Experiments with the ULTIMATE-MACHO Scalar Advection Scheme in SAM

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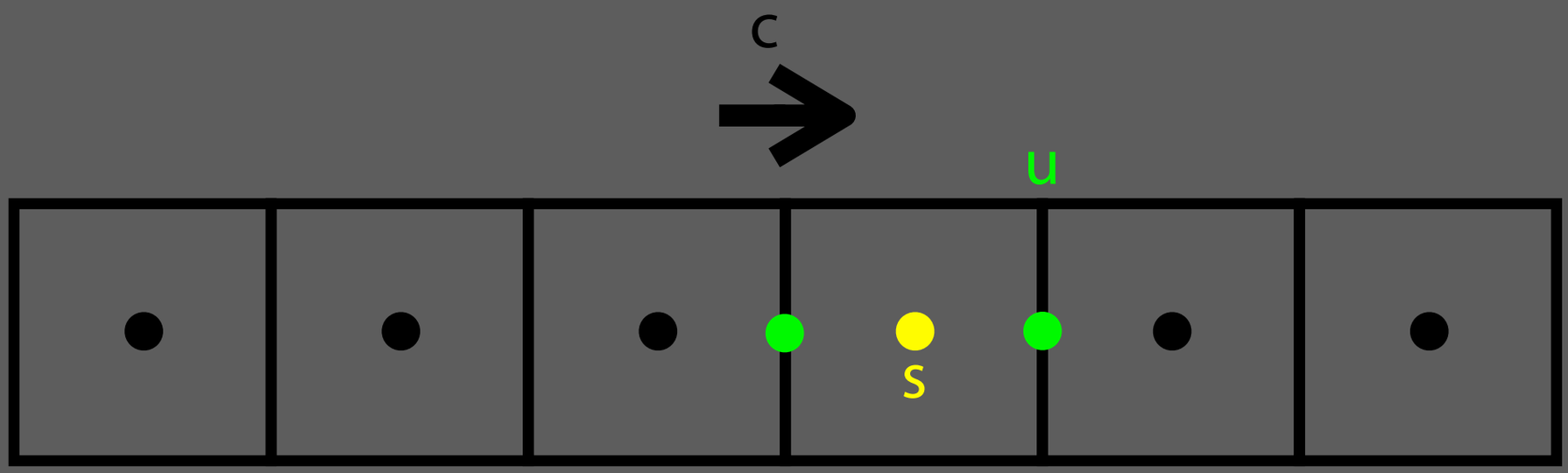
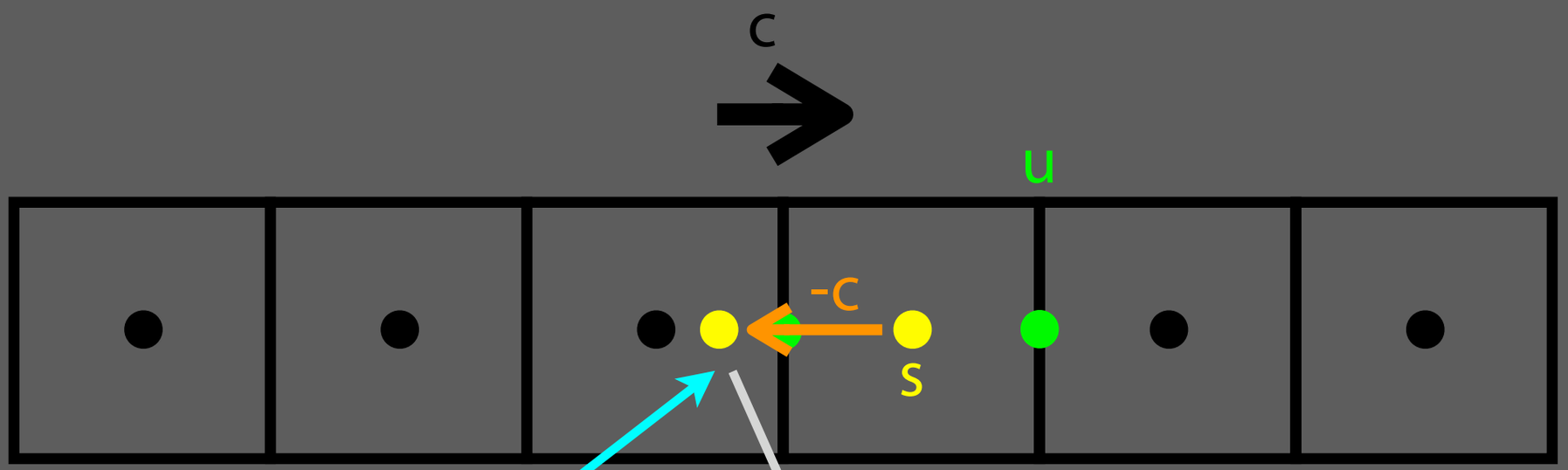
ULTIMATE-MACHO

- Current SAM's scalar advection scheme: MPDATA (Smolarkiewicz and Grabowski 1990) 2nd-order monotone scheme
- ULTIMATE: 1D scheme, any order based on Lagrange interpolation (Leonard 1991)
- MACHO: 3D scheme with direct use of 1D scheme (Leonard et al. 1996)
- Monotonicity: FCT (Zalesak 1979) works best for ULTIMATE-MACHO.

ULTIMATE



ULTIMATE



Lagrange interpolation

formulate left & right face value

MACHO

Operator splitting with

- flux form: conservation but not constancy & shape preservation
- advective form: constancy & shape preservation but not conservation

$$1.\ \hat{\phi}_x = f^{1D}\left(\phi^n\right),$$

$$2.\ \phi_{AX} = \phi^n + c_x^{\text{box}}\left(\hat{\phi}_w - \hat{\phi}_e\right),$$

$$3.\ \hat{\phi}_y = f^{1D}\left(\phi_{AX}\right),$$

$$4.\ \phi_{AY} = \phi_{AX} + c_y^{\text{box}}\left(\hat{\phi}_n - \hat{\phi}_s\right),$$

$$5.\ \hat{\phi}_z = f^{1D}\left(\phi_{AY}\right),$$

$$6.\ \phi^{n+1} = \phi^n + c_w\hat{\phi}_w - c_e\hat{\phi}_e + c_n\hat{\phi}_n - c_s\hat{\phi}_s + c_t\hat{\phi}_t - c_b\hat{\phi}_b,$$

