

# What's new in libmpdata++ (towards the 2.0 release)

Sylwester Arabas  
Faculty of Physics, University of Warsaw, Poland

seminar presented at the  
Graduate School for Computational Studies, Hyogo University

Kōbe, Japan, September 7, 2015

let me introduce myself

## alma mater (MSc/2008, PhD/2013, postdoc)

	est.	staff	students	
			BSc/MSc	PhD
University of Warsaw	1816	6000	55000	3000
Faculty of Physics	1816	300	1000	150
Institute of Geophysics	1948	30	20	20
Atmospheric Physics Division	1949	10	10	10

## collaboration with Shima-san

- 2010: first contact thanks to Enomoto-san
- 2010: 4 weeks at JAMSTEC/Yokohama: RICO-SDM project
- 2013: Arabas & Shima paper in J. Atmos. Sci.
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## 2015 super-droplet workshop at the University of Warsaw



let me introduce our team

## The team of the University of Warsaw, Poland



Anna  
Zimniak

prof. Hanna  
Pawowska

Anna  
Jaruga

Piotr  
Dzielan

Sylwester  
Arabas

Maciek  
Waruszewski



the team @ the University of Warsaw, Poland



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- 1 what's libmpdata++
- 2 libmpdata++: a hello-world program
- 3 libmpdata++ 1.0: summary of features
- 4 libmpdata++ 2.0: new features under development
- 5 closing remarks

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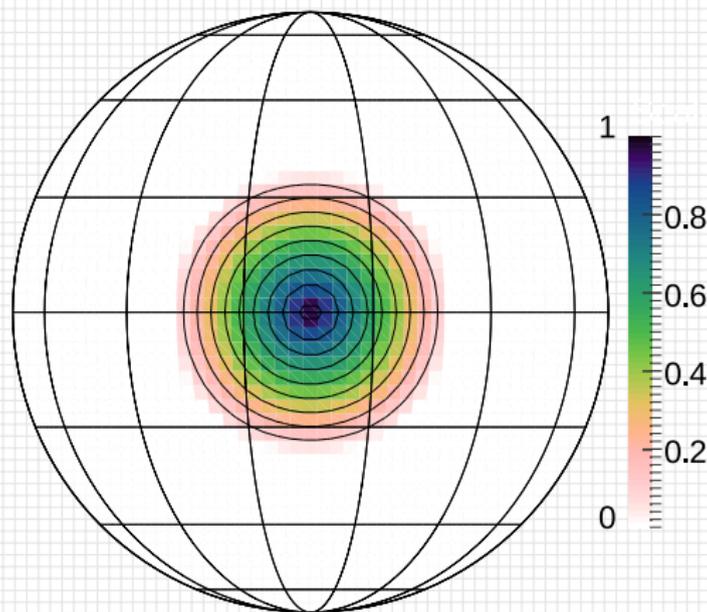
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$$\partial_t(G\psi) + \nabla \cdot (G\vec{u}\psi) = GR$$

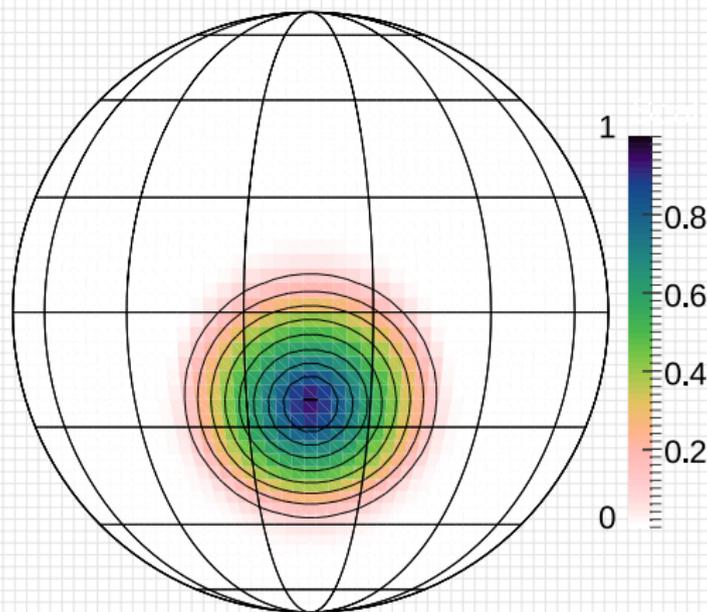
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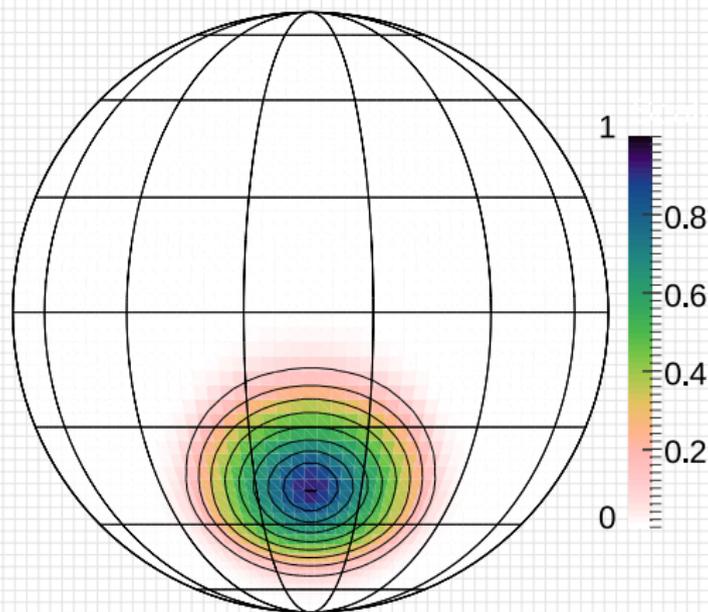
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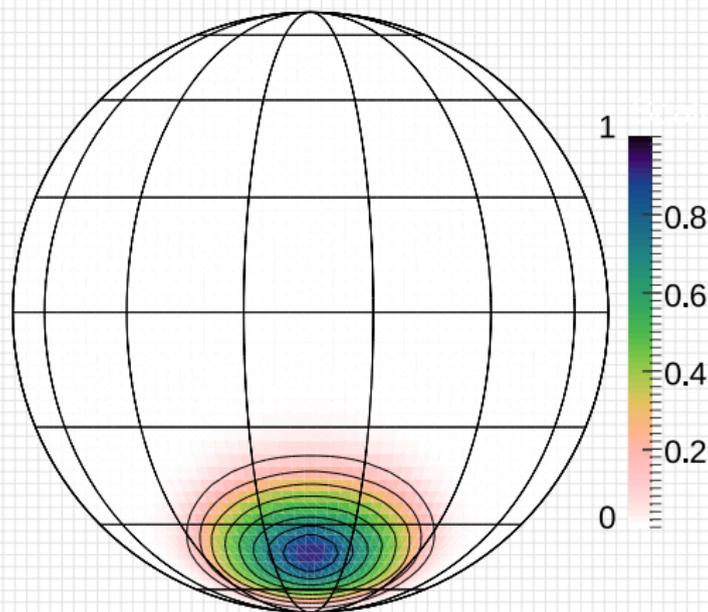
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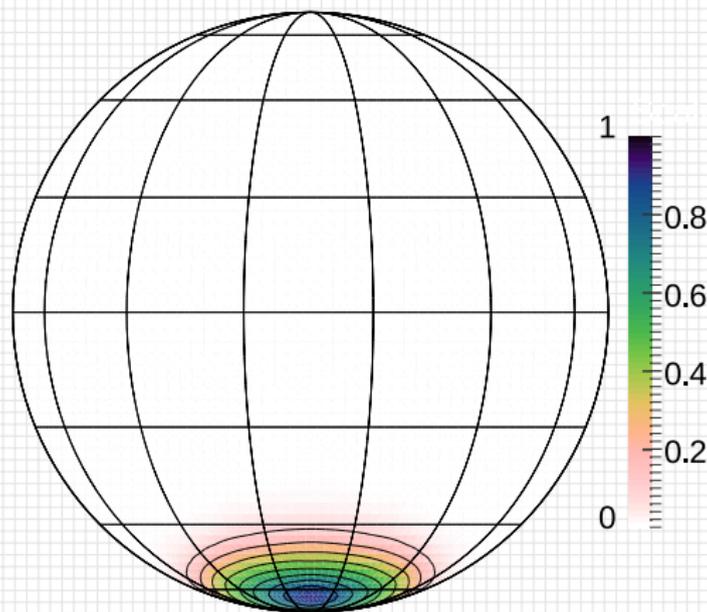
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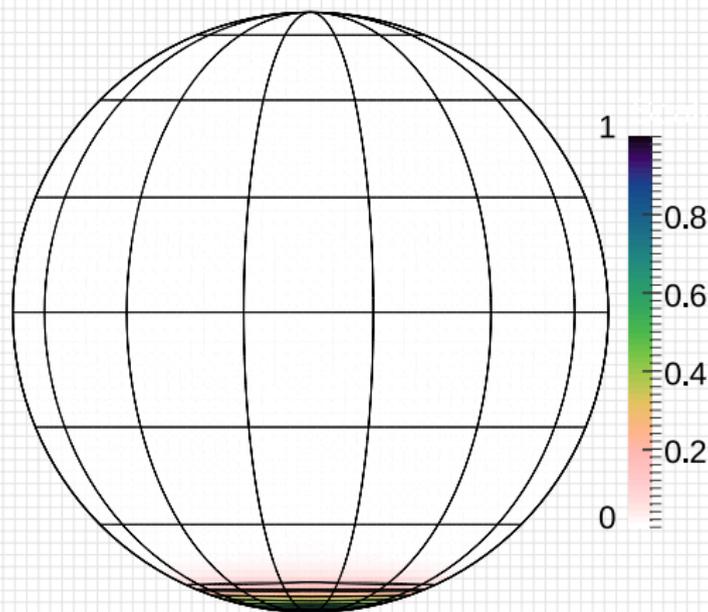
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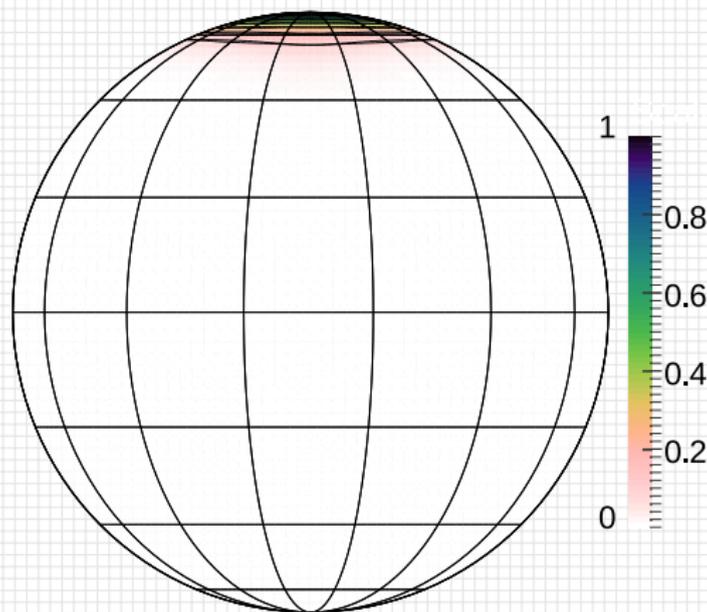
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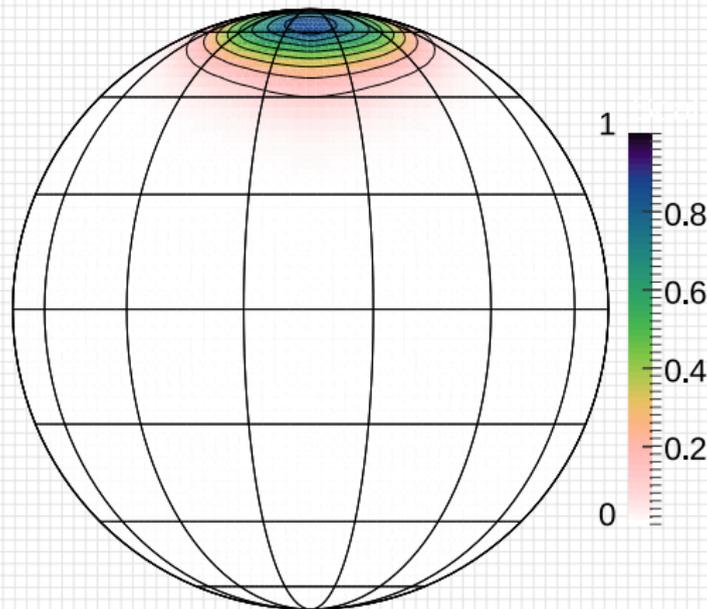
