Calhoun: The NPS Institutional Archive

DSpace Repository

Faculty and Researchers | Faculty and Researchers' Publications

2014-08

Does high order and dynamic adaptive mesh refinement improve the efficiency of atmospheric simulations?

Müller, Andreas; Kopera, Michal; Marras, Simone; Giraldo, Francis X.

Monterey, California. Naval Postgraduate School

https://hdl.handle.net/10945/47730

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun

http://www.nps.edu/library

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

Does high order and dynamic adaptive mesh refinement improve the efficiency of atmospheric simulations?

Andreas Müller,
Michal Kopera,
Simone Marras,
Francis X. Giraldo

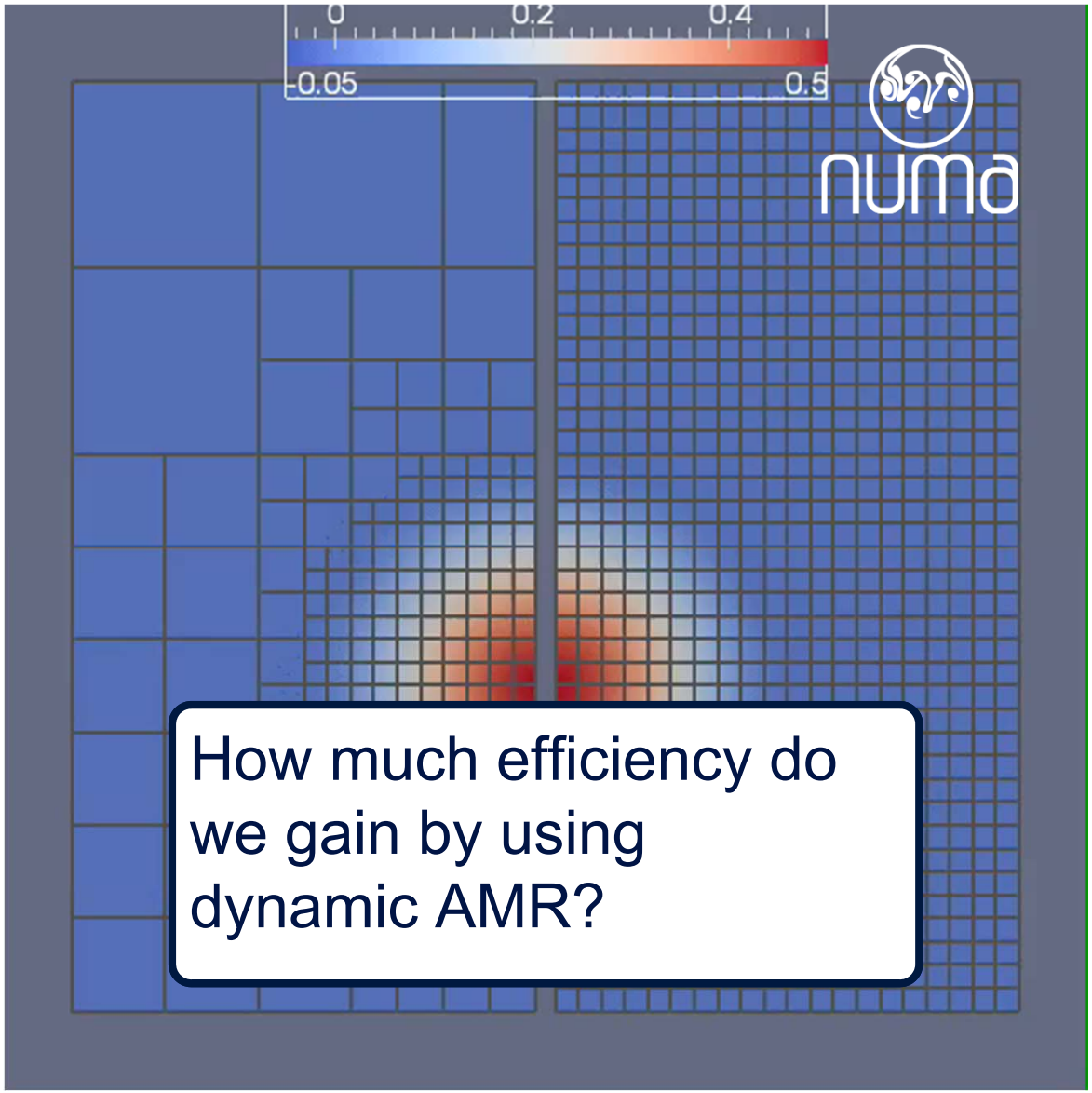
Department of Applied Mathematics
Naval Postgraduate School, Monterey (California), USA

overview

- Motivation
- Results: what do we gain by using AMR and high order?
- Next steps

Motivation

Warm air bubble test case with $\mu = 0.1 m^2/s$



Goal

methods

- dynamic AMR, uniform meshes
- high order, low order

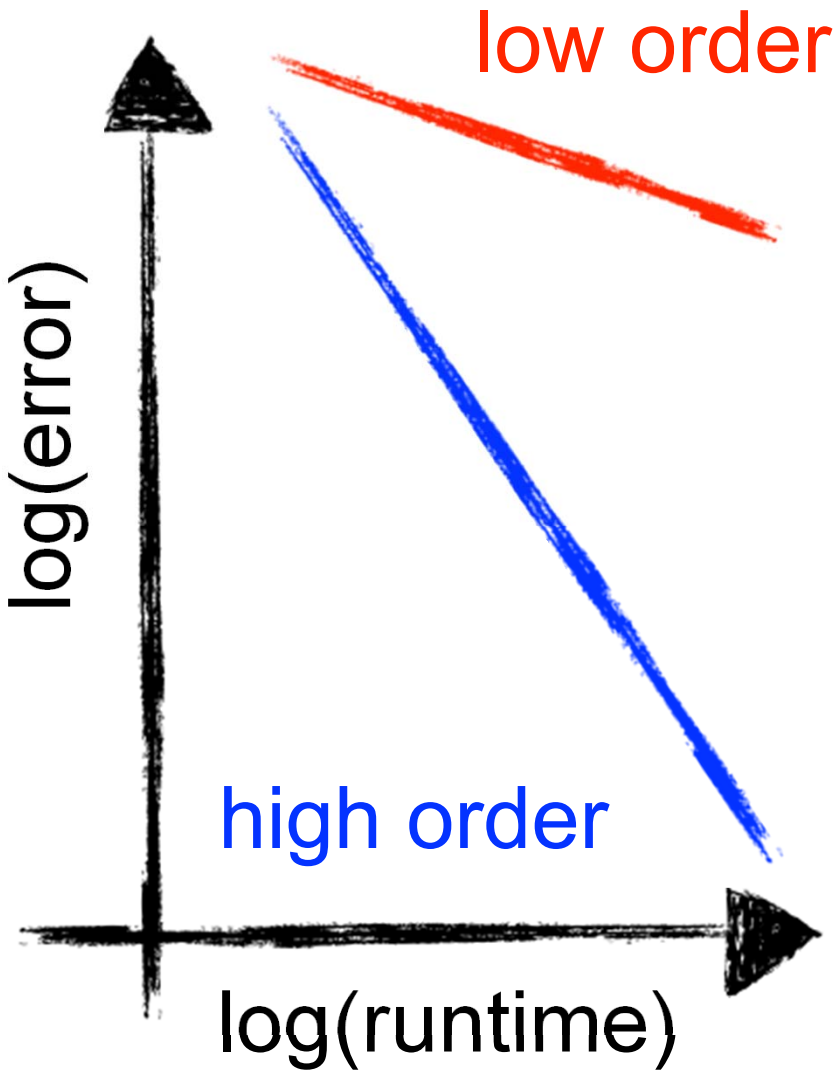
applications

- cloud simulations
- Hurricane simulations

For which of these applications should we use these methods and how should we use them?

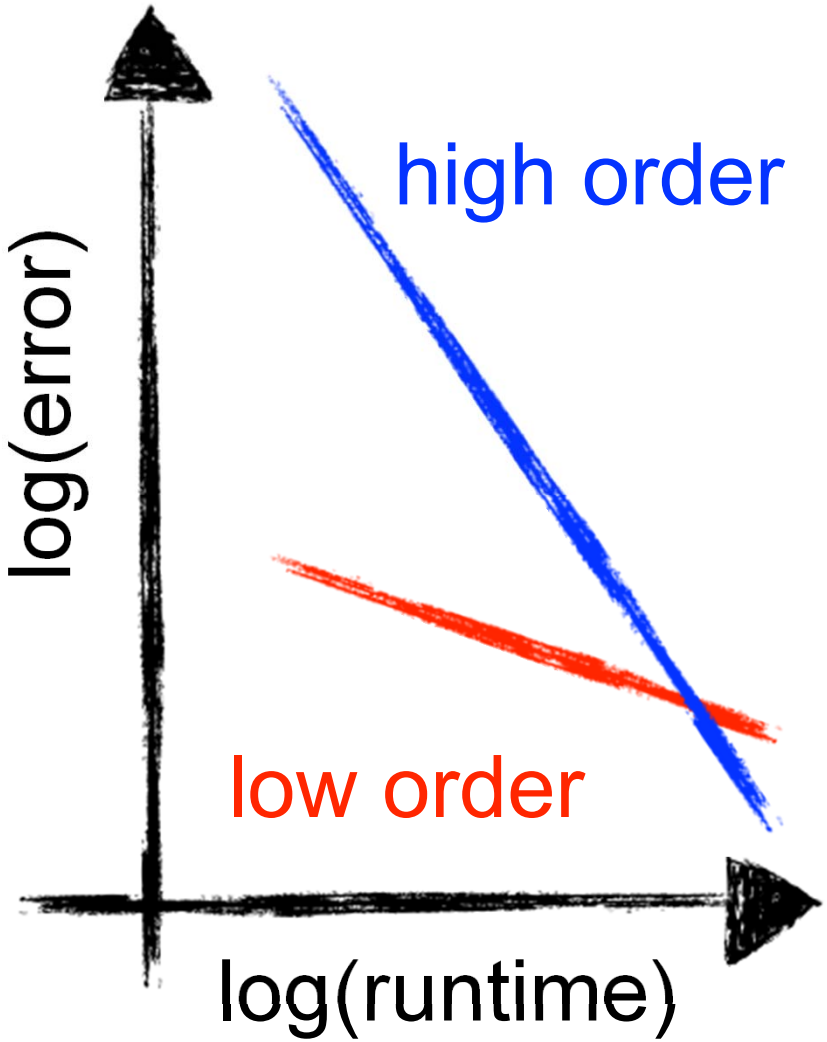
High vs. low order

theoretical expectations

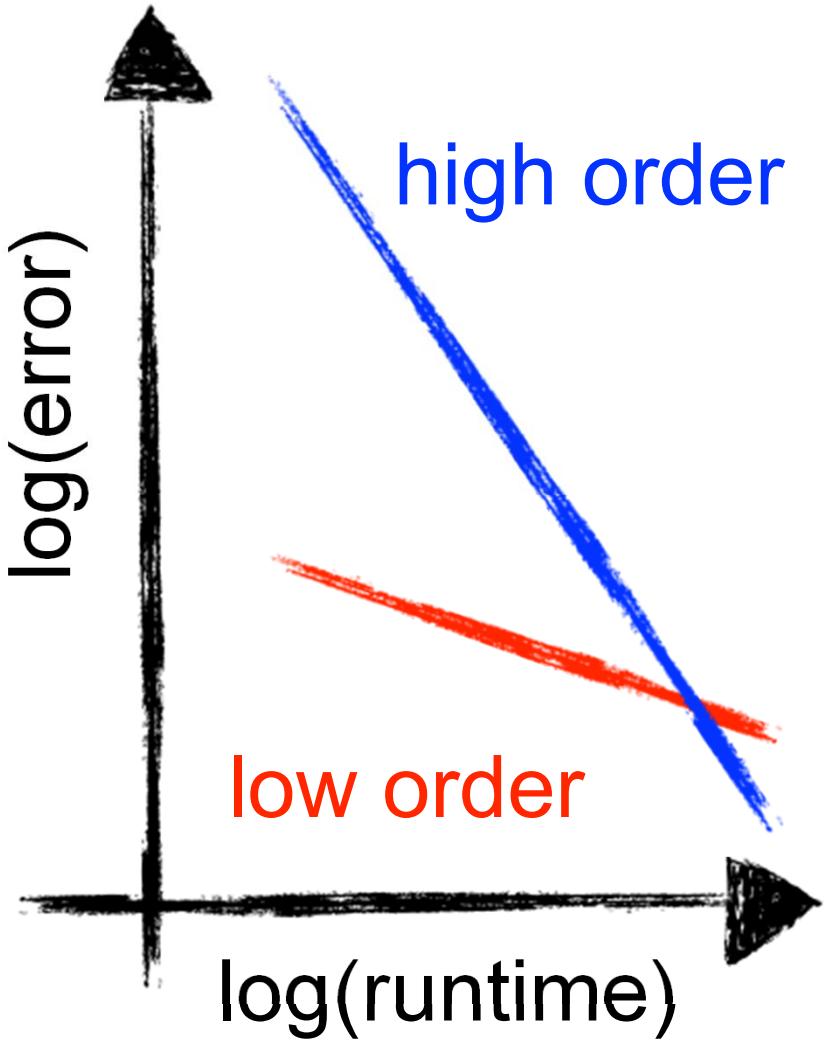


High vs. low order

theoretical expectations



High vs. low order
theoretical expectations

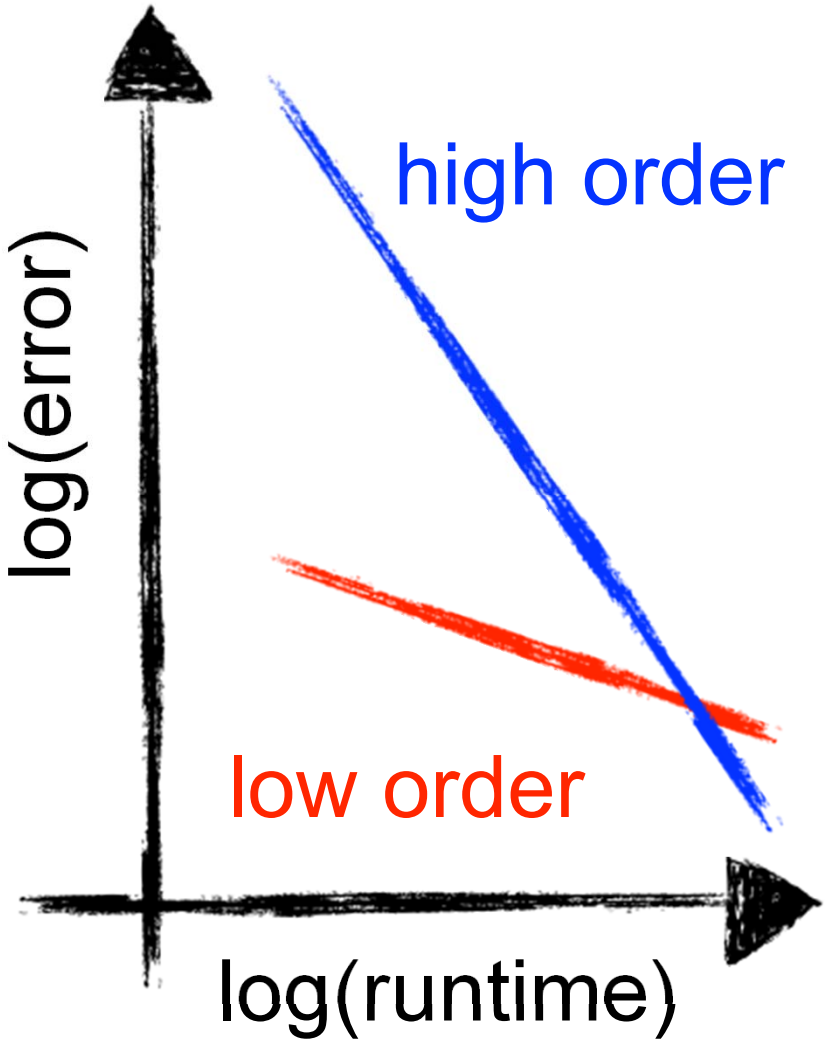


difficulties

- need convergence

➡add small amount of viscosity (such that highest possible resolution can be called truth)

High vs. low order
theoretical expectations



difficulties

- need convergence
  ➡add small amount of viscosity (such that highest possible resolution can be called truth)
- it is impossible to compare numerical methods. The runtime depends on the specific implementation!
  ➡keep as much code as possible unchanged

NUMA

Non-hydrostatic Unified Model of the Atmosphere

- **dynamical core** inside the Navy's next generation weather prediction system NEPTUNE
- **unified across numerics** (contains Continuous and Discontinuous Galerkin methods)
- **unified across applications** (regional and global modeling)
- 3D, DG, MPI: **strong scaling** for explicit time integration (tested up to 32000 CPUs)
- 2D, serial: allows **dynamic AMR**

NUMA

work in progress:

- 3D dynamic AMR
- GPU version

Questions for Today

Results for 2D bubble test cases simulated with NUMA

Questions:

1. Does high-order improve the efficiency?

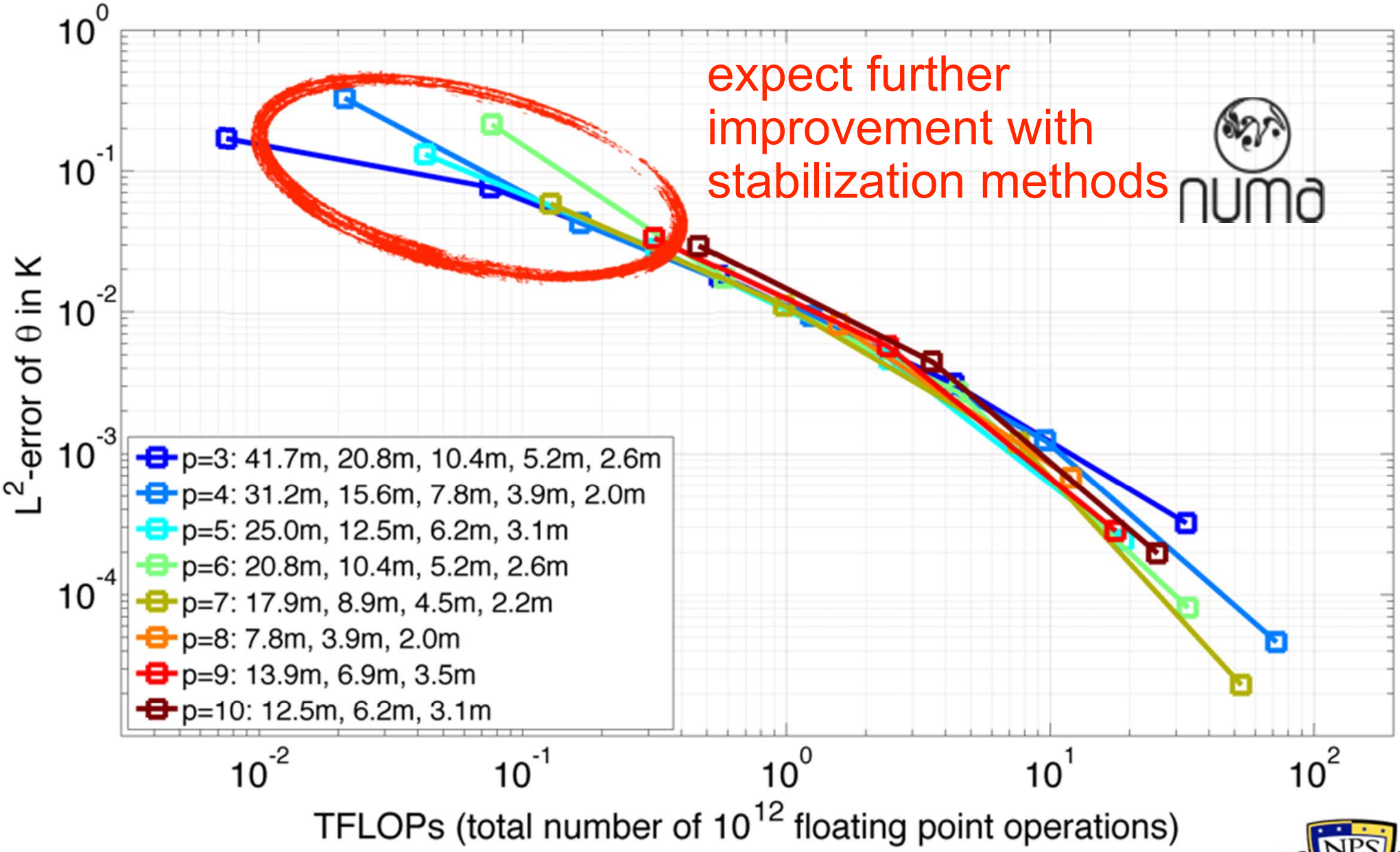
2. Does dynamic adaptive mesh refinement improve the efficiency?

3. Do moist dynamics reduce the order of convergence?

Results:

L^2-error of uniform simulations

as a function of number of floating point operations



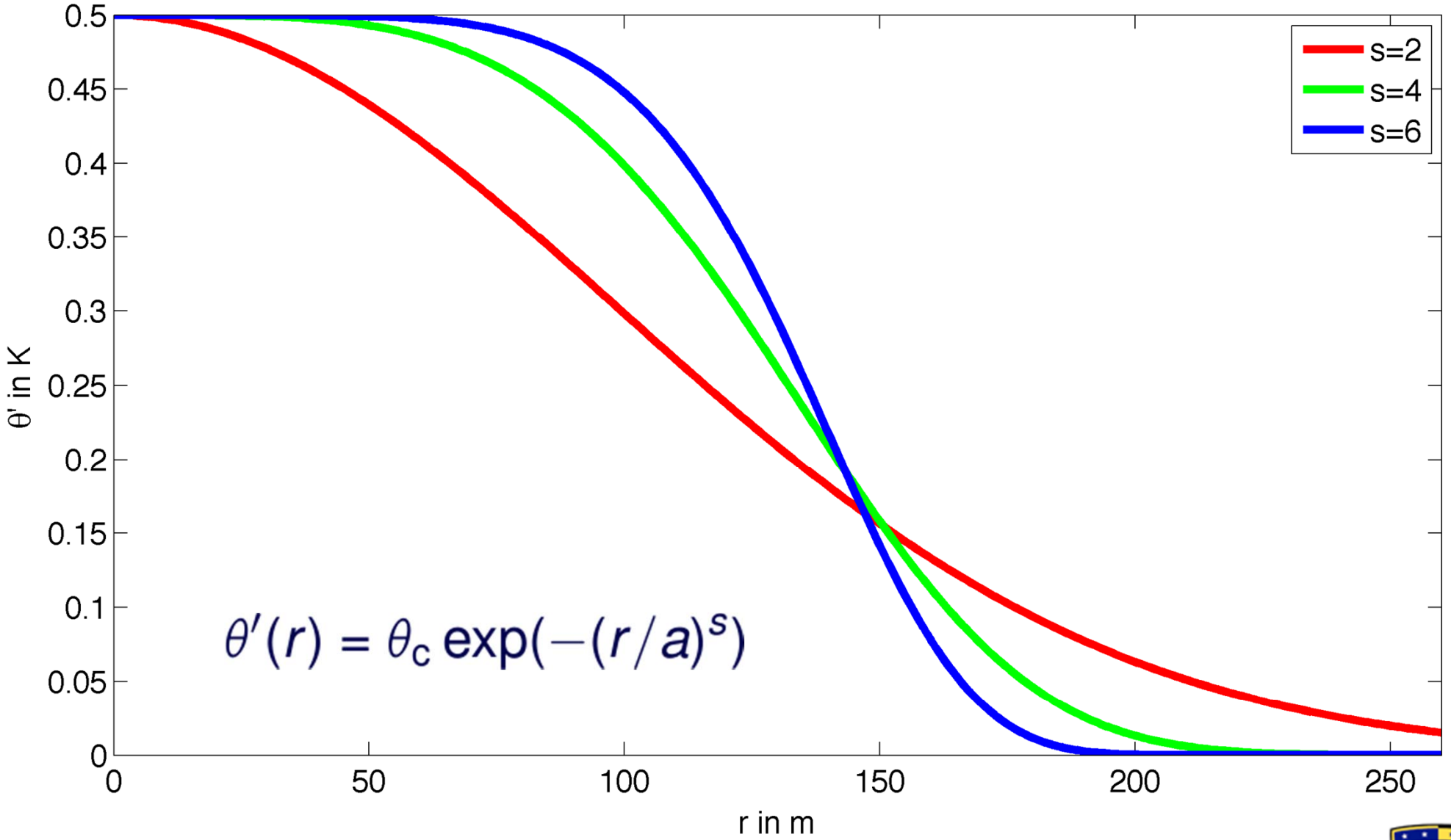
Questions for Today

Results for 2D bubble test cases simulated with NUMA

Questions:	**Results**:
1. Does high-order improve the efficiency?	High-order improves the efficiency if the flow is well resolved.
2. Does dynamic adaptive mesh refinement improve the efficiency?	
3. Do moist dynamics reduce the order of convergence?	

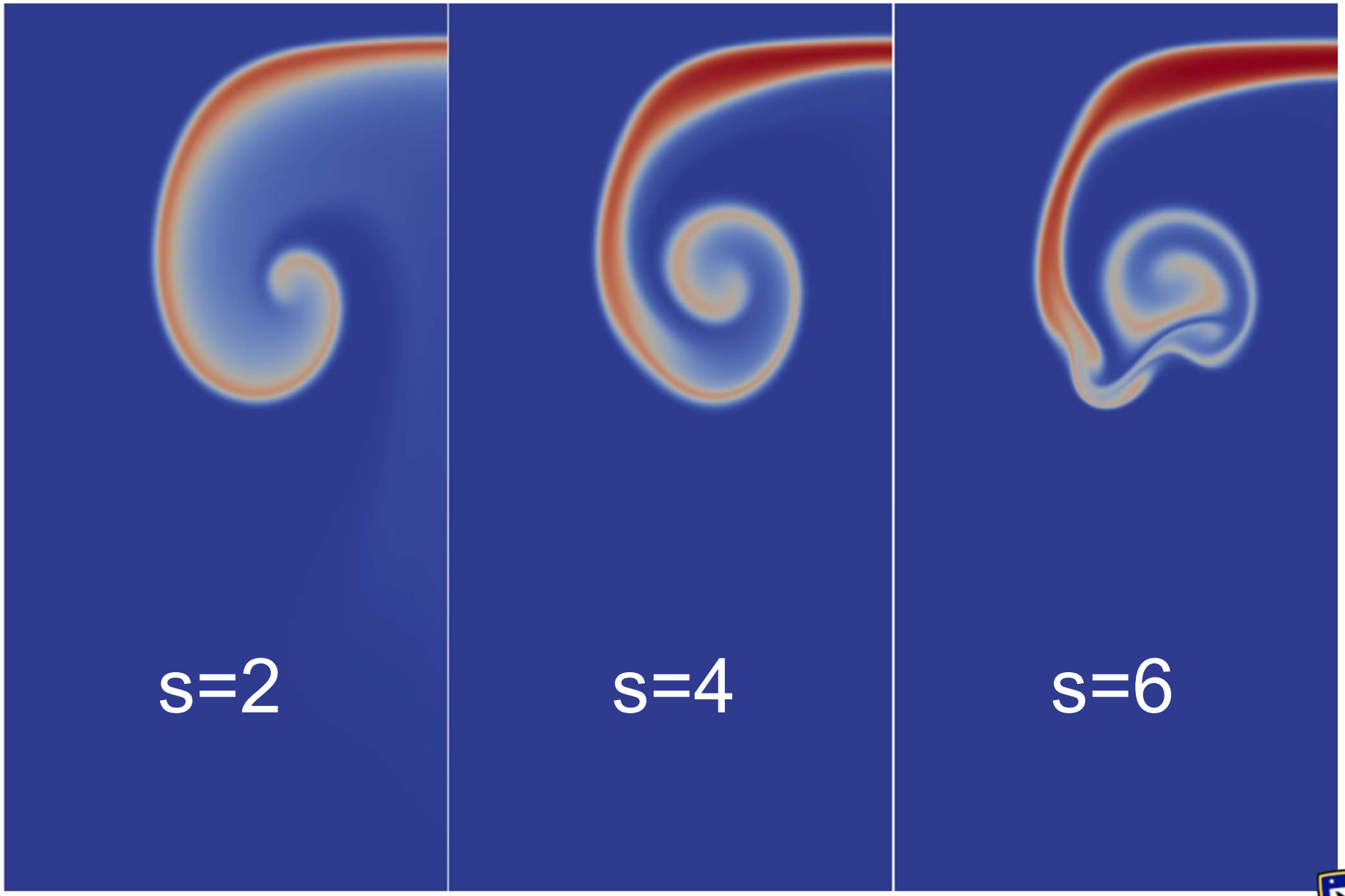
Three different initial profiles for θ'

as a function of distance from the center of the bubble *r*



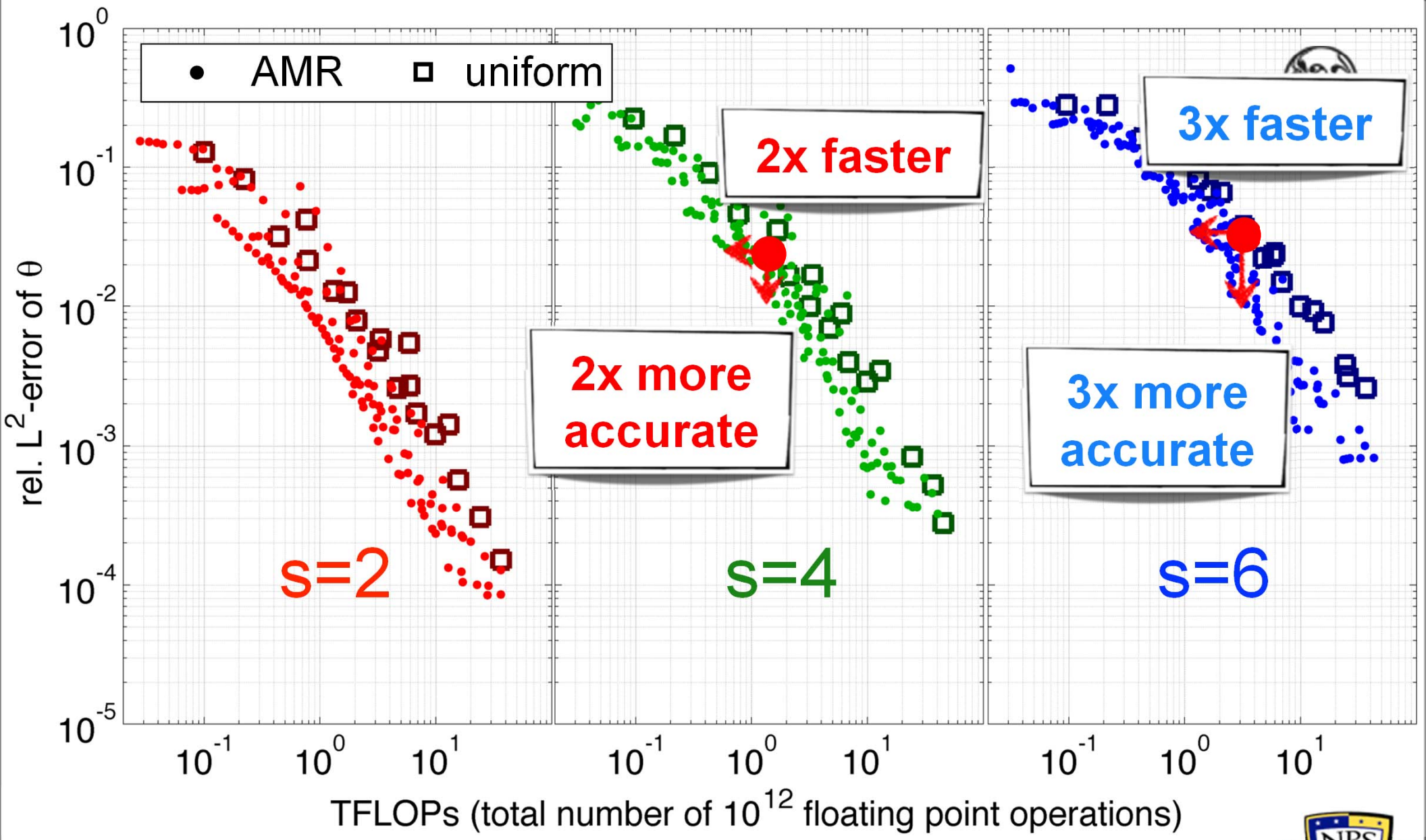
Reference result for 3 different bubbles

resolution Δx = 40cm, time t=700s



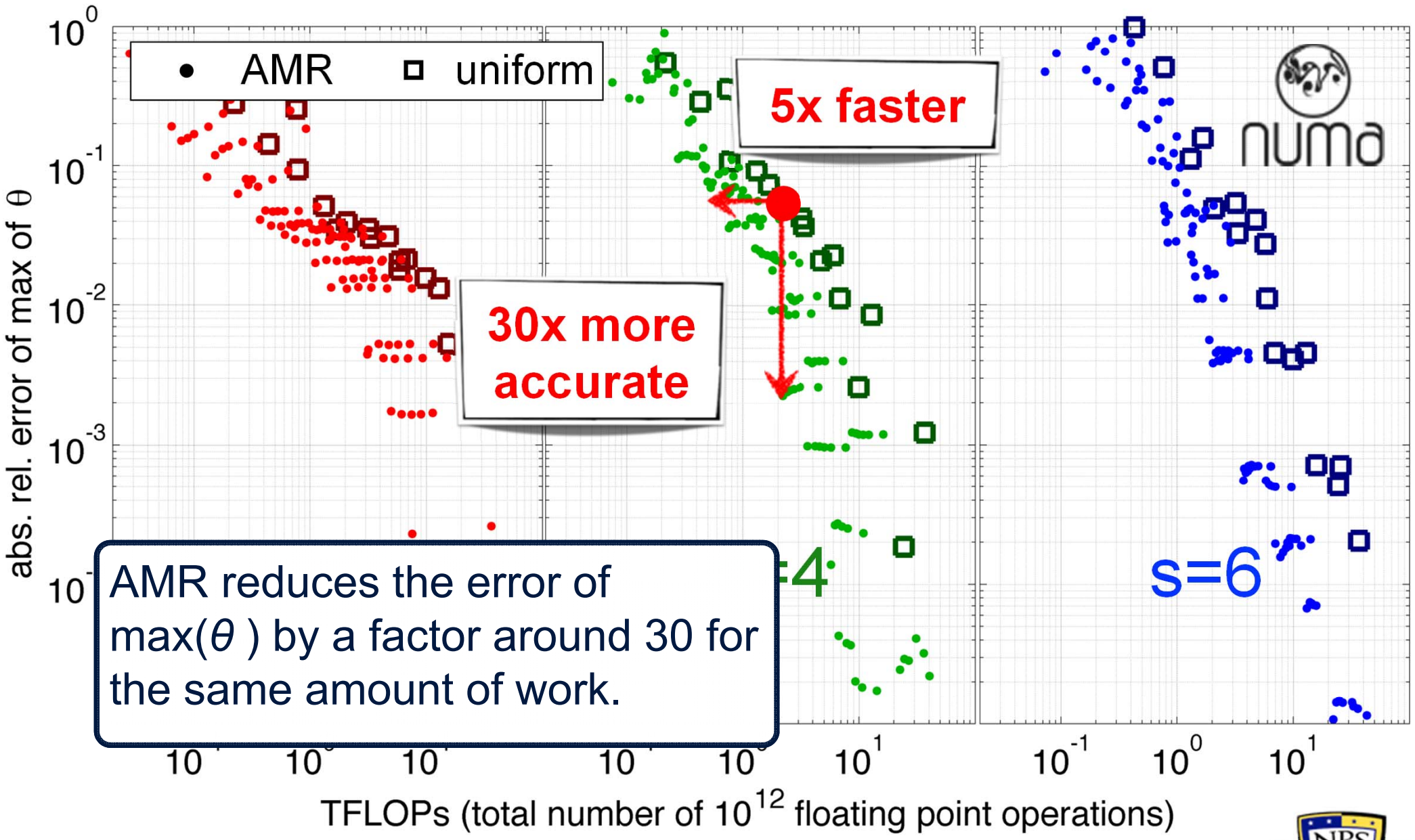
L^2-error for 3 different initial conditions

viscosity: $\mu=0.1 m^2/s$



relative error of max(θ)

viscosity: μ=0.1m^2/s



AMR reduces the error of max(θ) by a factor around 30 for the same amount of work.