f^{1D} = ULTIMATE

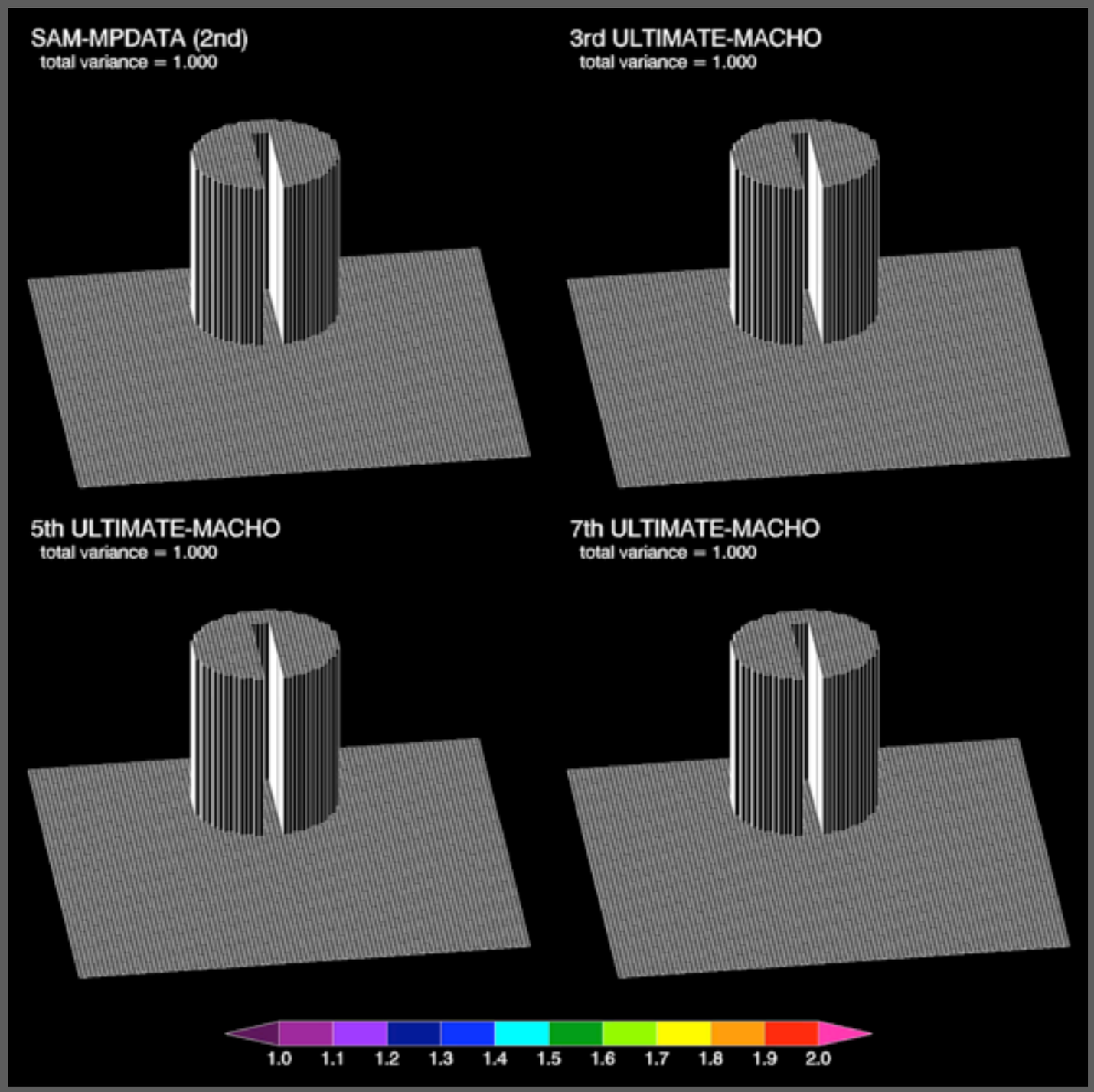
advective form update

flux form update

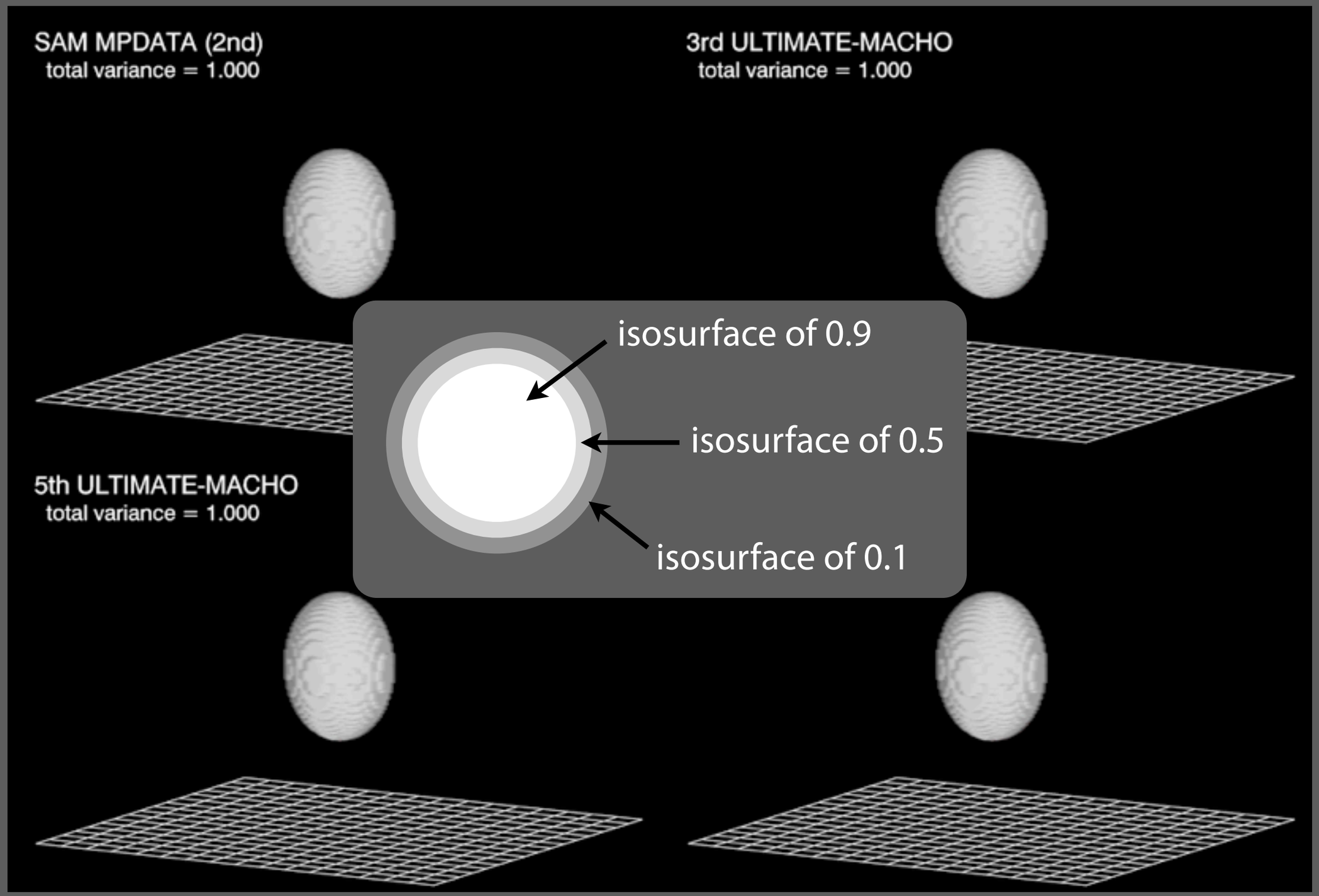
★ constancy preservation: an initially homogeneous scalar should remain identically equal to the initial value in initially solenoidal velocity field.

