Towards operational implementation:

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

MODIS Aqua 20130505

A stochastic shallow convection scheme

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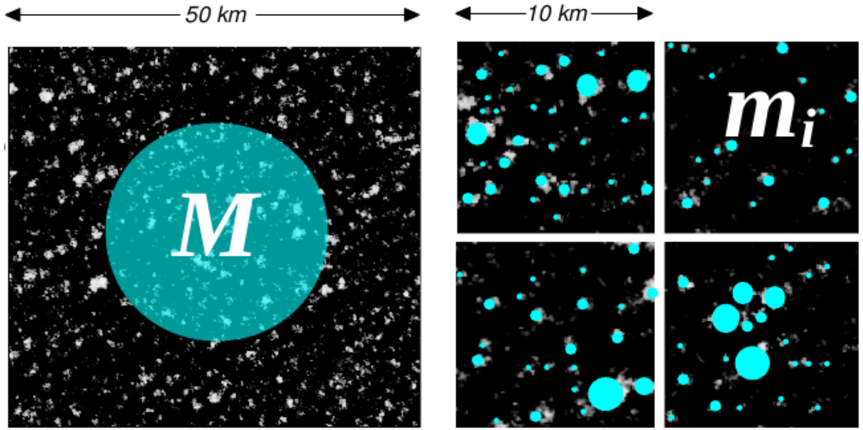
A km-scale grid box is too small to contain a representative shallow cloud ensemble

➔ Yet this is a fundamental assumption of traditional convection parameterizations

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



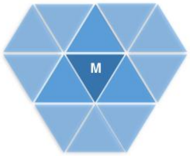
M: mass flux of the ensemble *mi: mass flux of an individual cloud*

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

➔ **The stochastic convection scheme adresses this particular limitation of conventional convection parameterizations**

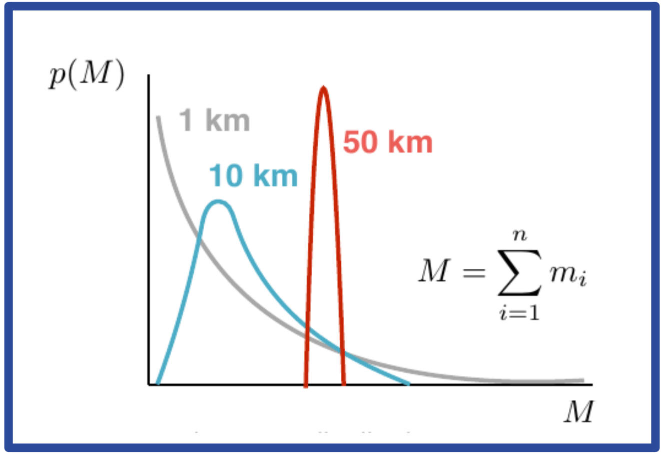
Predict cloud ensemble properties, stochastically sample ensemble to populate the grid box

1) Retain Tiedtke-Bechtold mass flux closure, but apply to a sufficiently large neighbourhood

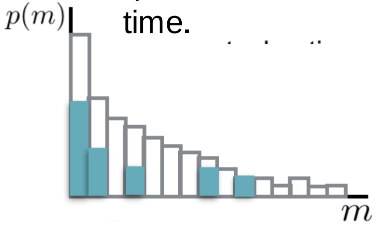


2) Construct the mass flux distribution. Distribution parameters include <M> and the Bowen ratio

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



3) Stochastically generate clouds within each grid cell, and assign each a „perturbed“ mass flux and life time.



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

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

(Craig and Cohen 2006; Plant and Craig 2008; Sadkradzija et al. 2015, 2016; Sakradzija and Hohenegger 2017, Sakradzija and Klocke 2018)

An approximation with Stochastic Differential Equations (SDE) is available

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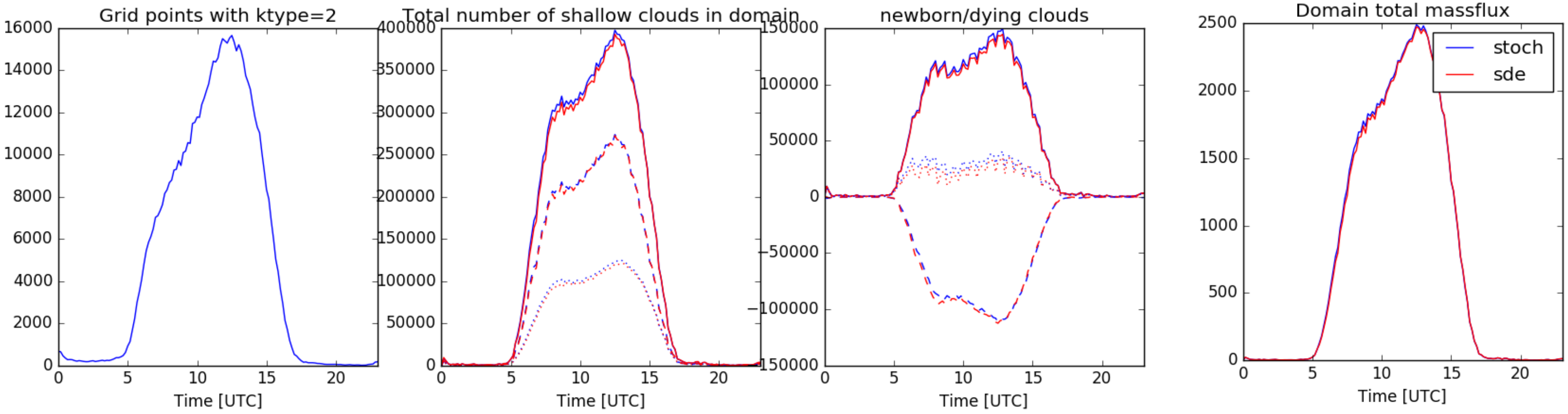
ICON D2 simulation of a single day 20130505 with shallow convection

Diurnal cycle of domain total cloud numbers and mass flux are comparable:



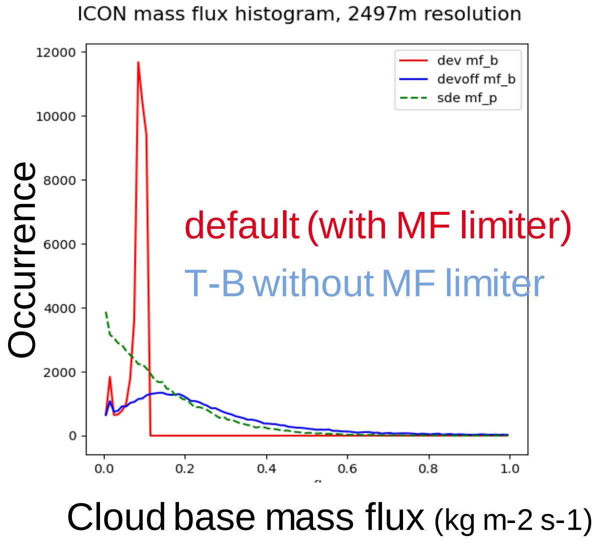
SDE version uses 4 prognostic variables to track state of cloud ensemble, can be saved for restart/cycling

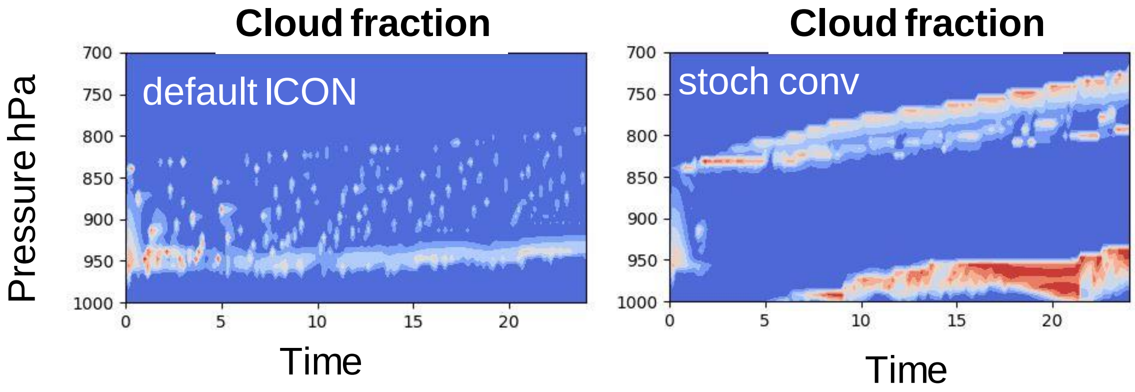
Explicit version keeps track of up to 5000 individual clouds per grid cell – easy to extend

(Machulskaya and Seifert, 2019)

The scheme still relies on traditional assumptions, does not converge to LES

- ➔ Inherits T-B mass flux closure – requires limiters and tuning in ICON to achieve acceptable convective activity
- ➔ Weak convection in small grid box -> converges to single cloud in grid cell. Yet updraft calculation of T-B assumes a plume representative of cloud ensemble
- ➔ Weaknesses of T-B scheme revealed:
  - ➔ on/off behavior in time compensates for poor instantaneous representation of the cloud ensemble





BOMEX SCM simulations

Extensions: explicit representation of updraft core, detrainement profile, spinup/decay

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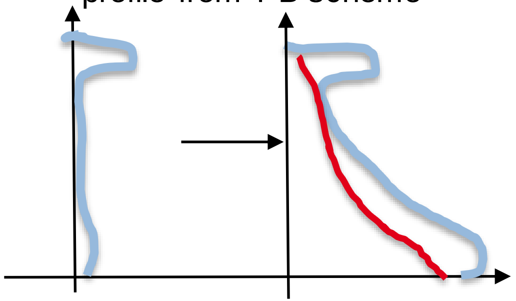
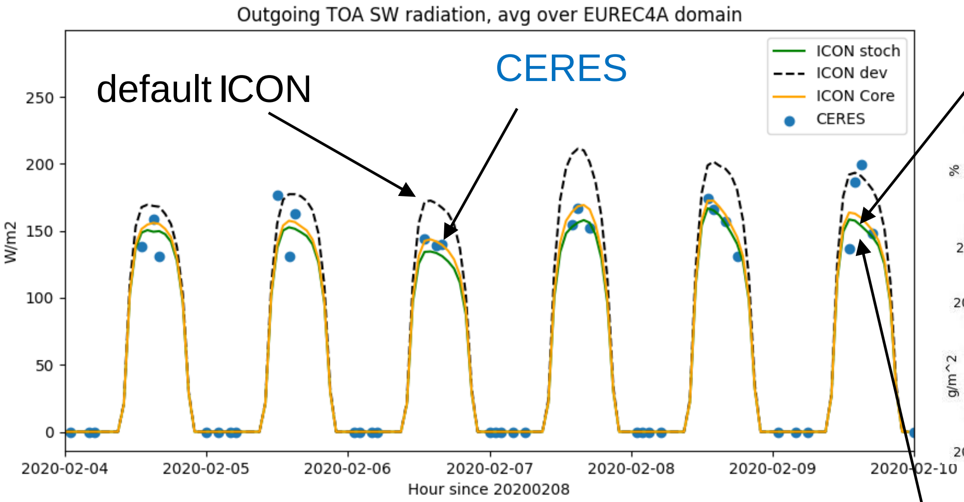
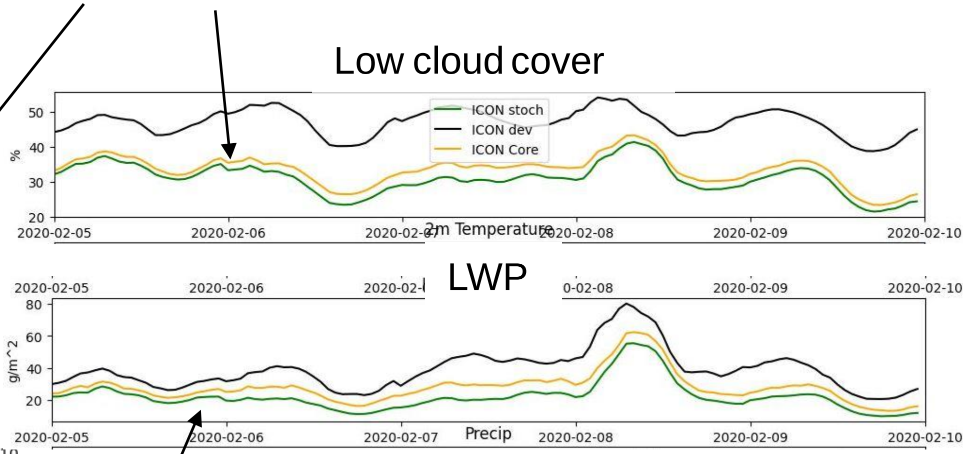
- ➔ Approximation using Stochastic Differential Equations (SDE) implemented
  - ➔ use either, or use in piggy-backing mode
- ➔ Spinup/decay options
  - ➔ let the cloud ensemble evolve gradually, or spin-up instantly to be in equilibrium with forcing?
- ➔ Representation of the updraft core
  - ➔ can we really assume that the updraft fraction is small relative to the grid size, and is it irrelevant for radiation?
- ➔ Lateral entrainment/detrainment profile
  - ➔ derive individual cloud's maximum height and use for construction of detrainment profile representative of the cloud ensemble within the grid box