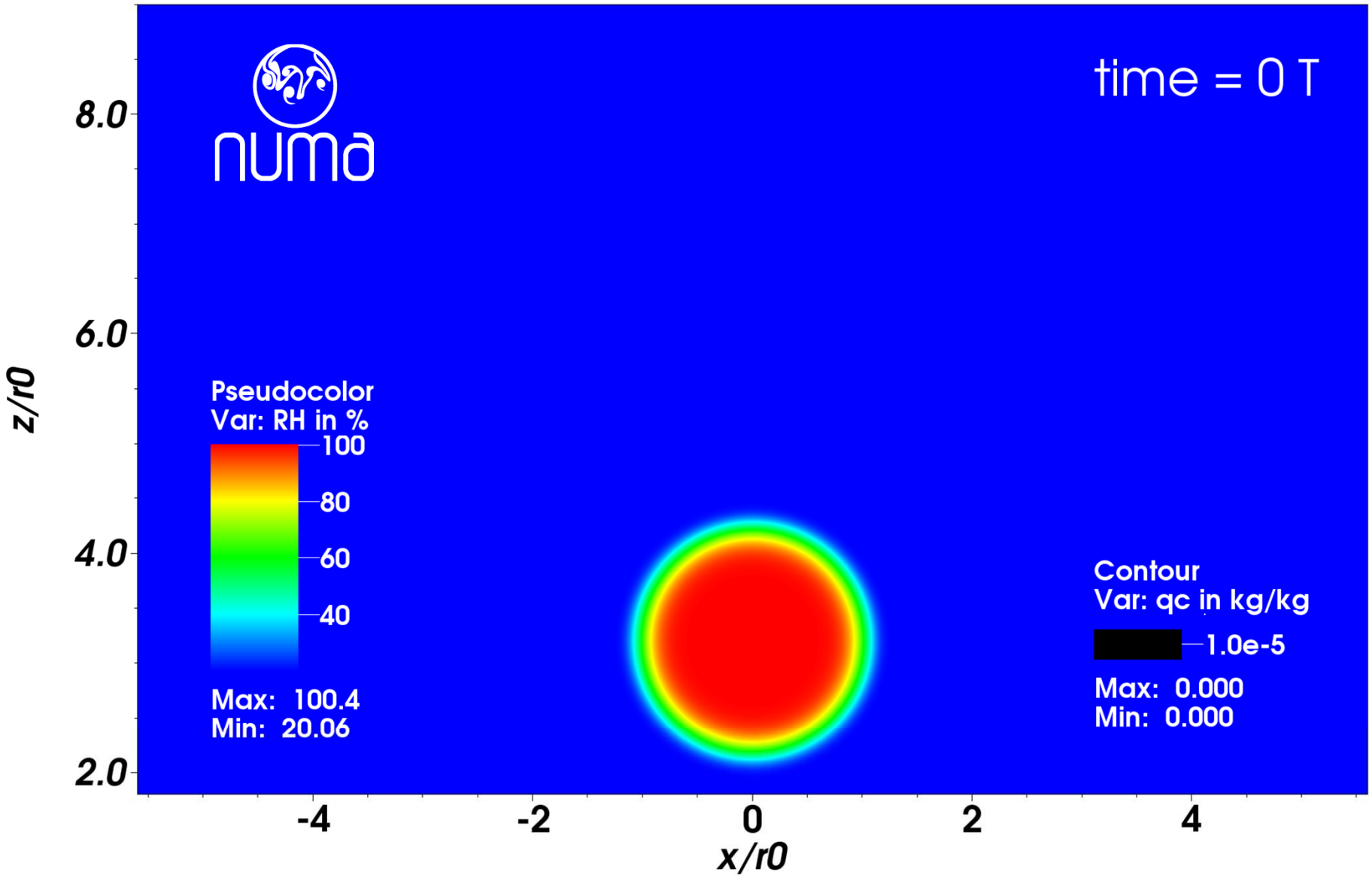
Questions for Today

Results for 2D bubble test cases simulated with NUMA

Questions:	**Results**:
1. Does high-order improve the efficiency?	High-order improves the efficiency if the flow is well resolved.
2. Does dynamic adaptive mesh refinement improve the efficiency?	2x smaller L2-error, 30x smaller error in max(θ). Bigger improvement expected for more localized problems.
3. Do moist dynamics reduce the order of convergence?	

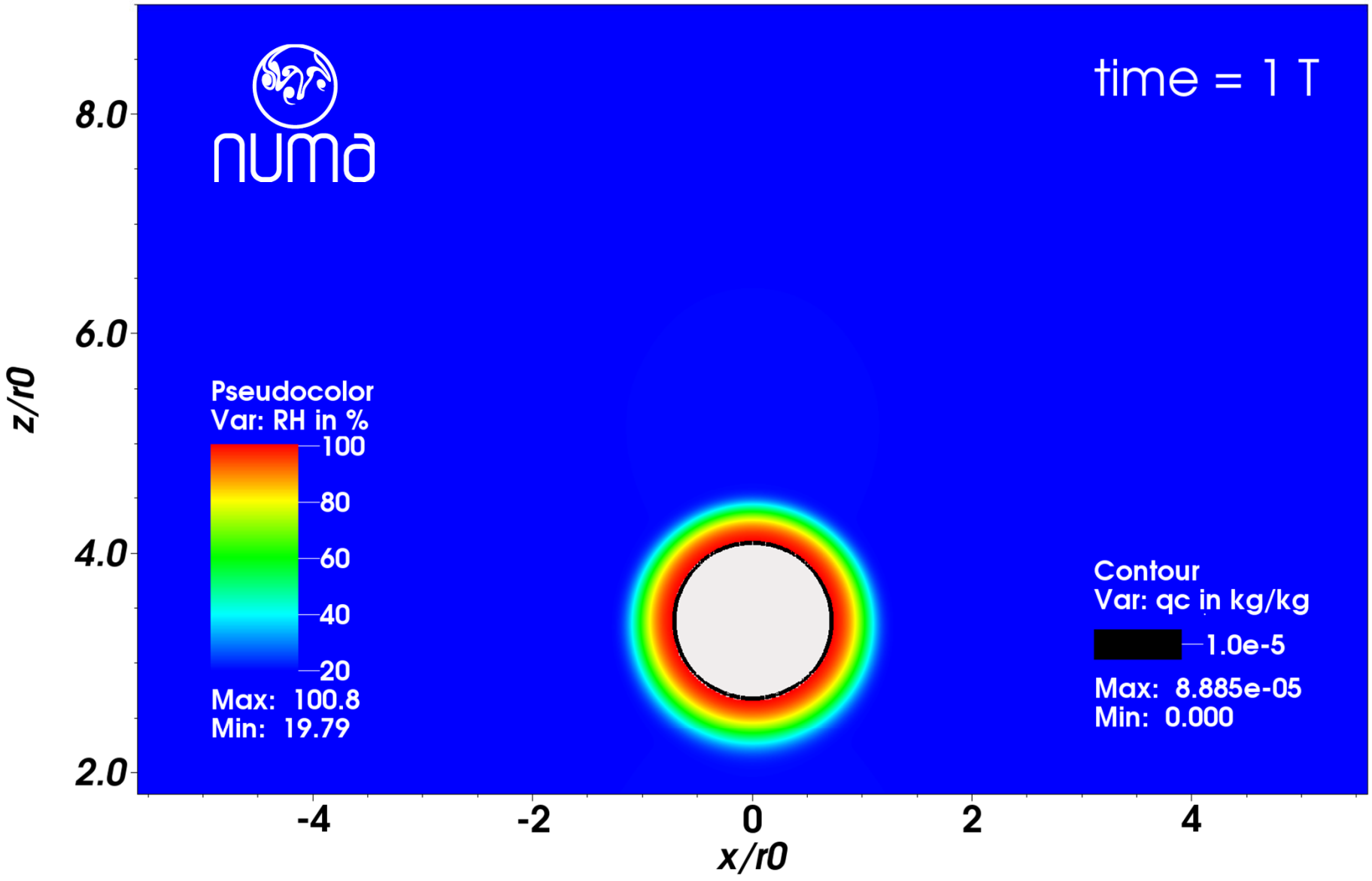
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5m^2/s$



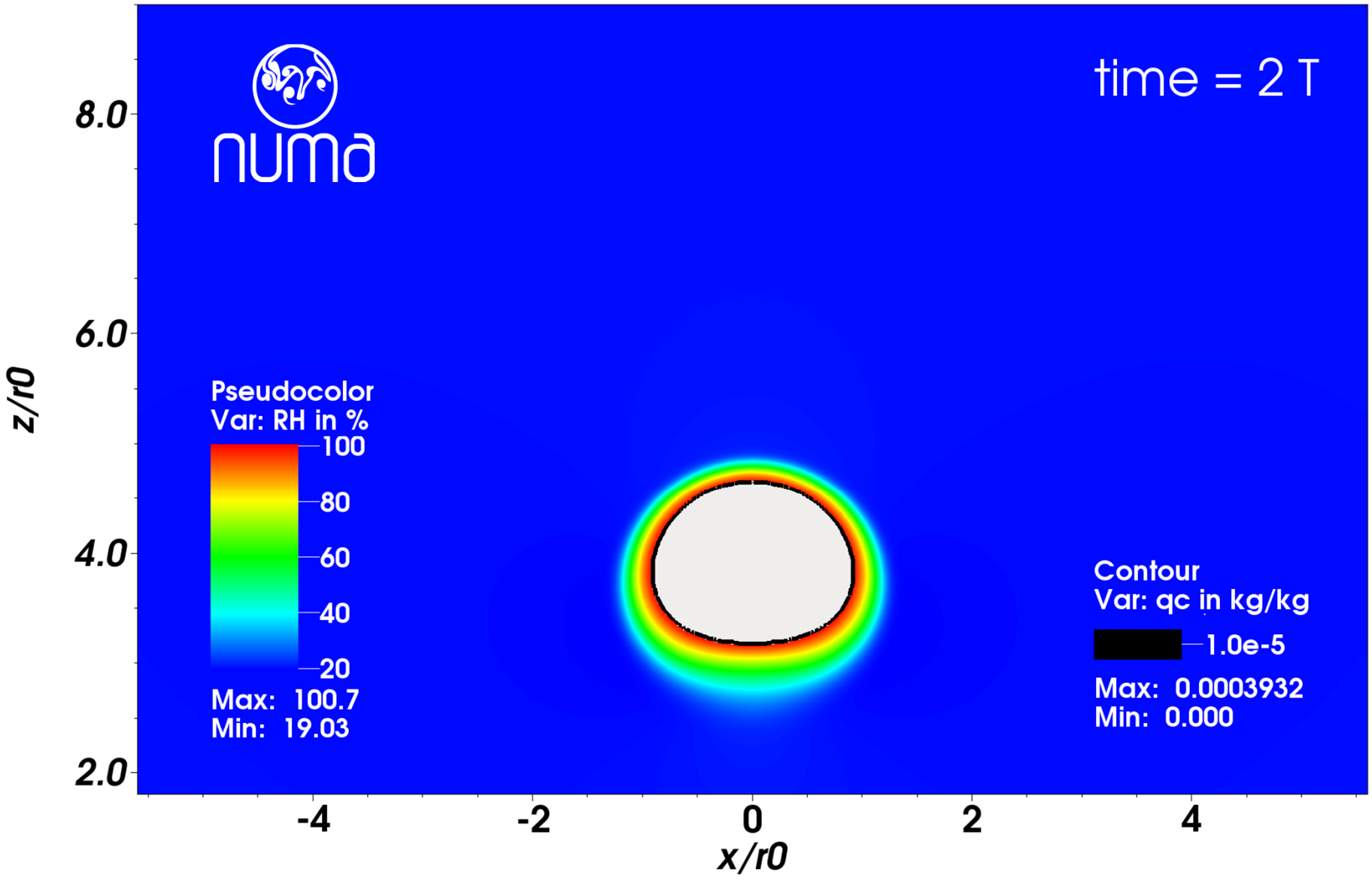
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5 m^2/s$



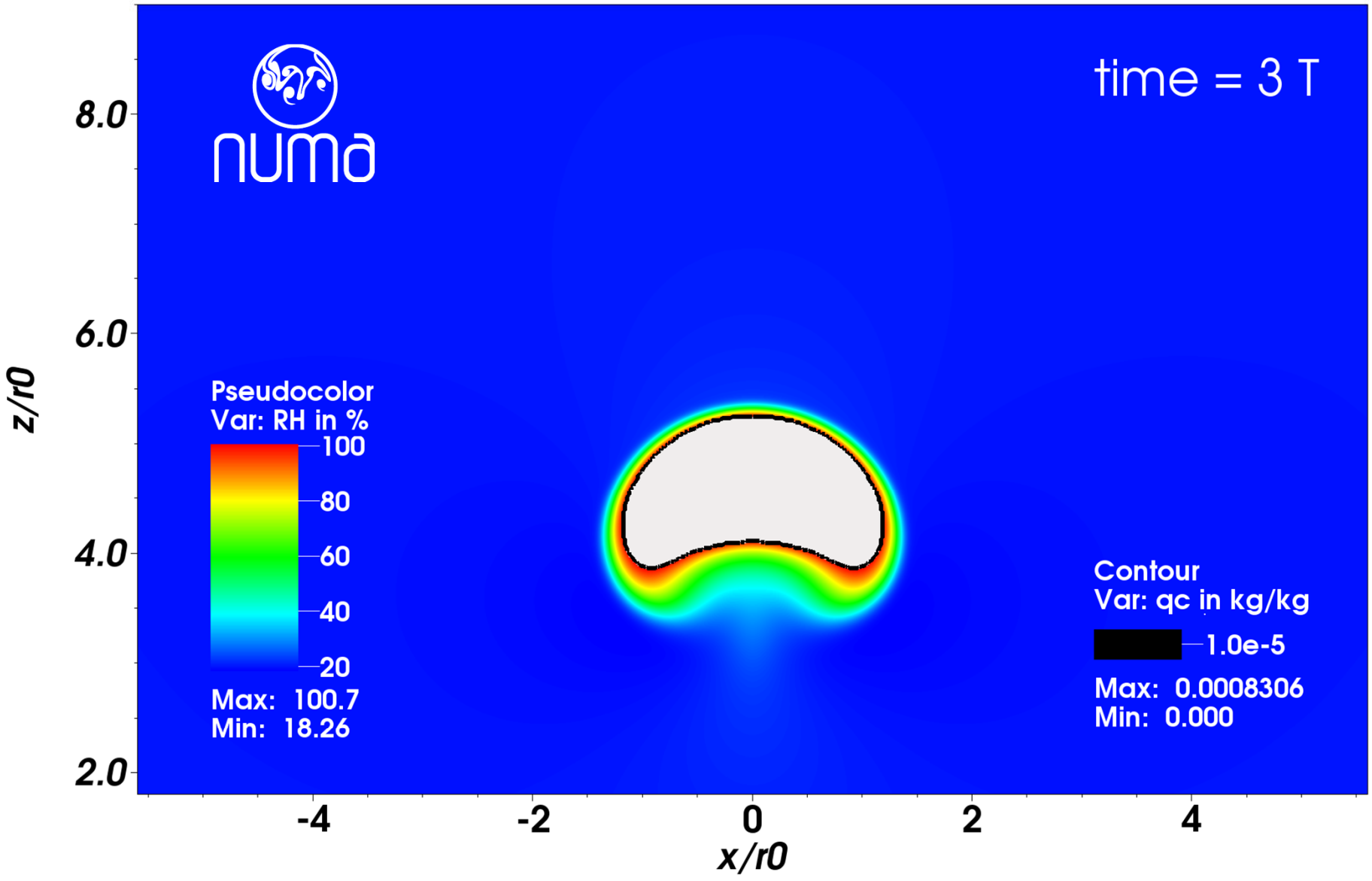
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5 m^2/s$



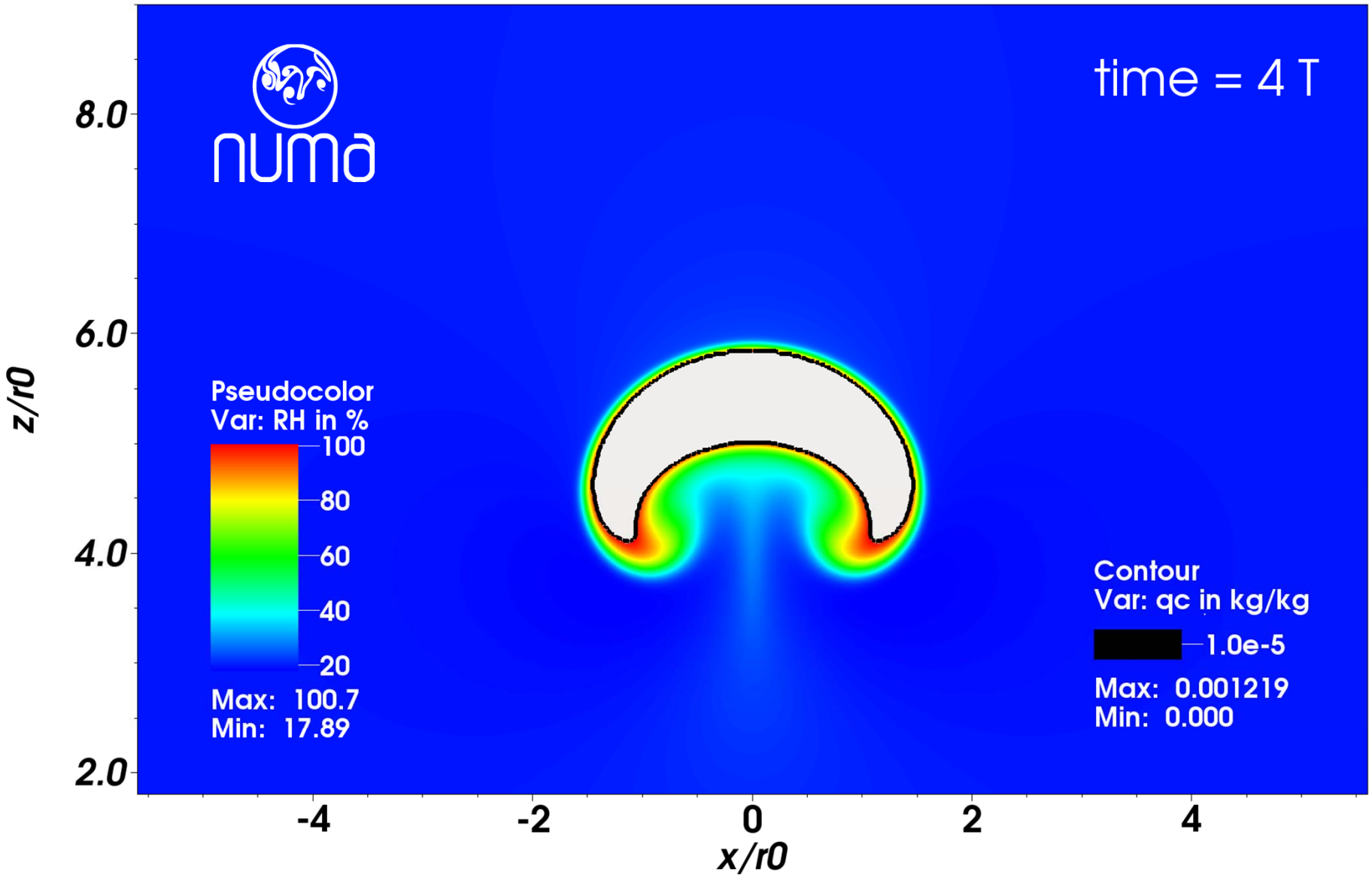
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5m^2/s$



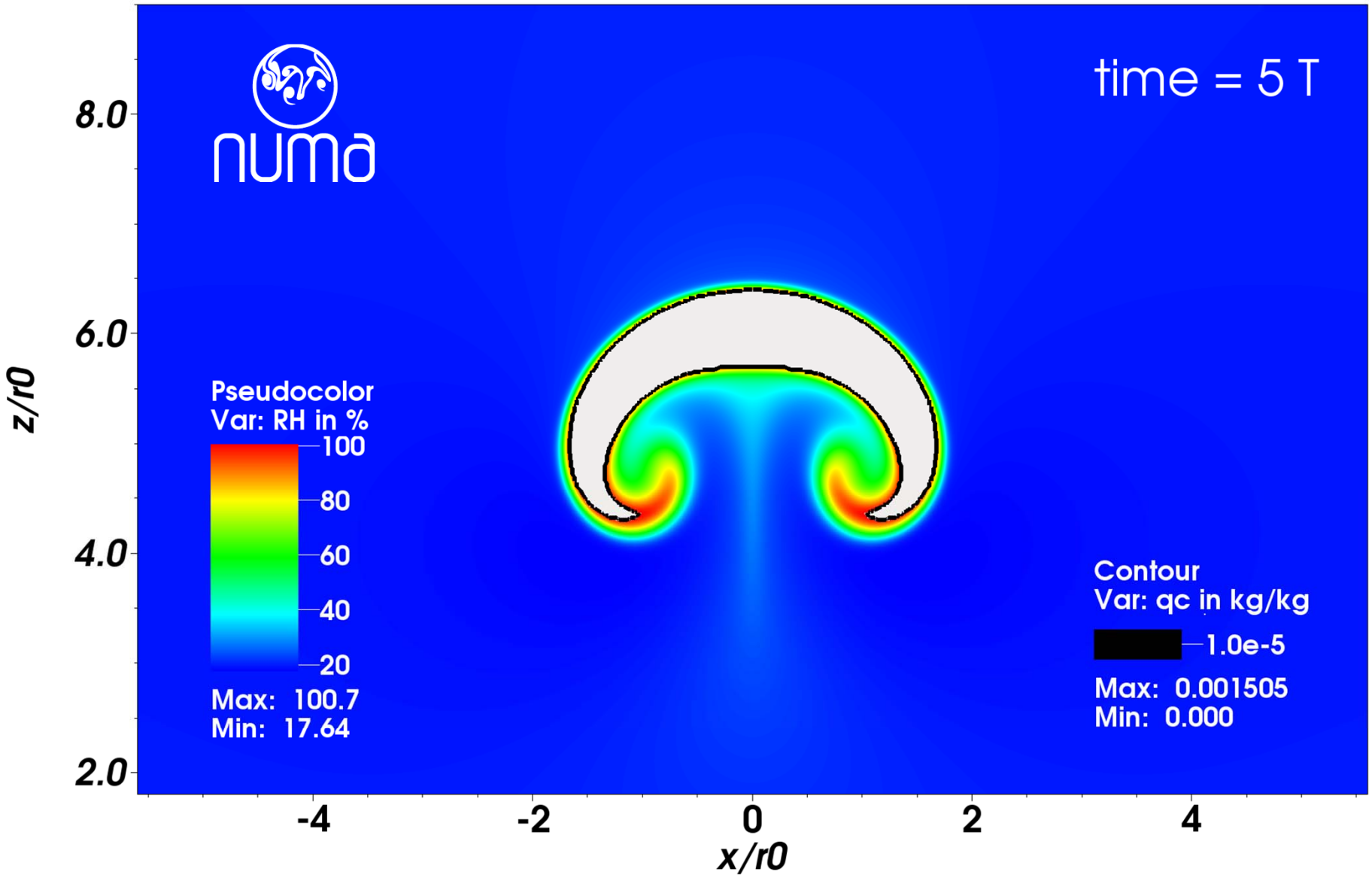
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5 m^2/s$



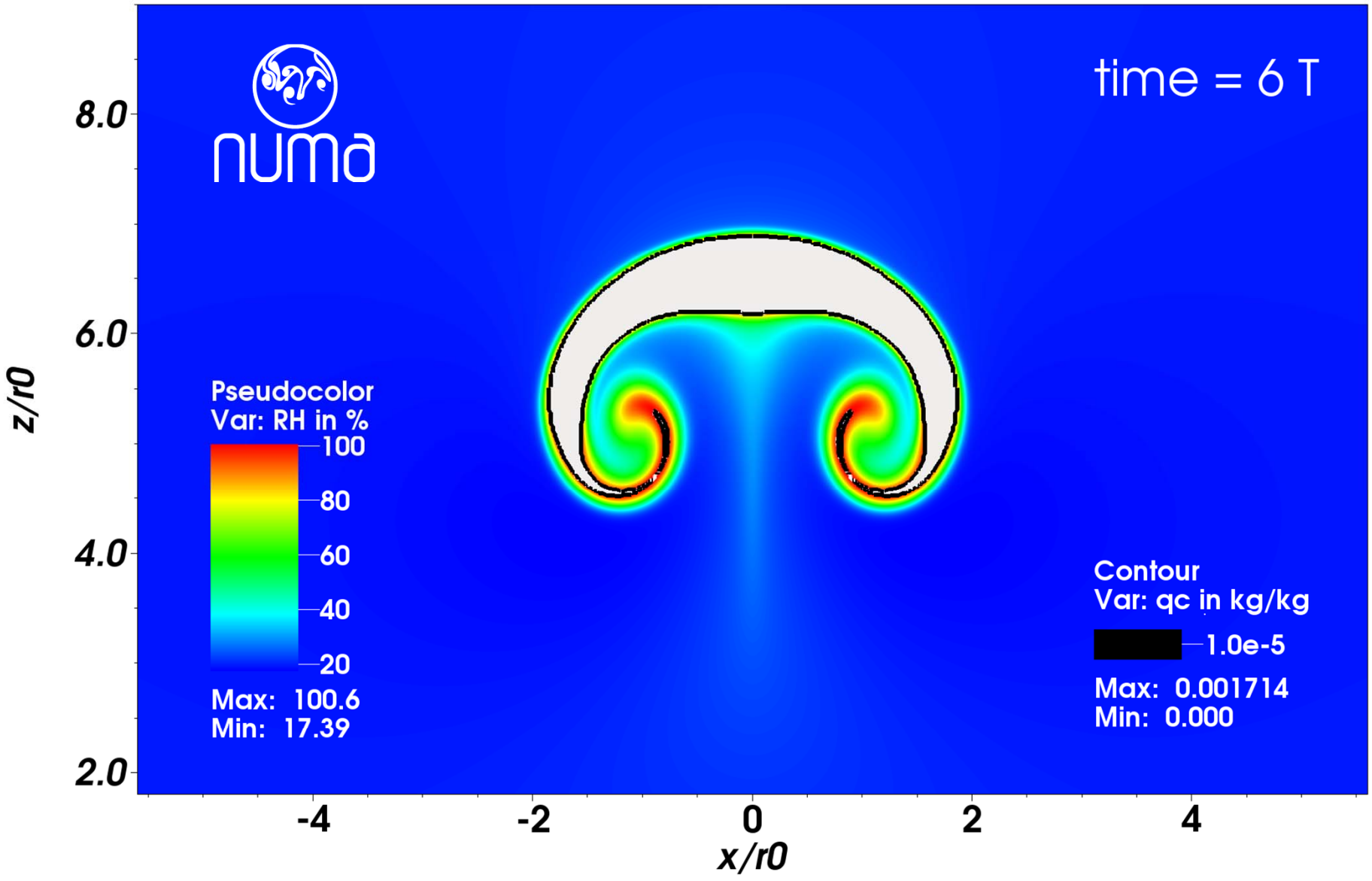
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5 m^2/s$