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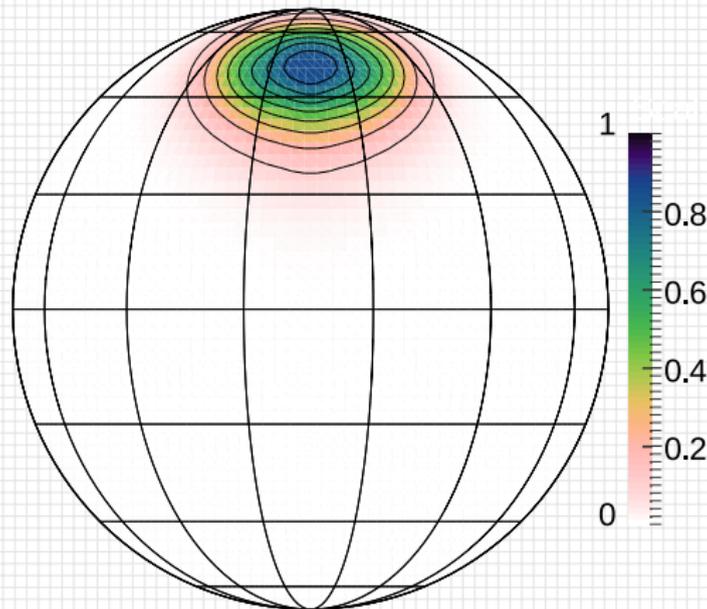
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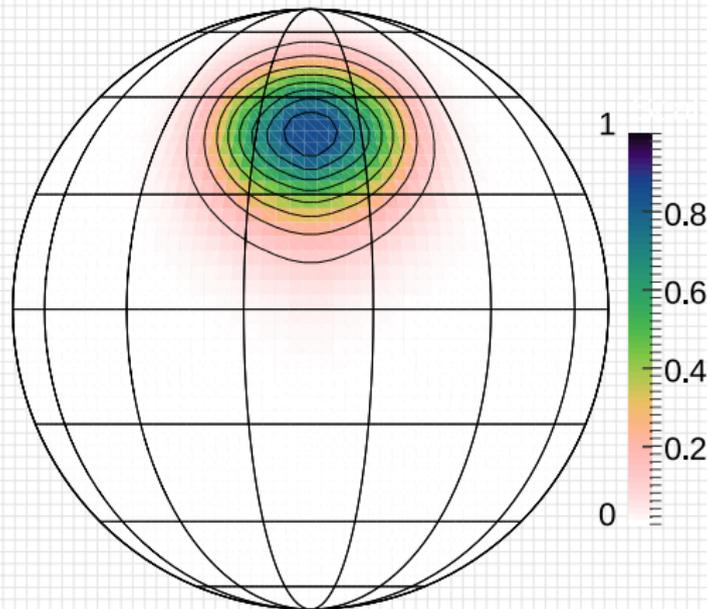
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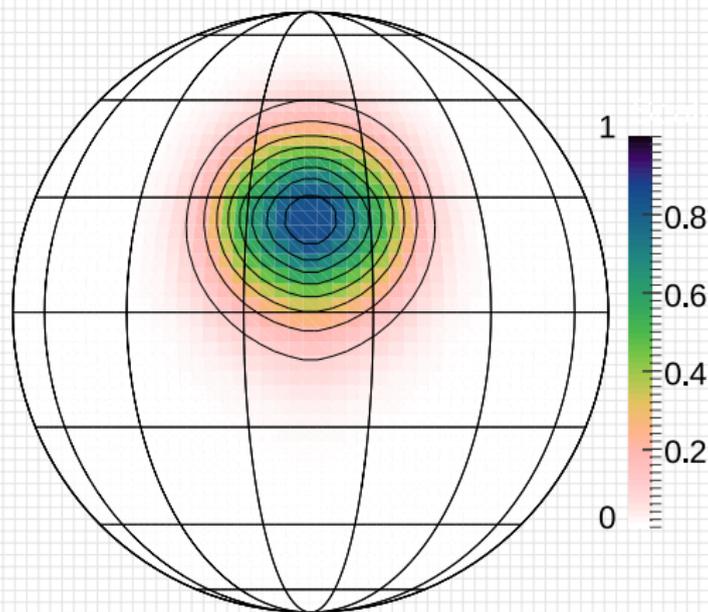
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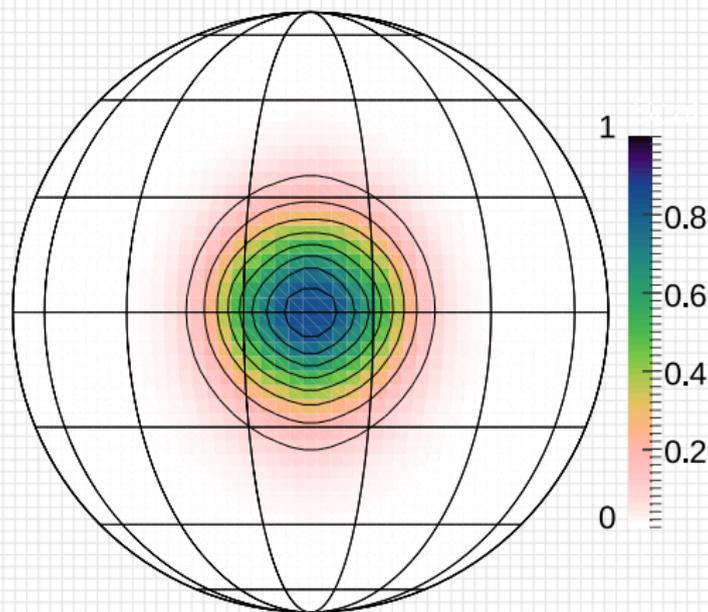
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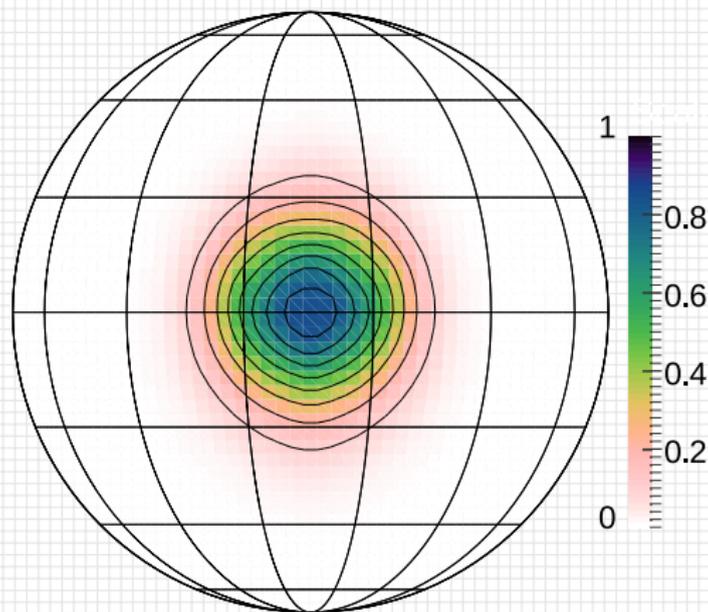
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numerical integration using MPDATA

# MPDATA (father: Piotr Smolarkiewicz)

## Multi-dimensional Positive-Definite Advection Transport Algorithm

a family of robust schemes for solving transport problems

- the seminal MPDATA article (Smolarkiewicz, 1984): >600 citations
- Google Scholar: ~ 700 research papers
- Google Books: ~ 200 mentions in books

original single-file Fortran 77 implementation used till today

- unspecified license, no versioning
- e-mail distribution, copy-paste-modify reuse
- no unit/regression tests

**libmpdata++**: a new C++11 / Blitz++ based implementation

- an over order-of-magnitude lower number of lines of code
- comparable performance
- major improvement in reusability and maintainability

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## priority: researchers' productivity

researcher = user

- **ease of obtaining and using**  
~> public repository, documentation, examples, free/libre/open code
- **result correctness**  
~> multifaceted peer-reviewed automated tests, free/libre/open code
- **result reproducibility**  
~> atomic versions, no legal nor tech. obstacles, free/libre/open code

researcher = developer

- **ease of extending**  
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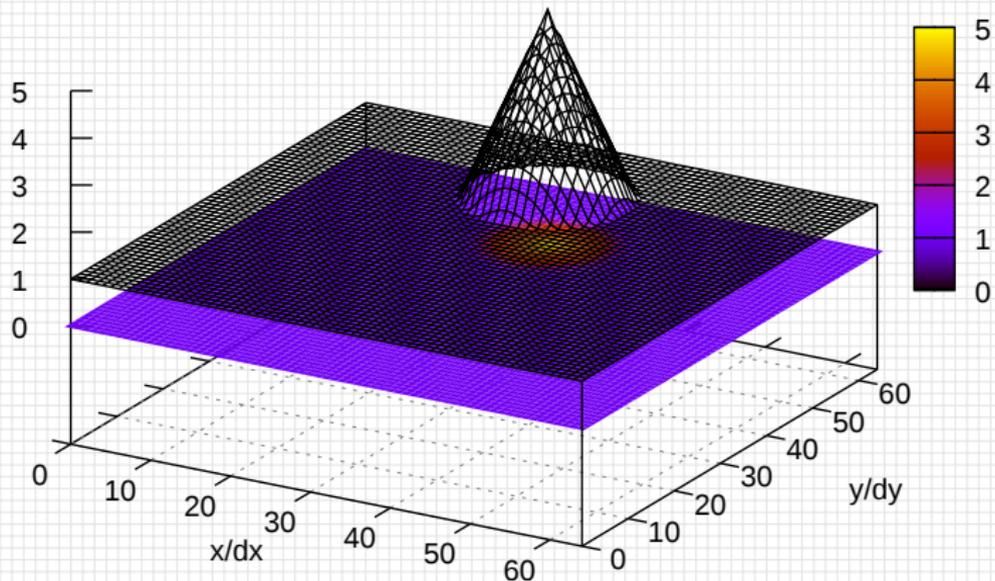
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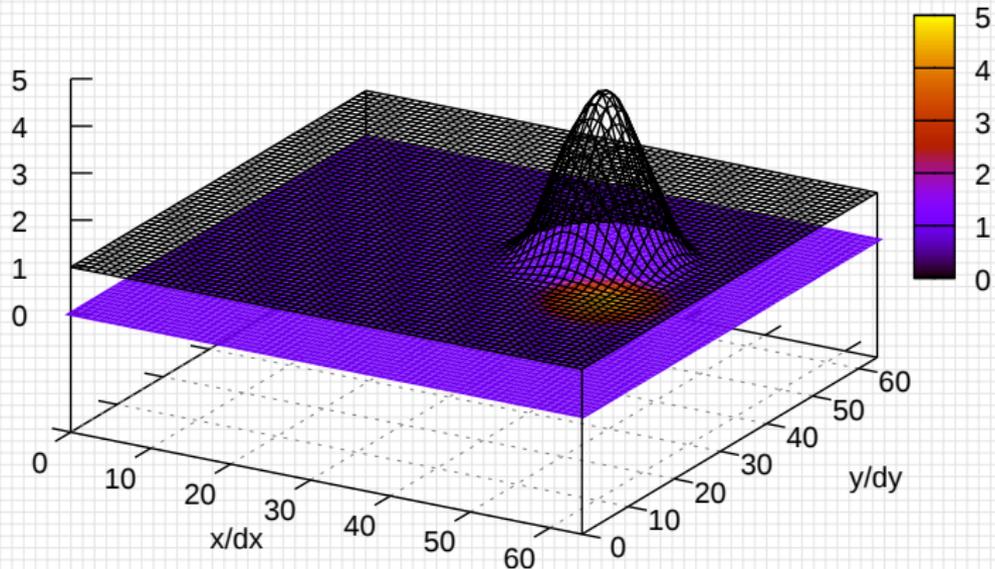
(t/dt=0)



64 LOC using libmpdata++

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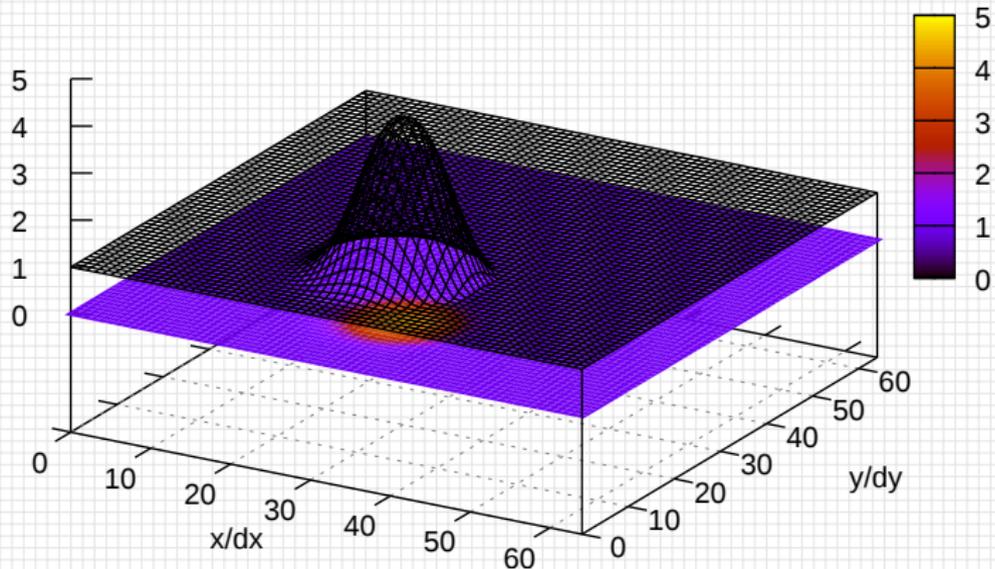
( $t/dt=157$ )



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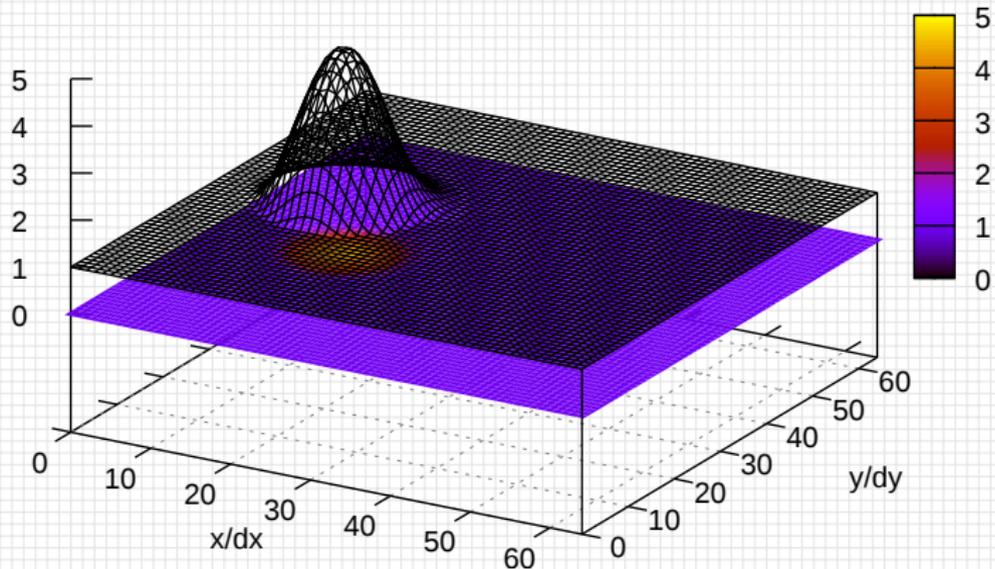
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64 LOC using libmpdata++

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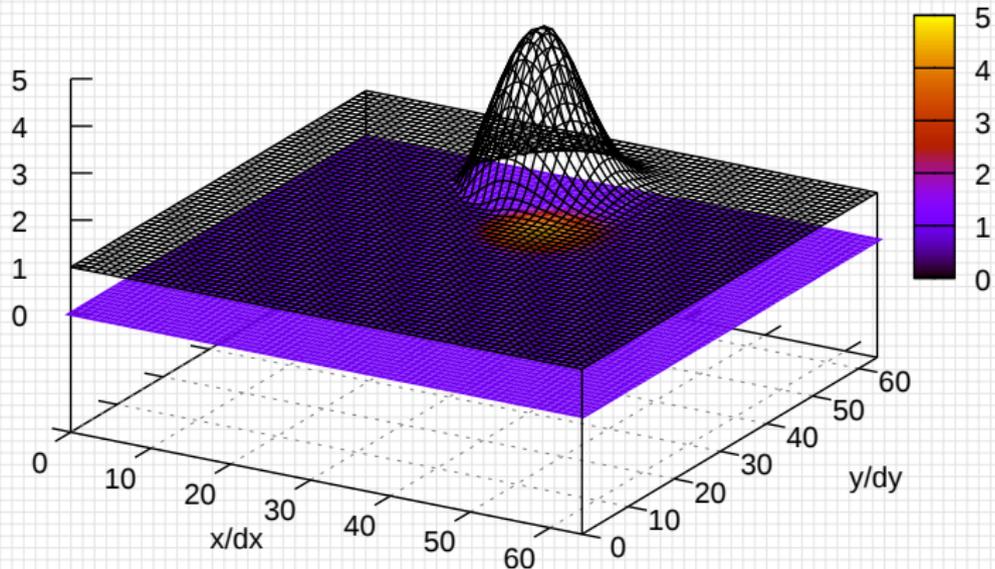
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64 LOC using libmpdata++

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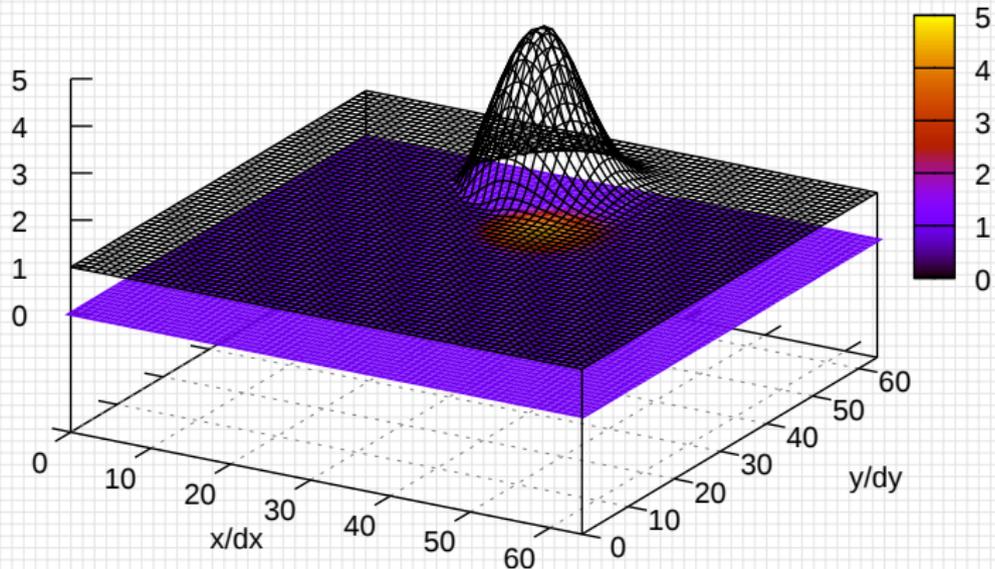
(t/dt=628)



64 LOC using libmpdata++

# libmpdata++: rotating cone test

(t/dt=628)



**64 LOC using libmpdata++**

```

1 #include <libmpdata++/solvers/mpdata.hpp>
2 #include <libmpdata++/concurr/serial.hpp>
3 #include <libmpdata++/output/gnuplot.hpp>
4
5 int main()
6 {
7     namespace lmpdt = libmpdataxx;
8     const int nx=64, ny=64, nt = 628;
9
10    // compile-time parameters
11    struct ct_params_t : lmpdt::ct_params_default_t
12    {
13        using real_t = double;
14        enum { n_dims = 2 };
15        enum { n_eqns = 1 };
16    };
17
18    // solver choice
19    using run_t = lmpdt::output::gnuplot< lmpdt::solvers::mpdata< ct_params_t >>;
20
21    // runtime parameters
22    typename run_t::rt_params_t p;
23    p.grid_size = {nx+1, ny+1};
24    p.outfreq = nt/4;
25    p.gnuplot_output = "out_%s_%d.svg";
26    p.gnuplot_with = "lines";
27    p.gnuplot_cbrange = p.gnuplot_zrange = "[0:5]";
28
29    // sharedmem concurency and boundary condition choice
30    lmpdt::concurr::serial<
31        run_t,
32        lmpdt::bcond::open, lmpdt::bcond::open, // x-left, x-right
33        lmpdt::bcond::open, lmpdt::bcond::open // y-left, y-right
34    > run(p);

```

```

35
36 // initial condition
37 {
38     using namespace blitz::tensor;
39     auto psi = run.advectee();
40
41     const double
42         dt = .1, dx = 1, dy = 1, omega = .1,
43         h = 4., h0 = 1, r = .15 * nx * dx,
44         x0 = .5 * nx * dx, y0 = .75 * ny * dy,
45         xc = .5 * nx * dx, yc = .50 * ny * dy;
46
47     // cone shape cut at h0
48     psi = blitz::pow(i * dx - x0, 2) +
49           blitz::pow(j * dy - y0, 2);
50
51     psi = h0 + where(
52         psi - pow(r, 2) <= 0,           // if
53         h - blitz::sqrt(psi / pow(r/h,2)), // then
54         0.                             // else
55     );
56
57     // constant-angular-velocity rotational field
58     run.advector(0) = omega * (j * dy - yc) * dt/dx;
59     run.advector(1) = -omega * (i * dx - xc) * dt/dy;
60 }
61
62 // time stepping
63 run.advance(nt);
64 }

```

```

35
36 // initial condition
37 {
38     using namespace blitz::tensor;
39     auto psi = run.advectee();
40
41     const double
42         dt = .1, dx = 1, dy = 1, omega = .1,
43         h = 4., h0 = 1, r = .15 * nx * dx,
44         x0 = .5 * nx * dx, y0 = .75 * ny * dy,
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54         0.                             // else
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56
57     // constant-angular-velocity rotational field
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59     run.advector(1) = -omega * (i * dx - xc) * dt/dy;
60 }
61
62 // time stepping
63 run.advance(nt);
64 }

```

CMakeLists.txt

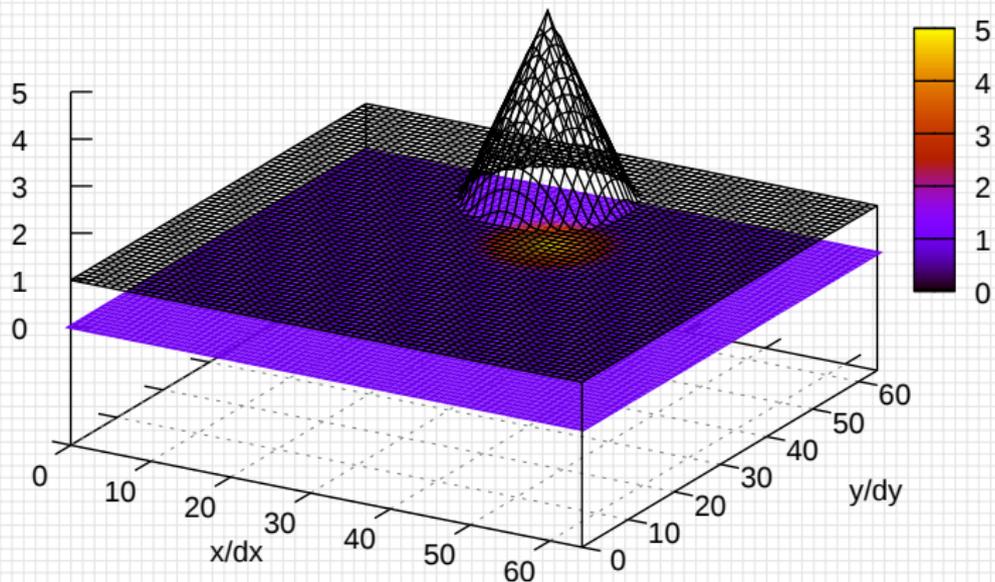
```

1 cmake_minimum_required(VERSION 3.0)
2 project(hello_world CXX)
3 find_package(Libmpdata++)
4 set(CMAKE_CXX_FLAGS ${Libmpdataxx_CXX_FLAGS_RELEASE})
5 add_executable(hello_world hello_world.cpp)
6 target_link_libraries(hello_world ${Libmpdataxx_LIBRARIES})

```

# libmpdata++: rotating cone test

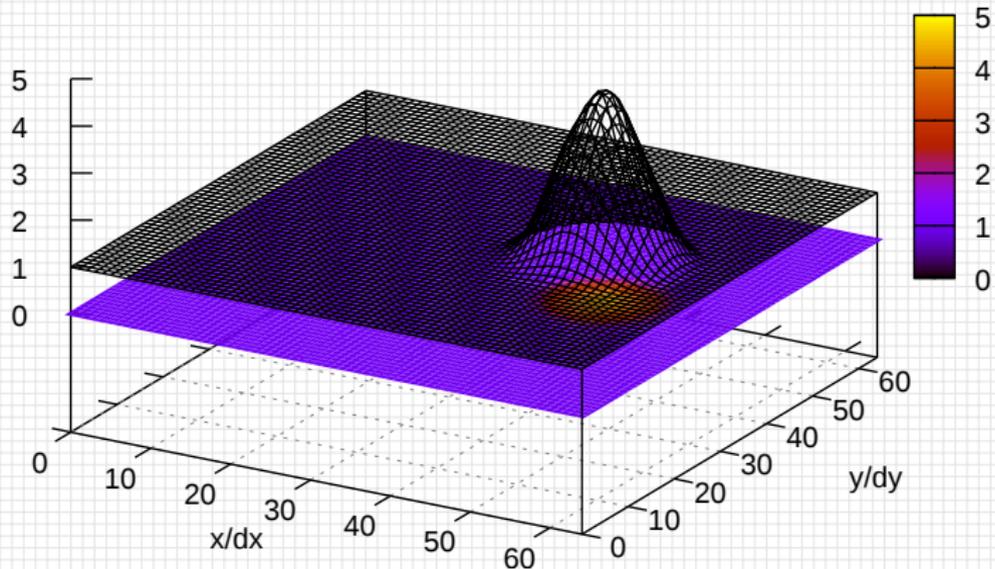
(t/dt=0)



64 LOC using libmpdata++

# libmpdata++: rotating cone test

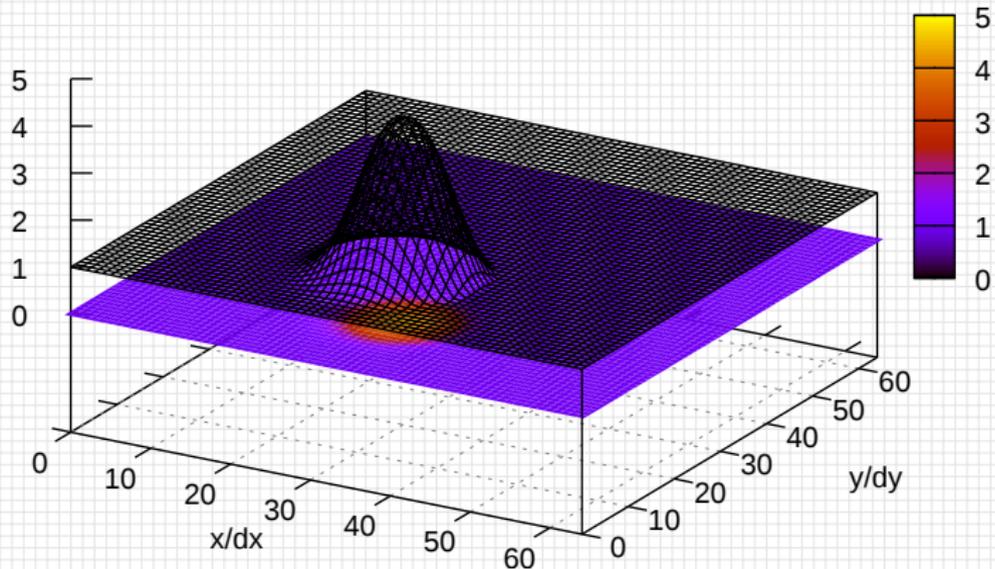
( $t/dt=157$ )



64 LOC using libmpdata++

# libmpdata++: rotating cone test

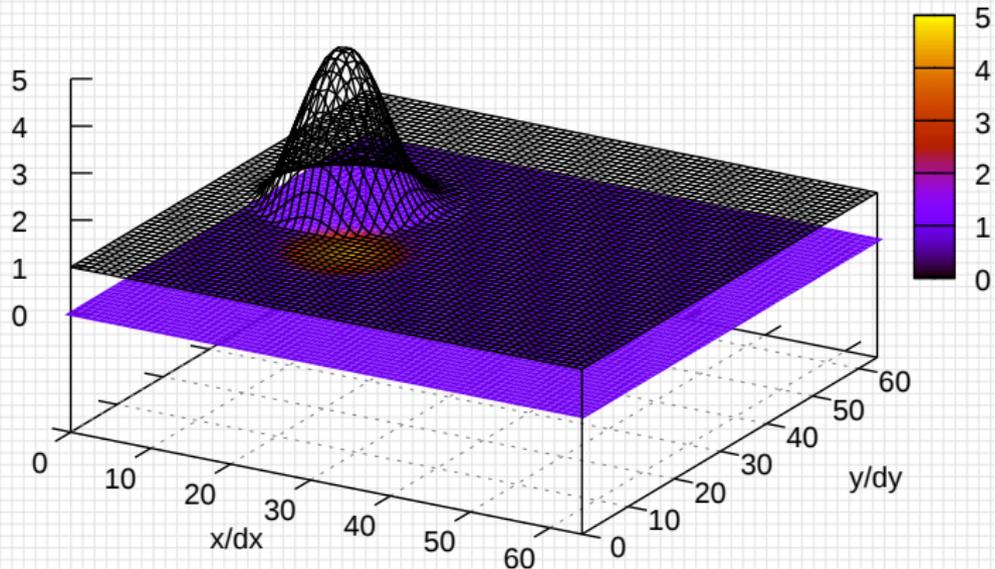
(t/dt=314)



64 LOC using libmpdata++

# libmpdata++: rotating cone test

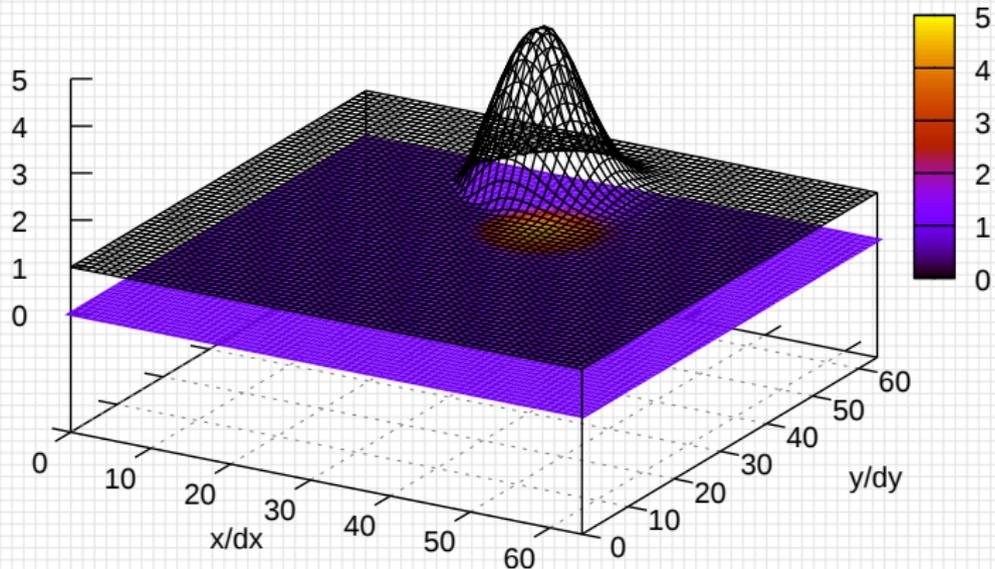
(t/dt=471)



64 LOC using libmpdata++

# libmpdata++: rotating cone test

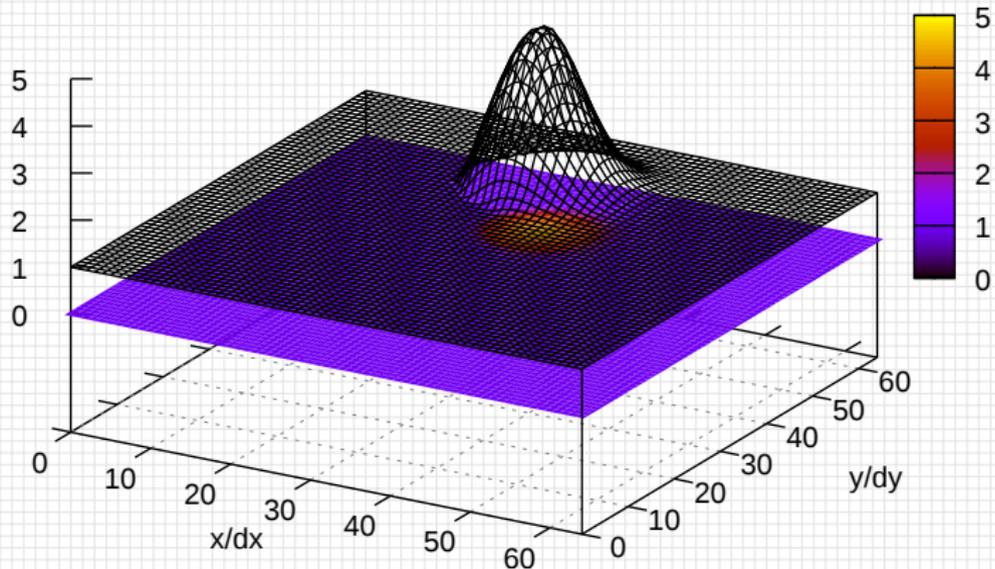
(t/dt=628)



64 LOC using libmpdata++

# libmpdata++: rotating cone test

(t/dt=628)



**64 LOC using libmpdata++**

with multi-threading  $\rightsquigarrow$  also 64 LOC!

```
2c2
< #include <libmpdata++/concurr/serial.hpp>
---
> #include <libmpdata++/concurr/threads.hpp>
30c30
<     lmpdt::concurr::serial<
---
>     lmpdt::concurr::threads<
```

```
$ top
```

```
...
  PID USER      PR  NI  S   %CPU %MEM nTH      TIME+ COMMAND  90%
21031 slayoo    20   0  R  73.7  0.1   4    0:01.68 hello_worl
```

# MPI + threads $\rightsquigarrow$ also 64 LOC!!! (recompilation only)

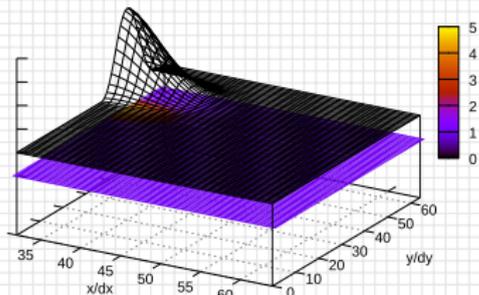
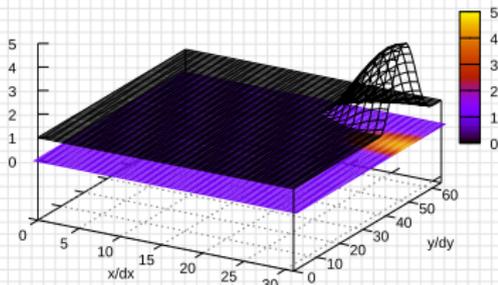
```
$ cmake . -DCMAKE_CXX_COMPILER=mpic++  
$ make  
$ OMP_NUM_THREADS=2 mpirun -np 2 ./hello_world
```

```
$ top
```

```
...
```

PID	USER	PR	NI	S	%CPU	%MEM	nTH	TIME+	COMMAND	
19640	slayoo	20	0	R	65.5	0.3	2	0:00.92	hello_worl	98%
19641	slayoo	20	0	R	64.0	0.3	2	0:00.91	hello_worl	99%

```
...
```