Performance example: EUREC4A

Averaging CERES FlashFlux over EUREC4A domain



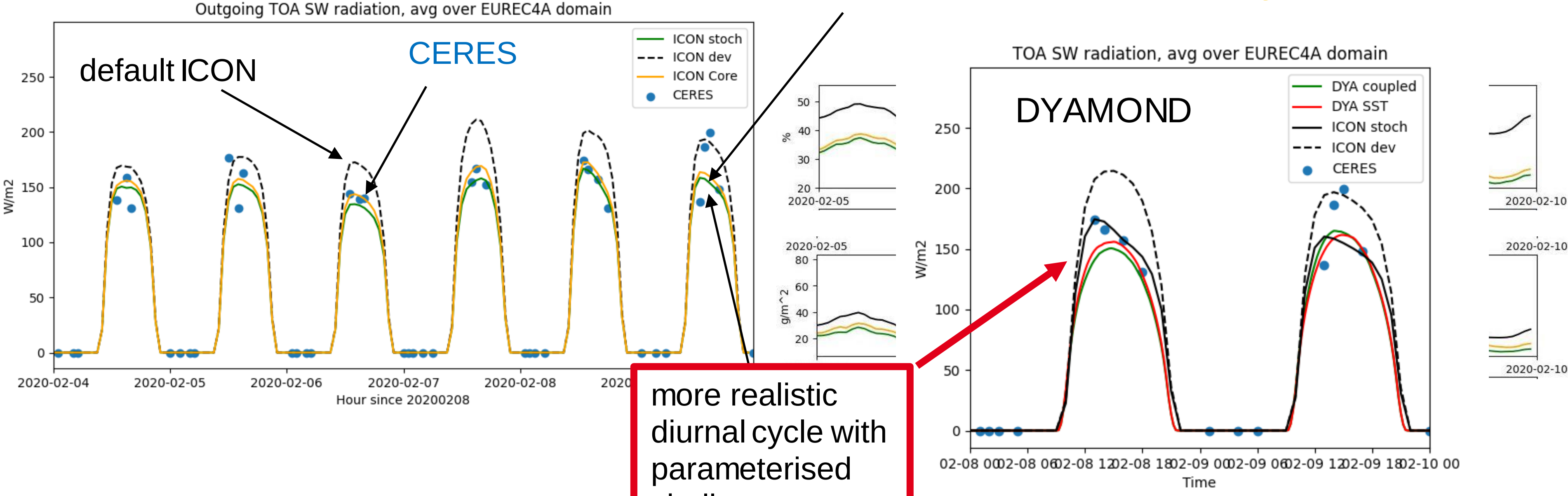


Upwelling SW reduced for stochastic scheme – more in line with CERES obs.

Performance example: EUREC4A

Averaging CERES FlashFlux over EUREC4A domain

stochastic scheme, accounting for cloud core



more realistic diurnal cycle with parameterised shallow convection

Upwelling SW reduced for stochas … re in line with CERES obs.

Benefits

- ➔ Scale-adaptive convection parameterization for grayzone resolutions
- ➔ Scheme models temporal evolution of convection; cohesive in time, stochastic in space
- ➔ Improved resolved-flow interaction *(see M. Sakradzija on Tropical Atlantic case)*
- ➔ Potential to produce more realistic, situation dependent spread in ensembles (tbd)
- ➔ More computationally efficient SDE version available (though still twice the cost of standard convection)

Challenges

- ➔ Hindcast scores promising, but not (yet) matching performance of parallel routine
  - ➔ alternative to tuning via mass flux limiter is required
  - ➔ big bug fix in ICON which has shifted model state significantly, required retuning now mixes shallow/deep parameterizations (interim solution) – need proper shallow scheme to work again
- ➔ Impact of convection scheme on radiation is “filtered” through subgrid diagnostic cloud scheme, and a lot can be “lost in translation” *(see M. Köhler on diagnostic cloud scheme)*