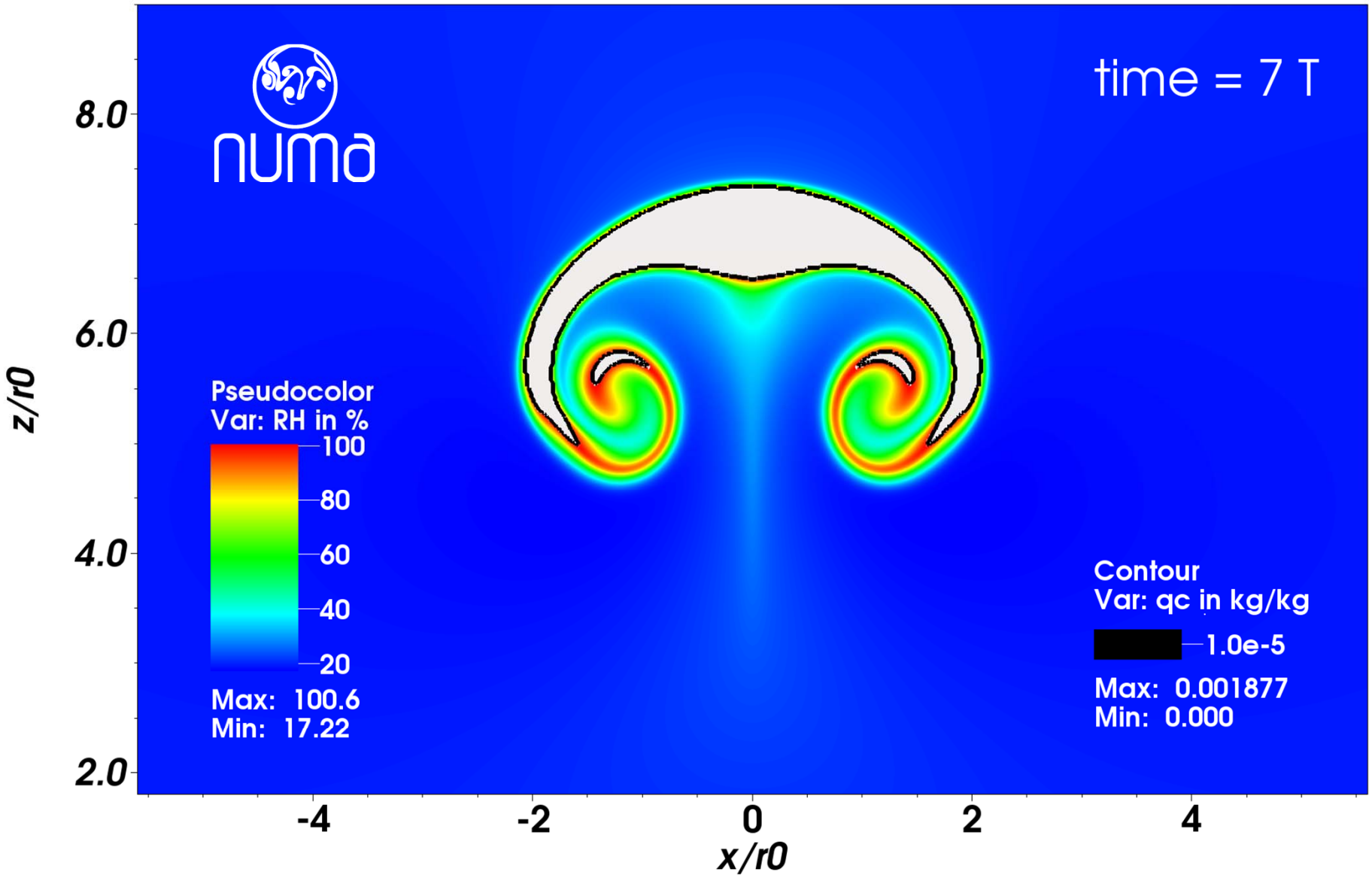
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5 m^2/s$



