1) An essentially Lagrangian model

- Traditional LES models: numerical diffusion hard to avoid.
- Diffusion erodes high LWC regions which are crucial for precipitation.
- Moist Parcel-In-Cell: moist convection with vortex-in-cell method.
- MPIC uses parcels which carry vorticity, volume, liquid-water potential temperature and moisture.
- Similar approach widely used in computer graphics/movies.
- Simplified moist dynamics and thermodynamics:
  \[
  \frac{D\mathbf{u}}{Dt} = \nabla P - \rho_0 b \mathbf{e}_z, \quad \frac{Db}{Dt} = 0, \quad \frac{Dq}{Dt} = 0, \quad \nabla \cdot \mathbf{u} = 0
  \]
  \[
  b = b_l + \frac{gL}{c_p \theta_0} \max \left(0, q - q_0 e^{-\lambda x}\right)
  \]
- Normalisation by volume needed to find buoyancy.
- Allows for a simple setup (Fig. 1).
- Initial thermal has asymmetry.
- Parcel splitting and merging used to represent mixing, see detailed description in Dritschel et al. (2018).

Key benefits:
- MPIC is an efficient method, simple parcel operations used.
- Exact conservation of parcel properties.
- More physical approach to mixing.
- MPIC provides a high effective resolution compared to the solver grid: subgrid diagnostics available.
- Lagrangian diagnostics can be studied consistently (Fig. 2).

2) MPIC/MONC comparison

- MONC: full rewrite of the Met Office Large Eddy Model for use on modern supercomputers (Brown et al. 2015).
- Comparison to MONC with identical dynamics and thermodynamics.
- Good agreement on cross-sections (Fig. 3, Böing et al 2019) and key profiles across resolutions (differences in liquid water content PDF).

3) Implementation in MONC’s framework

- MPIC: eCSE grant to implement hybrid openMP/MPI parallelism using MONC’s framework (Fig. 4).
- Extension of parallelism to handle parcels. New tridiagonal vorticity solver.
- Scaling influenced by inhomogeneities in parcel density and scaling of FFT routines. Code scales well going from 5,000 to 20,000 cores (Fig. 5).
- Ability to run much larger domains due to removal of memory constraints.
- Further improvement possible by limiting calls to FFTs. Best scaling achieved with pure MPI. Cause of OpenMP issues needs further investigation (could be due to use of allocatable arrays).

4) Future plans

Dynamics and thermodynamics
- Ongoing: surface fluxes, large-scale tendencies, Coriolis force.
- Anelastic version with more realistic saturation adjustment scheme.
- Standard cases (e.g. BOMEX/ARM).

Microphysics and chemistry
- MPIC would be a good match with a superdroplets-based model for microphysics, as MPIC already follows a Lagrangian approach. Water loading could be easily incorporated.
- Advection of many microphysical/chemical/dust species is cheap.
- Looking for collaborations on this topic.

Other
- MPIC could be applied to range of geo/astrophysical problems.
- New pathways to parametrisation using a parcel-based approach (i.e. using parcels to represent clouds)
- Visualisation on pyramid display (photo).

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References: