Implementation of the hybrid cumulus convection parametrization scheme HYMACS in ICON

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1) Introduction

- Representation of cumulus convection in numerical weather prediction (NWP) model is crucial
- Severe weather events (torrential rain, wind gusts etc.) driven by atmospheric circulation systems and multiscale interaction
- Classical convection parametrization schemes (CPS) designed for coarse grid spacing (dx~50 km)
- Contemporary NWP models operate in convective grey zone (dx~1–10 km) → deep convection is neither a grid scale nor a purely subgrid scale process (see Fig. 1)
- Assumption of local subsidence within convectively grid column has been questionable

2) Method and aim

Method:
- Overcome conceptual problem of local subsidence with an alternative approach developed for a wide range of different grid spacings in NWP models (dx~1–50 km)
- Hybrid Mass Flux Convection Scheme (HYMACS)
  - Up- and downdrafts are still subgrid scale processes
  - Subsidence is treated explicitly by grid scale dynamics
- HYMACS has already been implemented successfully in the non-hydrostatic COSMO model by Kuehl et al. (2007)

Aim:
- Improve dynamical response to deep convection within the model
- Improve spatio-temporal precipitation forecast by ICON

3) HYMACS core

a) Inclusion of a net convective mass transport
- Consideration of a fluid volume consisting of a convective part Vc and a non-convective environment Vnc (see Fig. 2) gives an additional convective mass flux term Jc, in the continuity equation

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v}_c) = 0
\]

b) Cloud model
- Describe the thermodynamics of the parameterized cloud, i.e. updraft and downdraft in HYMACS → diagnose ice/liquid water static energy \( \rho h \)

\[
\text{Udpdraft} + \text{Downdraft}
\]

The local change in density, i.e. the density of a grid box, can be split into an environmental mass flux divergence (grid scale advection) and into a convective mass flux divergence (parameterized HYMACS).

- The prognostic equation of any specific quantity \( \Psi \) can be derived analogously

\[
\frac{\partial \rho}{\partial t} = \nabla \cdot (\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v}_c) + \nabla \cdot (\rho \mathbf{v}_\Psi)
\]

- Calculation of deep convection for different grid spacings in a meteo model

4) On the benefit of HYMACS- A case study with COSMO

Approach:
- Perform 24-h simulations with COSMO during a period with strong convection (2016/05/30–2016/06/05)
- Compare simulations with different CPS: HYMACS (HYM) vs. Tiedtke (1993)

Results:
- Better representation of diurnal cycle with HYMACS
- Precipitation peak in the late afternoon in accordance with observations (Fig. 4+5)
- Reduced RMSE of total precipitation rates (110 kg/m²)

5) HYMACS in ICON

- HYMACS returns convective tendencies of enthalpy \( h \), density \( \rho \), momentum and of the moisture component \( q_r \)
- Tendencies have to be transformed to the appropriate prognostic variables of the respective hosting model

- Forecasting the case study of HYMACS in ICON and analyzing the grid scale (thermo-)
- Dynamic response with special regard to the generation of gravity waves and secondary circulations
- Further moisture convection experiments and comparison with respective COSMO simulations (see Kuehl et al. (2007) and Kuehl and Bott (2008))
- Idealized single convective cell in a conditionally unstable background atmosphere
- Idealized diurnal cycle of convection in a sea breeze simulation
- Perform real case studies with HYMACS in ICON including validation and verification against observations
- Further tuning of HYMACS (CAPE-based closure assumption, entrainment and detrainment rates mimicking behavior of convective cloud ensemble...)

6) Outlook

- Perform idealized dry mass lift experiments (i.e. no enthalpy and moisture transport with HYMACS in ICON and analyze the grid scale (thermo-)
- Dynamic response with special regard to the generation of gravity waves and secondary circulations
- Further moisture convection experiments and comparison with respective COSMO simulations (see Kuehl et al. (2007) and Kuehl and Bott (2008))
- Idealized single convective cell in a conditionally unstable background atmosphere
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- Perform real case studies with HYMACS in ICON including validation and verification against observations
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Literature: