Some recent physics developments in COSMO

for the ICON model

- Better treatment of super-saturation with respect to cloud-ice
- Shallow convection triggering based on estimated inversion strength
- Ocean skin-layer formulation
- Ice optical properties of large hydrometeors for ecRAD in ICON
- Actions around Aerosols and Reactive Trace gases
- More advanced treatment of roughness effects
- Adaptive Parameter Tuning

Long-lived Contrail Cirrus <-> Ice super-saturation

Axel Seifert, Maleen Hanst

Running improvement of 1-moment scheme:

- **Development of improved treatment of cirrus clouds** (according PhD of **Carmen Köhler**, formerly DWD)

  - Implementation of state-of-the-art parameterisations for homogeneous and heterogeneous nucleation:
    - New **2-moment treatment for cloud ice scheme** **(still monodisperse size distribution)**
    - **Limitation** of **heterogeneous nucleation** through **prognostic** budget variable for **activated ice nuclei** $n_{i,nuc}$

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

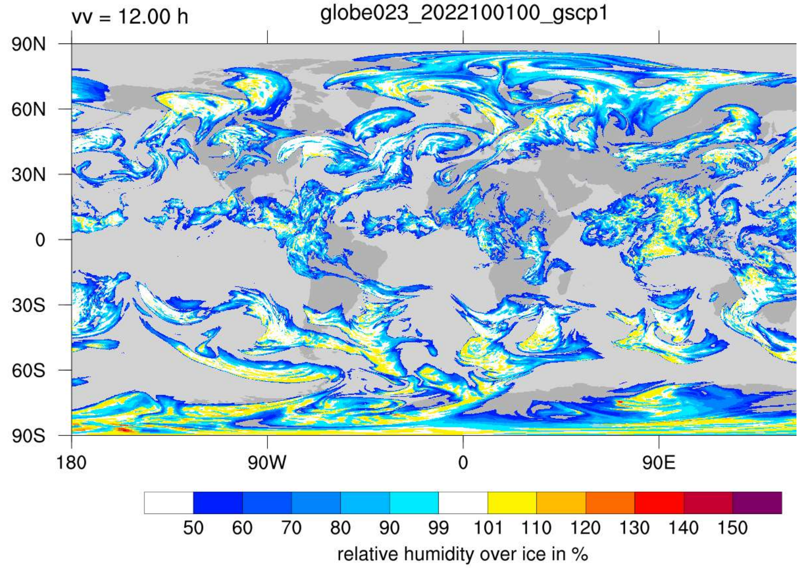
    - Changes in treatment of **depositional growth for cloud ice and snow** and **cloud ice sedimentation**

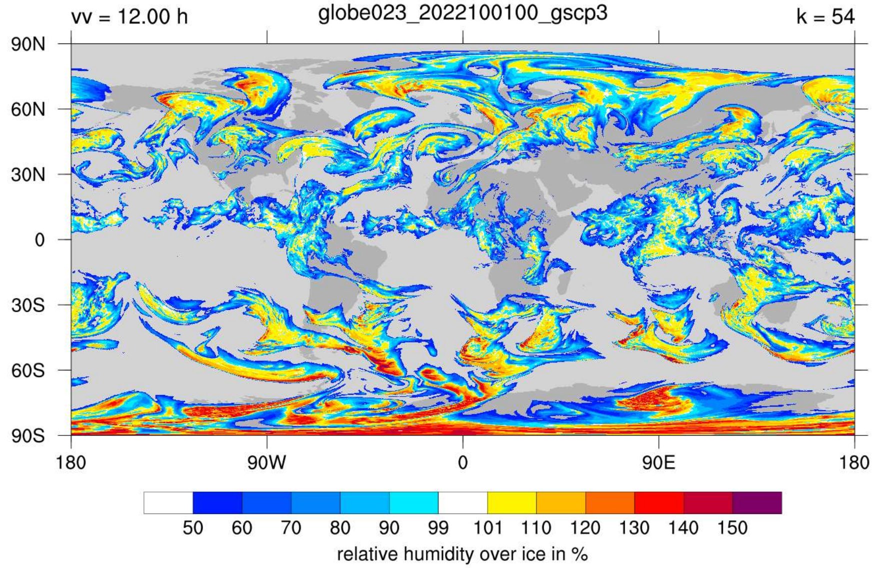
  - Enables more realistic representation **super-saturation with respect to ice**

Ice super-saturation in ICON (Axel Seifert, Maleen Hanst)

operational one-moment cloud ice (inwp_gscp = 1)

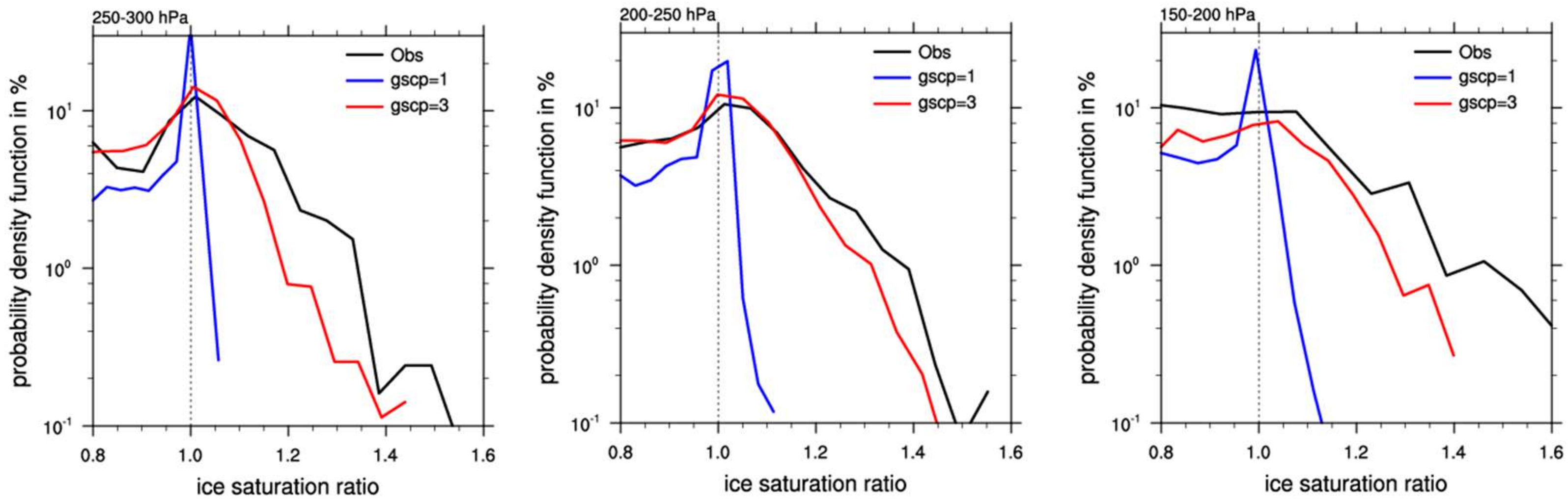
new two-moment cloud ice (inwp_gscp = 3)





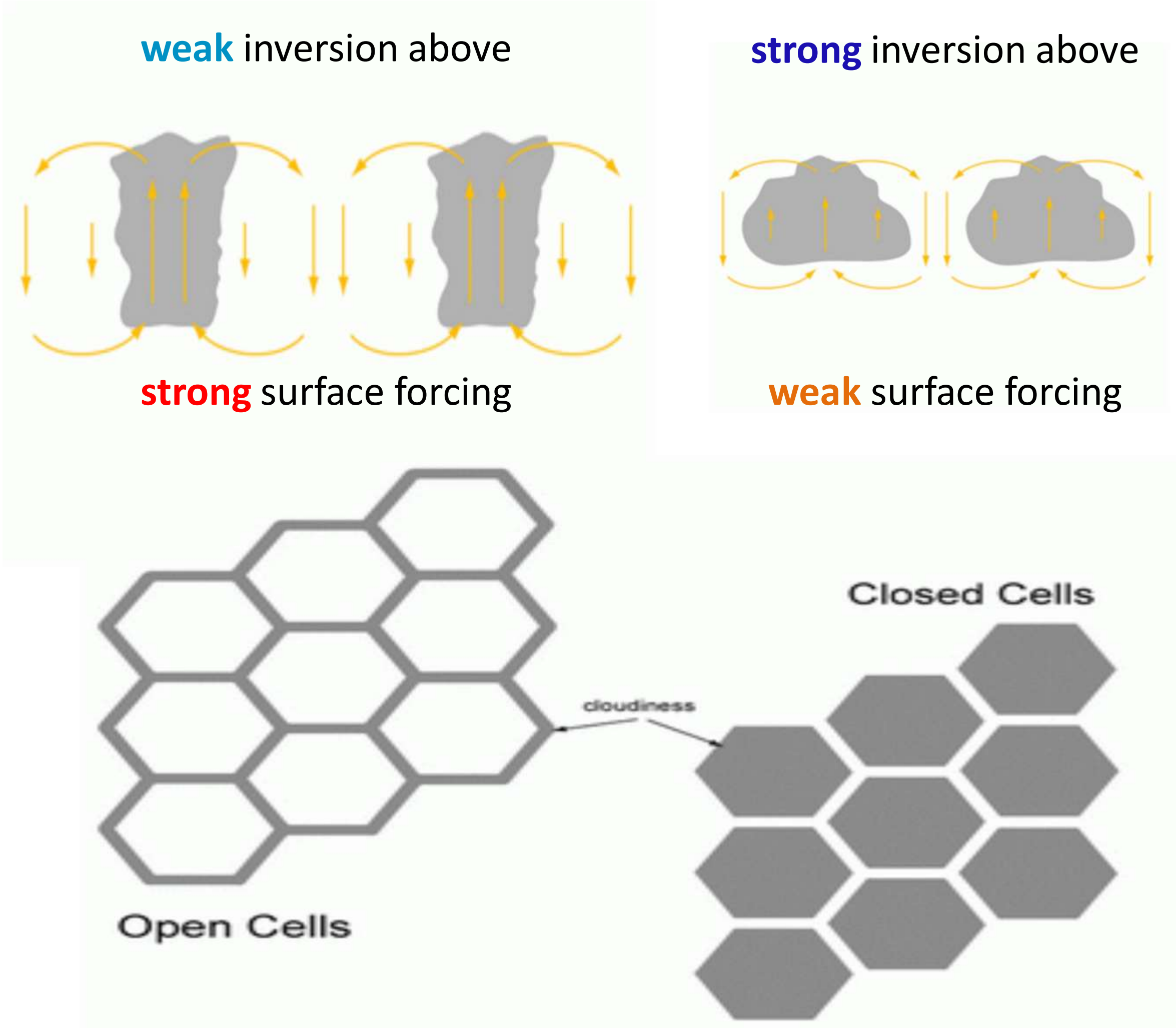
provided by Axel Seifert, Maleen Hanst

PDF of ice super-saturation



provided by Axel Seifert, Maleen Hanst

Shallow-convection triggering based on Estimated Inversion Strength (EIS):



sub-grid shallow convection tends to destroy top inversion

↓

resolved **closed** cells become **open**

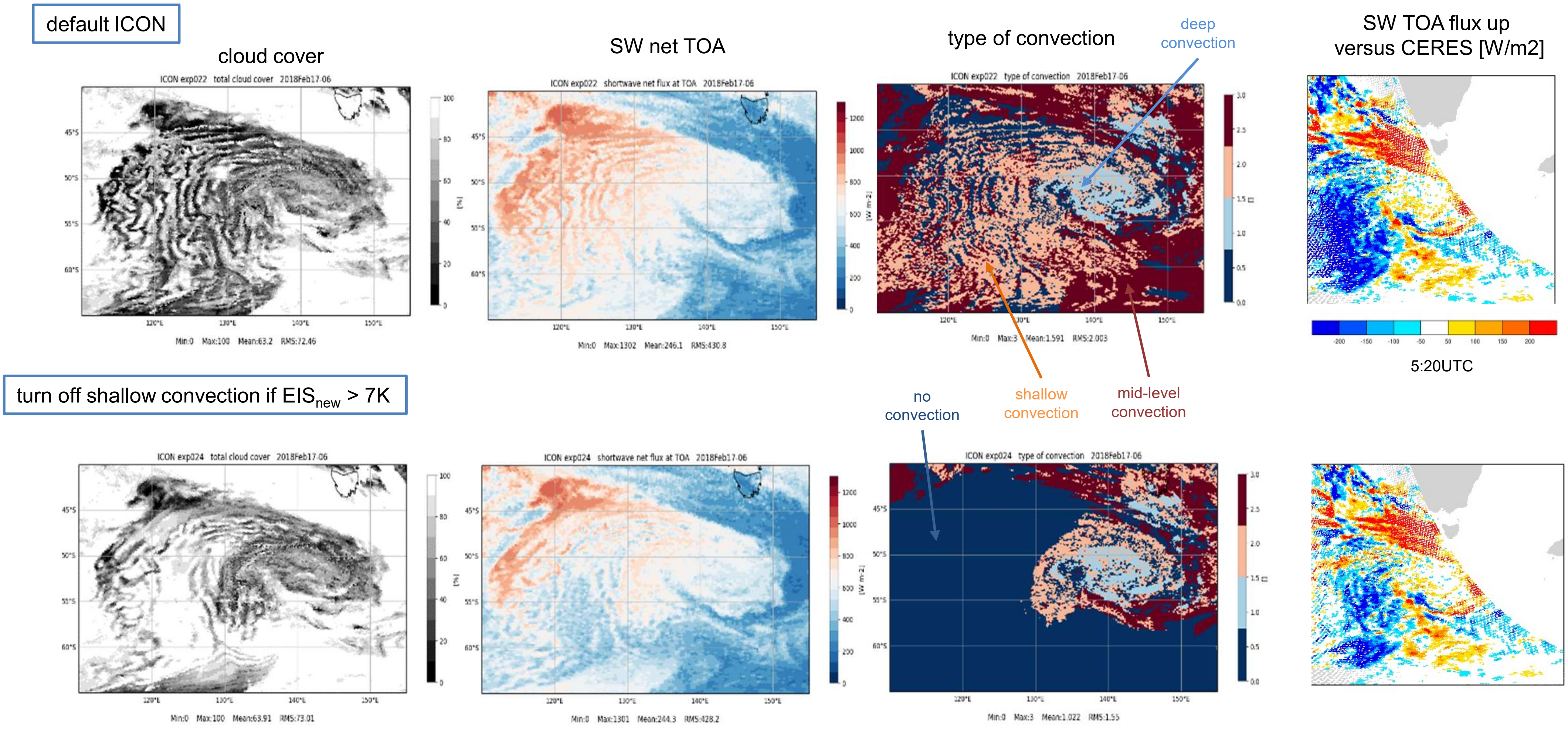
Practical solution (Martin Köhler):

Shallow-convection scheme **switched off** at **large** **E**stimated **I**nversion **S**trength according Marquet, Bechtold (2020):

$$\mathrm{EIS}_{\mathrm{new}} = \mathrm{Max}\,(S_{700} - S_{950}\,;\; S_{950} - S_{\mathrm{surf}})$$

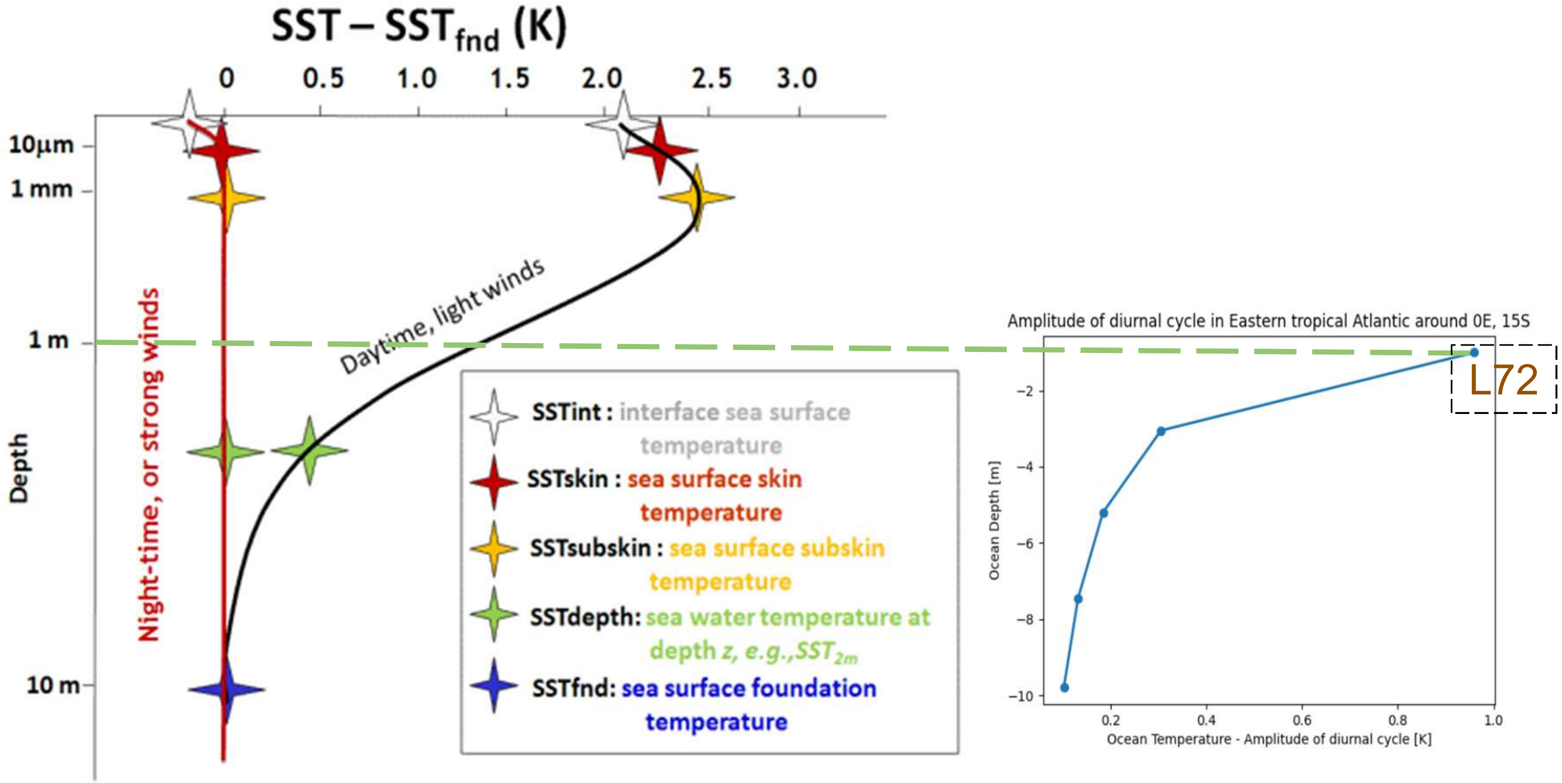
$$S_m = c_{pd}\,(1 + 5.87\,q_t)\,T - L_v\,q_l - L_s\,q_i + g\,z$$