★ shape preservation: 1D shape-preserving operator maintain shape preservation in 3D as well.

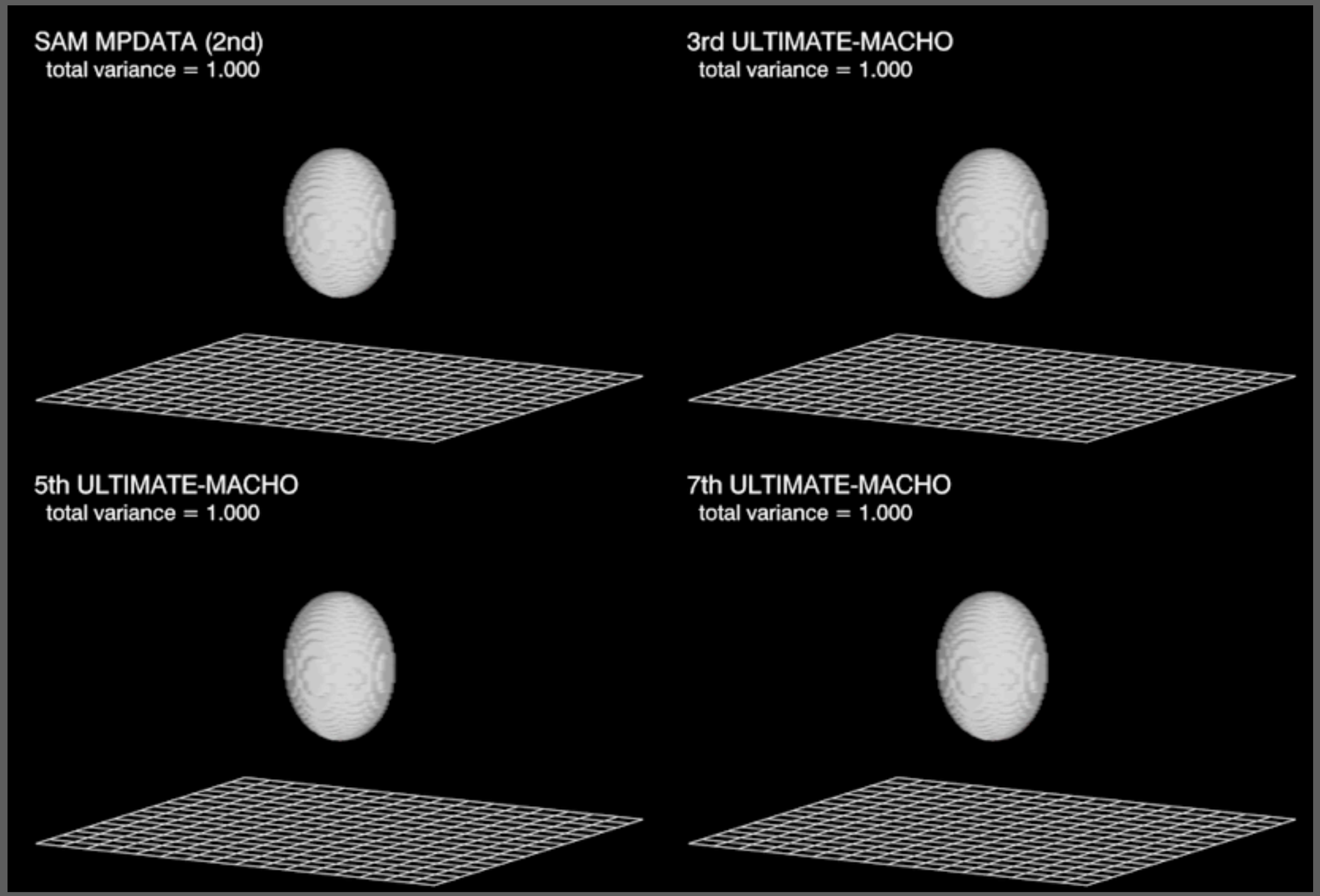
2D rotating split cylinder



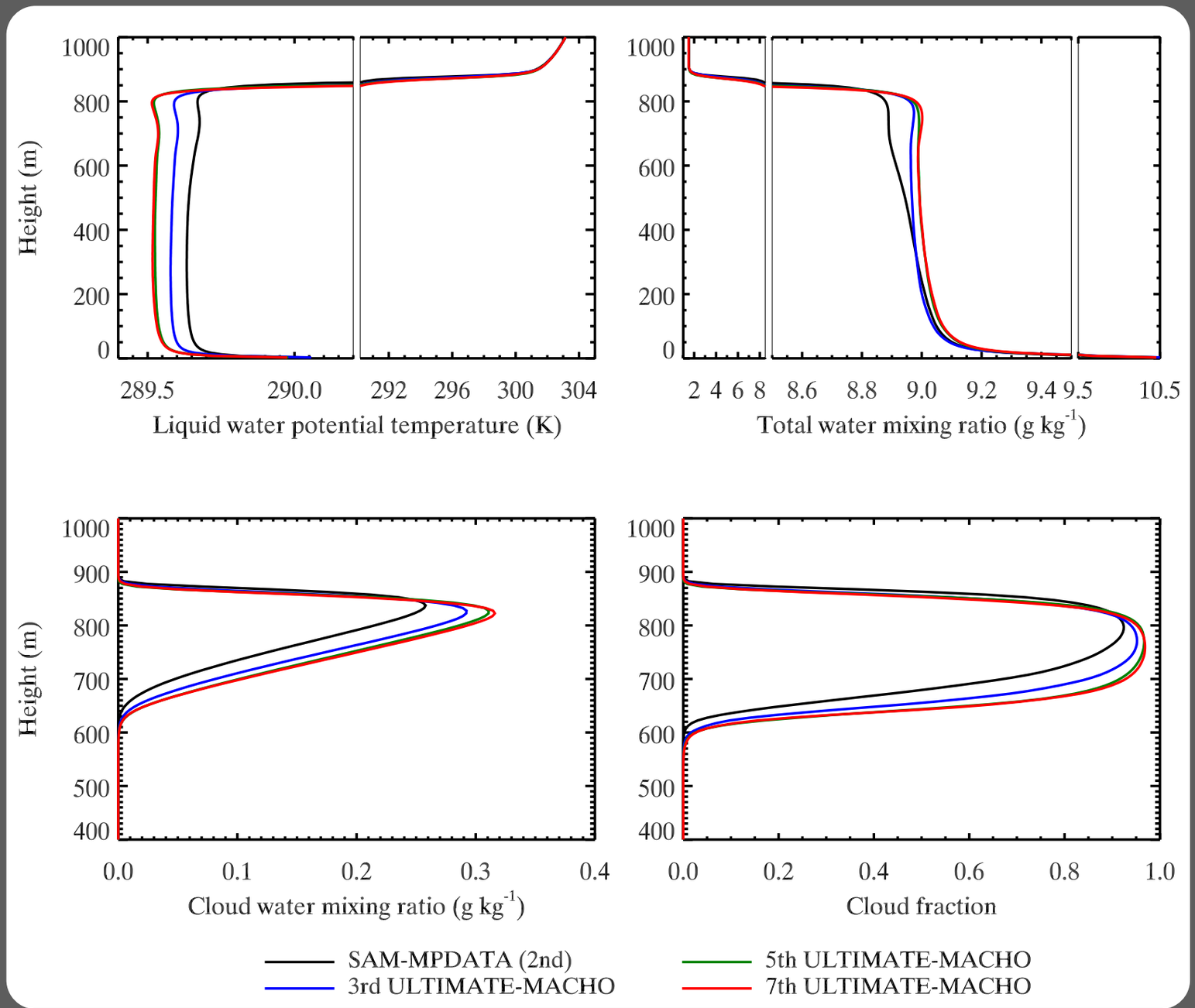
Distortion of a sphere in turbulence



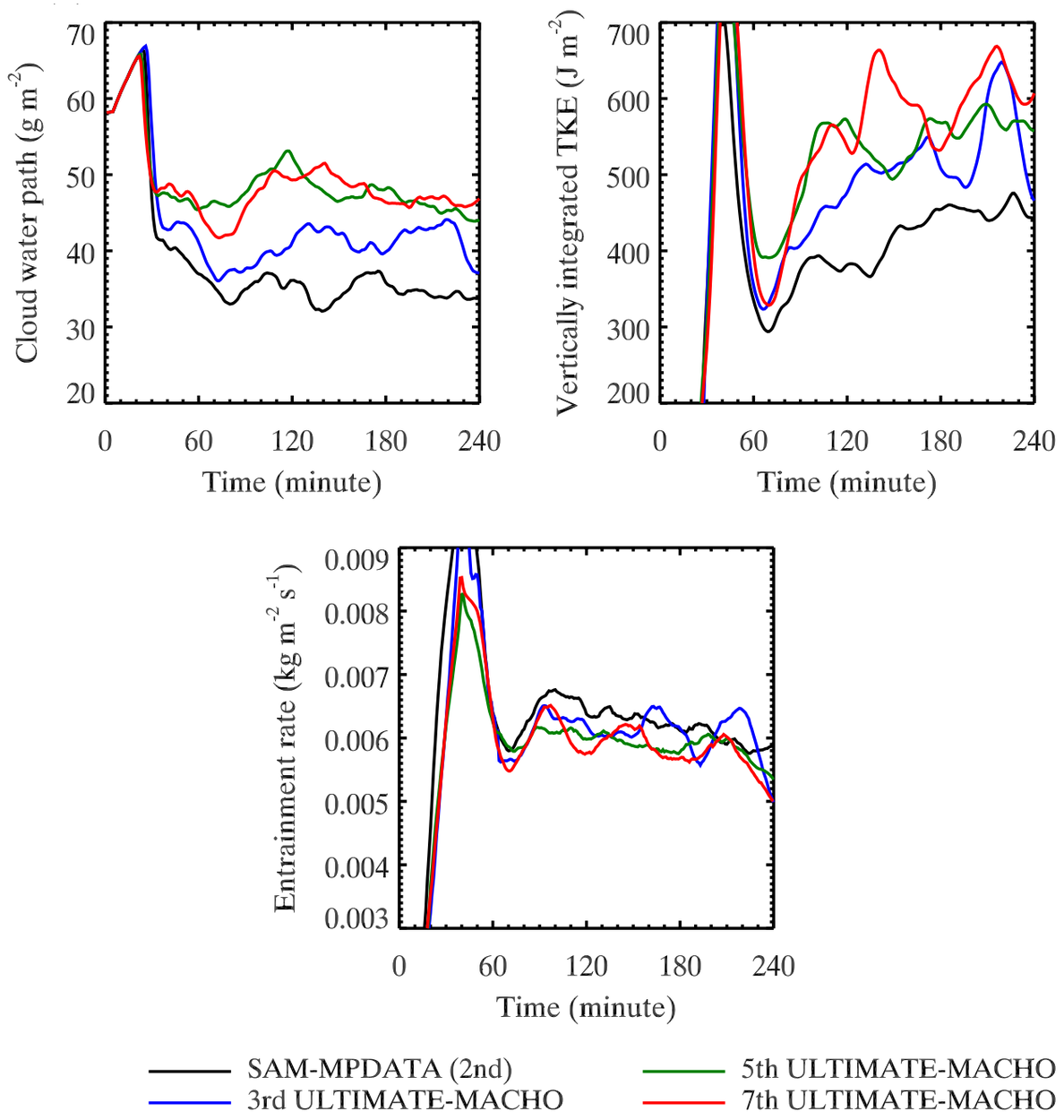
Distortion of a sphere in turbulence



