Modelling of Atmospheric Clouds

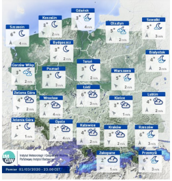
Sylwester Arabas

Faculty of Mathematics and Computer Science, Jagiellonian University

lecture+lab 2
Mar. 2 2020

previously on... (motiv. & applications of cloud models)

- prediction of cloudiness, precipitation, visibility, air quality (NWP)



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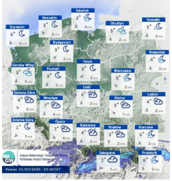

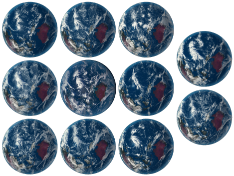

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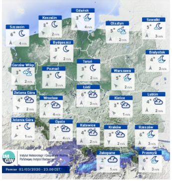
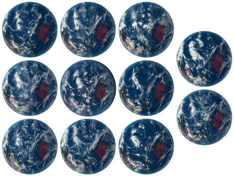
- physics and chemistry of aerosol-cloud-precipitation interactions (basic research)





【VR180 3D 4K】微速度撮影された雲の様子を観察してみよう：「京」コンピュータを使ったシミュレーション編２【2019年度R-CCS一般公開】

previously on... (thermodynamics of moist air)

Dalton's law

$p = p_d + p_v$

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dew point, boiling point

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relative humidity

$\mathrm{RH} = \frac{p_v}{p_{vw}(T)}$

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- 3 components of air velocity/momentum (i.e. wind)
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- microphysical variables $\rightsquigarrow$ statistical moments or detailed discretisation of the size spectrum of particles

evolution of the state vector (exceprts from R&Y book)

$$\frac{\partial \nu}{\partial t} = -\frac{\partial}{\partial r}\left(\nu \frac{dr}{dt}\right) \qquad (7.31)$$

$$\frac{\partial u_1}{\partial t} = -u_1 \frac{\partial u_1}{\partial x} - u_3 \frac{\partial u_1}{\partial z} - \frac{1}{\varrho_0} \frac{\partial \hat{p}}{\partial x} + F_{u_1}, \tag{15.5}$$

$$\frac{\partial u_3}{\partial t} = -u_1 \frac{\partial u_3}{\partial x} - u_3 \frac{\partial u_3}{\partial z} - \frac{1}{\varrho_0} \frac{\partial \hat{p}}{\partial z} + g\left(\frac{\hat{T}_v}{T_{v_0}} - \frac{\hat{p}}{p_0} - q\right) + F_{u_3}, \tag{15.6}$$

$$0 = \frac{\partial}{\partial x}(\varrho_0 u_1) + \frac{\partial}{\partial z}(\varrho_0 u_3), \tag{15.7}$$

$$\frac{\partial T}{\partial t} = -u_1 \frac{\partial T}{\partial x} - u_3\left(\frac{\partial T}{\partial z} + \Gamma\right) + F_T + \phi_T, \tag{15.8}$$

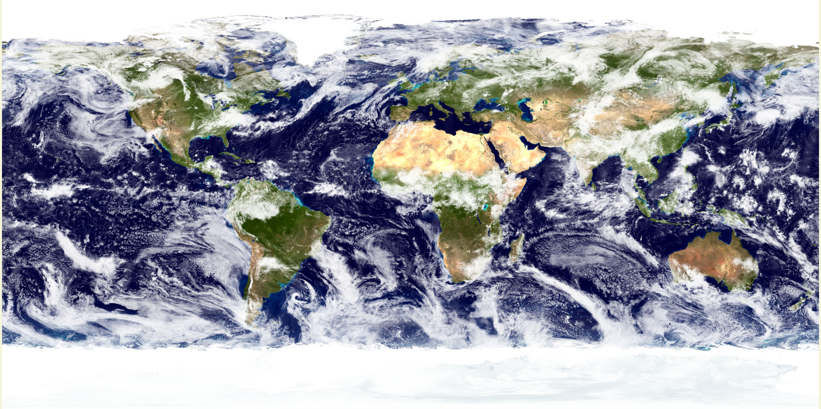
$$\frac{\partial w}{\partial t} = -u_1 \frac{\partial w}{\partial x} - u_3 \frac{\partial w}{\partial z} + F_w + \phi_w, \tag{15.9}$$

$$\frac{\partial \mu}{\partial t} = -u_1 \frac{\partial \mu}{\partial x} - u_3 \frac{\partial \mu}{\partial z} + F_\mu + \phi_\mu, \tag{15.10}$$

$$\frac{\partial R}{\partial t} = -u_1 \frac{\partial R}{\partial x} - u_3 \frac{\partial R}{\partial z} - \frac{1}{\varrho_0} \frac{\partial}{\partial z}(\varrho_0 R V) + F_R + \phi_R. \tag{15.11}$$

transport/advection/conservation/continuity equation

$$\partial_t G\psi + \nabla \cdot (G\vec{u}\psi) = GR$$



http://earthobservatory.nasa.gov/Features/BlueMarble/BlueMarble_2002.php

upwind/upstream/donor-cell discretisation

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$$\psi^{n+1} = f(\psi^{n}, \vec{u})$$

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„upwind” scheme in 1D

$$\psi^{n+1}_{i} = \psi^{n}_{i} - \left[\mathrm{flux}\left(\psi^{n}_{i}, \psi^{n}_{i+1}, C_x\right) - \mathrm{flux}\left(\psi^{n}_{i-1}, \psi^{n}_{i}, C_x\right)\right]$$

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$$C_x = u_x \frac{\Delta t}{\Delta x}$$

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$$\begin{aligned}\text{flux}(\psi_l, \psi_r, C) &= \max(C, 0) \cdot \psi_l + \min(C, 0) \cdot \psi_r \\ &= \tfrac{C+|C|}{2}\psi_l + \tfrac{C-|C|}{2}\psi_r\end{aligned}$$

MPDATA in a nutshell (Smolarkiewicz 1983 MWR . . .)

transport PDE: $$\frac{\partial\psi}{\partial t} + \frac{\partial}{\partial x}(v\psi) = 0$$

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$$\underbrace{F(\psi_L, \psi_R, \mathcal{C}) = \max(\mathcal{C}, 0) \cdot \psi_L + \min(\mathcal{C}, 0) \cdot \psi_R}_{\text{upwind}}$$

$$\mathcal{C} = v\Delta t / \Delta x$$

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upwind

modified eq.: $\frac{\partial \psi}{\partial t} + \frac{\partial}{\partial x}(v\psi) + \underbrace{K\frac{\partial^2 \psi}{\partial x^2}}_{\text{numerical diffusion}} + \ldots = 0$

MEA

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$$\frac{\partial \psi}{\partial t} + \frac{\partial}{\partial x}(v\psi) + \frac{\partial}{\partial x}\underbrace{\left[\left(-\frac{K}{\psi}\frac{\partial \psi}{\partial x}\right)\psi\right]}_{\text{antidiffusive flux}} = 0$$

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$$\mathcal{C}'_{i+1/2} = (|\mathcal{C}_{i+1/2}| - \mathcal{C}^2_{i+1/2})A_{i+1/2}$$
$$A_{i+1/2} = \frac{\psi_{i+1} - \psi_i}{\psi_{i+1} + \psi_i}$$

MPDATA: reverse numerical diffusion by integrating the antidiffusive flux using upwind (in a corrective iteration) attendance list!!!

job offer @ BSC

https://www.bsc.es/join-us/job-opportunities/5020esgesr2

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

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  - Scholarships
  - Job Opportunities

Researcher for high-resolution global climate prediction (R2)

Job Reference	Position	Closing Date
50_20_ES_GES_R2	Researcher for high-resolution global climate prediction (R2)	Tuesday, 31 March, 2020

Reference: 50_20_ES_GES_R2
Job title: Researcher for high-resolution global climate prediction (R2)

job offers @ Caltech / CliMA Project

https://clima.caltech.edu/join-our-team/

Caltech

Research Software Engineer

Pasadena, CA

We are seeking a Research Software Engineer to develop, implement, and integrate components of the first Earth system model (ESM) that learns automatically from global observations and targeted high-resolution simulations of clouds, turbulence, and other elements of the Earth system. As a CliMA Research Software Engineer at Caltech, you will work in a dynamic, multi-disciplinary team of curious and creative scientists, engineers, and applied mathematicians, spanning the CliMA partner institutions.

Software Engineer

Pasadena, CA

Do you love translating mathematical concepts into code? Do you find shaving microseconds off your function calls satisfying? Are you tenacious in tracking down obscure bugs? Can you build high-level abstractions without sacrificing performance? Have you helped maintain large shared codebases, shepherding changes while keeping continuous integration tests passing? Do you enjoy learning about new technologies and pushing their limits? Are you interested in joining world-leading experts to help solve one of the most important scientific problems of our time?

job offers @ Caltech / CliMA Project

https://clima.caltech.edu/join-our-team/

As **minimum qualification**, you are expected to have

- Completed a BS degree or equivalent experience in computer science, applied mathematics, mechanical or civil engineering, or Earth science;
- Demonstrated expertise in numerical methods for partial differential equations, through coursework and/or research experience;
- Experience developing large software projects in a distributed fashion, e.g., contributing to an open source project with distributed contributors; and
- Experience with at least two programming languages (e.g., C, C++, Fortran, C#, Objective C, Python, Julia, Matlab/Octave).

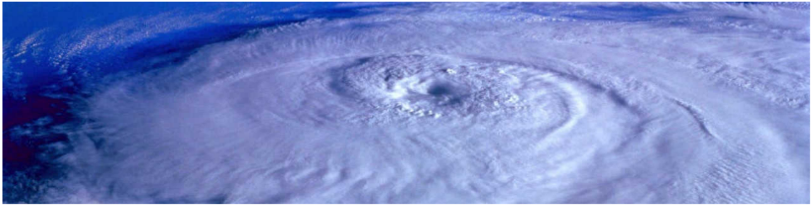
Preferred qualifications:

- A graduate degree in computer science, applied mathematics, mechanical or civil engineering, or Earth science;
- Experience working with high-performance computing systems, including multicore processors and GPUs or other accelerators;
- Experience in physics, computational fluid dynamics, and/or machine learning; and
- Experience working in multi-disciplinary teams and interacting cross-functionally with a wide variety of people.

summer school @ Univ. Reading (deadline: March 6)

https://hps.vi4io.org/events/2020/esiwace-school

Summer School on Effective HPC for Climate and Weather



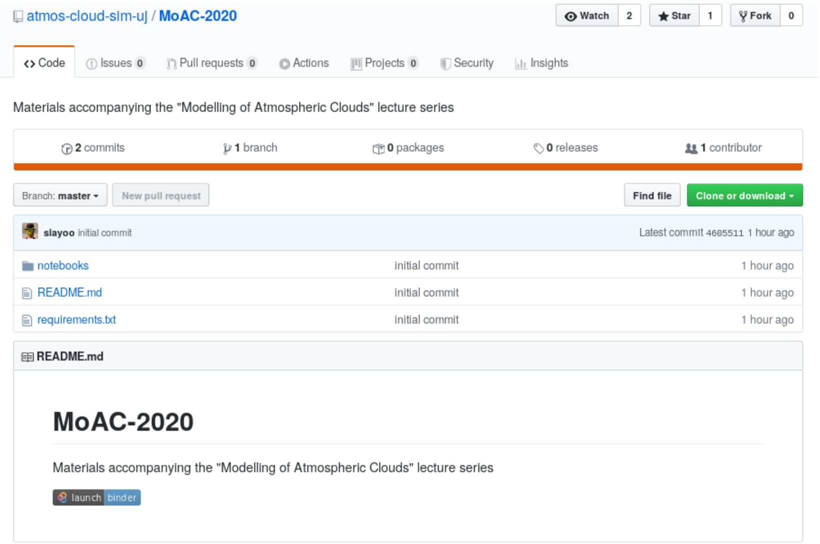
Aim and Scope

Making effective use of HPC environments becomes increasingly challenging for PhD students and young researchers. As their primary intent is to generate insight, they often struggle with the technical nature of the tools and environments that enable their computer-aided research: computation, integration, and analysis of relevant data.

The scope of the summer school is the training of young researchers and software engineers in methods, tools, and theoretical knowledge to make effective use of HPC environments and generate insights.

Date	23-28 August 2020

LAB: github.com/atmos-cloud-sim-uj/MoAC-2020



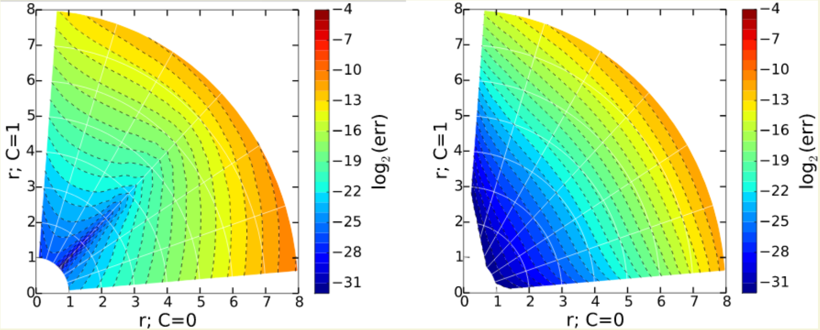
please clone or launch on binder and open notebooks/01_...

LAB: plan

- upwind hello world
- MPDATA hello world
- MPyDATA example

MPyDATA project idea: convergence “maps”

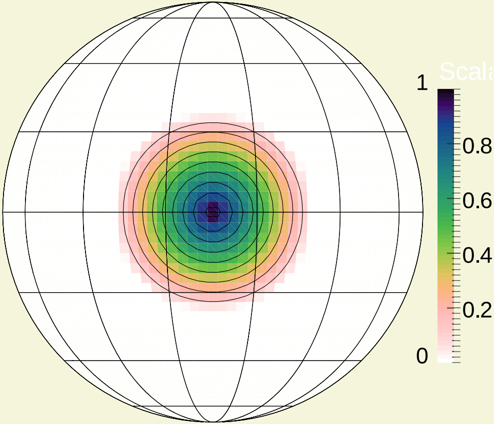
Jaruga et al. 2015: Figs. 10 & 11



https://github.com/igfuw/libmpdataxx/blob/master/tests/paper_2015_GMD/2_convergence_1d/plot.py

MPyDATA project idea: polar coordinates

Jaruga et al. 2015: Fig 14



https://github.com/igfuw/libmpdataxx/blob/master/tests/paper_2015_GMD/5_over_the_pole_2d/plot.py

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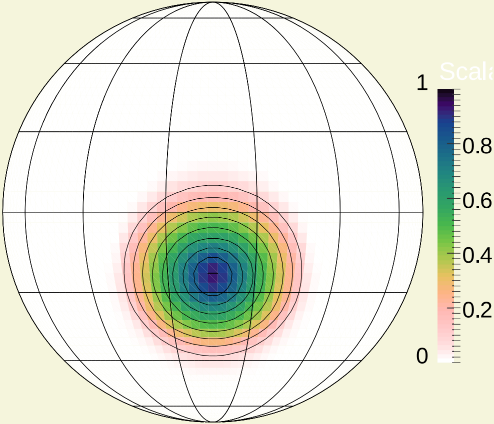

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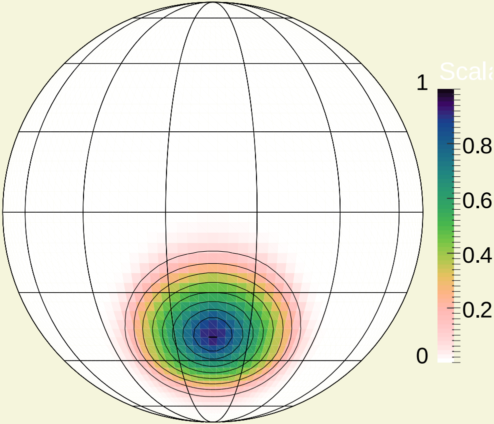

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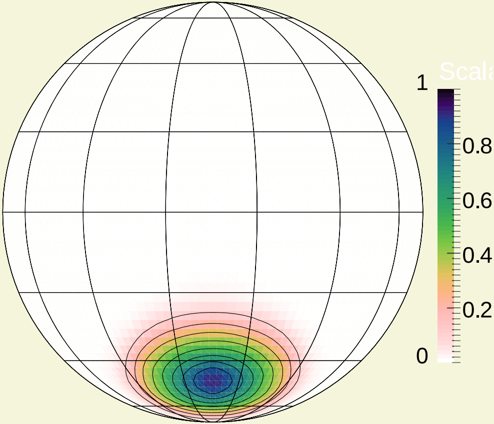

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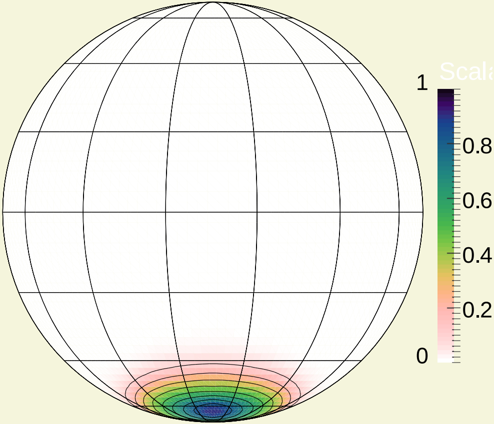

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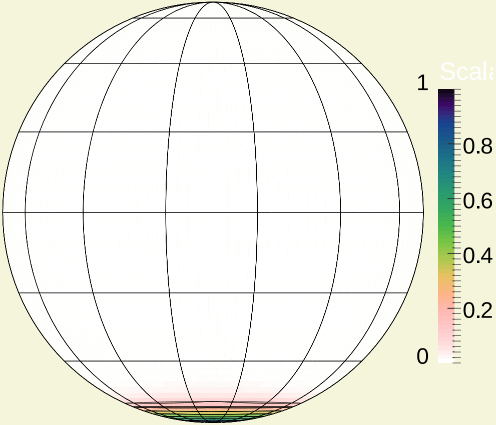

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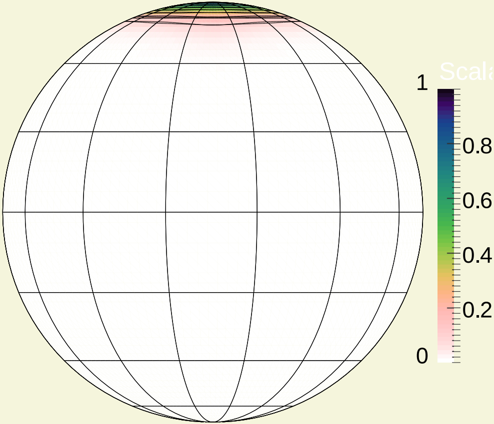

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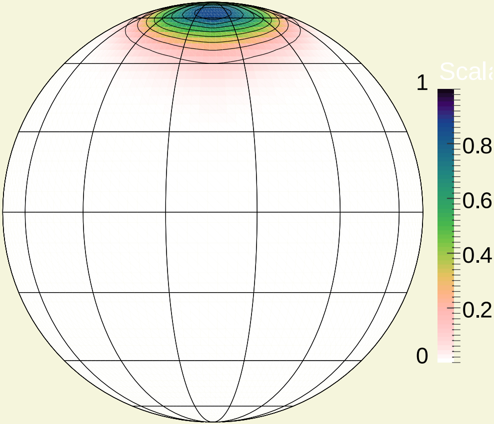

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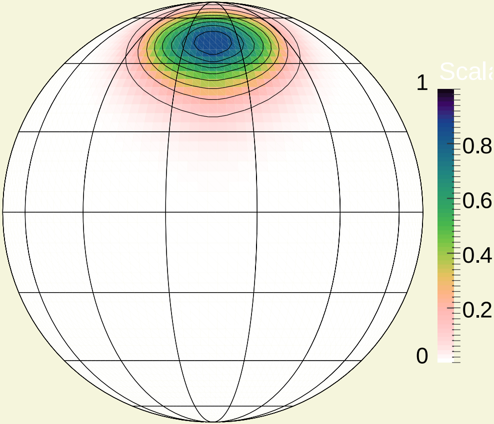

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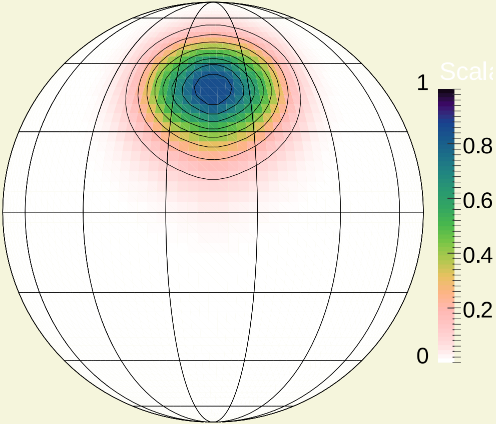

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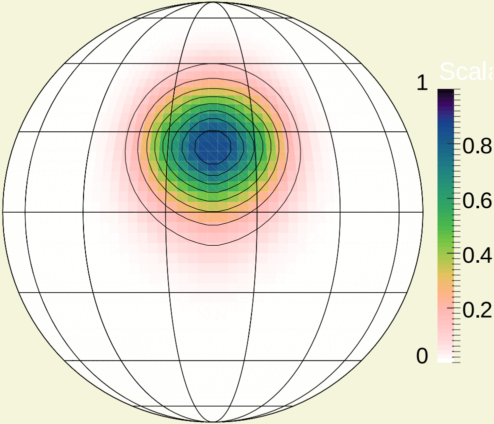

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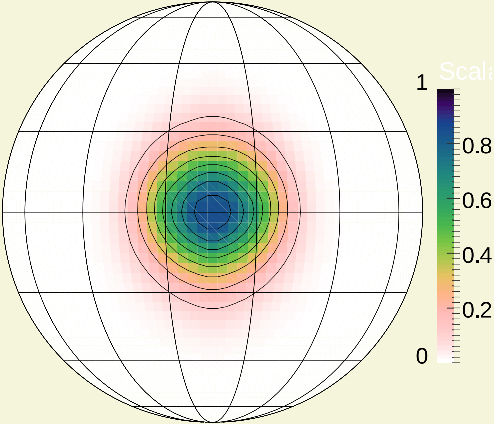

https://github.com/igfuw/libmpdataxx/blob/master/tests/paper_2015_GMD/5_over_the_pole_2d/plot.py

MPyDATA project idea: spurious supersaturation study

selected literature

- Stevens et al. 1996, Mon. Wea. Rev. 124
  doi:10.1175/1520-0493%281996%29124%3C1034:TSPOCE%3E2.0.CO;2
- Jeffery & Reiser 2006, J. Atmos. Sci. (63(11))
  doi:10.1175/JAS3760.1
- Hoffmann 2016, Mon. Wea. Rev. 144(1)
  doi:10.1175/MWR-D-15-0234.1

the problem (one of may)

$e_s(T) = e_s(T(q_v, \theta))$ is a non-linear function of the advected (conserved) quantities, good example to showcase applicability of different variants of MPDATA

MPyDATA project idea: advection-diffusion equation

Lange 1978 (J. Appl. Meteorol. 17)

$$\frac{\partial \psi}{\partial t} + u\frac{\partial \psi}{\partial x} - \nu\frac{\partial^2 \psi}{\partial x^2} = 0 \quad \rightsquigarrow \quad \frac{\partial \psi}{\partial t} + \frac{\partial}{\partial x}\left[\left(u - \frac{\nu}{\psi}\frac{\partial \psi}{\partial x}\right)\psi\right] = 0$$

quantitative finance example

ELSEVIER

Journal of Computational and Applied Mathematics

Available online 20 June 2019, 112275

In Press, Corrected Proof

Derivative pricing as a transport problem: MPDATA solutions to Black–Scholes-type equations ☆

Sylwester Arabas [a], Ahmad Farhat [b]

[a] Jagiellonian University, Kraków, Poland

[b] HSBC Service Delivery (Polska) Sp. z o.o., Kraków, Poland

https://github.com/atmos-cloud-sim-uj/MPyDATA/tree/master/MPyDATA_examples

MPyDATA project idea: inhomogeneous system hello world

Jaruga et al. 2015: Fig. 15

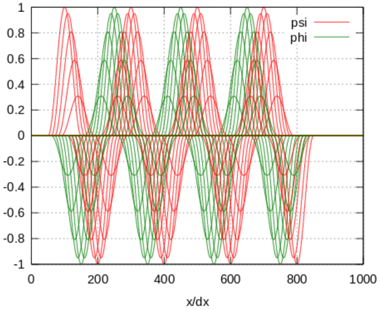

Figure 15. Simulation results of the example presented in Sect. 4.3. Abscissa marks the spatial dimension and ordinate represents the oscillator amplitude. The oscillator state is plotted every 20 time steps.

A system of two one-dimensional advection equations,

$$\begin{aligned} \partial_t \psi + \partial_x (u_o \psi) &= \omega\phi, \\ \partial_t \phi + \partial_x (u_o \phi) &= -\omega\psi, \end{aligned} \tag{16}$$

represents a harmonic oscillator translating with $u_o =$ constant; see Sect. 4.1 in Smolarkiewicz (2006) for a discussion.[19] Applying the trapezoidal rule to integrate the PDE

[19]The implicit manner of prescribing forcings, similar to the one presented herein, is an archetype for integrating Coriolis force in Prusa et al. (2008).

MPyDATA project idea: shallow-water equations solver

ELSEVIER

Journal of Computational Physics

Volume 289, 15 May 2015, Pages 53-61

A spreading drop of shallow water

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Codes for reproducing Figs. 1-3.

For plotting Figs. 1-3, you need Python with scientific libraries (e.g. NumPy, SciPy, Matplotlib, h5py).

Figure 1 (both panels) can be obtained by running:

```
$ python ellipse_evolution_odeint.py
```

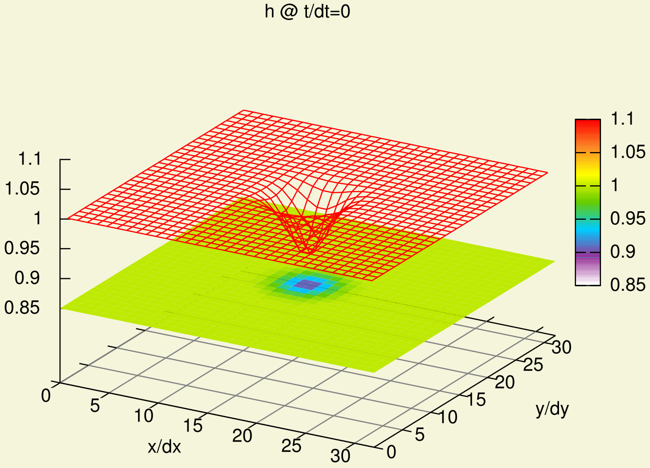
Figure 2 can be obtained by running:

```
$ python energy_conserv.py
```

Figure 3 can be obtained by running:

```
$ python circle_evolution.py
```

MPyDATA project idea: shallow-water equations solver



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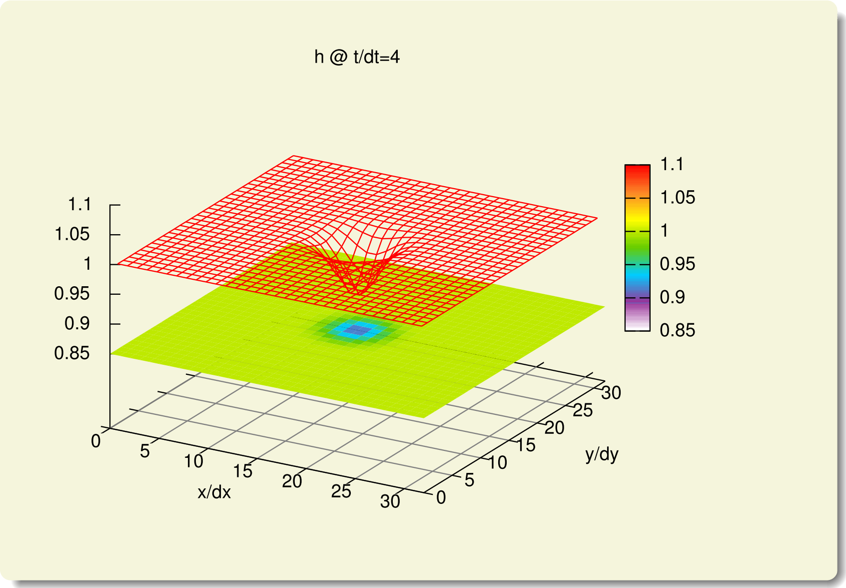

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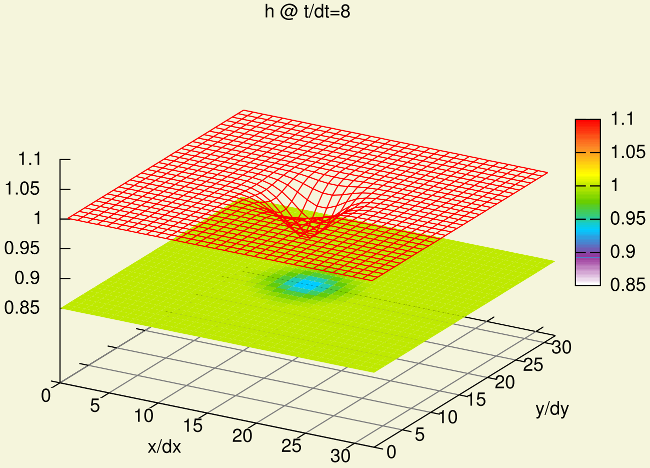