Bias in Southern Ocean: ICON in SOCRATES region 20180217 6UTC



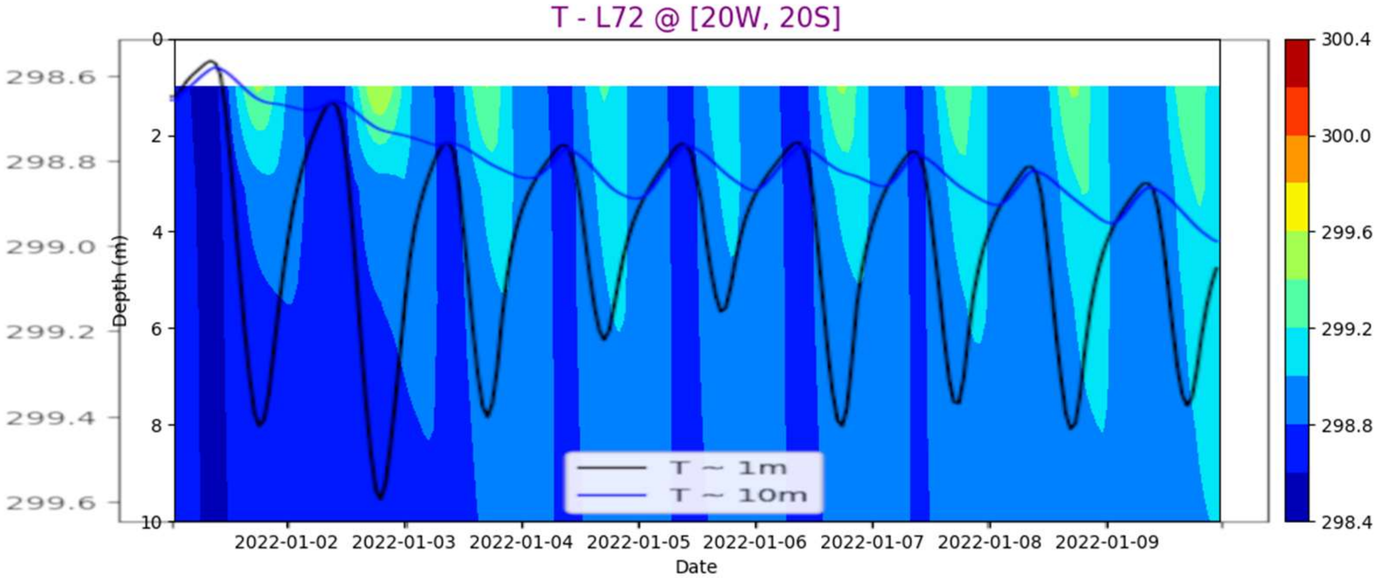
provided by Martin Köhler

Ocean skin-layer formulation (Zeng & Beljaars, 2005)



provided by Martin Köhler

Ocean skin-layer formulation (Zeng & Beljaars, 2005)



The trend and the change of diurnal variations are similar between OSTIA observations (lines) and model simulations (contour colors) at [20W, 20S].

provided by Martin Köhler

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)

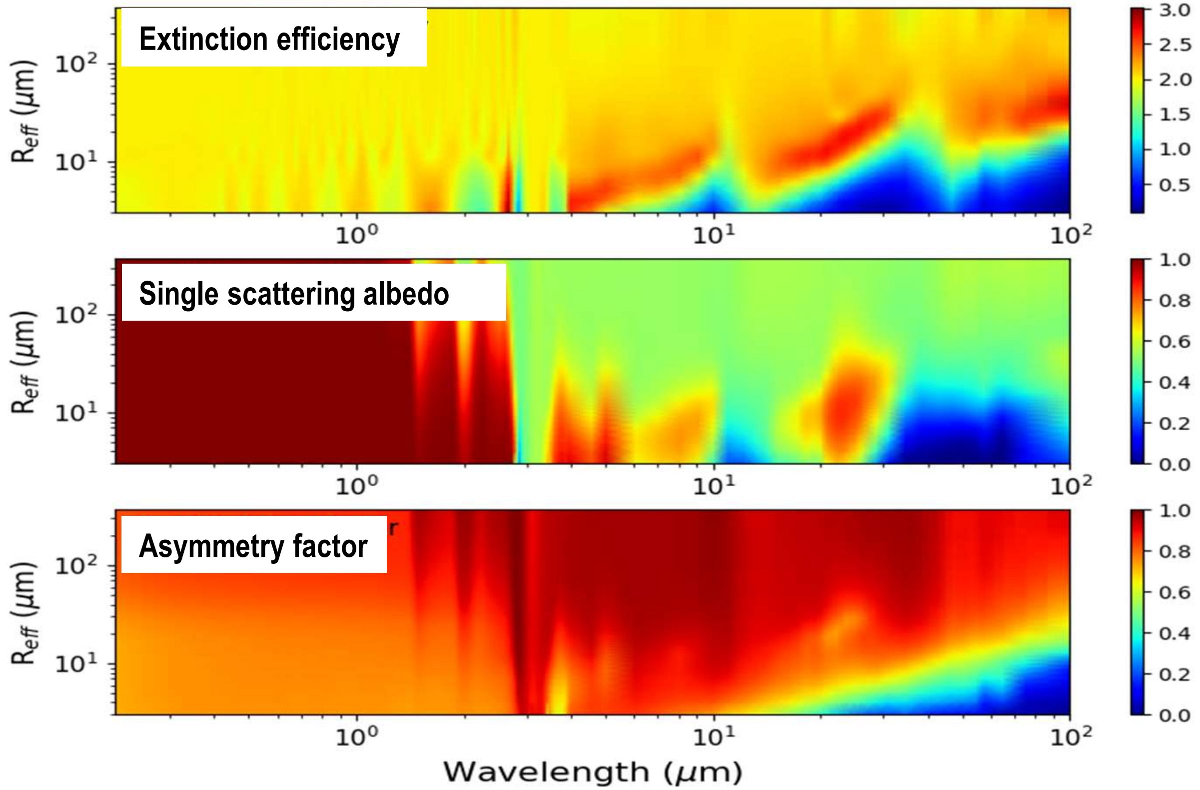
Alexey Poliukhov (RHM)
Julia Khlestova (RHM)
Gdaly Rivin (RHM)
Natalia Chubarova (RHM)
Marina Shatunova (RHM)

- 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 de Mott (2015) into ICON
- Implementing more-realistic information about aerosols:
  - CAMS (climatology and forecast), prognostic 2D AOD, direct prognostic ICON-ART
- Implementing of sophisticated (warm-phase) spectral-bin microphysics as a reference tool

Some details of the related physics behind are contained in the talks of previous years

New ice optical properties for ecRAD

Muskatel, Blahak, Khain, Levi & Fu; *Atmosphere* 2021, *12*, 89.



Extended size:
60 μm → 300 μm

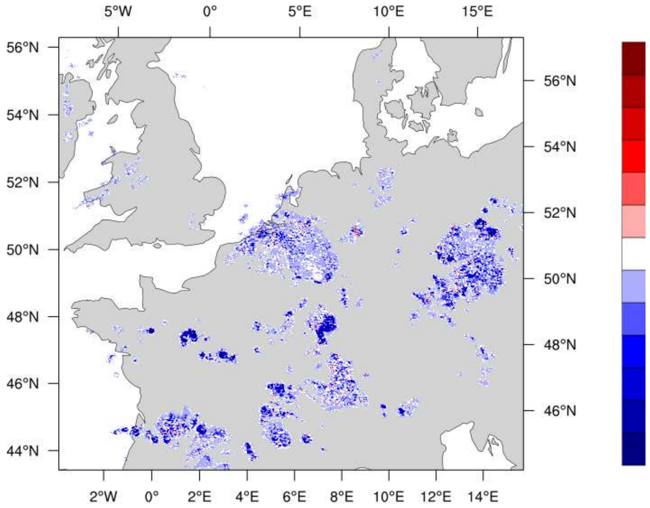
Ice particles surfaces:
Rough/Smooth

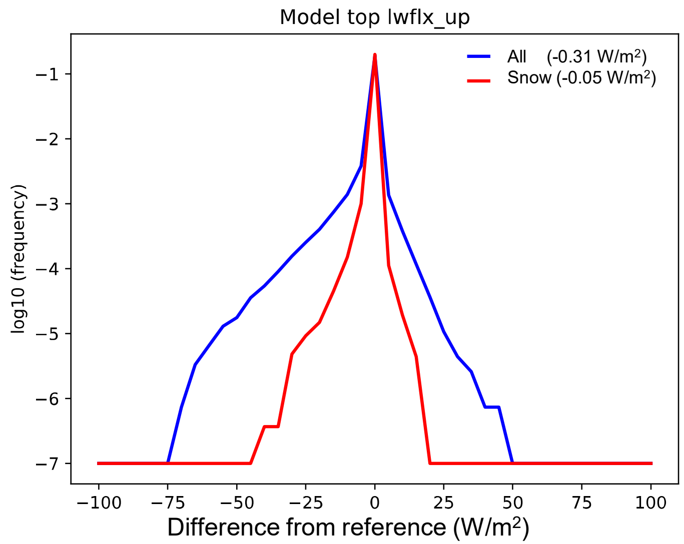
High resolution:
Reff / Wavelength

provided by Harel Mulkatel

Net direct radiation effect of large particles

Upwelling LW TOA ($q_c q_i q_s q_g q_r - q_c q_i$) (W/m²)





➔ **Graupel and snow** in high clouds **block the long-wave radiation from the surface** resulting in **less upwelling radiation at the top of the atmosphere**.

