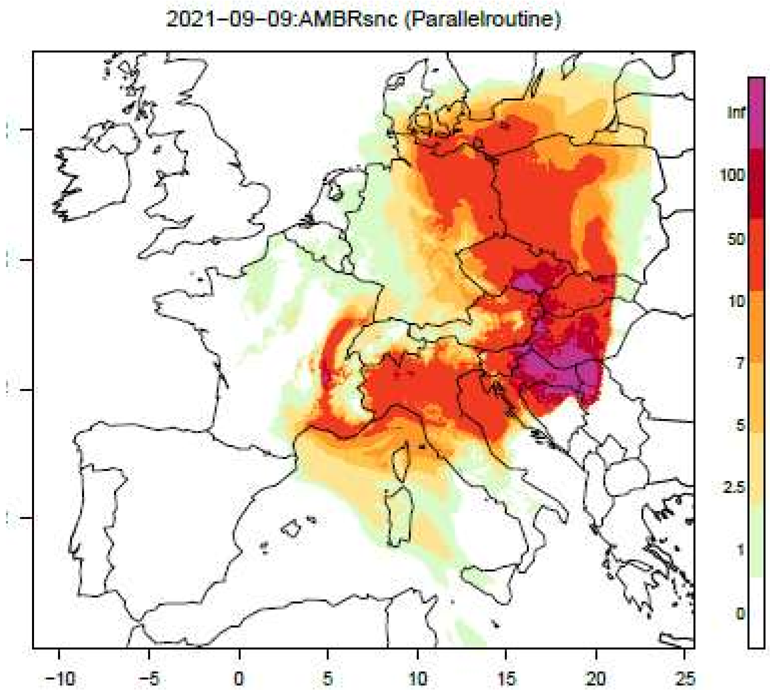


ICON-ART-LAM: 6.5 km

144h-forecast (00 UTC)

4 species: alder, birch, grasses, ragweed

operational in 2021

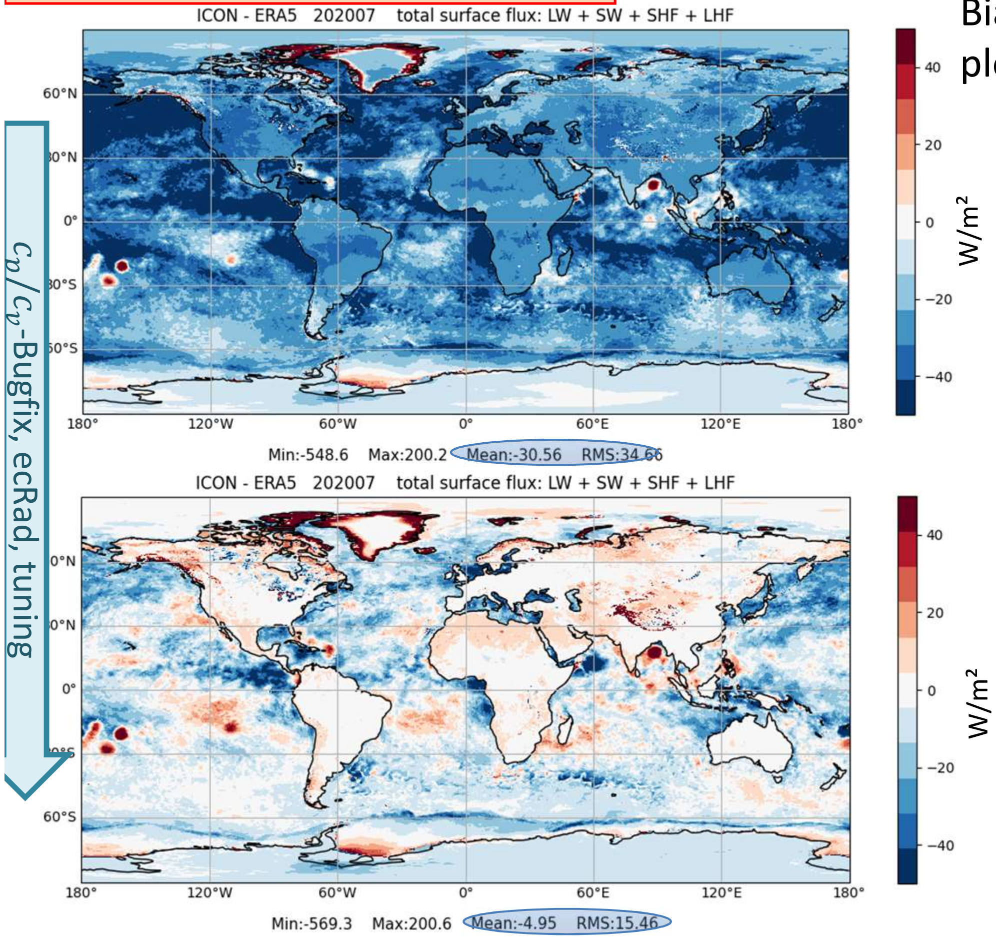


Jochen Förstner, Christina Endler, Stefan Muthers et al.

Side by **Bernhard Vogel**, KIT

- ecRAD-could much better be adapted to the corrected cp/cv-bug (with regard to the turbulent tendencies used in ICONs isochoric T-equation):

Old routine: c_p/c_v-Bug, tuned RRTM



New routine: c_p/c_v-Bugfix, ecRad + LW scat., new CAMEL emissivity

Bias of ICON total surface flux July 2020 vs. Era5, plots by M. Köhler

- Surface flux bias reduced by 26 W/m², mainly due to 20 W/m² radiation bias reduction; improved sensible heat flux

- New radiation scheme **ecRad improves ICON** model, especially clouds and radiation, still some regional biases.
- **Radiation uncertainties**: solver, cloud (ice) optics, cloud inhomogeneity, 3D: 1-2 W/m² in global fluxes; vertical overlap: 5 W/m²

Slide by **Sophia Schäfer**, DWD

Physical Process in COSMO ICON-LAM		Method		Name	Authors
Local Parameteriz. of atmospheric source terms	Radiation Transport	δ two-stream (in COSMO only)	utilization of different aerosol input; revised optical cloud properties [COSMO_nwp->ICON] new cloud activation		Ritter/Geleyn (1992)
	Aerosols and Reactive Tracers (ART)	Rapid Radiative Transfer		RRTM	Mlawer et al. (1997)
				ecRAD	Hogan et Bozzo (2018)
	Microphysics	1-moment; 3 prognostic ice phases; prognostic rain and snow		Doms (2004) Seiffert (2010)	
		opt. 2-mom. version (with ML-based ext.)			
SGS cloud generation	Not yet completely considered sub-grid scale processes such as: Separated Horizontal Shear circulations, Thermal Sub-grid Scale Orography (TSSO) circulations				
Grid-scale Parameteriz. of sub-grid scale atmospheric processes (dependent on horizontal resolution)	Convection: deep; shallow (stochastic)	2-class (updraft-downdraft) mass-flux equations with moisture convergence closure and simplified microphysics and a **stochastic component for shallow conv.**		Tiedke (1989) / Bechthold et al. (2008), Plant/Craig (2008)	
	Mechanical Sub-grid Scale Orography (MSSO) impact	orographic blocking and breaking of vertically propag. 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-extens.; turbulent saturation-adjustment		TURBDIFF	Raschendorfer (2003,->)
	Surface-to-Atmosphere Transfer and Roughness-Layer effects; surface tiling	transfer-resistances based on vertically const. **turbulent/lamin.** near-surface fluxes normal to roughness-covering surfaces (**direct application of turbulence scheme**) Implicit treatment of surface-temperature;		TURBTRAN	
Below surface processes		substantial and semi-transparent canopy layer [COSMO_tst->ICON]		TERRA (incl. partial sl/ml snow cover), FLAKE	

Some other related promising general activity:

(partly still rather basic research)

- 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

- Turbulence-Interaction with **M**icro-**P**hysics beyond pure SA:
  - 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

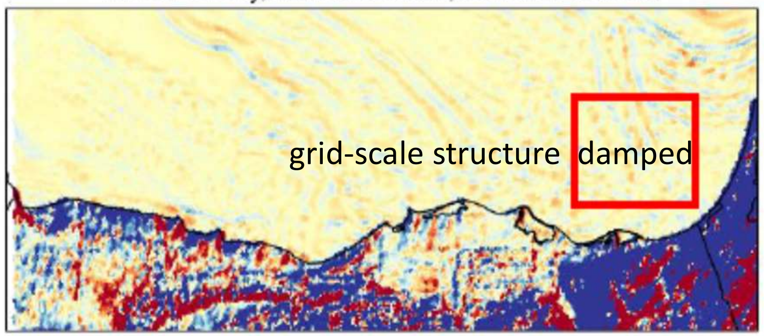
Dimitrii Mironov, Ekatarina Maschulskaya

Effect of shallow convection parameterization on resolved precipitation :

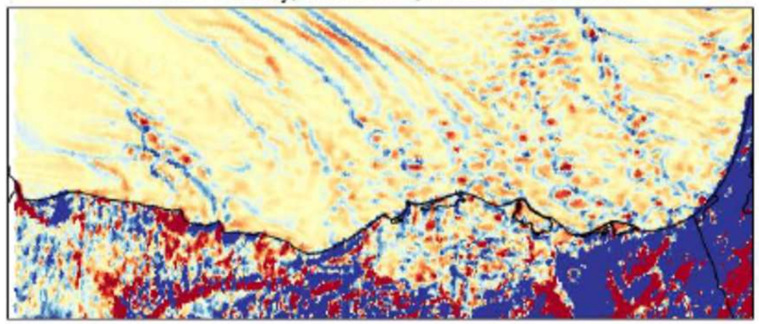
Pave Khain (Isreaeli Met Service), Maike Ahlgrimm (DWD), …

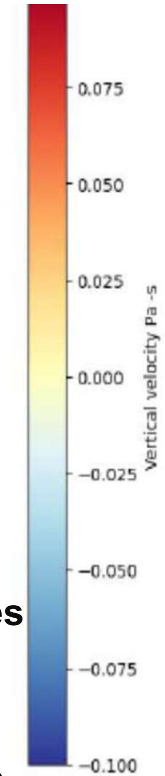
ICON-simulation (about 2km resolution)

Fully active shallow convection



Shallow convection switched off





- **Parameterized Shallow Convection (PSC) is still necessary, particularly at convective regimes**
- **But at more advective regimes (mainly at wintertime) with mainly shallow cumulus clouds, PSC considerably reduces resolved vertical motion, and with it, overall precipitation**
- **PSC can't be tuned in order to produce the needed complementary SGS rain. Rather it needs to be artificially suppressed for those regimes: new <u>stochastic version</u> performs a bit better**

➢ **Some necessary interaction with grid-scale dynamics seems to be missing, which <u>may</u> be:**

- **Insufficient scale-adaptation of PSC against turbulence and Grid-Scale (GS) motions**
- **Inconsistent thermodynamics in connection with SGS cloud-processes** **(related condensation heat becomes not (completely) active for grid scale dynamics)**
- **Missing effect on dynamics by SGS motions apart from turbulence and convection**

Picture by **Pavel Khain**, IMS

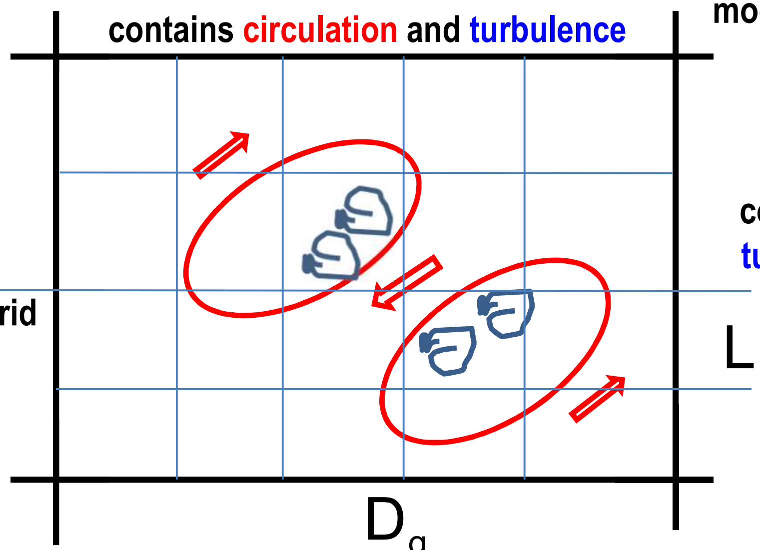
The STIC-impact on turbulence : (Raschendorfer 2011 ->)

S cale-**s**eparated SGS

T urbulence

I nteracting with non-turbulent SGS

C irculations



- **3D-shear production of turbulence**
  - **From the grid-scale flow**
  - **From non-turbulent sub-grid flow patterns (circulations)**
    - **Connected with coherent structures being not in accordance with turbulence closure**
    - **Would be expressed by grid-scale 3D-shear, if the patterns were resolved by a smaller grid**
    - **Extracts kinetic energy from the circulation flow and feeds turbulence** — representing the spectral kinetic-energy cascade
      - **Additional shear production terms in TKE-equation due to scale interaction**
      - **Missing link with particular value for the stable BL**
    - **Often connected with the destruction of coherent circulation structures (de- and en-trainment)**

The related new parameterization-paradigm: (Raschendorfer 2011 ->)

- **By means of the STIC-approach:**

  - **Source-term equilibrium for Circulation Kinetic Energy (CKE):**

Specific (e.g. buoyant) production of CKE ≈ Destruction by turbulent friction of non-turbulent circulation

action of 3D-shear by the circulation motion ≈ STIC-term from circulation in TKE-equation of turbulence scheme

- Due to the impact of non-turbulent SGS circulations, STIC-terms allow for a physical solution of the turbulence scheme, even if shear production of TKE by the grid-scale flow is negligible:

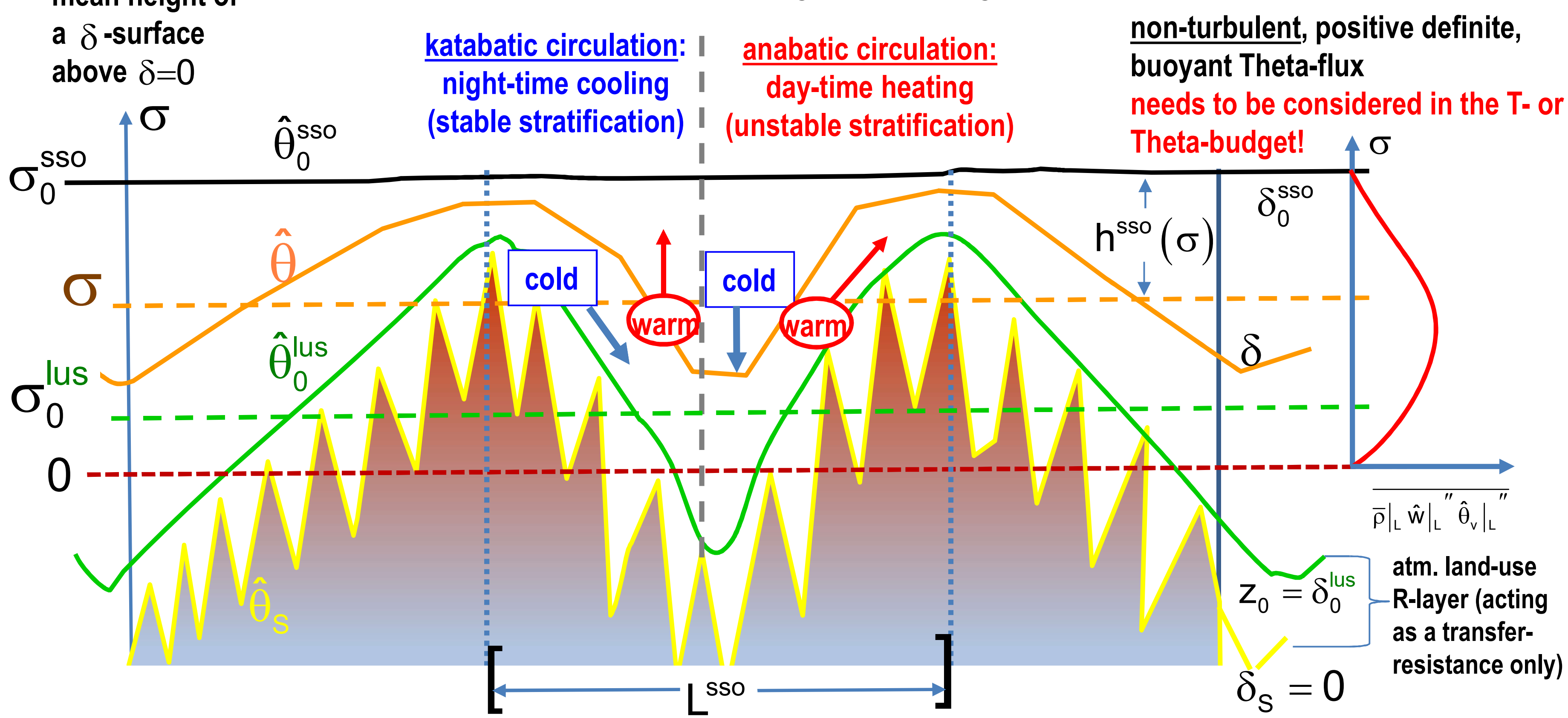
additional Shear -Production of TKE by:

– near surface density circul.	<-> in the SBL with vanishing wind shear	essential for aviation- turbulence forecast
– SSO wake-eddies	<-> within the BL close to SSO-wakes	
– separated horiz. shear eddies	<-> above the BL within the stable stratosphere	
– vertical convective currents	<-> above the BL close to convective plumes	

Thermal effect of SSO (TSSO): (M. Raschendorfer)

- grid levels according to the turbulent distance $\delta = \ell / \kappa$ from the rigid surface as a generalized vertical coordinate

  (ℓ: integral turbulent length scale)



$$s^{sso}(\sigma) = \frac{h^{sso}(\sigma)}{L^{sso}/4}$$ mean slope of a σ-surface due to SSO

$$h^{sso}(\sigma) = 0 = s^{sso}(\sigma) \text{ at } \sigma \geq \sigma_0^{sso}$$

external SSO-parameter

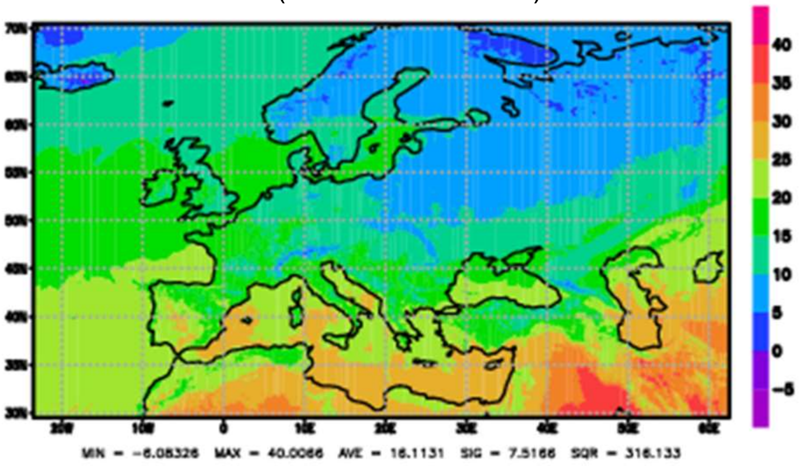
$$\begin{cases} h_0^{sso} := h^{sso}(\sigma_0^{lus}) \\ s_0^{sso} := s^{sso}(\sigma_0^{lus}) \end{cases} \xrightarrow{\text{(linearly)}} \begin{aligned} h^{sso}(\sigma_0^{sso}) &= 0 \\ s^{sso}(\sigma_0^{sso}) &= 0 \end{aligned}$$

$$\Rightarrow \frac{g}{\hat{\theta}_v} \overline{\bar{\rho}|_L \hat{w}|_L'' \hat{\theta}_v|_L''} \approx Q_{TKE}^{tso}$$

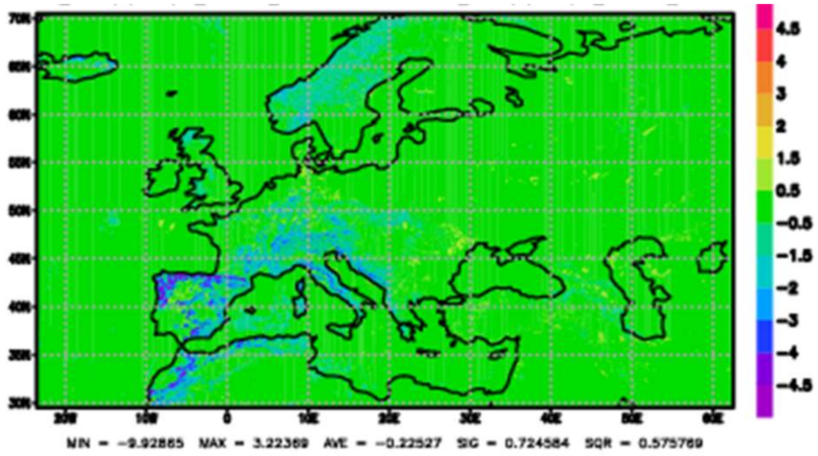
($|_L$:) separation-scale between turbulence and circulations

2m−temperature [C] (at nocturnal conditions)

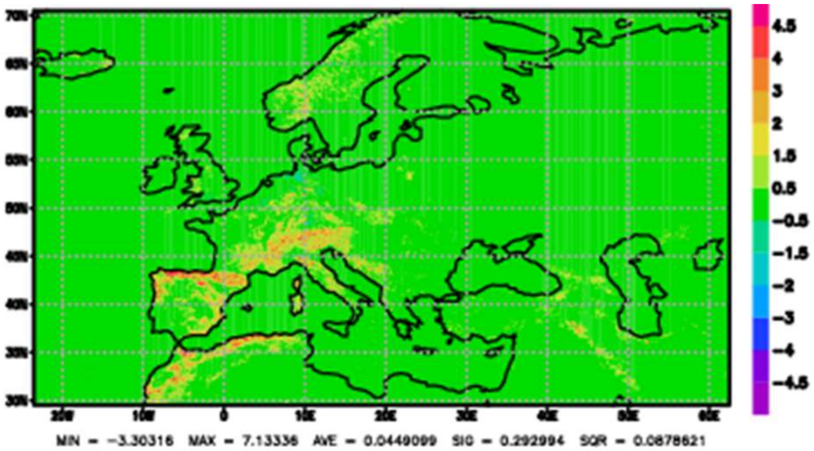
reference (old circulation term)



