ICON-D2-EPS status and developments

C. Marsigli, Ch. Gebhardt, M. Sprengel
Deutscher Wetterdienst

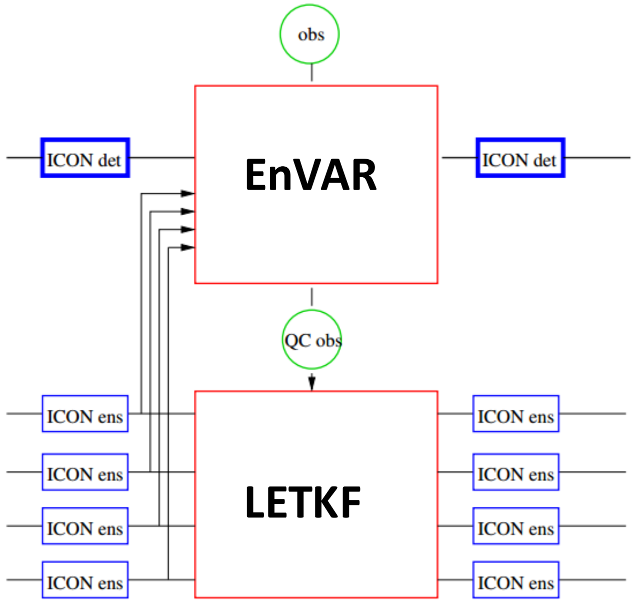
Outline

- ICON-D2-EPS: current status
- Stochastic workshop
- On-going works on model perturbations
- Internal DWD cooperation: WG EPS Perturbations

The operational NWP system at DWD

EnVAR
hybrid
DA-system

ICON-EDA
global
ensemble
data assimilation
40 members
40/20 km

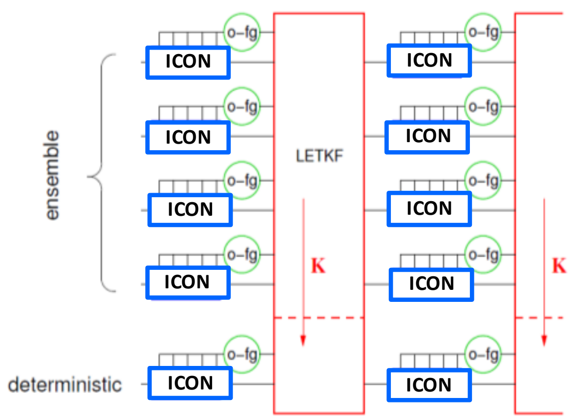


ICON
deterministic
13 / 6.5 km (Europe)

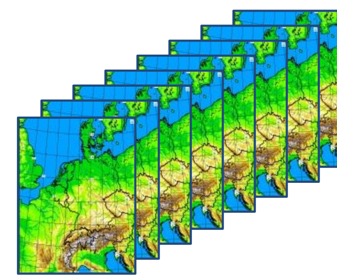
ICON-EPS
global **ensemble**
40 members
40 / 20 km (Europe)

GLOBAL

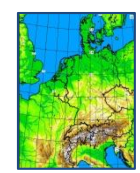
KENDA
regional
ensemble data
assimilation
40 members
2.2 km



ICON-D2-EPS
regional **ensemble**
20 members
2.1 km



ICON-D2
deterministic
2.1 km



REGIONAL

Ongoing work on EPS perturbations

Model perturbations

- Parameter Perturbation (currently operational method)
- Stochastic Shallow Convection (SSC)
- Physically based Stochastic Perturbations for boundary layer turbulence (PSP2)
- Stochastic Model of the Model Error (SMME)

Parameter Perturbation: operational

- A set of parameters of the model physics schemes are perturbed both in ICON-EPS and in ICON-D2-EPS.
- The parameters receive a value from a distribution (including the default value), different at each forecast start and for each member (the value is kept fix during the run):

$$pert\_param = ref\_param + 2.*(rand\_num - 0.5)*range$$

$rand\_num \in [0,1]$ is drawn from a uniform distribution

- ICON-EPS: the random number is used at face value
- ICON-D2-EPS: the random number is always set either to 0 or 1, i.e. only the boundary values of the specified range are used besides the default value

Time-dependent parameter perturbation

- aim: perturbation in the assimilation cycle
- temporally coherent perturbations between data assimilation and forecast ensembles
- time-dependent perturbations varying sinusoidally within their range. The randomisation is accomplished by a phase shift of the sinusoidal wave depending on the member ID (G. Zängl)
- variation of the parameters on a sinusoidal wave with a 2 week period
- evaluation is being performed in the DA cycle (WG1)

Parameter Perturbation: developments

- Introduce new parameter petrurbations
- Increase of the amplitude of the parameter ranges, as in ICON-EPS, is tested in ICON-D2-EPS (G. Zängl)
- Identify the new parameters to be perturbed or the parameters which values can be modified (based on the list of ICON parameters by Schlemmer et al.)

parameter	description	meaningful range	comment from the developers	model tuning	EPS perturbation	EPS perturbation in production
turbulence						
q_crit	critical value for normalised super-saturation	1.6-4.0	∄	identified as "sensitive" for COSMO in [1]	∄	ICON-D2-EPS
convection						
entrorg	Entrainment parameter in convection scheme valid for dx=20km	$1.95 \cdot 10^{-3} \pm 0.2 \cdot 10^{-3}$	corresponds to entr_sc in the shallow convection part of COSMO Tiedtke scheme	∄	∄	ICON-D2-EPS

Stochastic Workshop

- 2nd and 3rd of March 2021
- Several activities in the field of stochastic physics are on-going at DWD, to include these methods in the ICON model
- Purpose: to make the point about the activities on-going in the COSMO Consortium and in the other European Consortia in the field of "stochastic physics", in particular intrinsically stochastic parametrisations, in view of their usage in ensembles
- About 50 participants, from COSMO members, ECMWF, LMU, Meteo France, Met Office, Met Eireann, KNMI, SMHI, Met No, Met Hu, AEMET, NCAR, KIT
- Presentations and minutes: http://www.cosmo-model.org/content/tasks/workGroups/wg7/default.htm

Stochastic physics

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

A stochastic scheme to parameterise shallow convection

MODIS Aqua 20130505

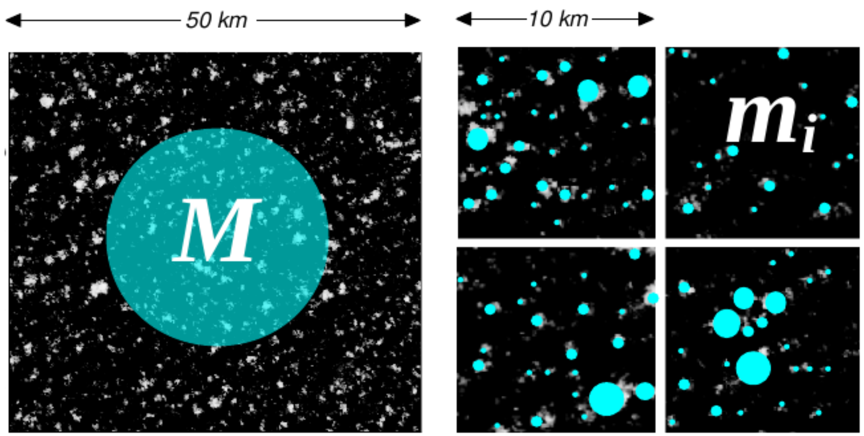
Maike Ahlgrimm, Mirjana Sakradzija, Alberto de Lozar, Ekaterina Machulskaya , Daniel Klocke,

Cathy Hohenegger, Axel Seifert …

Why stochasticity?

➔ We will never be able to predict individual clouds with accuracy – but we can predict their distribution statistics!

- Grid box area **too small** to contain a complete ensemble of convective clouds



M: mass flux of the ensemble   *mi: mass flux of an individual cloud*

➔ Convection is **not** in equilibrium with the large-scale state (closure)

➔ The resolved atmospheric state no longer predicts a **unique** (deterministic) convective state – there are many possible realisations!

- Parametrise effect of unresolved shallow convection (at km scale)
- A scheme that is resolution-independent and adapts automatically into the gray zone

M. Ahlgrimm, DWD

Stochastic shallow convection (SSC)

- first experiments run for 1 month in August/September 2020, only 00 UTC runs
- without grayzone-tuning
  (requires mass flux limiter to be switched on → conflict with SSC)
- neutral results
- next: tests in ensemble mode (ICON-D2-EPS) in BACY on-going
  - stochastic shallow convection only
  - parameter perturbation only
  - stochastic shallow convection + parameter perturbation
- Evaluation of diagnostic variables:
  - mf_b: "bulk" mass flux - used by the default convection scheme to measure convective activity
  - mf_p: stochastically "perturbed" mass flux - used in the stochastic scheme
  - ddt_qv_conv: convective tendency for qv
  - ddt_qc_conv: convective tendency for qc (liquid) condensate
  - ddt_temp_pconv: convective tendency for temperature

C. Gebhardt, C. Marsigli, DWD

Stochastic physics

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

WAVES TO WEATHER

Physically based stochastic perturbations for boundary layer turbulence : PSP (Kober and Craig, 2016)

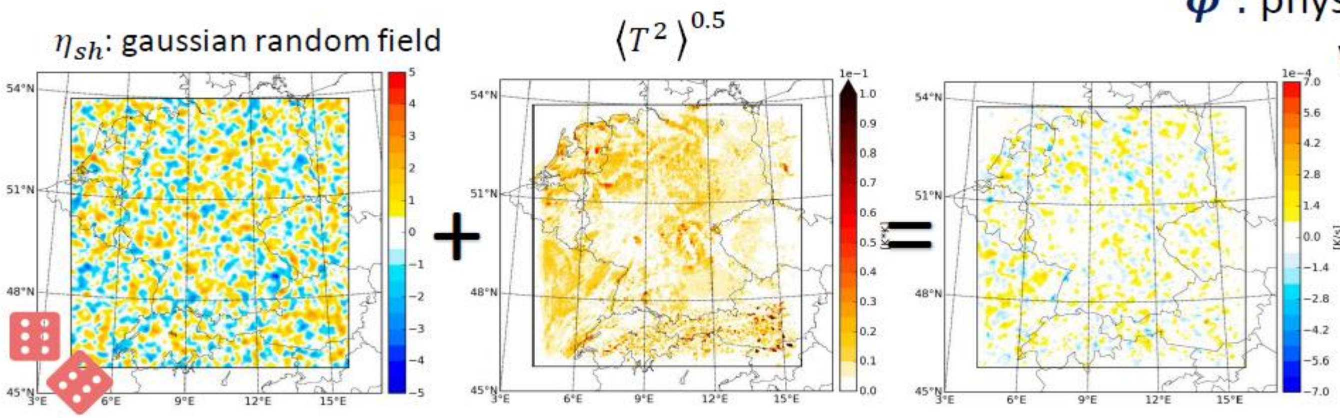
$$\left(\frac{\partial \phi}{\partial t}\right)_{all} = \frac{\partial \phi}{\partial t} + \underbrace{\alpha \cdot \boxed{\eta} \cdot \sqrt{\overline{\phi'^2}}}_{\text{Stochastic perturbations}}$$

ϕ ={T, q, w}

$\boldsymbol{\eta(t,\sigma)}$: Random field , regenerated every 10 min with spatial correlation σ

$\boldsymbol{\alpha}$: perturbation ampl., scaling factors

$\boldsymbol{\phi'}$: physical scaling/subgrid-scale variance of variable ϕ



(Kober and Craig, 2016)

It reintroduces the influence of the lost small-scale variability by adding perturbations to the tendencies of T, q_v, w on the smallest effectively resolved scale (5Δx)

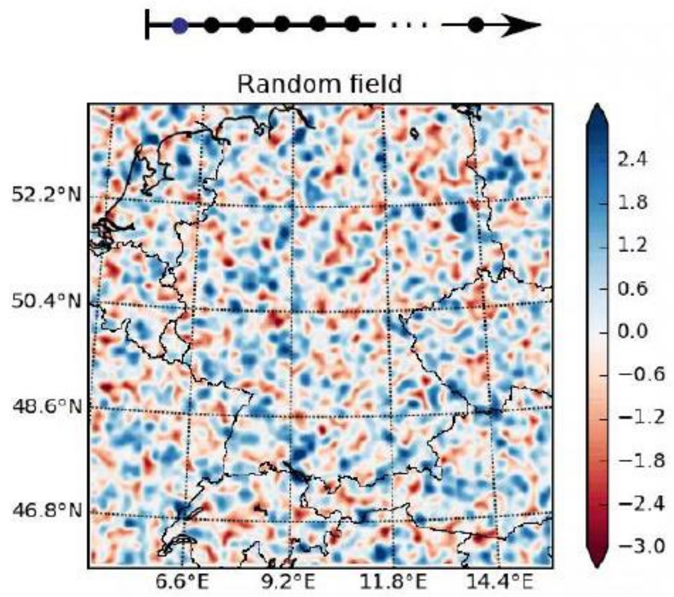
Modifications for improved physical consistency → PSP2

(Hirt et al., 2019, MWR)

- **Autoregressive Process**: Continously modifying η at every time step, but temporally correlated:

$$\eta_t = \sigma_t \cdot \eta_{t-1} + \epsilon_t$$

- Constraining the perturbations to the boundary layer (HPBLcut)
  → Reduce impact of perturbations at night
  →Scheme developed for buoyant turbulence, not shear (vertically correlated perturbations)



WAVES TO WEATHER

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

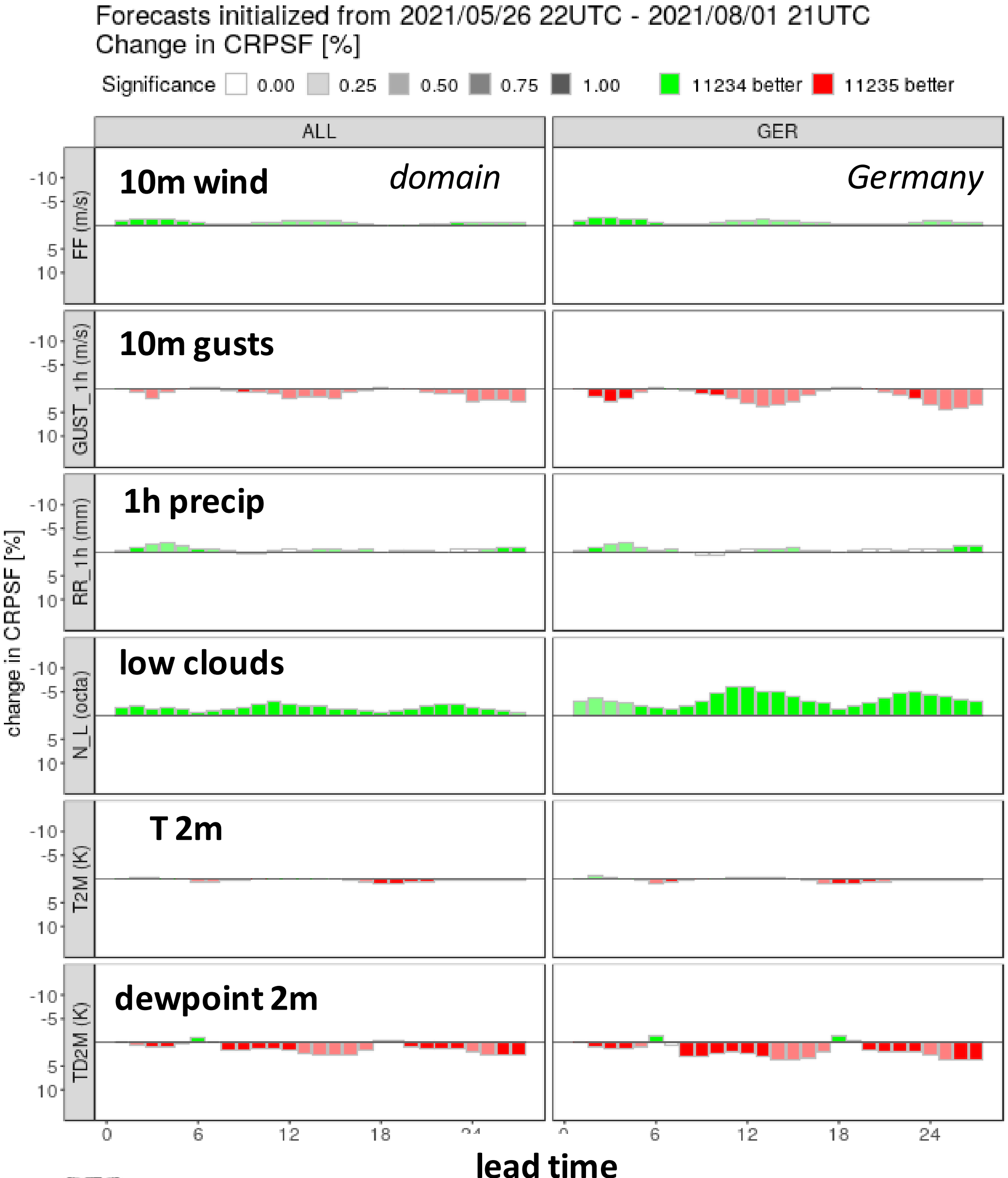
Physically based stochastic perturbations for boundary layer turbulence (PSP2)

- cooperation with Ludwigs-Maximilian-Universität in Munich (LMU)
- first promising tests at LMU
- PSP2 is implemented in the ICON at LMU based on the "current" version of the branch "icon-nwp/icon-nwp-dev" (including cp/cv bugfix & ecRad)
- next:
  - BACY tests for a short period in August 2020 with ICON-D2-EPS
  - Test run from May 26th to August 1st 2021 at DWD

WAVES TO WEATHER

C. Gebhardt, C. Marsigli, DWD

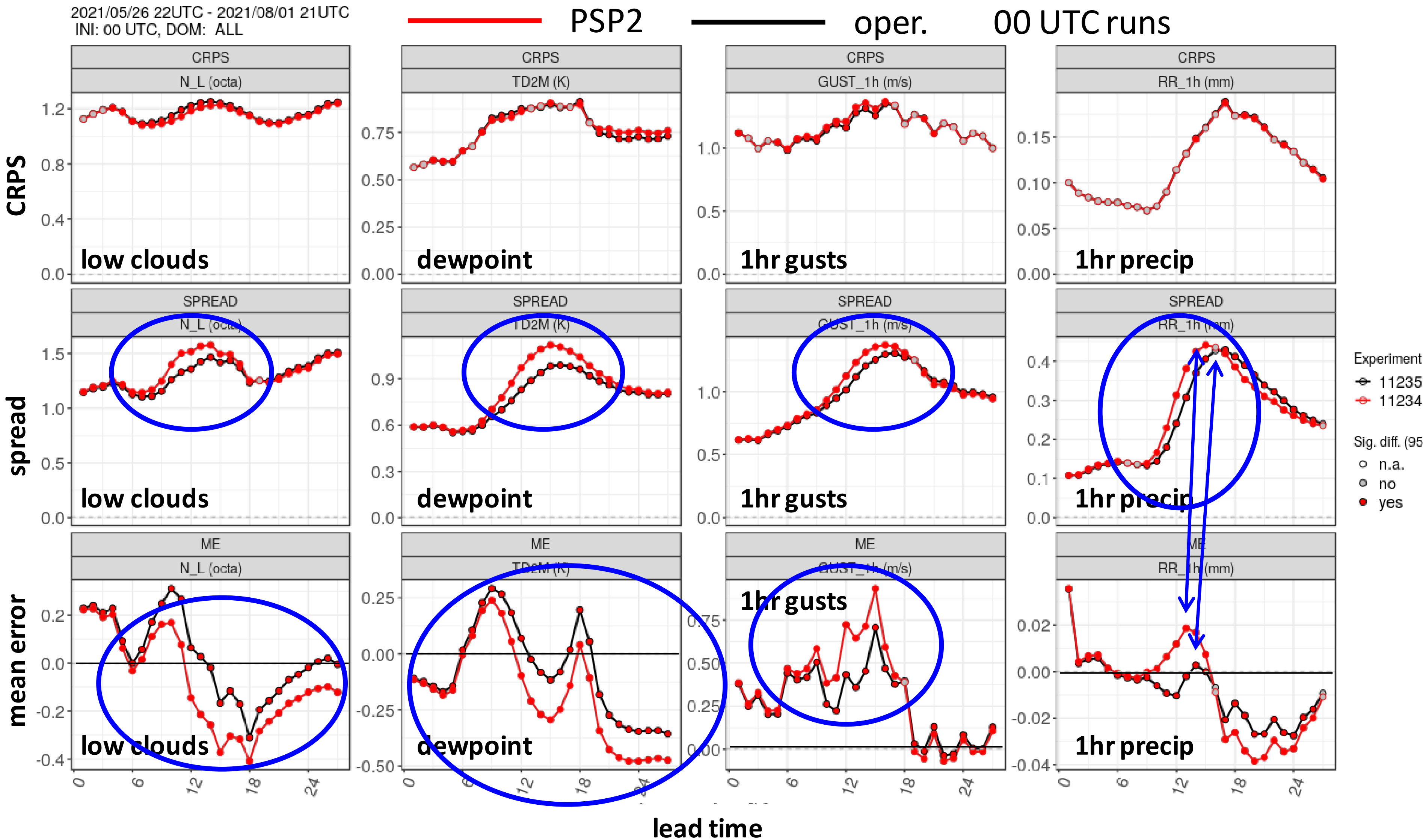
Stochastic physics



- ICON-D2-EPS with PSP2 vs. operational set up
- Change of CRPS
- green: PSP2 better
  red: PSP2 worse
- 26th May – 1st Aug 2021
  00 and 12 UTC runs
- SYNOP observations

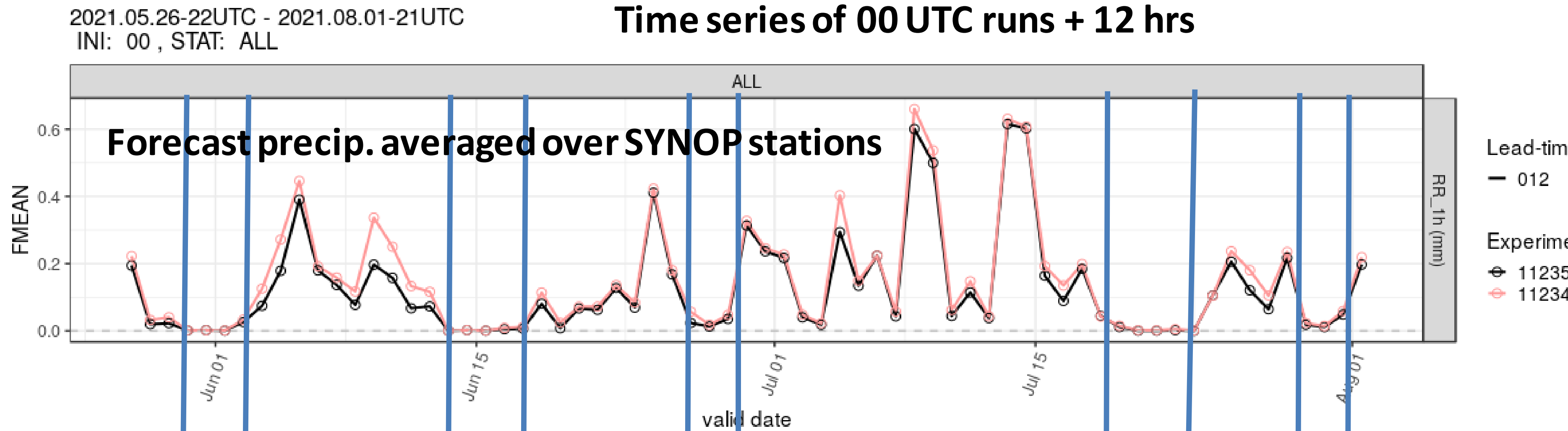
Stochastic physics

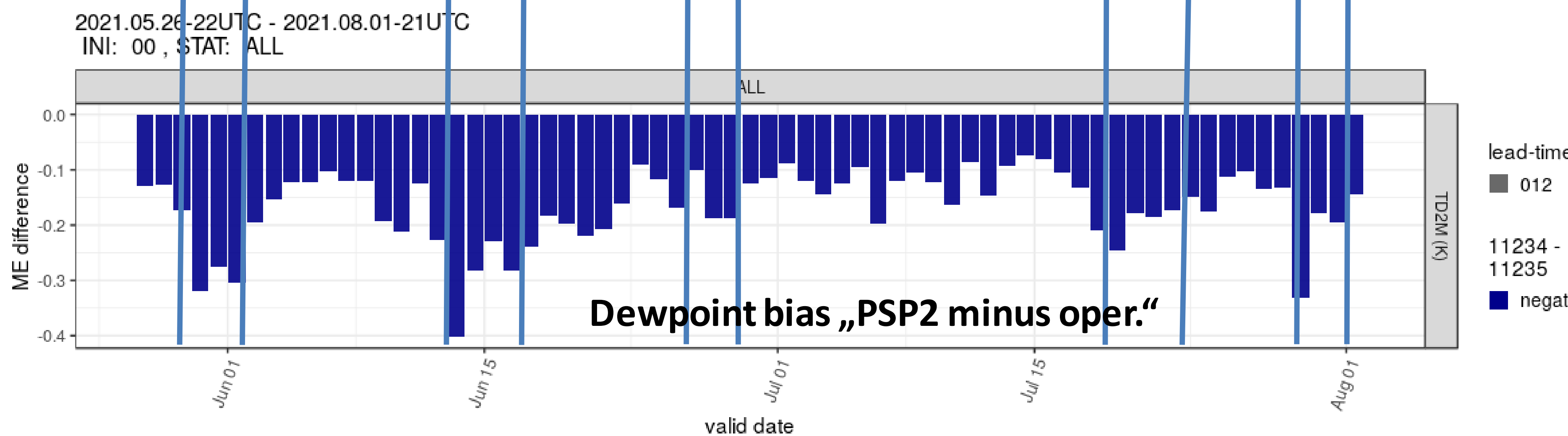
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Stochastic physics

Time series of 00 UTC runs + 12 hrs





Stochastic Model of the Model Error (SMME)

- SMME aims at modeling the model error by integrating a stochastic partial differential equation at different heights levels for u, v, and T.
- The solution of the SPDE has spatial and temporal correlations corresponding to the model error in the training data set.
- These solutions of the SPDE (of course different in each member of the ensemble) are added to the tendencies in the slow physics scheme

$$\frac{\partial \psi}{\partial t} = \left[\frac{\partial \psi}{\partial t}\right]_{\mathrm{det}} + \eta(t) \qquad \frac{\partial \eta}{\partial t} = -\gamma\eta + \gamma\nabla\cdot(\lambda^2\nabla\eta) + \sigma\xi(t)$$

ψ : perturbed variables (T, U, V)