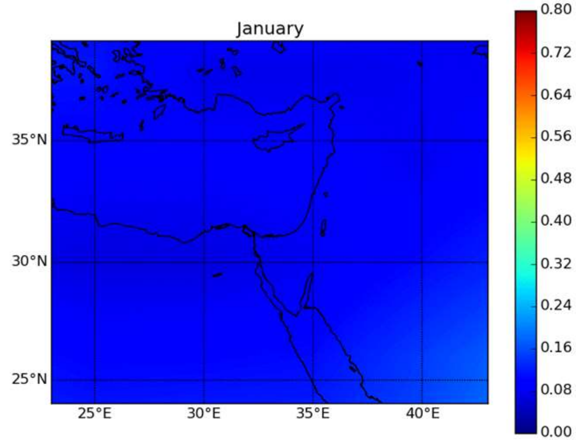
➔ In the above example, the atmosphere warms by **0.31 W/m²** (in average domain) due to the additional consideration of **all lager particles**

0,05 **snow only**

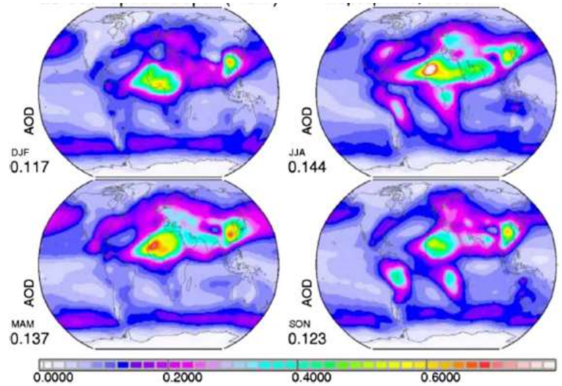
provided by Alberto De Lozar

Aerosols Inputs in ICON Radiation scheme

Tegen (1997)
irad_aero = 6

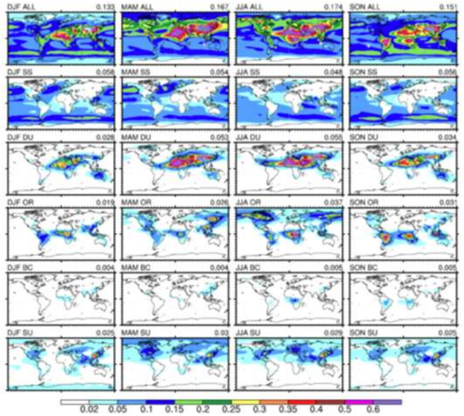


Kinne (2013)
irad_aero = 13

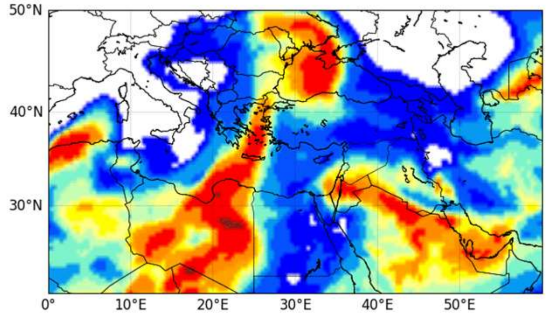


Trang Pham-van (DWD)

CAMS climtology
irad_aero = 7

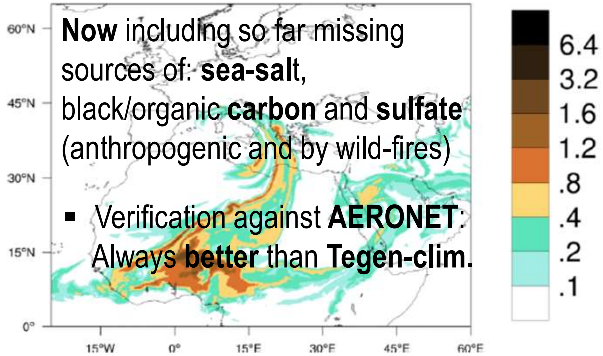


CAMS forecast
irad_aero = 8



5 days forecast

Prognostic 2D AOD
irad_aero=6 & iprog_aero=1

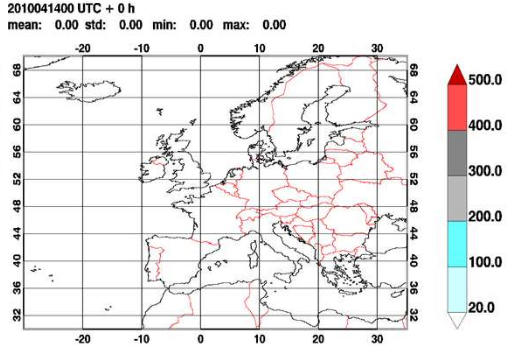


Now including so far missing sources of: **sea-salt**, black/organic **carbon** and **sulfate** (anthropogenic and by wild-fires)

- Verification against **AERONET**: Always **better** than **Tegen-clim.**

provided by Harel Mulkatel

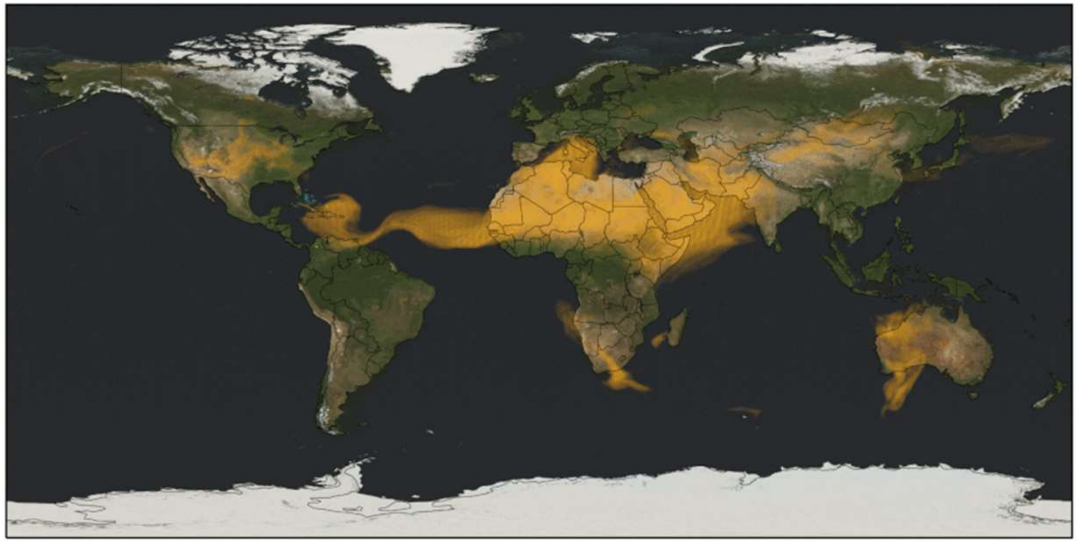
ICON-ART
irad_aero = 9



Expanding ICON-ART to multi-aerosol global simulations

Dust was investigated in **PerduS**; in **PermaStrom** expansion to **wildfire** and **sea salt** aerosols

1. Sea Salt Emission Parameterizations
2. Sea Salt Aerosol Modes
3. Effects of Aerosol Dynamical Processes on Atmospheric Burden
4. Biomass Burning Aerosols - Combined Global Simulation



Daily forecast using ICON-ART:

Mineral Dust

Sea Salt

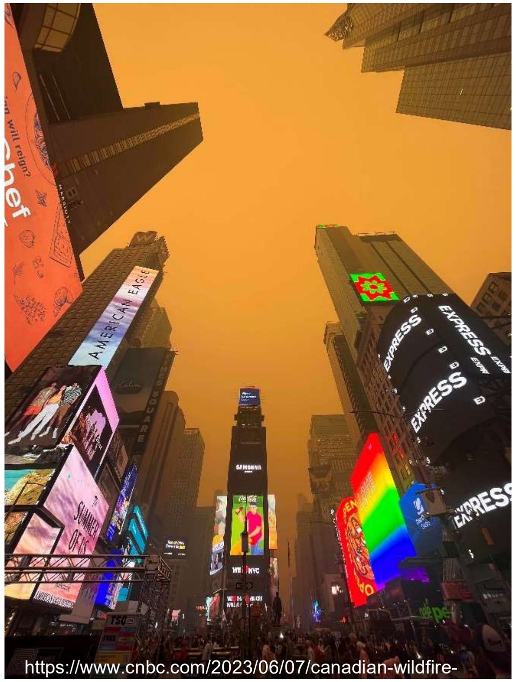
Biomass Burning Aerosols

as to estimate **reduction of photovoltaic power supply**

provided by Anika Rohde

Institute of Meteorology and Climate Research

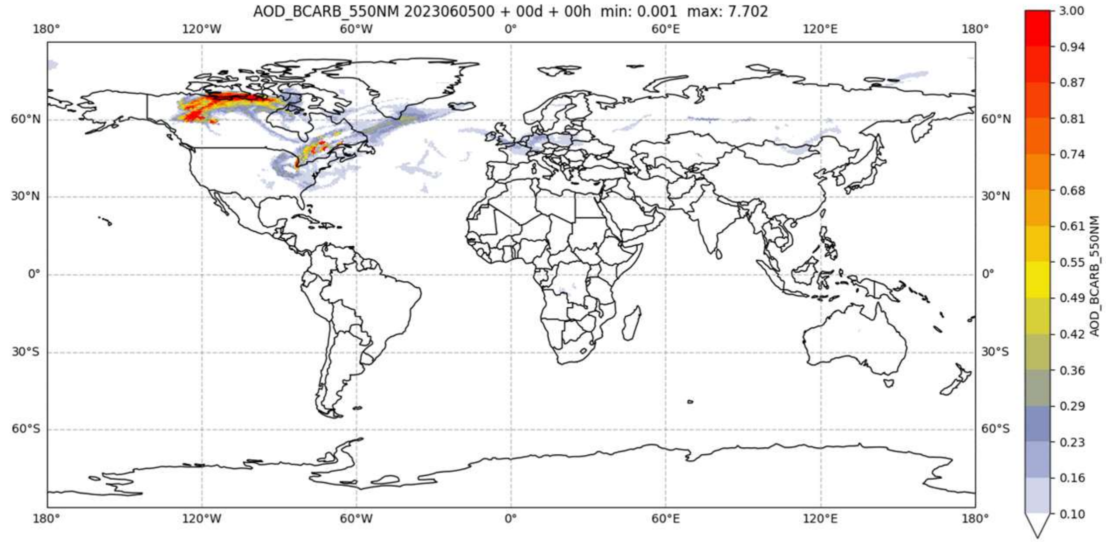
Wildfire smoke from Canada arrives in NYC



Nikolas Porz

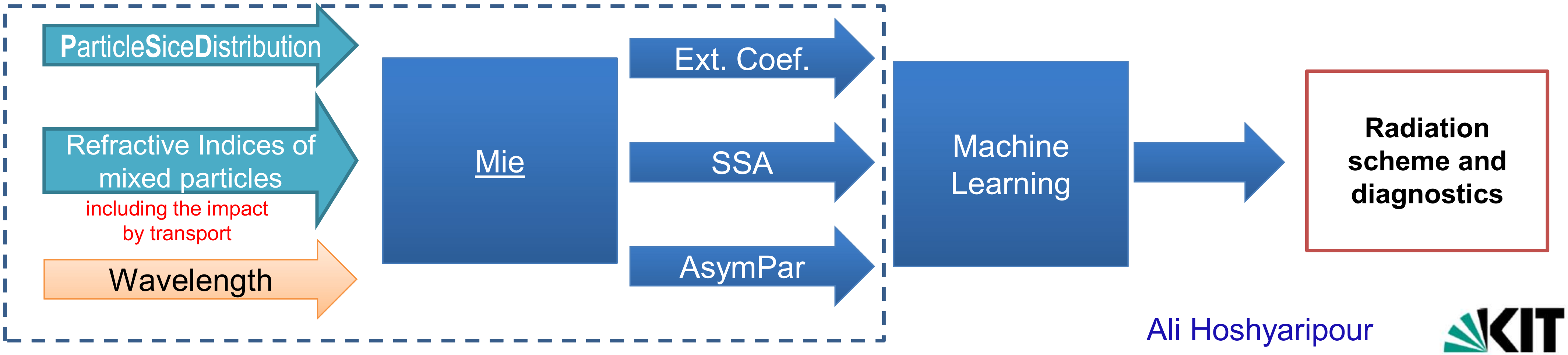
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

PermaStrom@DWD



Speeding up complicated calculations by AI/ML:

- Investigating the emulation of optical-property calculations by **AI/ML**:



Ali Hoshyaripour — KIT Karlsruhe Institute of Technology

- Investigating the emulation of microphysical source-terms by **AI/ML**:

Axel Seifert — Deutscher Wetterdienst, Wetter und Klima aus einer Hand

➢ **Enormous speed-up at reasonable accuracy!**

❖ **Another possibility: AI/AM**-Emulation of new **spectral-bin** microphysics (**66 bins**: droplets + CCN tracers) being about 7-times slower than current **1-moment scheme !?**

A general and common Task of Physics WGs

Current topic:

Better overall treatment of surface Roughness (R) in the tiled model (around the packages 'turbdiff', 'turbtran' and 'terra')

According to the (new) **combined** theoretical concepts: **GBLA** and **STIC**

Current contributor: Matthias Raschendorfer

Other thematically involved people:

Günther Zängl, Martin Köhler, Daniel Reinert/Rieger
Jürgen Helmert, Jan-Peter Schulz, Roland Wirth
Ekaterina Maschulskaja, Dimitrii Mironov
Contributors to the PP/PTs: CITTA, SAINT and VAINT, …
ICON-projects: ICON_land/seamless/c

A) Separated Turbulence Interacting with non-turbulent Circulations (STIC):

- Takes into account the **interaction** of **turbulence** with other **Sub-Grid Scale (SGS) Non-Turbulent Circulations (NTCs)** (such as SSO-wakes or near surface thermals)
- Is a **missing link** for a **consistent overall closure** of **SGS variability**, and is essential, e.g., for representing the **nocturnal BL**

❖ **Turbulence closure** automatically **restricted** to scales being **valid for that closure!!**

➢ **Securing necessary consistency by strictly separating:**

- **(pure) turbulence:**
  - **Gaussian distribution functions; 3-rd order moments negligible; related to TKE**

e.g.: turb. transport of turb. 2-nd od. moms. (like TKE)

STIC-conversion by NTC-shear

- **Non-Turbulent SGS Circulations (NTCs):**
  - May be **non-Gaussian**; **Extra NTC-transport** (e.g. of **heat** or even **TKE**); related to **CKE**

- **Lower Limits of Diffusion Coefficients (LLDCs):**
  - **So far: LLDCs are only effective in resulting representation of turbulent fluxes**
  - **STIC:** $K^H_{min} - K^H$ **corresponds to not yet considered SGS shear forcing for TKE**

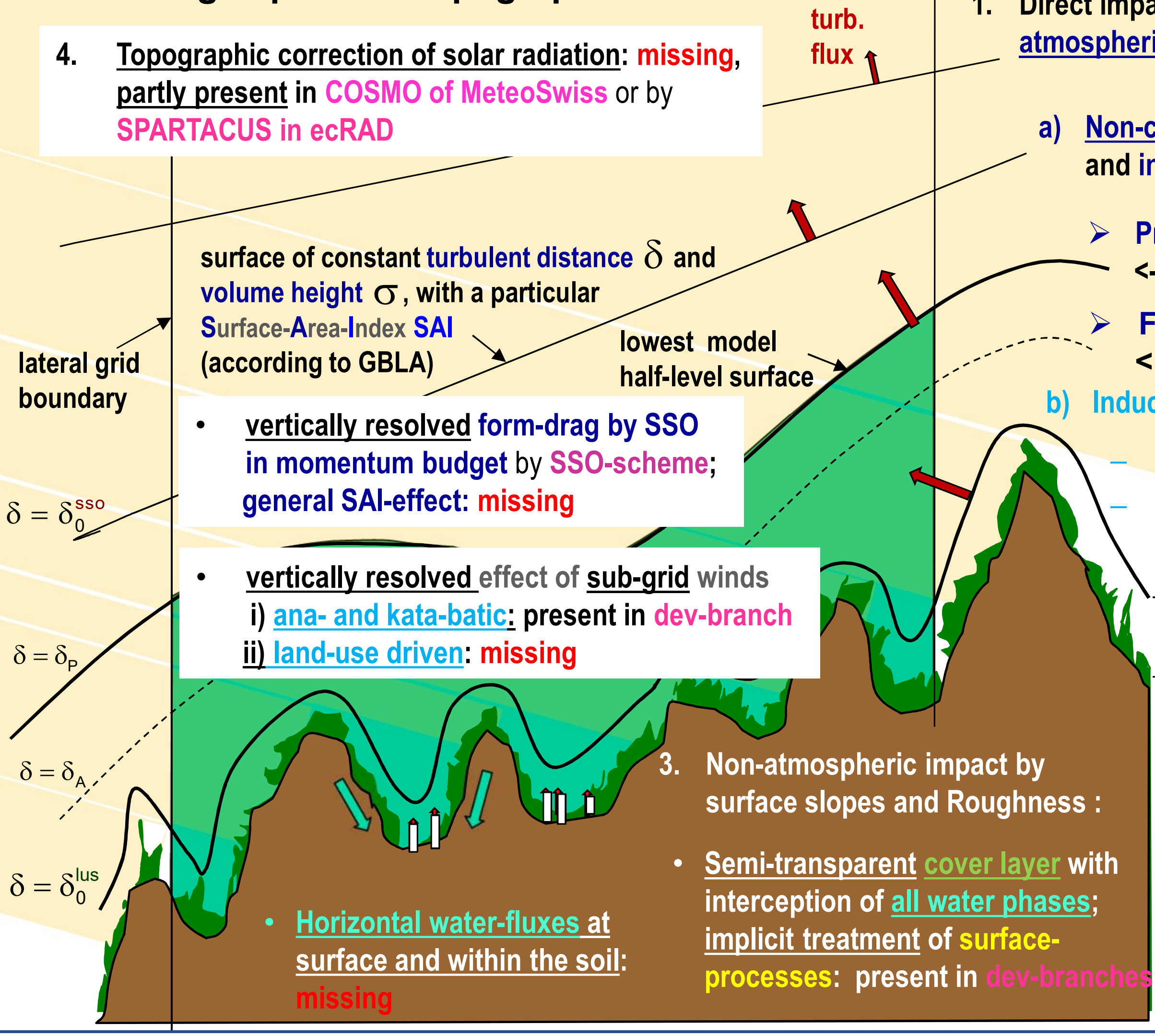
    $K^M_{min} - K^H_{min}$ **corresponds to not yet considered form drag in momentum equation**
    - ➢ **TKE as well as surface-layer shear needs to be adapted/increased accordingly (going to become 'master'-code) !**

B) Generalized Boundary-Layer Approximation (GBLA):

- Essential setup for a **treatable approximation** of **2nd-order equations** in a **Tangent-to Stream (TS) system along NTCs** including **the flow deflected by sub-grid surface structures**, that is Roughness (**R**)
- Enables the **principal application** of the TKE-based **turbulence model (TURBDIFF)** also within the **R**-layer and particularly for the bulk **SAT scheme (TRUBTRAN)**

Consolidation of Surface-to-Atmosphere Transfer (ConSAT):

- **Missing impacts of topographic structure:**



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: present in dev-branch
   - Continuous R-smoothing by snow: large impact at forested areas; going to become 'master-code'
   - Surface-Shear Amplification by NTCs: present in dev-branch

So far introduced STIC terms and related NTC-parameterizations:

Additional Shear-Production of TKE by:		
– SSO wake-eddies	dTKEsso	derived from current dynamic SSO-scheme
– vertical convective currents	dTKEcon	derived from current convection scheme
– separated horiz. shear eddies	dTKEshs	extra parameterizations of large horizontal shear circulation
– NS thermal density currents	dTKEtdc	extra parameterizations of thermal SSO-effect: (so far in dev-branch only)