GCSS DYCOMS-II RF01



GCSS DYCOMS-II RF01



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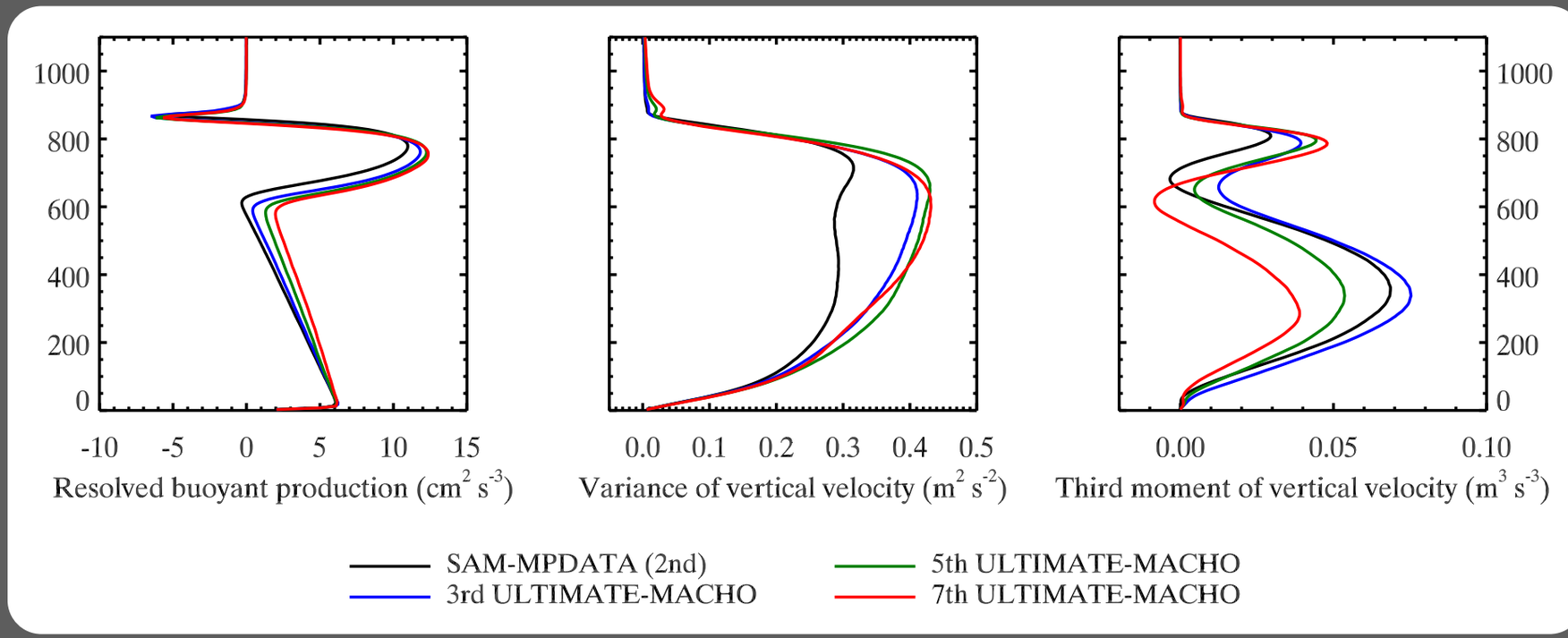

Cost

	SAM-MPDATA	GCSS DYCOMS-II
SAM-MPDATA	1	1
UM3	1.8	1.2
UM5	2.2	1.3
UM7	3	1.5

Summary

- 5th ULTIMATE-MACHO is optimal among the schemes tested.
- Higher-order scalar advection scheme
  - Thicker cloud layer
  - More energetic PBL turbulence
  - Smaller entrainment rate
- Implemented ULTIMATE-MACHO in SAM
  - 3rd, 5th, 7th for uniform grid
  - 3rd and 5th for non-uniform grid
- Future improvement: Selective flux limiter by Blossey and Durran (2008)