$\eta(t)$: noise field / model error, correlated in time and space

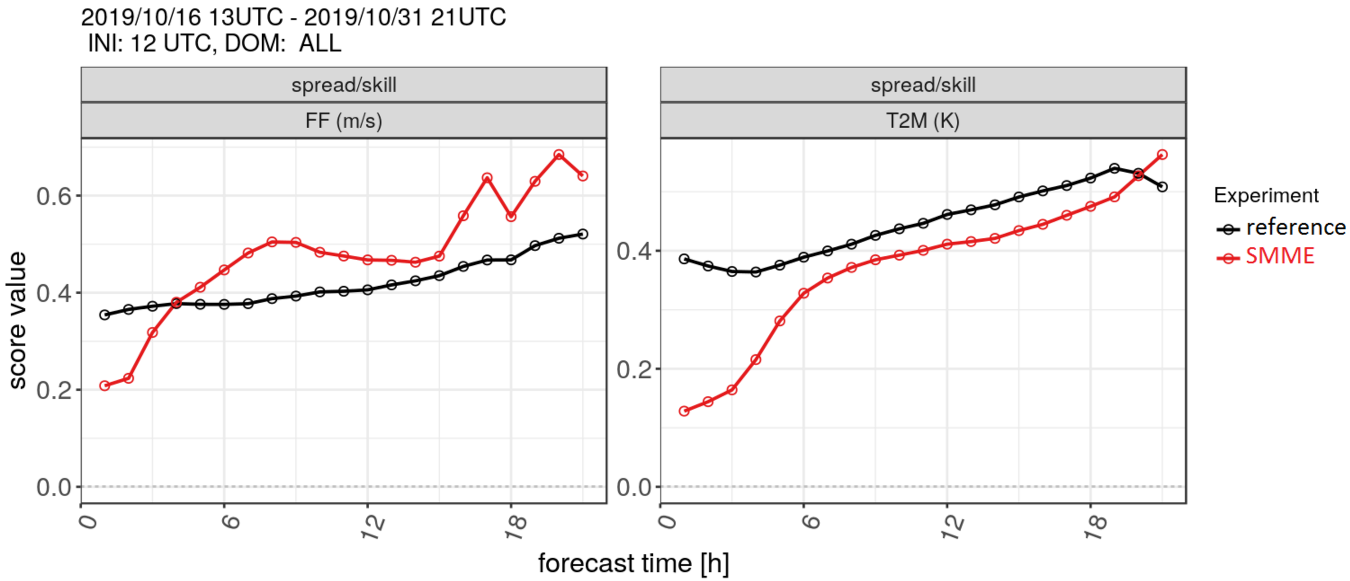
$\xi(t)$: Gaussian noise

γ, λ and σ are weather-dependent parameters and are derived from past data

M. Sprengel, DWD

Stochastic Model of the Model Error (SMME)

- First experiments with COSMO-D2-EPS looked promising
- Currently porting the SMME to ICON-D2-EPS
  - Parameter estimation for ICON-D2-EPS is completed
  - First runs with ICON-D2-EPS show mixed results (SMME exp; reference)



  - spread/skill improvement for wind speed but not for T2m
    → further work needed

M. Sprengel, DWD

FE1 Working Group Ensemble Perturbations for ICON-EPS, global and regional

- The WG synchronizes the activities dealing with Ensemble Perturbations which take place in the different areas of the Numerical Modelling department (FE1), in particular when these activities require advice or contributions from other areas or when they have an impact on their activities
- It provides an opportunity for solving issues of synchrony and efficiency internally to DWD

Representing model error in ensemble systems

Multi-approach

Multi parametrisation
Multi parameter
Multi model

PP

Stochastic physics

PSP2

SSC

Probabilistic representations of a specific subgrid process: the perturbations directly represent model uncertainties at its known sources.

Process-level stochasticity

AMPT

SPPT

SMME

Pragmatic approaches characterise uncertainty in deterministic models. Provide a bulk representation for many types of model error.

Bulk stochasticity

Thank you for your attention!

Parameter list for ICON

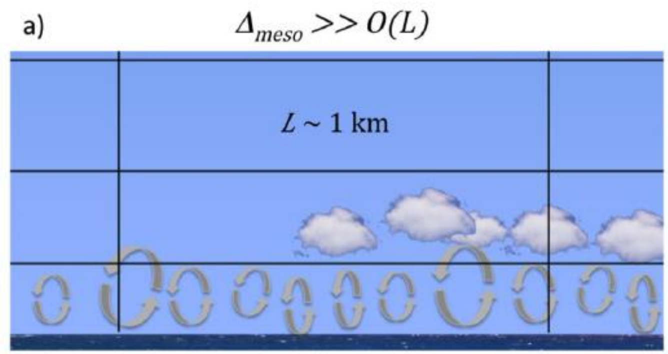
- A list of ICON parameters for tuning and model perturbation has been provided by L. Schlemmer et al.
- A dedicated webpage has been prepared on the COSMO website: http://www.cosmo-model.org/content/support/icon/tuning/default.htm
- It aims at including also the experience matured on the usage of the parameters

parameter	description	meaningful range	comment from the developers	model tuning	EPS perturbation	EPS perturbation in production
turbulence						
q_crit	critical value for normalised super-saturation	1.6-4.0	∄	identified as "sensitive" for COSMO in [1]	∄	ICON-D2-EPS
convection						
entrorg	Entrainment parameter in convection scheme valid for dx=20km	$1.95 \cdot 10^{-3} \pm 0.2 \cdot 10^{-3}$	corresponds to entr_sc in the shallow convection part of COSMO Tiedtke scheme	∄	∄	ICON-D2-EPS

