Deutscher Wetterdienst
Wetter und Klima aus einer Hand

MODIS Aqua 20130505

A stochastic scheme to parameterise shallow convection

Maike Ahlgrimm, Mirjana Sakradzija, Daniel Klocke, Cathy Hohenegger, Axel Seifert…

How is this relevant to ensemble prediction?

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- Parameterised convection typically produces too little spread in the EPS
- Difficult to add artificial perturbations that are physically consistent, situation-aware and persist in time

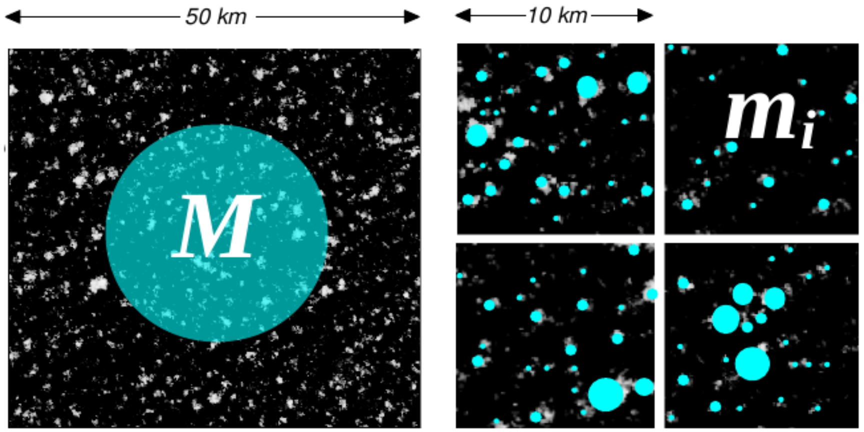
- Stochastic convection scheme is scale adaptive and produces perturbations to the convective tendencies that are consistent with the model state and the large-scale forcing
- We hope: Scheme will produce sufficient spread that additional measures will be superfluous

Photo: B. Stevens, eurek4a.eu; Shallow convection during the NARVAL1 Experiment

Basic concept:

1) Large-scale state **determines** convective activity at scales 50-100km, expressed as **cloud-base mass flux**

2) At higher resolution, grid box area **too small** to contain a complete ensemble of convective clouds -> mass flux no longer deterministic!



M: mass flux of the ensemble

mi: mass flux of an individual cloud

3) Predict **cloud ensemble properties**, then draw stochastic sample of clouds from distribution for each small grid cell

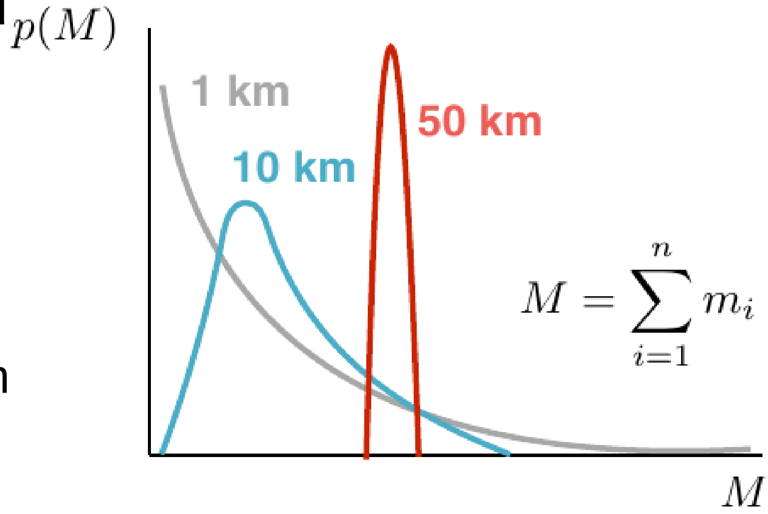
4) Average over individual clouds' mass flux in grid cell (m_i) is the "stochastically **perturbed mass flux**" used to calculate convective tendencies

The idea: Predict the cloud ensemble

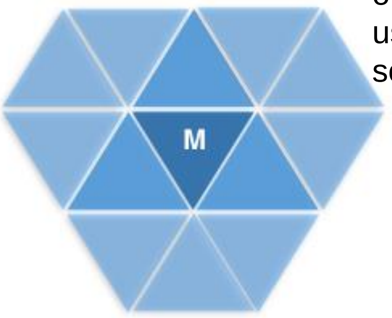
- The **mass flux on large scales** (where traditional assumptions are a good approximation) is determined with the **classical parameterisation** (Tiedtke-Bechtold/IFS)

- At **individual grid points**, a **stochastic cloud ensemble** is generated whose mass flux (averaged across larger scales) converges to that of the classical parameterisation

- Bonus: The **ensemble automatically adapts to the grid resolution**. The smaller the grid spacing, the greater mass flux departures from the ensemble mean



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>

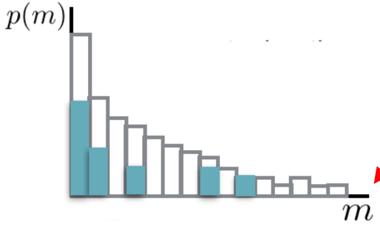
first call to convection

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

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

3) Draw number of newly generated clouds from Poisson distribution

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



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

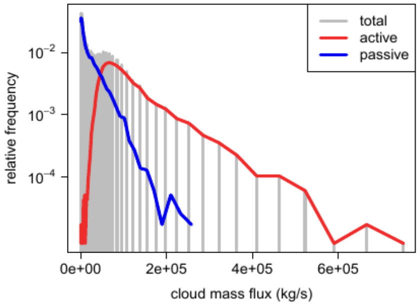
second call to convection

(Craig and Cohen 2006; Plant and Craig 2008; Sakradzija et al. 2015, 2016)

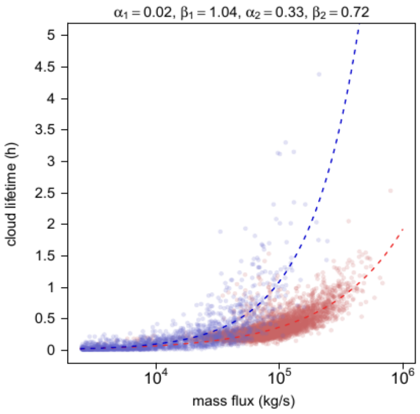
Distributions are based on LES studies

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

(a) cloud rate distribution



(b) cloud lifetime



Sakradzija et al. 2015

LES mass flux distribution has **two modes**:
active and passive Cu
Is well-appoximated by a **mixed Weibull distribution.**

$$p(m) = \sum_{j=1,2}^{2} f_j \frac{k_j}{\lambda_j} \left(\frac{m_j}{\lambda_j} \right)^{k_j - 1} e^{-(m_j/\lambda_j)^{k_j}}$$

The **lifetime** of individual clouds depends on their mass flux – large clouds (with large mass flux) live longer.

$$\tau_i = \alpha_i m^{\beta_i}$$

LES studies show that the difference between **maritime** and **continental shallow convection** is determined largely by the **Bowen ratio**.

-> lambda(B)
k, beta constants from LES

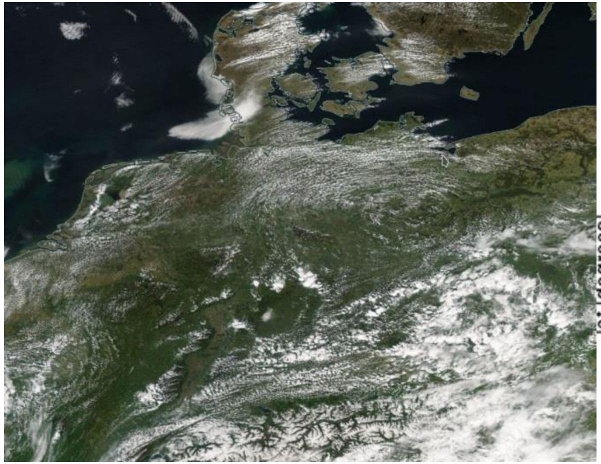
Sakradzija und Hohenegger 2017

The mass flux of **each individual cloud** within the grid cell is tracked over time.

Important points in implementation

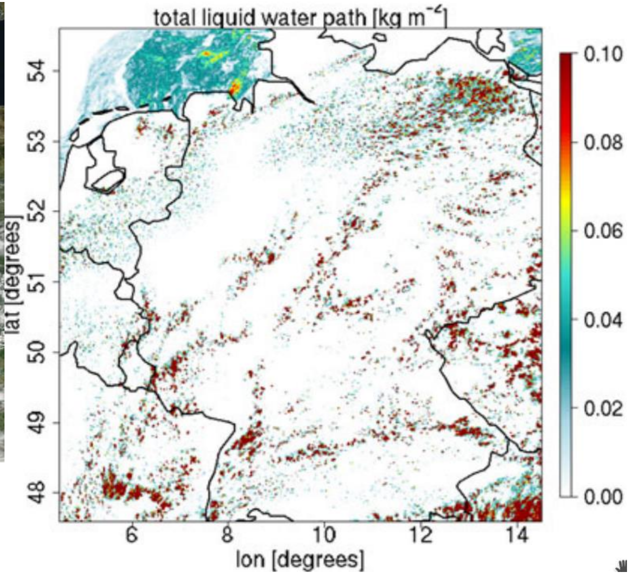
- ➔ We still assume that the traditional closure and parameterization holds for large scales
- ➔ The scheme is scale-adaptive, but does not necessarily converge at LES resolution (i.e. mass flux concept may be inappropriate at scales of ~100m)
- ➔ Two convection calls are necessary
- ➔ Two “flavours” of the scheme: explicit stochastic or stochastic differential equations. The first needs lots of memory (keeps track of individual clouds), the second needs four additional prognostic variables (simple restart possible!)
- ➔ Tendencies are calculated using the normal convective closure, i.e. tendencies are entirely consistent with model state
- ➔ Perturbations depend on large-scale state – e.g. no perturbations in non-convective areas, perturbations scaling with convection intensity in areas with convection.
- ➔ Mass flux limiters and resolution-dependent tuning parameters can (and must) be turned off for scheme to perform

Case study: 2013-05-05

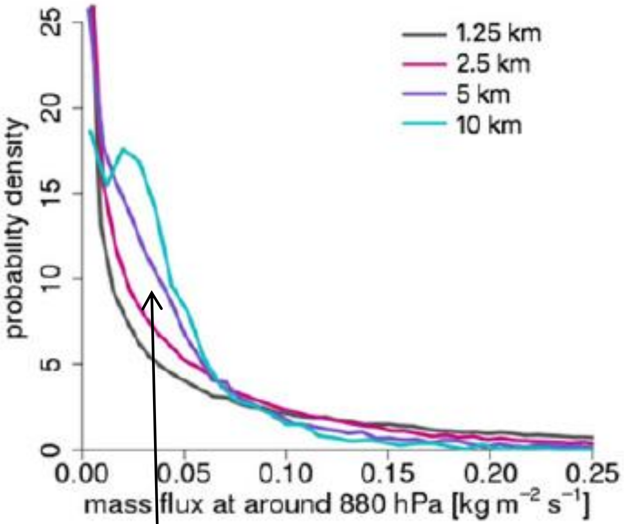


MODIS Aqua VIS

Day with shallow convection over Germany



Liquid water path

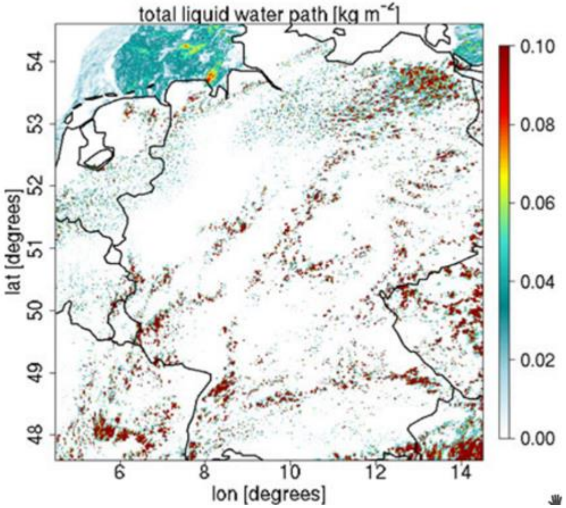


Expected scale-adaptivity of the mass flux

ICON LES reference

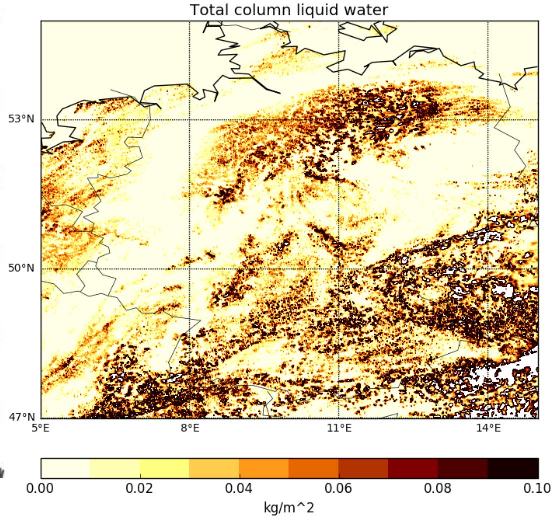
Stochastic convection scheme is able to reproduce characteristics of LES

LES

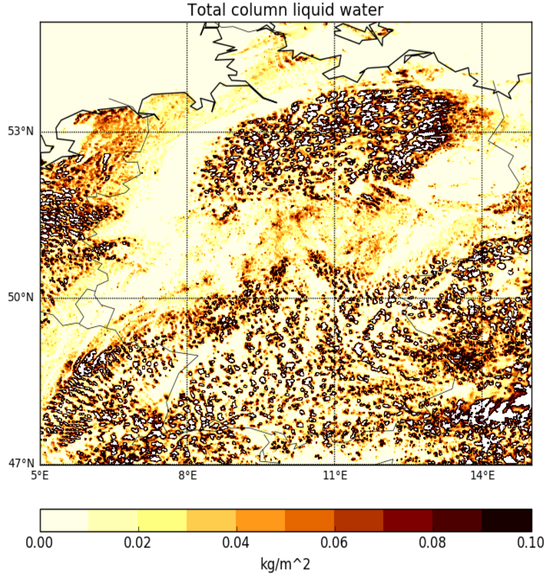


Sakradzija und Klocke 2018

stochastic convection



conventional convection*

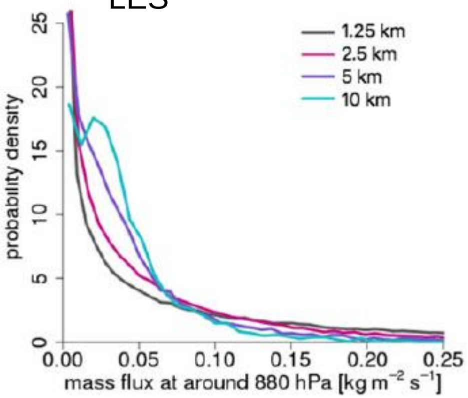


liquid water path

*without MF limiter or cloud tuning

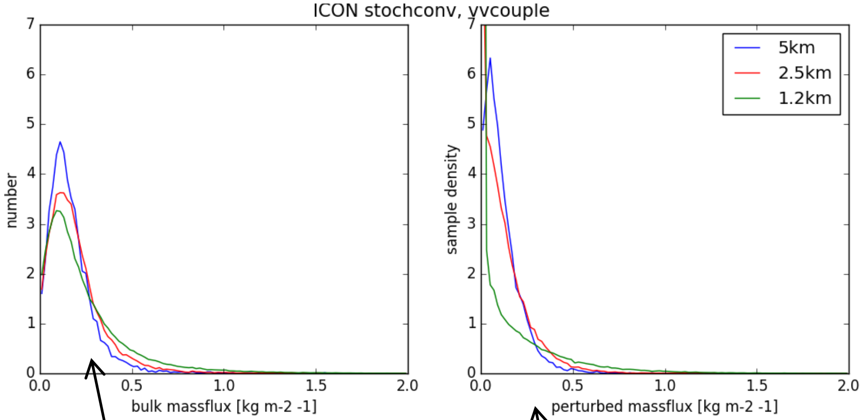
Stochastic convection scheme is able to reproduce characteristics of LES

LES



Sakradzija und Klocke 2018

stochastic convection



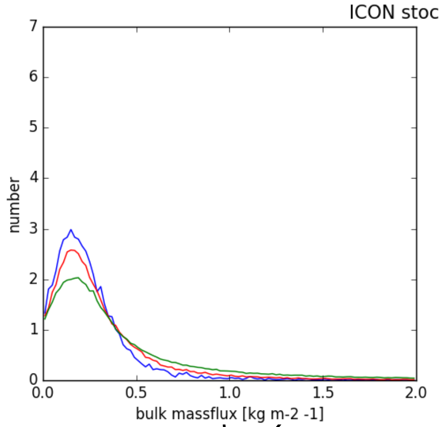
bulk mass flux

should be scale-invariant if calculated at a fixed 50km scale, but isn‘t due to varying size of halo stencil with resolution