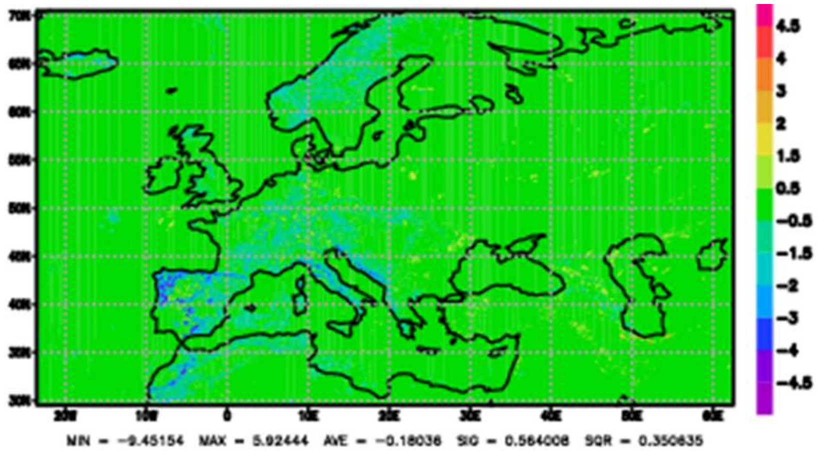
TSSO with circ. heat-flux - SSO without circ. heat-flux



TSSO without circ. heat-flux - reference



TSSO with circ. heat-flux - reference

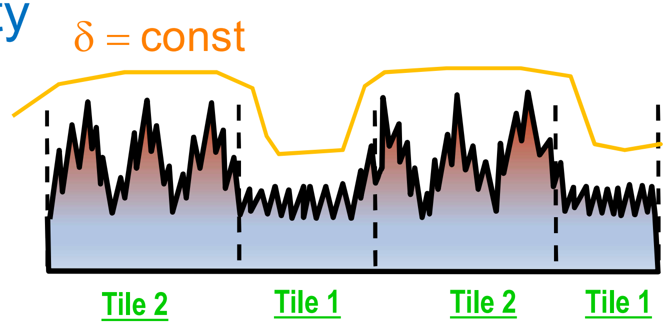


ICON-EU Pr.-Time = 06Z06SEP2021 Pr.-hour = 6 Reference <-> TSSO +/- circ.-flux

- TSSO increases low-level mixing: warmer at night near the surface
- Additional upward heat-flux overcompensates the turbulent warming at night

<u>Running</u> development related to the roughness-layer: (Matthias Raschendorfer)

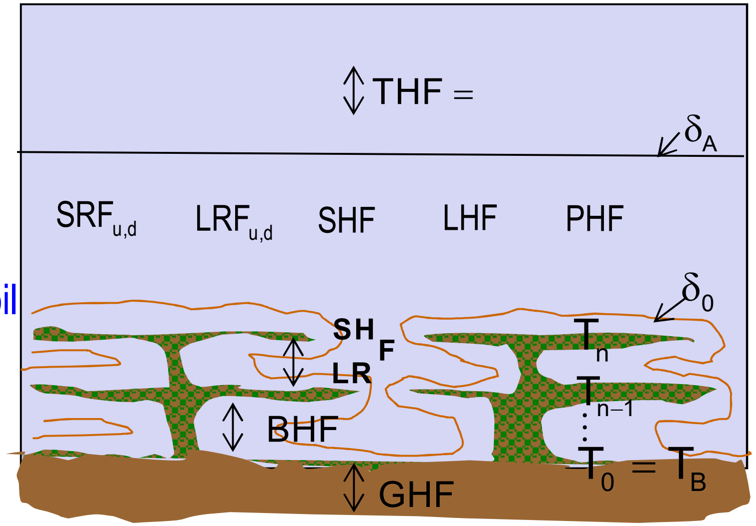
- Consideration of roughness from inter-tile variability
  - Somewhat **reduced Prandtl-layer resistance for momentum**
  - Could be employed as a contribution to SSO as well
  - Not yet fully implemented



- Implicit treatment of surface-temperature
  - **Linearization of surface processes** with respect to temperature and linearly coupled to T_soil- and (multi-layer) T_snow-profiles of a <u>partial</u> snow-cover
  - **Vertical diffusion between atm. model layers** is forced by the **tile-aggregated surface fluxes**
  - Solves the problem of **oscillating T_surf and T_snow** at time steps of several minutes
  - Being merged from an ICON side branch

Strong impact on diurnal cycle of T2m and Td2m !!

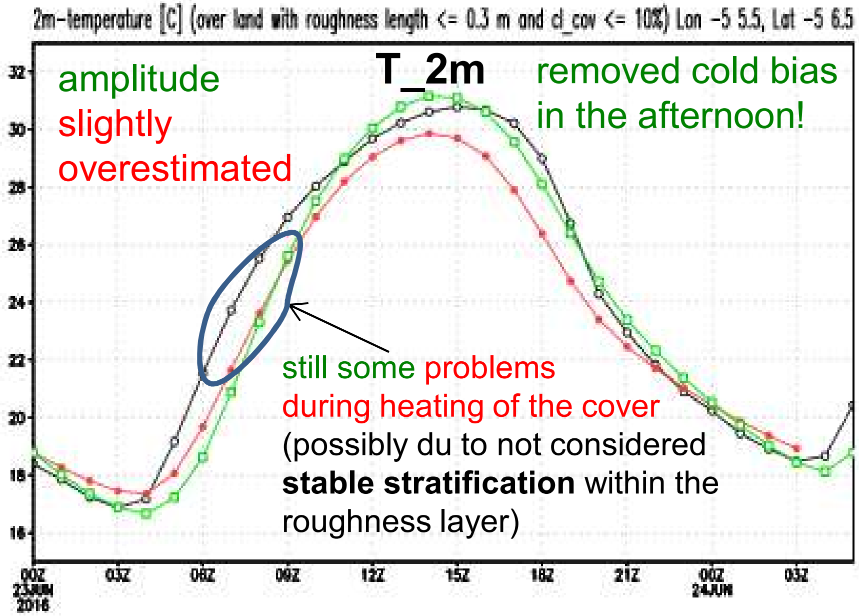
- Semi-transparent and mass-carrying R-cover
  - Number of semi-transparent material R-sublayers above the compact soil dependent on the total **surface area index**
  - **Material R-sublayers vertically coupled by LRF and SHF**
  - **Partial shading** of material R-sublayers further down and the soil
  - **Evapotranspiration** with regard to $\mathbf{T_0,\cdots,T_n}$ and a **semi-parallel resistance chain**
  - Interception, dripping and phase transitions of precip. prepared
  - Being integrated into ICON from a COSMO test-version

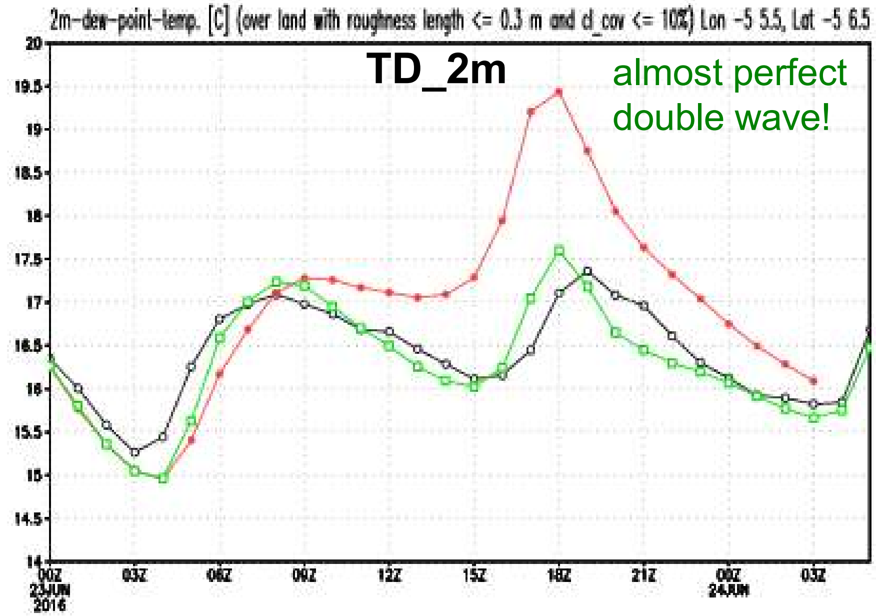


Case study in COSMO-DE: Testing an existing prototype of a mass-carrying and semi-transparent canopy:

- Experiment with **the existing test-version in COSMO for an quasi-ideal test case:**
  - **COSMO-DE with lateral boundaries from ICON-EU**
  - **domain averaged daily cycles of near-surface variables**
  - **almost saturated soil due to long standing rain period before**
  - **only for rather smooth surfaces: applied filter**
  - **almost no clouds due to high pressure situation + applied filter**

conditional diagnostic





direct analysis of T_2m and TD_2m

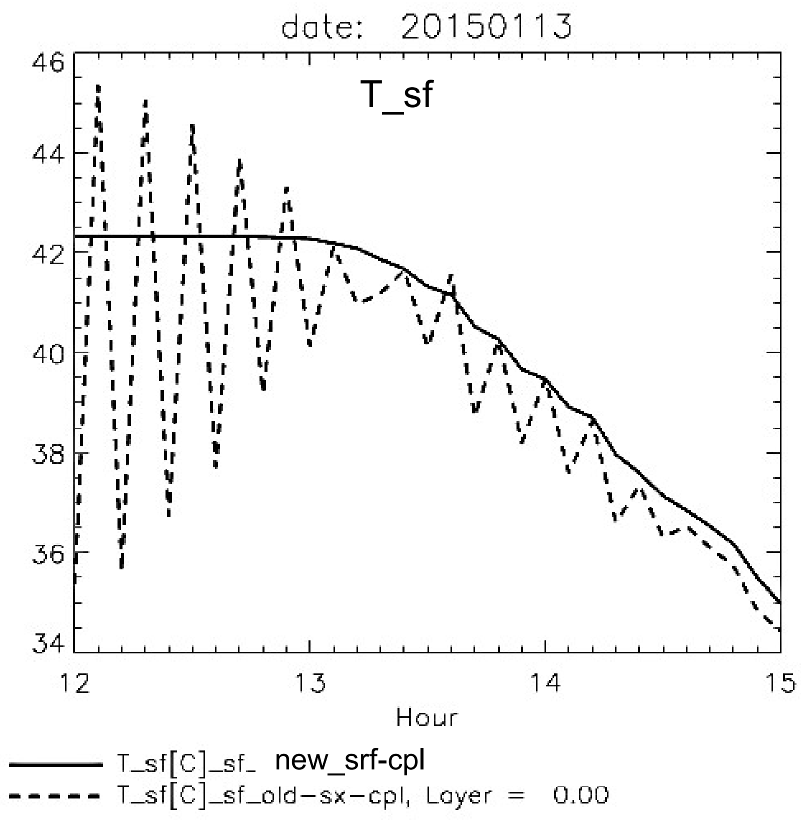
revised TURBDIFF imported from ICON

full C-layer treatment : semi-transparent + loosely coupled + heat-storage + adapted evapo-transpiration

Coupled system of linearized heat equations with implicit temperature treatment:

Test-grid-point Kenia (+33.71_+7.89) (already shown earlier) :

- After-noon situation; tropical hot with strong radiation forcing
- 3 hour ICON-global test-run (R2B6) with defaults of the new SAT/TERRA-scheme (dt=6 min)
- Non-default settings only for the special grid-point:



- Oscillations almost completely eliminated by <u>new implicit treatment</u> of surface processes.
- So far operational flux-limiter switched off <u>only for new treatment</u>.

Prepared development related to the roughness-layer:

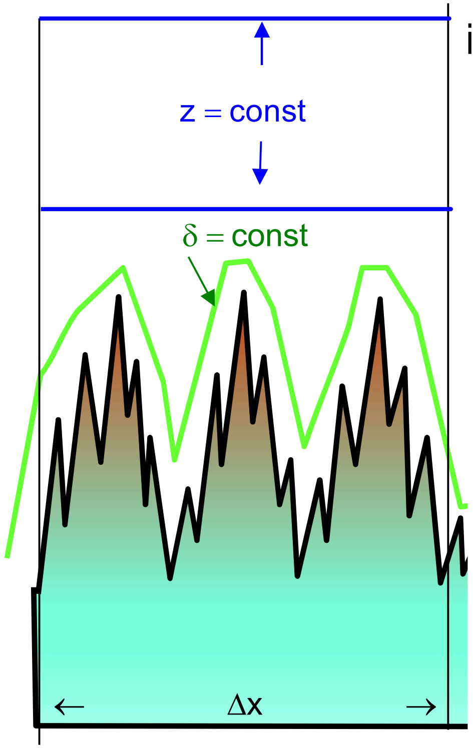
- Vertically resolved atmospheric land-use R-layer
  - Principal related problem for numerical simulation:

$$\overline{\nabla\zeta} = \nabla\overline{\zeta} + \overline{\nabla'\zeta'}$$

if model layers are intersected by R-elements or layer-surfaces have got SGS slopes

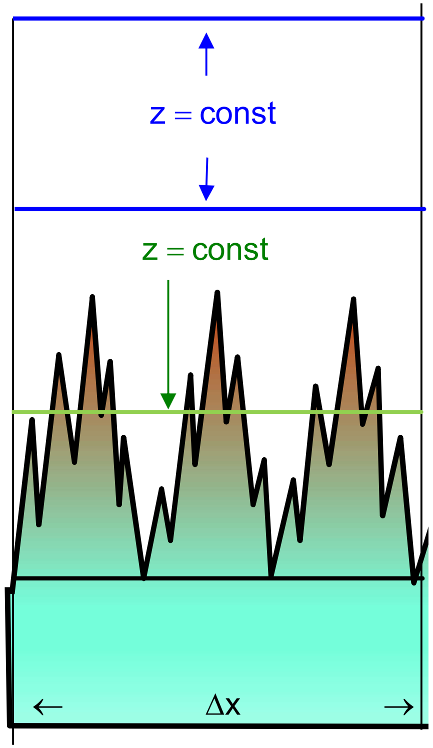
↓ e.g. form-drag in case of pressure-gradient ⟷ wake-production of TKE

  - Two Paradigms:



i. Prognostic atmospheric δ-layers **excluding** R-elements

- Layering according to (turbulent) distance from surface
- Generalized BL-approximation (similar treatment like SSO)



ii. Prognostic atmospheric z-layers **intersected** by land-use R-elements

- Surface transfer for all intersected layers
- Flow through porous medium

Thank you for your attention!