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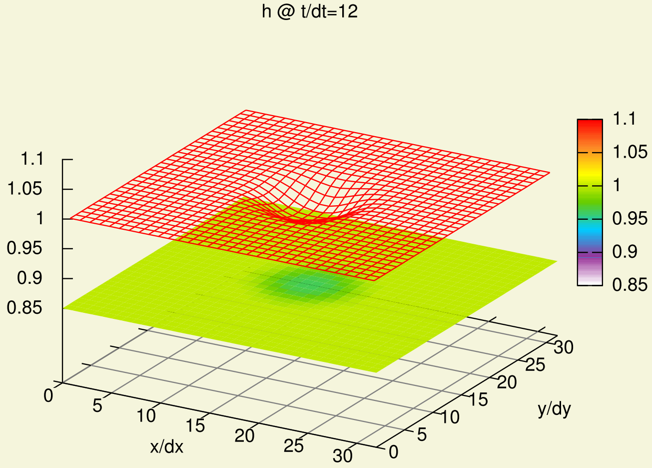

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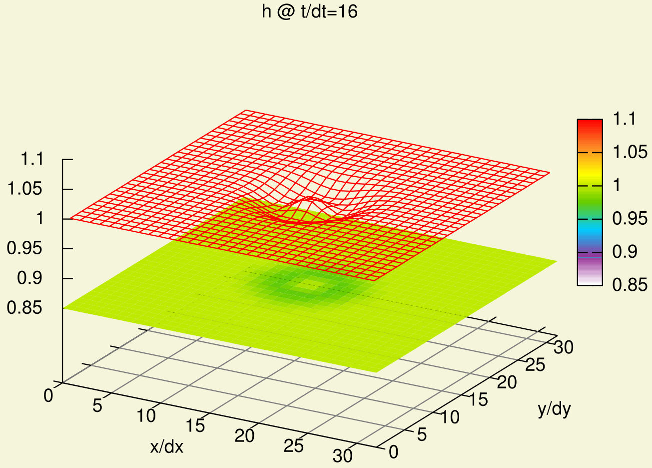

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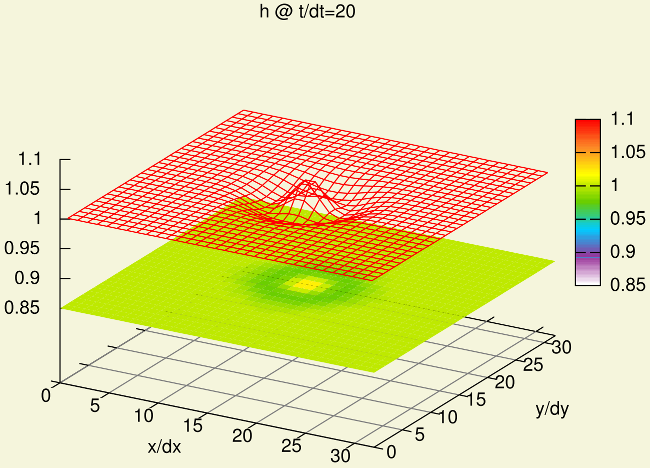

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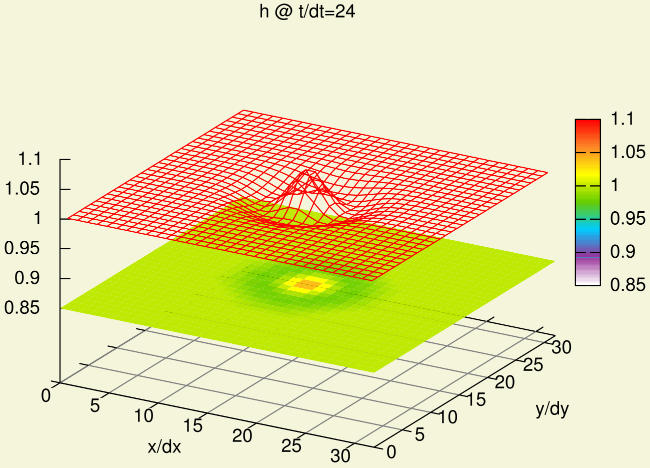
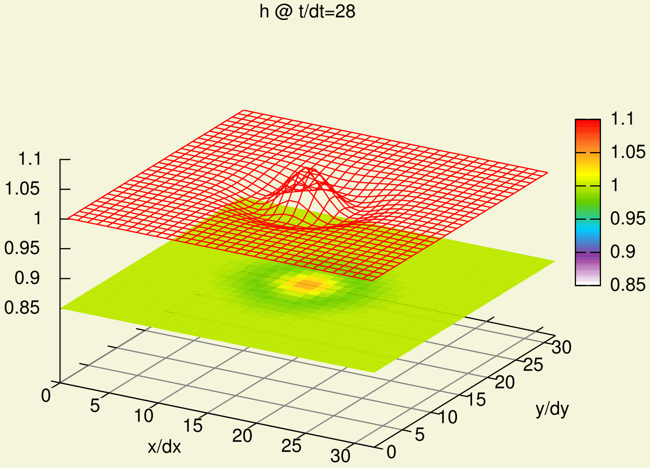
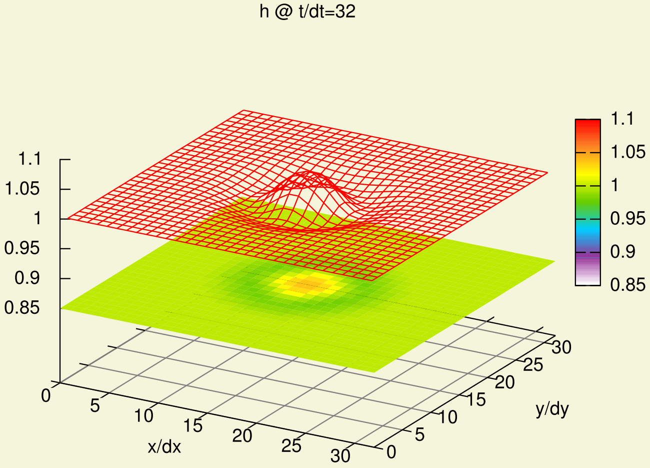


MPyDATA project idea: shallow-water equations solver



MPyDATA project idea: shallow-water equations solver



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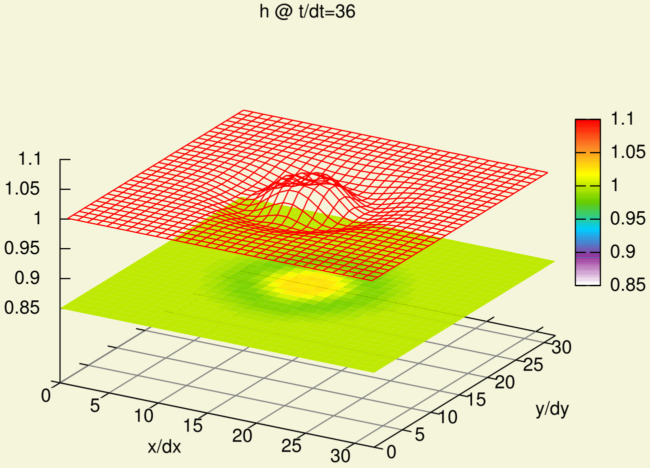

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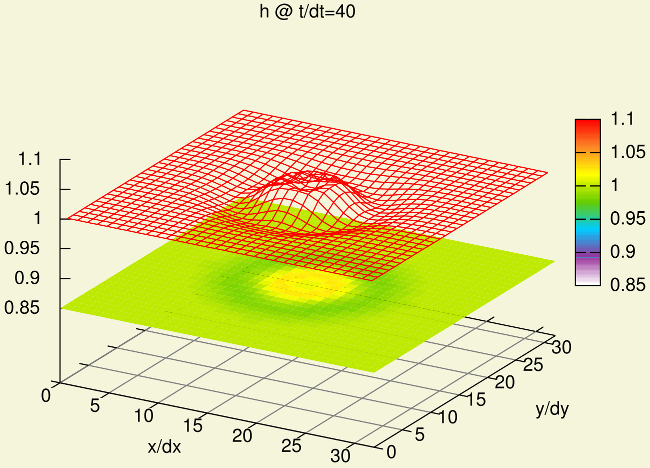

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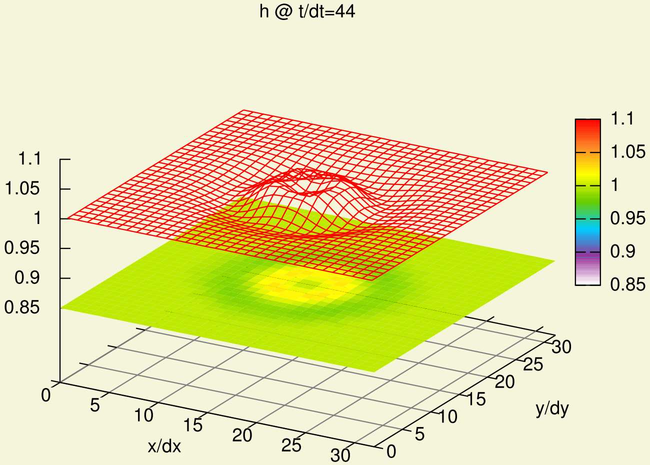

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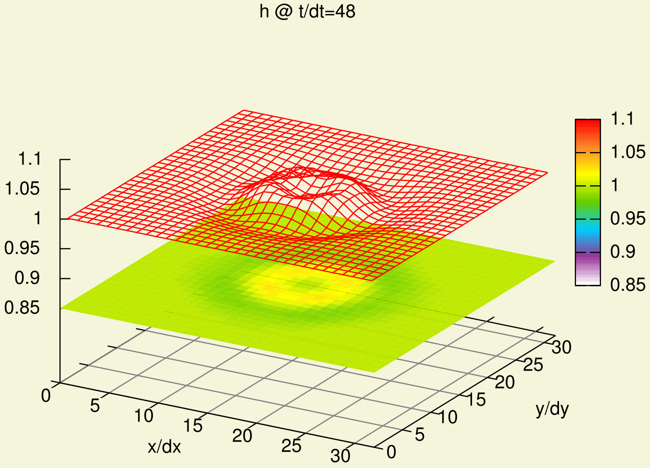

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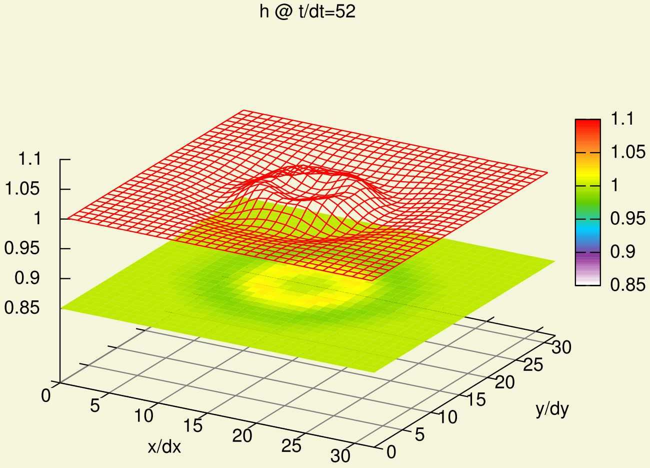
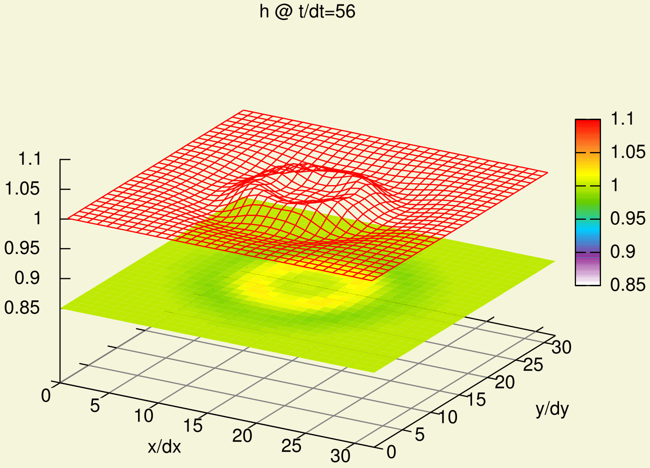
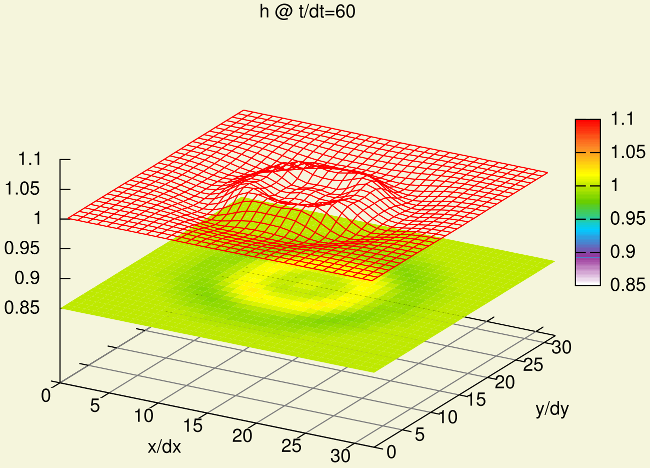


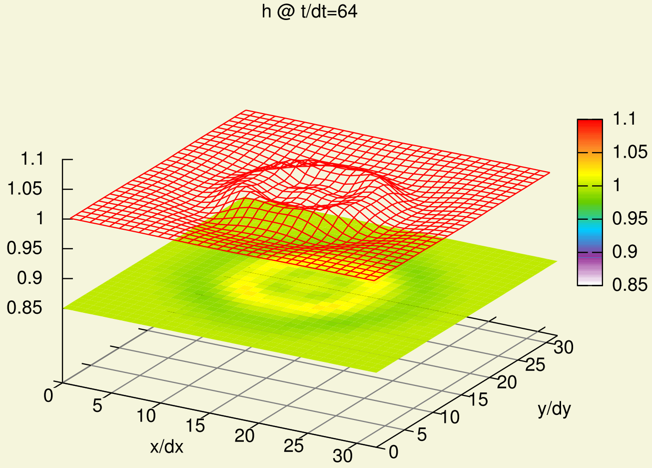
MPyDATA project idea: shallow-water equations solver



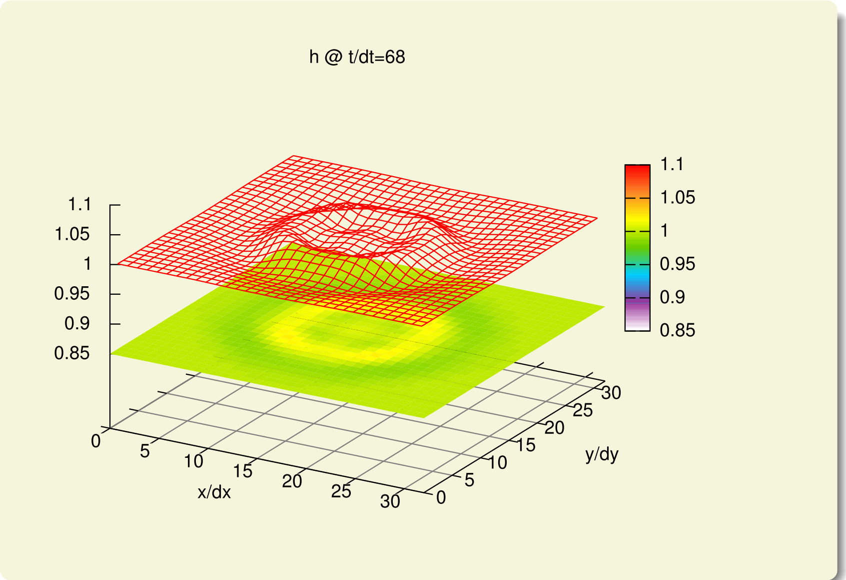
MPyDATA project idea: shallow-water equations solver



MPyDATA project idea: shallow-water equations solver



MPyDATA project idea: shallow-water equations solver



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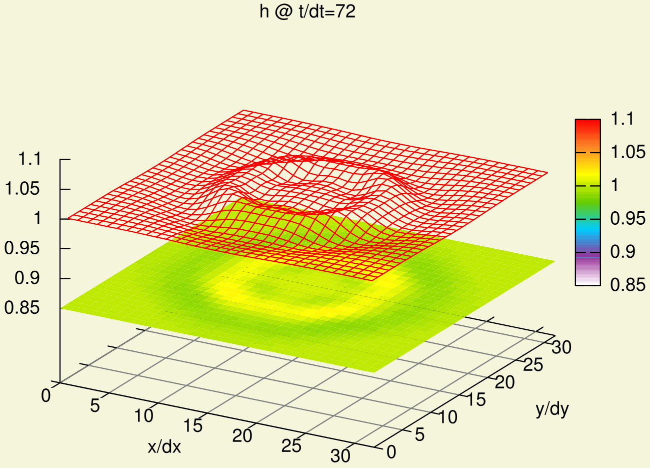

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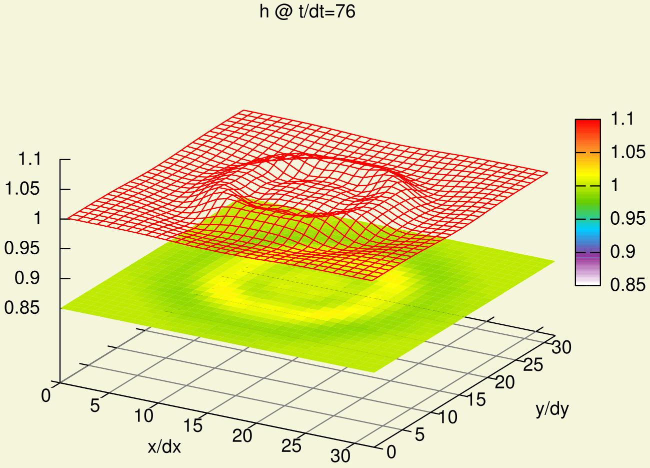

MPyDATA project idea: DPDC variant of MPDATA

https://www.osti.gov/servlets/purl/7049237

DPDC: A SECOND-ORDER MONOTONE SCHEME FOR ADVECTION

C. W. Beason

L. G. Margolin

This paper was prepared for submittal to
Fifth Nuclear Code Developers' Conference
October 11-14, 1988, Boulder, CO

September 26, 1988

Lawrence Livermore National Laboratory

Thank you for your attention!