stochastic mass flux

expected scale-adaptivity with more exponential-like perturbed mass flux distribution at higher resolution

conventional convection

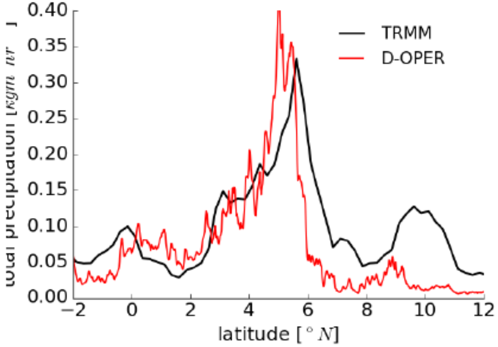


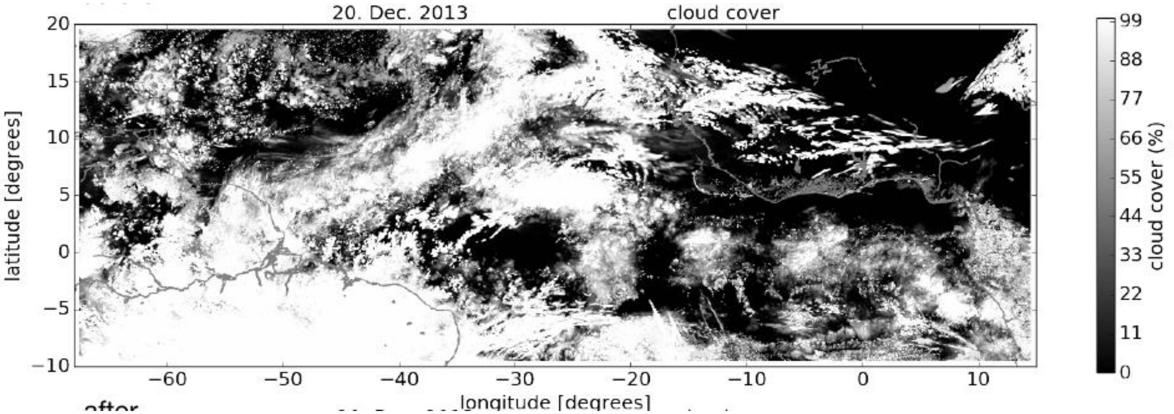
effect of mass flux limiters

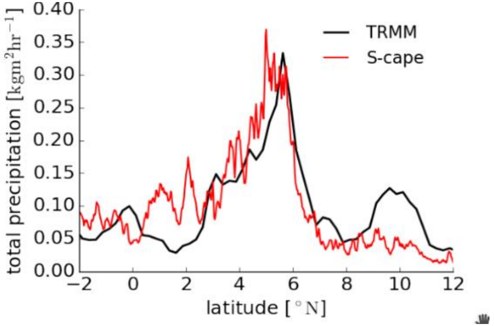
Works for maritime convection, Atlantic

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Cooperation mit Mirjana Sakradzija, Fabian Senf (Daniel Klocke, Leonhard Scheck)







Improved cloud cover and position/intensity of precipitation in the ITCZ

Branch: icon-nwp/icon-nwp-newsde (preliminary!)


```
&nwp_phy_nml
lstoch_conv      = .false.      ! explicit stochastic scheme
lstoch_sde       = .true.       ! stochastic differential equations
lvvcouple        = .false.      ! use vertical velocity criterion to disallow shallow Cu parameterisation
lvv_shallow_deep = .false.  ! use vv to differentiate between shallow/deep convection
                                (default: use cloud depth)
lrestune_off     = .true.       ! switch off resolution-dependent tuning in convection scheme
luse_poisson     = .true.     ! draw from Poisson distribution, default (alternative: Gauss)
/
&io_nml
 inextra_3d        = 2          ! 3D extra variables
/
```

To enable piggy-backing: set lpassive in mo_nwp_conv_interface.f90

Status:

- ➔ Two “flavours” now quite consistent
- ➔ Testing so far largely in hindcast mode
- ➔ SDE probably more suitable for use in EPS since the state of the stochastic convection can be saved for restart with only 4 prognostic variables (rather than having to save the entire explicit cloud ensemble state)
- ➔ Currently performing further evaluation to assess performance