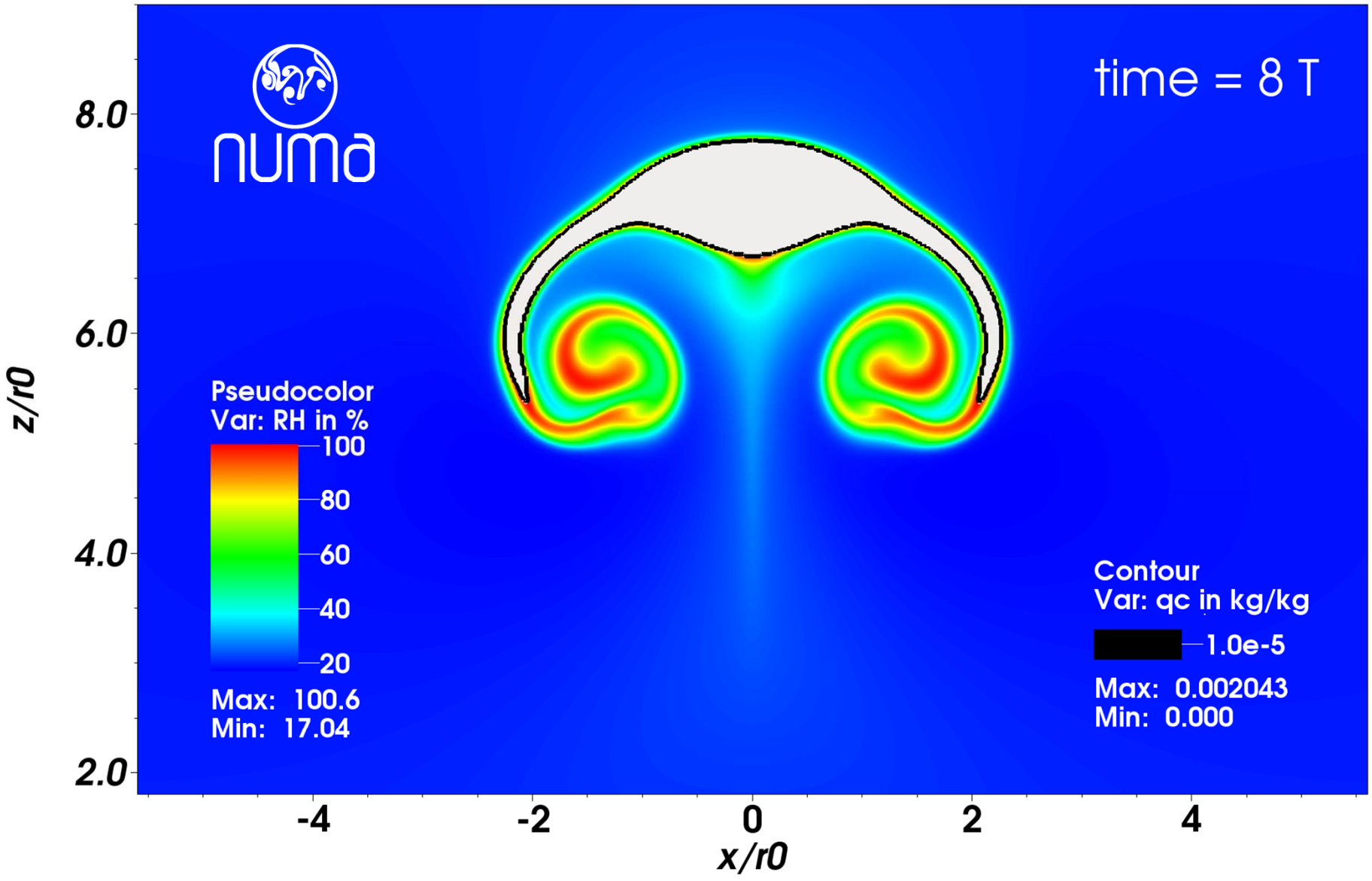
moist bubble

from Kurowski et al. (2013). Viscosity: μ=2.5m²/s



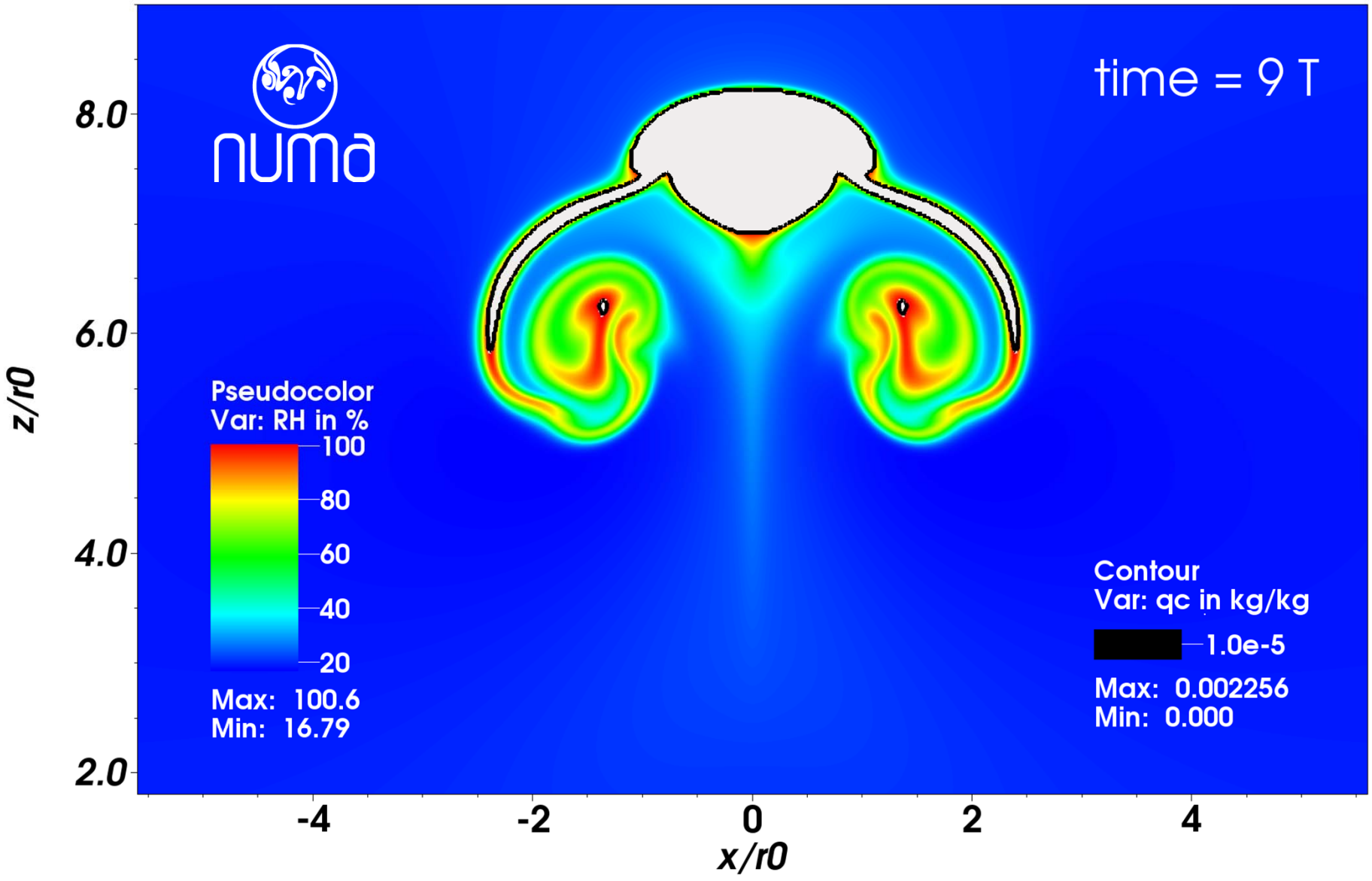
moist bubble

from Kurowski et al. (2013). Viscosity: μ=2.5m²/s



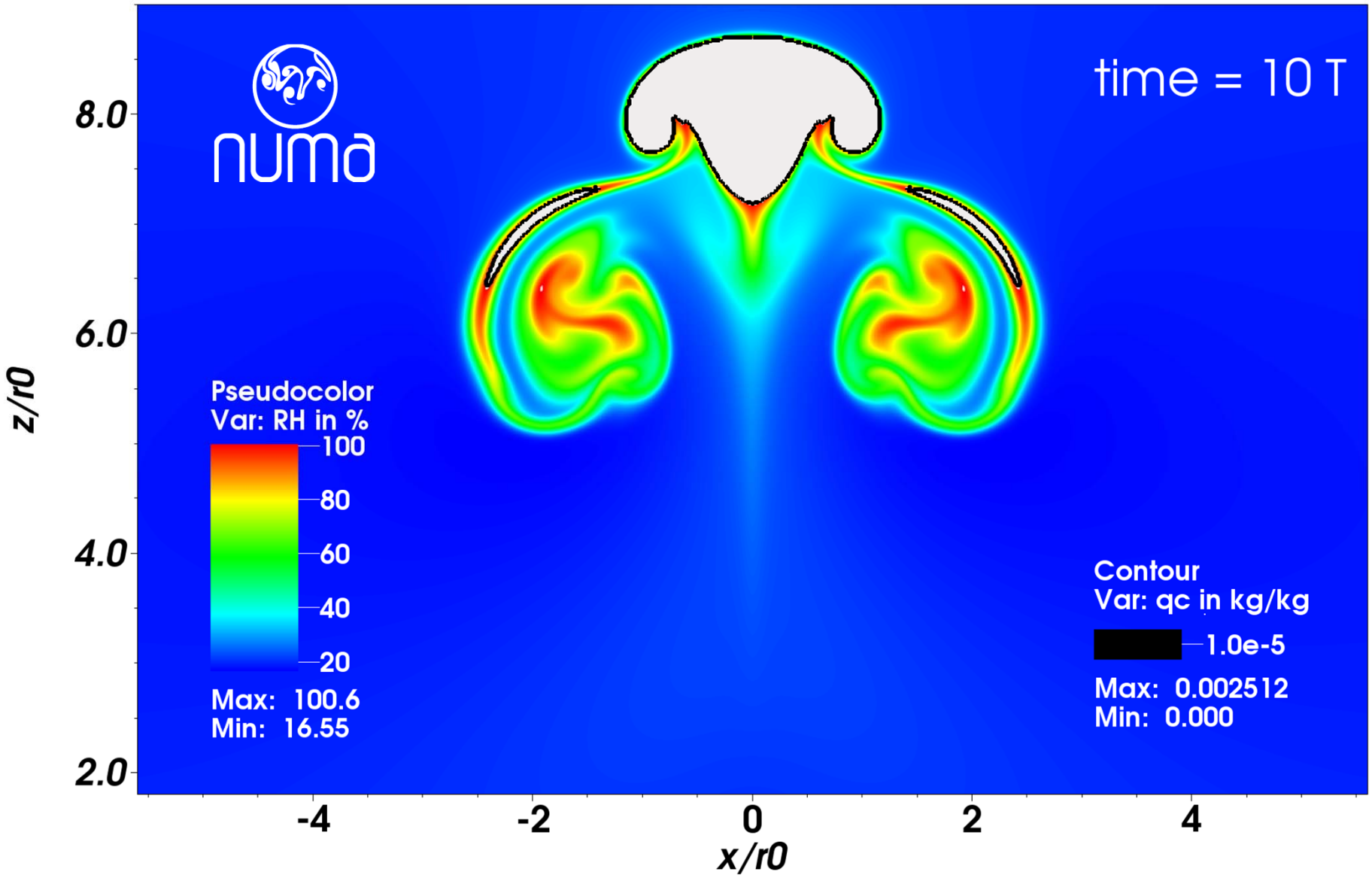
moist bubble

from Kurowski et al. (2013). Viscosity: $\mu=2.5 m^2/s$



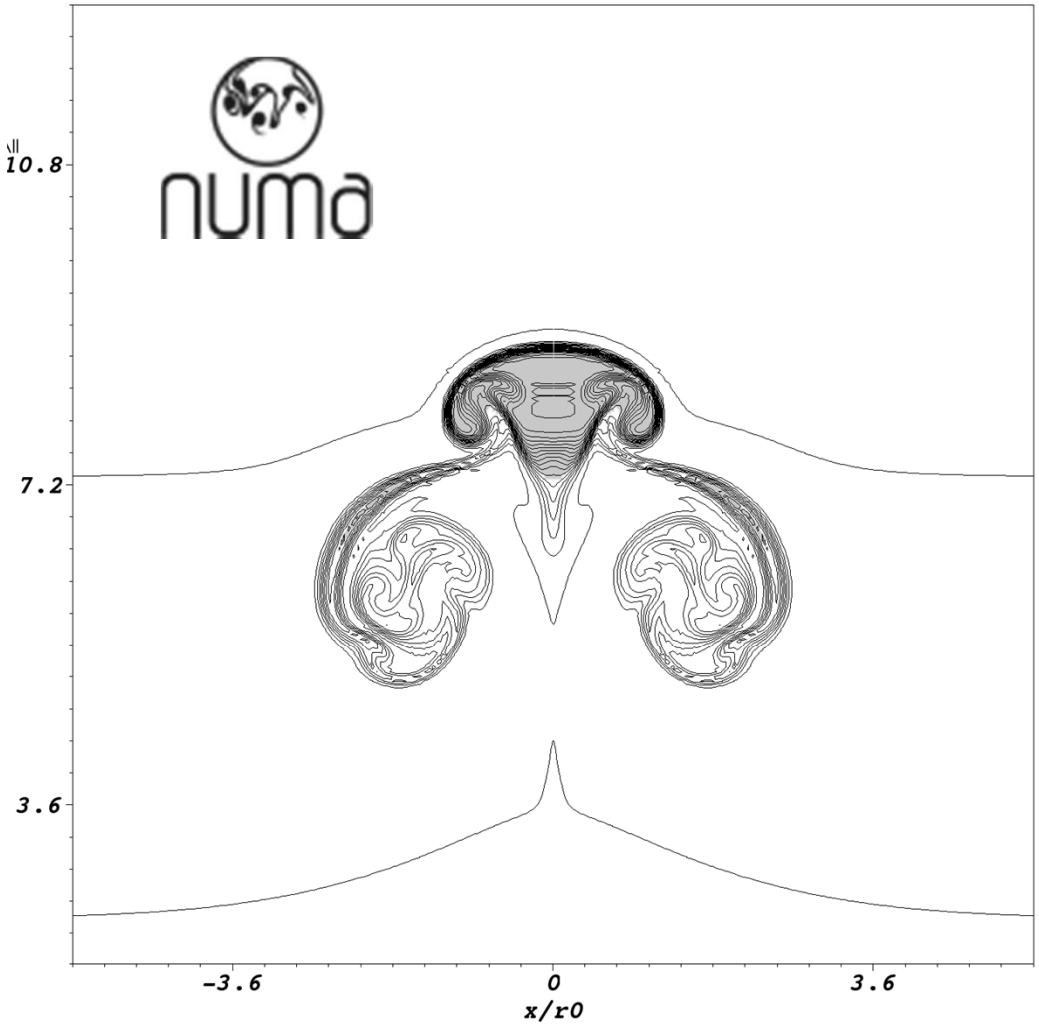
moist bubble

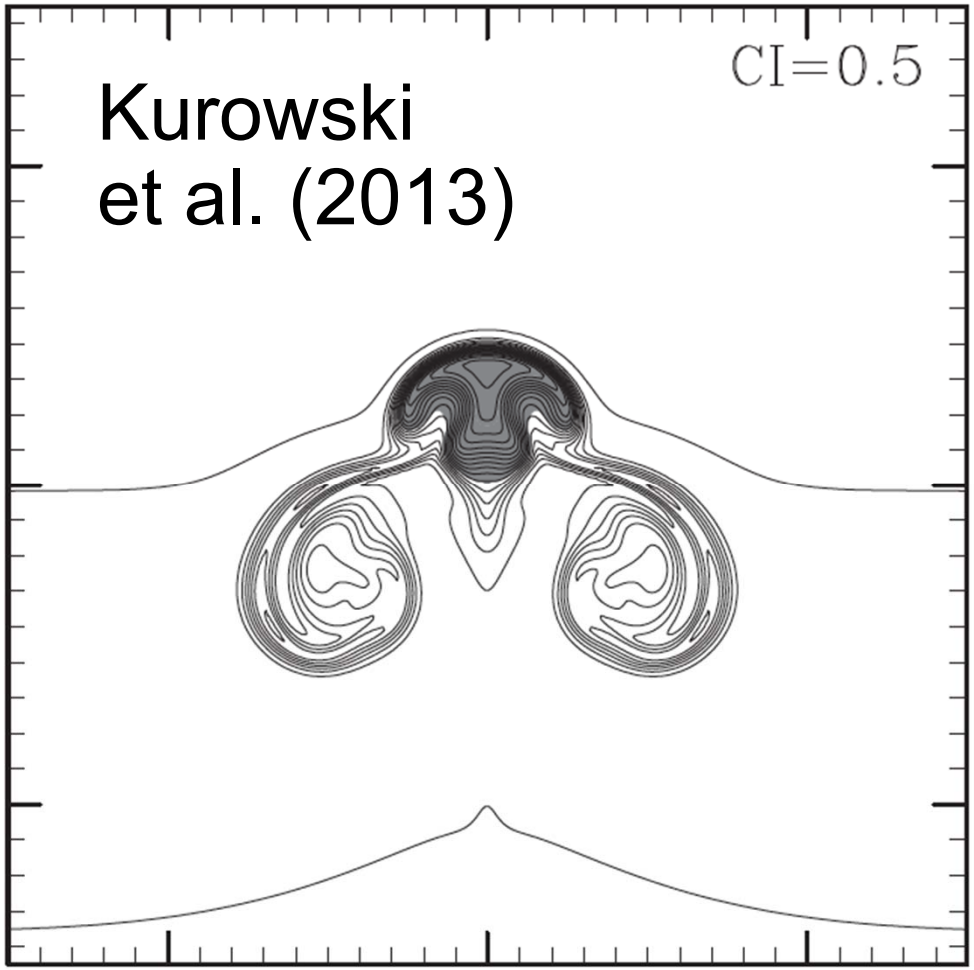
from Kurowski et al. (2013). Viscosity: $\mu=2.5 m^2/s$



moist bubble

comparison with Kurowski et al. (2013)