(first three:) determines EDR above BL used to forecast aviation-turbulence

forced by **horizontal pressure-gradient** due to heating or cooling of **sloped surfaces** at sub-grid scales

anabatic: during day-time: may trigger convection

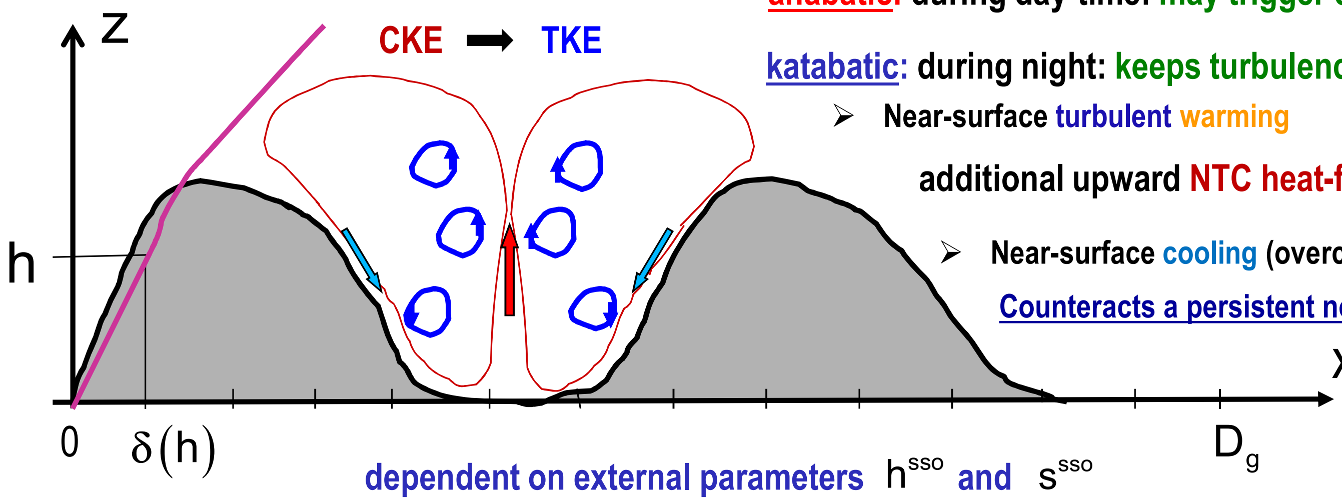
katabatic: during night: keeps turbulence alive

- Near-surface turbulent warming

additional upward NTC heat-flux:

- Near-surface cooling (overcompensating the turbulent warming):

Counteracts a persistent nocturnal warm-bias of near-surface temp. !!

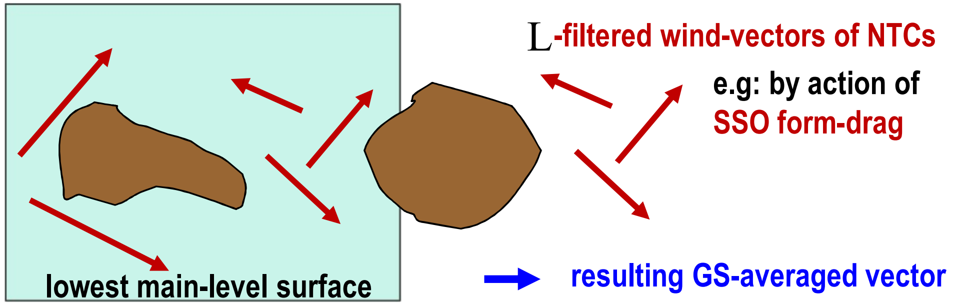


dependent on external parameters h^{sso} and s^{sso}

Implementation of a Surface-Layer Shear-Amplification (SLSA) by the action of NTCs (or active Lower Limits of Diffusion-Coeffitieants) - going to become 'master'-code:

Matthias Raschendorfer

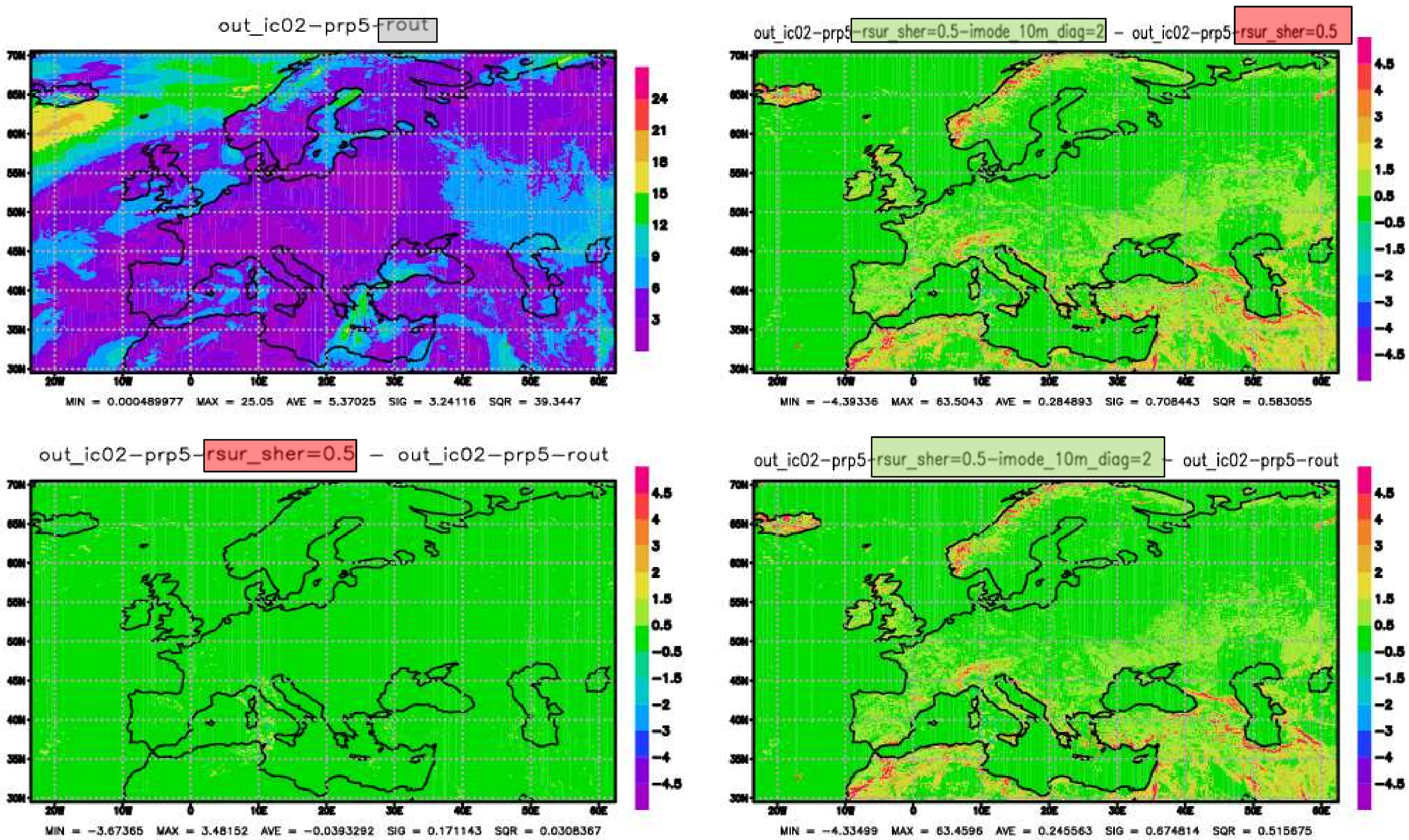
– Locally averaged, tangent NTC wind-vector at the lowest model level (representing MKE + CKE) may be much larger than the grid-scale averaged horizontal wind-vector.



- Driving wind shear for transfer scheme is systematically underestimated !!
  - ⟺ rather small effect
- Low level wind (at 10m-level) is systematically underestimated !!
  - ⟺ strong effect at mountainous regions!!

cf. verification results at mountainous regions!!

Horiz. wind speed at 10m [m/s]



❖ **Increased 10m-wind** at places with high wind-speed and large SSO-roughness

pr time=12Z20SEP2020 pr hour=12hr

6. Physics

Author: Matthias Raschendorfer (DWD)

COSMO Science Plan 2015-2020 about

Empirical extensions of physical parameterizations:

- **General aspects**
- **Future challenges**

For the scope of this science plan we are aware of the following general challenges:

ix. **Improving model diagnostics** and developing methods of an **objective determination of optimal parameter values**. In the long run we're thinking also about a kind of **statistical hyper-PM**, in order to remove the **remaining dependency of model parameters on the model state**, what always is a characteristic **of incomplete physical PM schemes** (see chapter 11.2 about "**Processing verification feedback on model development**").

11.2 Processing verification feedback on model development: WG 1, 3a, 3b, 4, 5, 7

Authors: Matthias Raschendorfer (DWD), Flora Gofa (HNMS), Christoph Schraff (DWD)

Basic scientific background, motivation and strategy

Evidently, Physical Parameterisations (PMs) can't be developed solely by **analytical derivation**. Rather they must be based on various **assumptions** and related **effective parameters** in order to close the system of **discretised model equations**. As a consequence, … **measurements** used for **data assimilation** and **model verification** are the best available estimate of atmospheric observables and thus should be used for the purpose of model development as well. This issue may be called "**verification with feedback**" and requires the implementation of **specific procedures**.

Consequently, **3D component testing** needs to be **integrated into data assimilation runs**. In such an approach, the **error estimate** for the model (component) should be based on **assimilation increments**.

[Usually], … optimal values for the "**internal parameters**" are not constant in space and time or "external parameters" are not only dependent on external conditions. Rather these parameters are likely to **depend on the model state itself**. In this case, it might be a further strategy to express each **physical parameter** by a **regression function** of some model variables dependent on a few **regression parameters** substituting the prior **physical parameter**. This could be called "**automatic parameterisation**" or "**statistical hyper-parameterisation"** and is a kind of natural consequence of most likely always incomplete physical parameterisations.