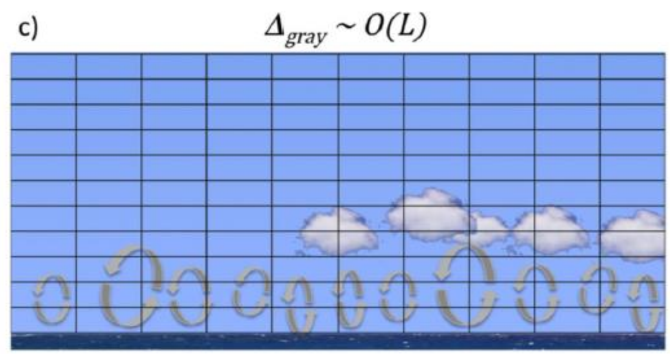
Stochastic physics

Parameterizations are intrinsically stochastic

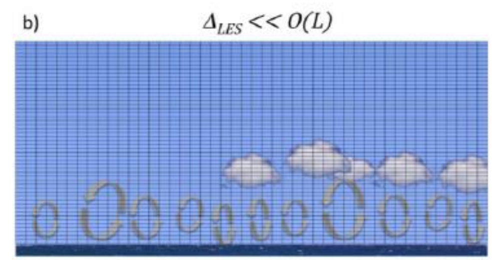
- Parameterization gives net effect of many small elements (size *L*)
- Scale separation, grid length $\Delta >> L$, ensures well-defined result



- Gray zone, $\Delta \sim L$, range of possible results on grid scale – **stochastic**



...or resolve elements $\Delta << L$, LES



Chow et al. *Atmosphere* 2019

Courtesy of George Craig (LMU)

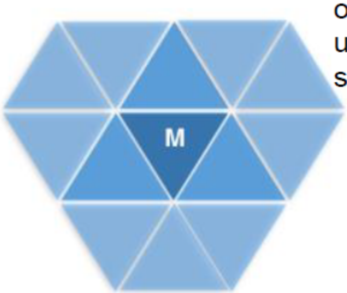
Stochastic Workshop

- Some perturbations need surprisingly large scales to be effective
  - What are the optimal length scales for spatial patterns at the convective scale?
- Error growth changes for strongly and weakly forced regimes
- Epistemic uncertainty and aleatoric uncertainty:
  - aleatoric uncertainty is associated with the many subgrid-scale states associated to the same grid-scale state. However, since we do not have a perfect paramterisation, we are still addressing the epistemic uncertainty. Likely the latter will be reduced as long as the former is developed.
- It is not possible yet to develop the two components independently from each other

Stochastic shallow convection (SSC)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

How is the cloud ensemble at a single grid point generated?



1) Mass flux representative of large scale is calculated using the Tiedtke-Bechtold scheme <M>

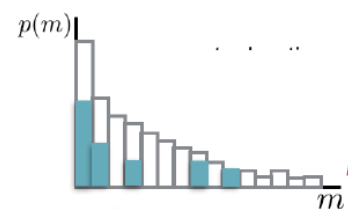
first call to convection

$$p(m) = \frac{k}{\lambda^k} m^{k-1} e^{-\left(\frac{m}{\lambda}\right)^k}$$

2) Construct the mass flux distribution. Distribution parameters include <M> and the Bowen ratio

3) Draw number of newly generated clouds from Poisson distribution, and randomly assign them a mass flux mi

$$p(n) = \frac{\langle N \rangle^n e^{-\langle N \rangle}}{n!}$$



4) Add up mass flux (m) of individual clouds to get the grid box mean mass flux (M)

$$M = \sum_{i=1}^{n} m_i$$

5) Call Tiedtke-Bechtold scheme a second time (this time using the stochastically perturbed mass flux M) to generate convective tendencies

second call to convection

M. Ahlgrimm, DWD

COSMO: Schemes for model perturbation in ICON

- DWD, MeteoSwiss, RHM are implementing different schemes for (bulk) model perturbation in ICON
- The implementation should be made in a consistent way and possibly using a unified interface.
- It is a very good testbed for the organization of the inclusion of COSMO contributions in the ICON code

- DWD: SMME scheme
- MCH: (i)SPPT scheme
- RHM: AMPT scheme based on the Stochastic Pattern Generator