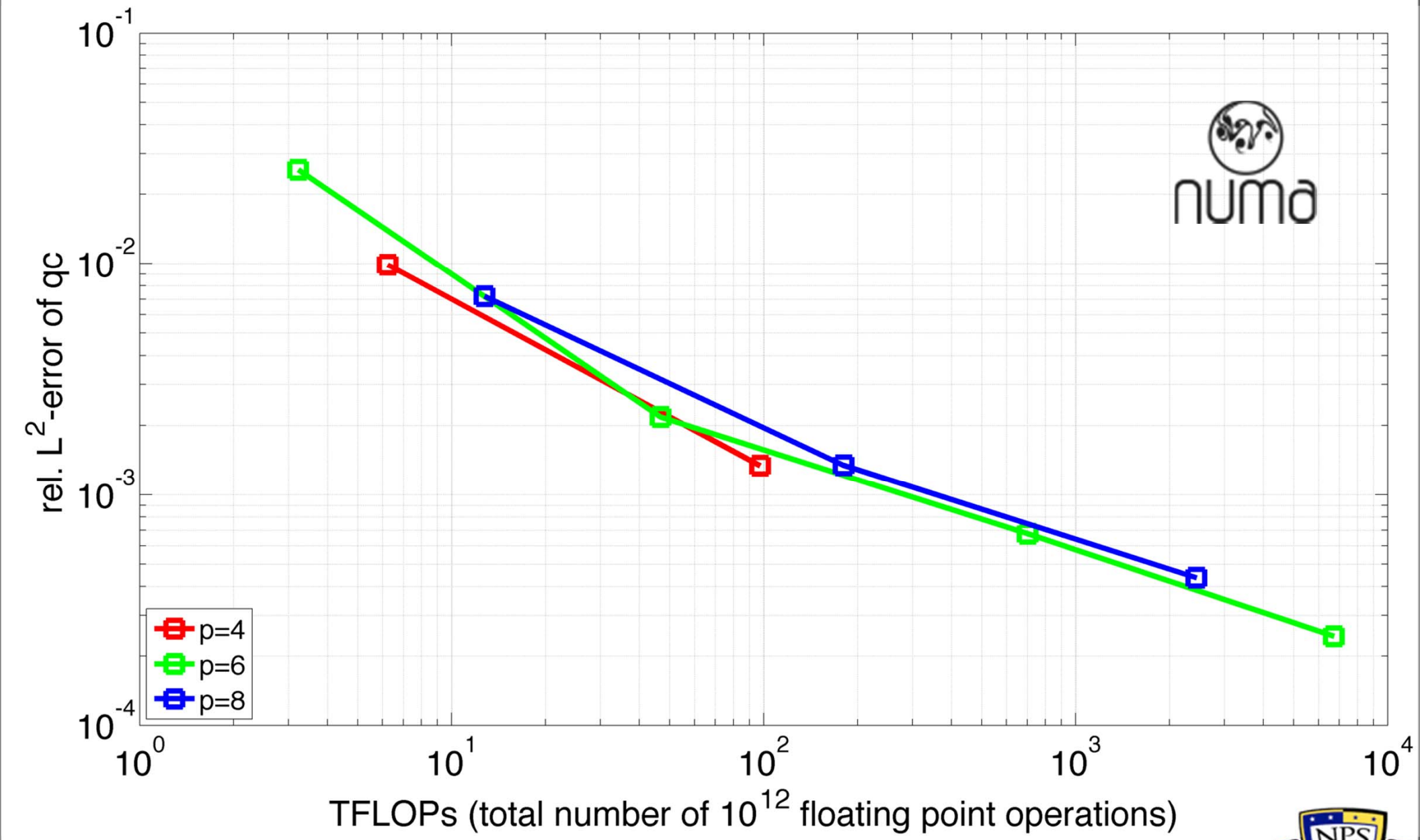




contour lines: total water mixing ratio q_t, contour interval: 0.5gr/kg

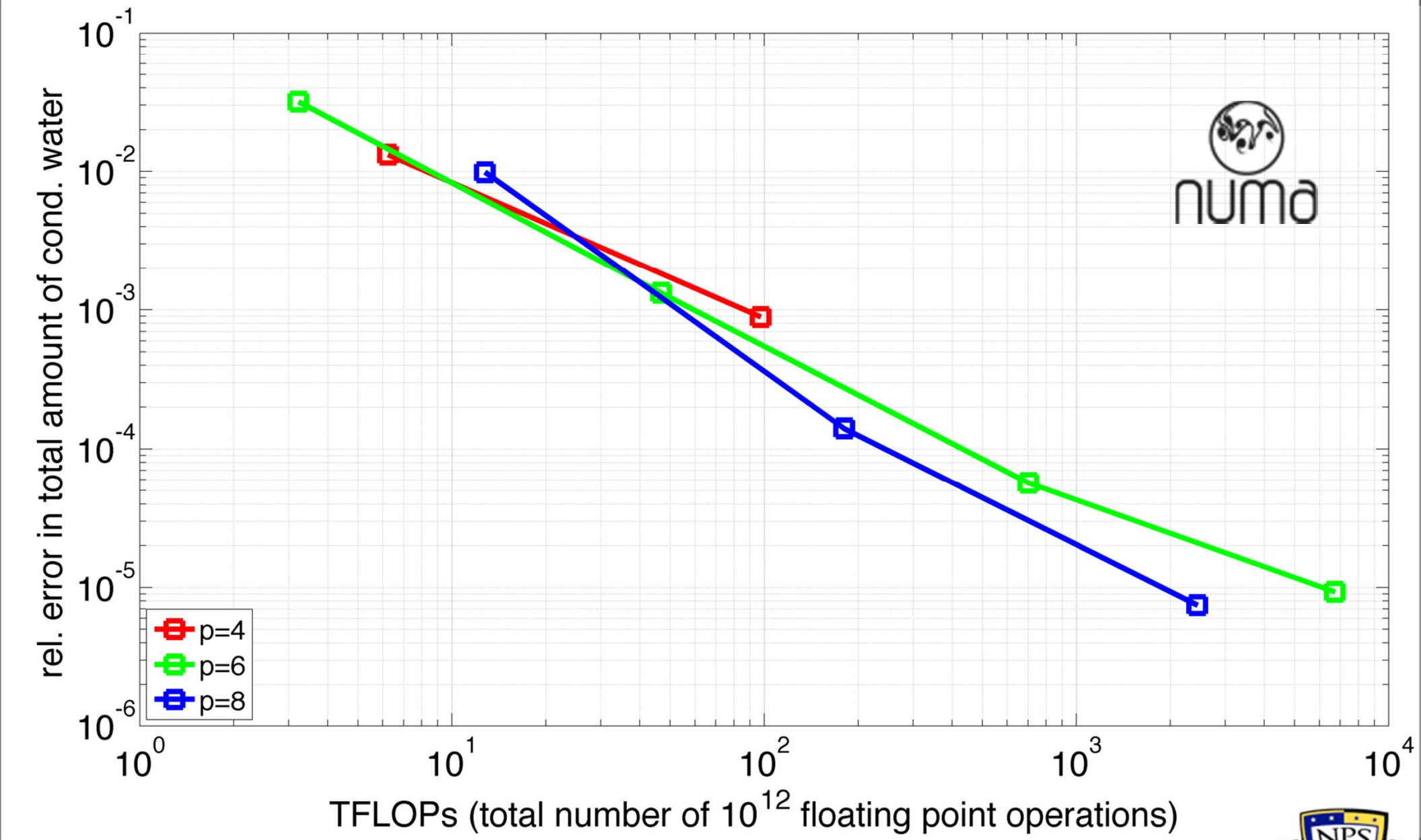
convergence for moist bubble

from Kurowski et al. (2013). Viscosity: μ=2.5m2/s



convergence for moist bubble

from Kurowski et al. (2013). Viscosity: μ=2.5m2/s



Questions for Today

Results for 2D bubble test cases simulated with NUMA

Questions:	**Results**:
1. Does high-order improve the efficiency?	High-order improves the efficiency if the flow is well resolved.
2. Does dynamic adaptive mesh refinement improve the efficiency?	2x smaller L2-error, 30x smaller error in max(θ). Bigger improvement expected for more localized problems.
3. Do moist dynamics reduce the order of convergence?	Only first order convergence, but high-order has still some benefit (e.g. more accurate total amount of condensated water)

Questions for Today

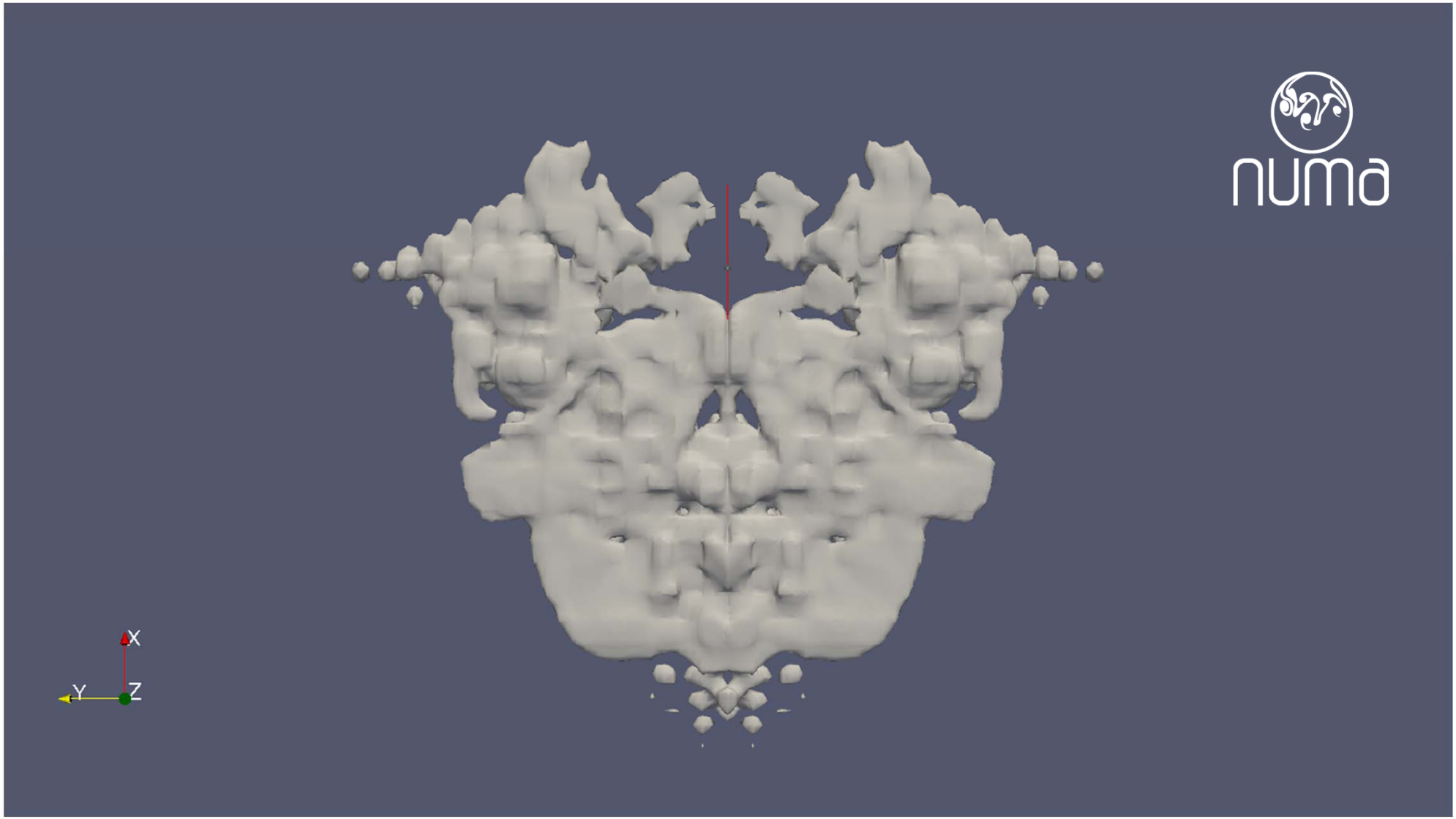
Results for 2D bubble test cases simulated with NUMA

Questions:	**Results**:
1. Does high-order improve the efficiency?	High-order improves the efficiency if the flow is well resolved.
2. Does dynamic adaptive mesh refinement improve the efficiency?	2x smaller L2-error, 30x smaller error in max(θ). Bigger improvement expected for more localized problems.
3. Do moist dynamics reduce the order of convergence?	Only first order convergence, but high-order has still some benefit (e.g. more accurate total amount of condensated water)

Open question: can we develop numerical methods and physical parameterizations that are specifically designed for each other?

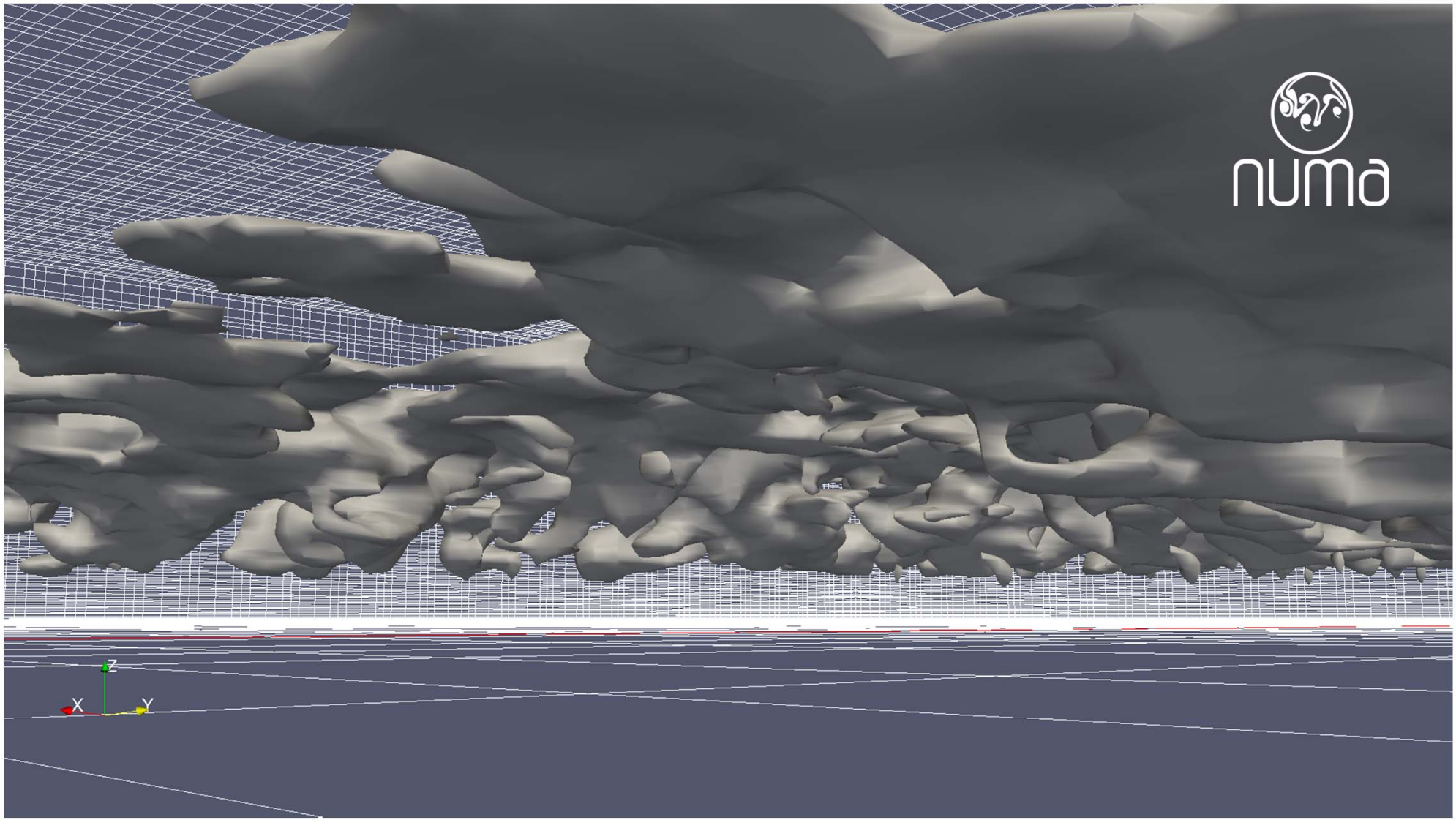
Super cell simulation at fourth order

isosurface of cloud water content q_c=0.0035 at t=7500s



Super cell simulation at fourth order

isosurface of cloud water content q_c=0.0035 at t=7500s



Super cell simulation at fourth order

visualization with Maya® (see http://anmr.de for instructions)

Thank you for your attention!