Empirical Extensions of Physical Parameterizations:

<u>non-confident</u> model parameters:

- treated as a constants
- turn out to be functions of the <u>model state (including gradients)</u>

any derived variable of a specific SGS process

estimated <u>model errors</u>

$$\psi = F_{\underline{P}_{\underline{\pi}}(\underline{\phi})}(\underline{\phi}) = \tilde{F}_{\underline{\pi}}(\underline{\phi}) = F_{\underline{P}_{\underline{\tilde{\pi}}}(\underline{\Delta\phi})}(\underline{\phi})$$

Current incomplete parameterization function

<u>new</u> parameters of a statistical **hyper-parameterization**

Desired **complete** parameterization function

<u>new</u> parameters of an **Adaptive Parameter Tuning**

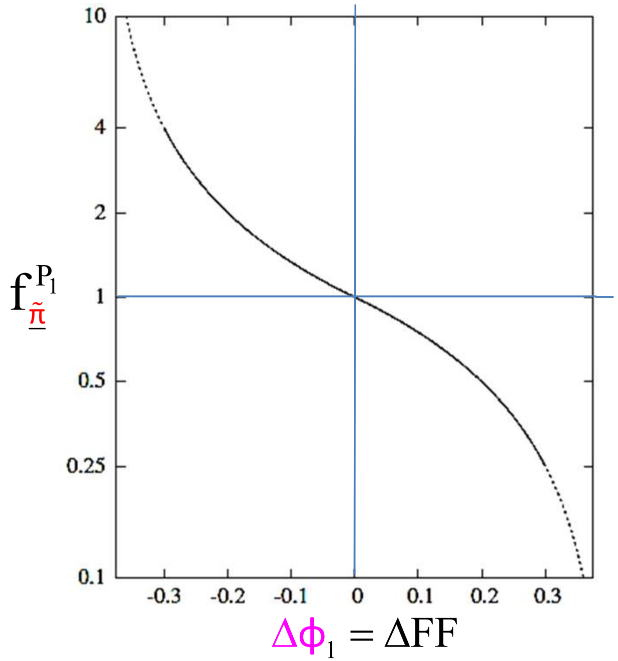
❖ **<u>Expectations</u>** related to $\underline{P}_{\underline{\tilde{\pi}}}(\underline{\Delta\phi})$:

- It is dependent only on a **few sensitive components** of full $\underline{\Delta\phi}$!
- It is easier to find than $\underline{P}_{\underline{\pi}}(\underline{\phi})$!

Adaptive Parameter Tuning (ADP) by Günther Zängl:

	i = 1	2	3	4	
▪ **Time-filtered DA-increments** $\Delta\phi_i$ of $\phi_i \in \{$	FF	T	RH and	$T \cdot \cos\left(2\pi \frac{t_{local}}{\Delta t_{day}}\right)\}$	at the **lowermost model level**
○ **Dominated** by **measurements** of	FF10M	T2M	RH2M		
○ **Proxies** for **local systematic error** of	FF	T	RH and	T -amplitude	**adapting to weather condition**

○ **Used** as **predictors** for **multiplicative empirical correction-factors** $f_{\tilde{\pi}}^{P_j}\left(\Delta\phi_{1,\ldots4}\right)$ **for uncertain parameters** P_j **:**

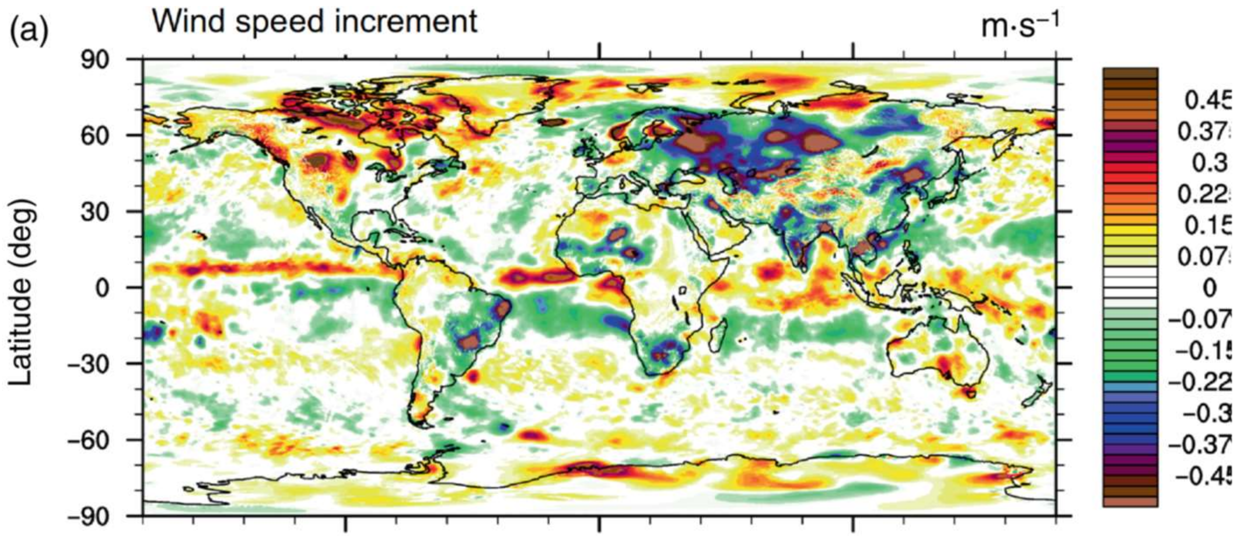


P_1 :	**Land-use roughness** and **SSO blocking tendency**	$\Delta\phi_1$
P_2 :	**Minimal evaporation resistances of bare soil** and **plant stomata**	$\Delta\phi_{2,3,4}$
P_3 :	**Heat-conductivity** and **-capacity**	$\Delta\phi_4$
P_4 :	**Snow-albedo**	$\Delta\phi_2$
P_5 :	**Minimal diffusion coefficient**	$\Delta\phi_{2,4}$

$$P_j = f_{\tilde{\pi}}^{P_j}\left(\Delta\phi_{1,\ldots4}\right) \cdot P_j^0$$

https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.4535

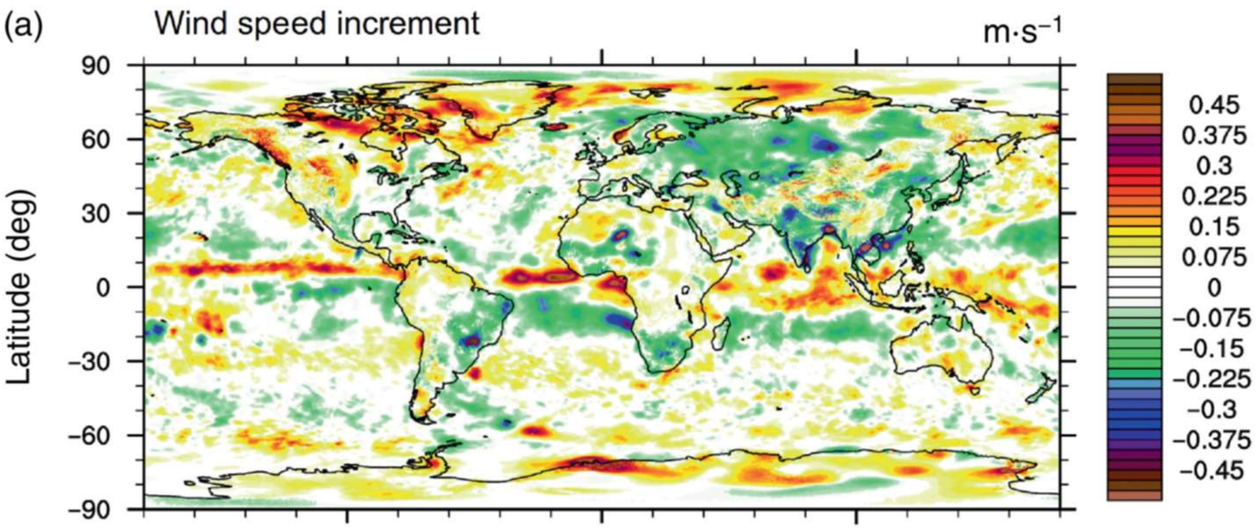
default value of **(internal global** or **external local) parameter**



Reference:

Filtered assimilation increment
without APT

for ICON (13km, 90 level)
at lowest level
averaged over each day of November 2020

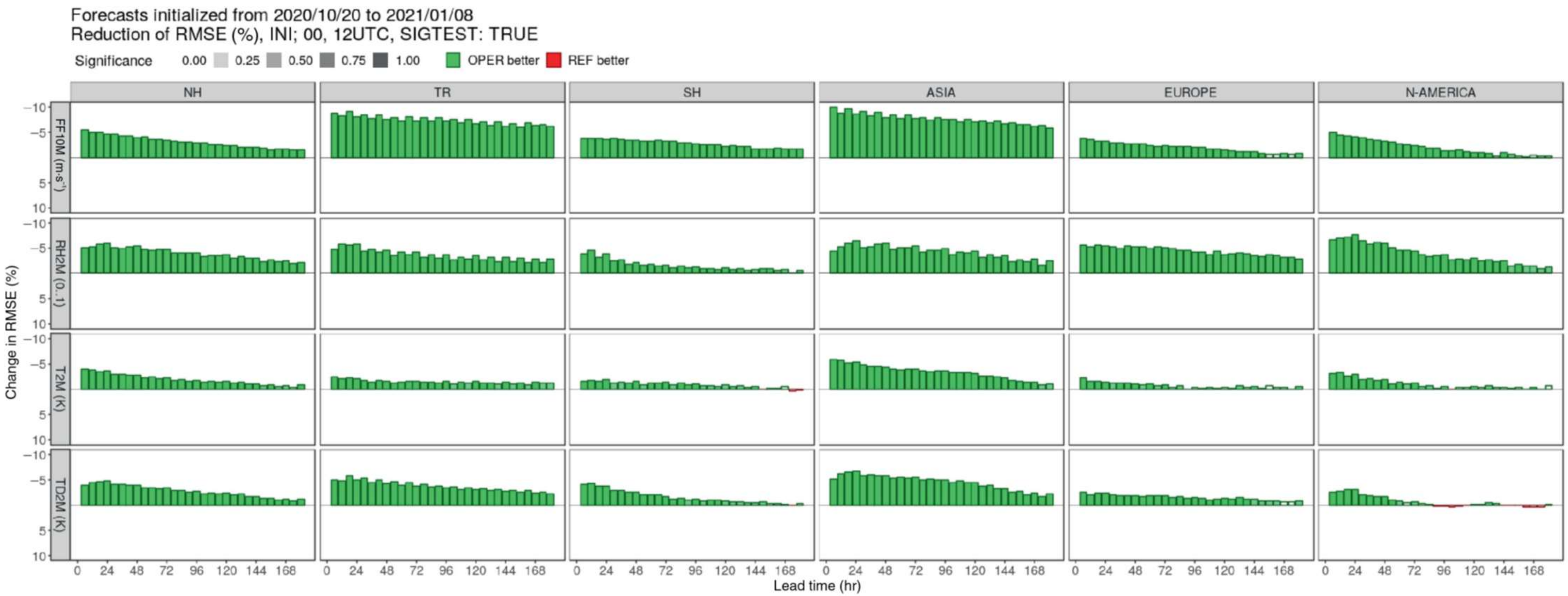


New routine:

Filtered assimilation increment
including APT

provided by Günther Zängl

Impact of APT for ICON output of near-surface variables:

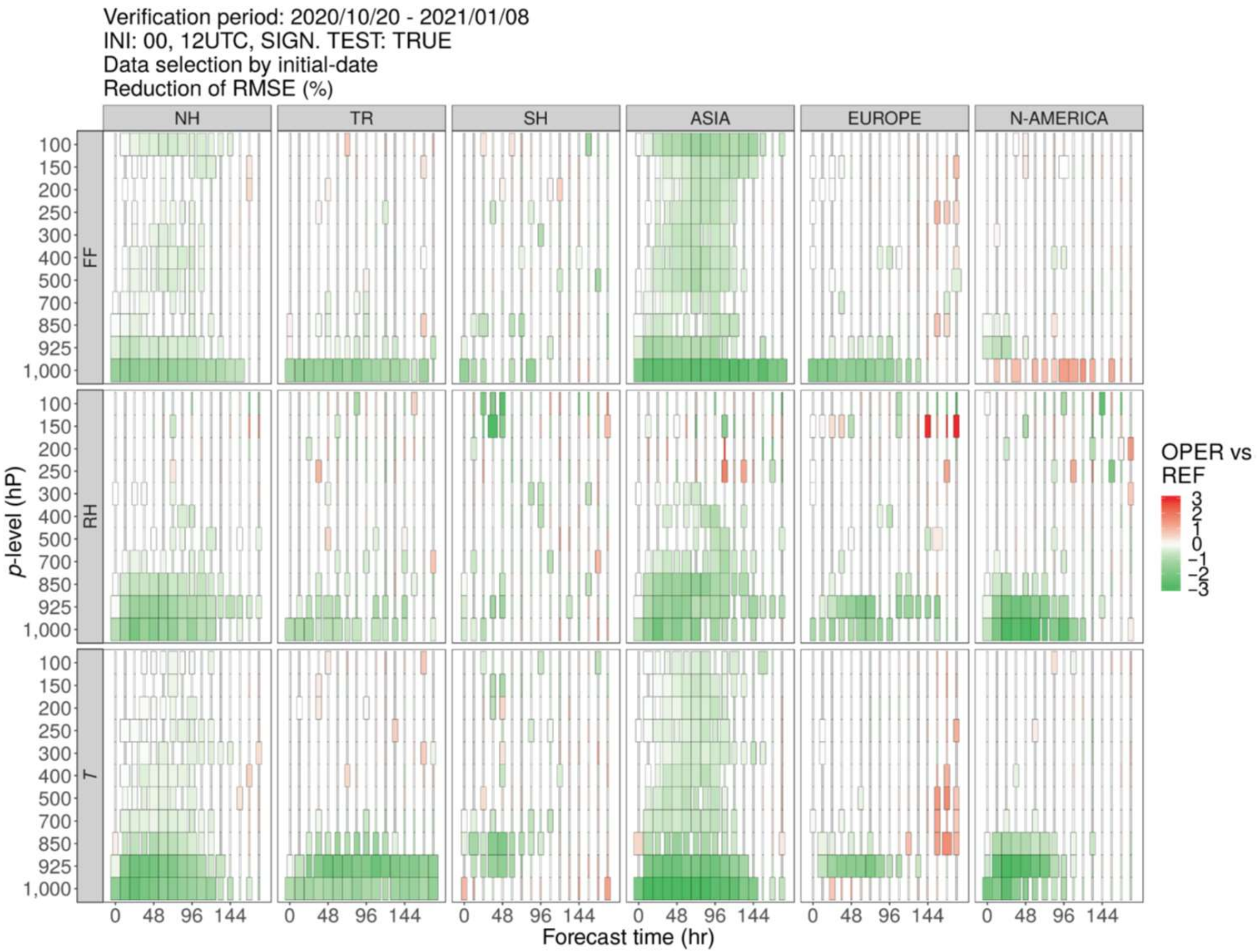


- Score-card for the verification against SYNOP stations, averaged over 0000 UTC and 1200 UTC forecasts of the full experiment period

➢ **RMSE reduction of about 5% during first forecast days**

provided by Günther Zängl

Impact of APT for ICON upper air output:

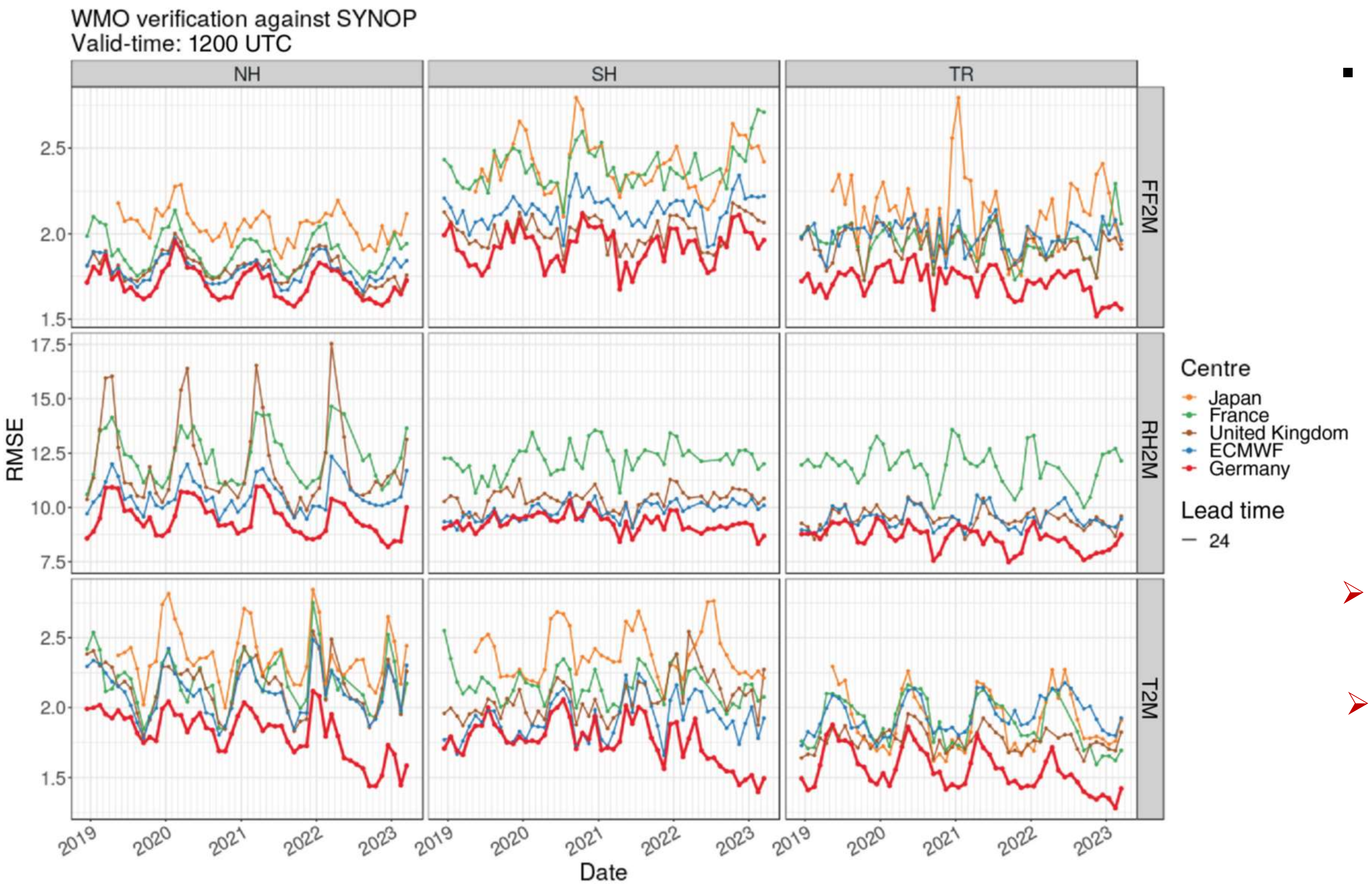


- Score-card for the verification against **radiosonde ascents**, averaged over 0000 UTC and 1200 UTC
  - Green (red) bars indicate an improvement (degradation) due to APT;
  - Filling indicates statistical significance at the 95% level.

➢ **RMSE reduction also for upper levels**

provided by Günther Zängl

WMO intercomarison about operational forecast of near surface variables:



- WMO intercomparison for operational forecast verification against SYNOP stations at a lead time of 24 hr.

- DWD leading since a couple of years.
- May 2022: Introduction of T2M assimilation and related APT-components

provided by Günther Zängl

A general problem that may be tackled by AI/ML:

- **Non-adaptive empirical measures** partly **counteract ConSAT** development
  - Particular **over-tuning** of some **direct parameters** $\underline{P}$
  - **Static** empirical **hyper-parameterizations** with **fixed** internal parameters $\underline{\pi}$

always **adapted to <u>present</u> model errors** (**partial error-compensation**)!

- **APT automatically adapts** to improvement by **classical parameterization <u>qualitatively</u>**
  - **Retuning** of APT **scaling-functions** $f_{\underline{\tilde{\pi}}}^{P_1}$ required for **<u>quantitative</u> optimization**

➢ **Automatic optimization** of remaining parameters $\underline{P}$, $\underline{\pi}$ or $\underline{\tilde{\pi}}$ should b e a matter for **ML/AI !!**

May

Surface-Layer Shear Amplification

keep moderate tomorrow afternoon!!