# Plan of the talk

- 1 what's libmpdata++
- 2 libmpdata++: a hello-world program
- 3 libmpdata++ 1.0: summary of features
- 4 libmpdata++ 2.0: new features under development
- 5 closing remarks

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- 2 libmpdata++: a hello-world program
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- 5 closing remarks

# libmpdata++ 1.0: from hello-world to real-world problems

- support for integration in 1D, 2D & 3D

- support for multiple transported fields

- numerous MPDATA options implemented:

- `MPDATA::MPC` (MPC, multi-point coupling)
- `MPDATA::MPC2` (MPC2, multi-point coupling)
- `MPDATA::MPC3` (MPC3, multi-point coupling)
- `MPDATA::MPC4` (MPC4, multi-point coupling)
- `MPDATA::MPC5` (MPC5, multi-point coupling)
- `MPDATA::MPC6` (MPC6, multi-point coupling)
- `MPDATA::MPC7` (MPC7, multi-point coupling)
- `MPDATA::MPC8` (MPC8, multi-point coupling)
- `MPDATA::MPC9` (MPC9, multi-point coupling)
- `MPDATA::MPC10` (MPC10, multi-point coupling)
- `MPDATA::MPC11` (MPC11, multi-point coupling)
- `MPDATA::MPC12` (MPC12, multi-point coupling)
- `MPDATA::MPC13` (MPC13, multi-point coupling)
- `MPDATA::MPC14` (MPC14, multi-point coupling)
- `MPDATA::MPC15` (MPC15, multi-point coupling)
- `MPDATA::MPC16` (MPC16, multi-point coupling)
- `MPDATA::MPC17` (MPC17, multi-point coupling)
- `MPDATA::MPC18` (MPC18, multi-point coupling)
- `MPDATA::MPC19` (MPC19, multi-point coupling)
- `MPDATA::MPC20` (MPC20, multi-point coupling)
- `MPDATA::MPC21` (MPC21, multi-point coupling)
- `MPDATA::MPC22` (MPC22, multi-point coupling)
- `MPDATA::MPC23` (MPC23, multi-point coupling)
- `MPDATA::MPC24` (MPC24, multi-point coupling)
- `MPDATA::MPC25` (MPC25, multi-point coupling)
- `MPDATA::MPC26` (MPC26, multi-point coupling)
- `MPDATA::MPC27` (MPC27, multi-point coupling)
- `MPDATA::MPC28` (MPC28, multi-point coupling)
- `MPDATA::MPC29` (MPC29, multi-point coupling)
- `MPDATA::MPC30` (MPC30, multi-point coupling)
- `MPDATA::MPC31` (MPC31, multi-point coupling)
- `MPDATA::MPC32` (MPC32, multi-point coupling)
- `MPDATA::MPC33` (MPC33, multi-point coupling)
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- `MPDATA::MPC89` (MPC89, multi-point coupling)
- `MPDATA::MPC90` (MPC90, multi-point coupling)
- `MPDATA::MPC91` (MPC91, multi-point coupling)
- `MPDATA::MPC92` (MPC92, multi-point coupling)
- `MPDATA::MPC93` (MPC93, multi-point coupling)
- `MPDATA::MPC94` (MPC94, multi-point coupling)
- `MPDATA::MPC95` (MPC95, multi-point coupling)
- `MPDATA::MPC96` (MPC96, multi-point coupling)
- `MPDATA::MPC97` (MPC97, multi-point coupling)
- `MPDATA::MPC98` (MPC98, multi-point coupling)
- `MPDATA::MPC99` (MPC99, multi-point coupling)
- `MPDATA::MPC100` (MPC100, multi-point coupling)

- coordinate transformations

- open, cyclic, polar & rigid boundary conditions

- source-term handling

- shallow-water and Boussinesq dynamics



# libmpdata++ 1.0: from hello-world to real-world problems

- support for integration in 1D, 2D & 3D
- support for multiple transported fields
- numerous MPDATA options implemented:
  - arbitrary number of corrective iterations
  - Flux-Corrected Transport (FCT, non-oscillatory) option
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Jaruga et al. 2015

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Geosci. Model Dev. policy (doi: 10.5194/gmd-6-1233-2013)

- *"paper must be accompanied by the code, or means of accessing the code, for the purpose of peer-review"*
- *"we strongly encourage referees to compile the code, and run test cases supplied by the authors"*

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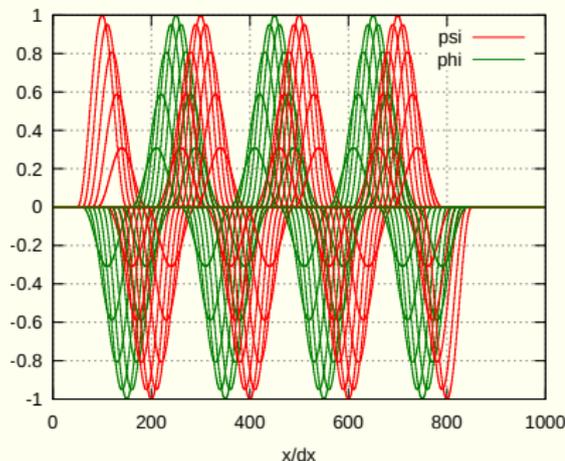
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<sup>3</sup>European Centre for Medium-Range Weather Forecasts, Reading, UK

Geosci. Model Dev. policy (doi: 10.5194/gmd-6-1233-2013)

- *“paper must be accompanied by the code, or means of accessing the code, for the purpose of peer-review”*
- *“we strongly encourage referees to compile the code, and run test cases supplied by the authors”*



**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.

(partial differential equation) system (16) leads to the following system of coupled implicit algebraic equations:

$$\begin{aligned}\psi_i^{n+1} &= \psi_i^* + 0.5 \Delta t \omega \phi_i^{n+1}, \\ \phi_i^{n+1} &= \phi_i^* - 0.5 \Delta t \omega \psi_i^{n+1},\end{aligned}\quad (17)$$

```
#include <libmpdata++/solvers/mpdata_rhs.hpp>

template <class ct_params_t>
struct coupled_harmonic : public
    libmpdataxx::solvers::mpdata_rhs<ct_params_t>
{ // aliases
    using parent_t =
        libmpdataxx::solvers::mpdata_rhs<ct_params_t>;
    using ix = typename ct_params_t::ix;
    // member fields
    typename ct_params_t::real_t omega;

    // method called by mpdata_rhs
    void update_rhs(
        libmpdataxx::arrvec_t<
            typename parent_t::arr_t
        > &rhs,
        const typename parent_t::real_t &dt,
        const int &at
    ) {
        parent_t::update_rhs(rhs, dt, at);

        // just to shorten code
        const auto &psi = this->state(ix::psi);
        const auto &phi = this->state(ix::phi);
        const auto &i = this->i;

        switch (at)
        { // explicit solution for R~{n}
          // (note: with trapez used only at t=0)
          case (0):
            rhs.at(ix::psi)(i) += omega * phi(i);
            rhs.at(ix::phi)(i) -= omega * psi(i);
```

# libmpdata++ 1.0: solver/algorithm hierarchy

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$$\partial_t(G\psi) + \nabla \cdot (G\bar{u}\psi) = 0$$

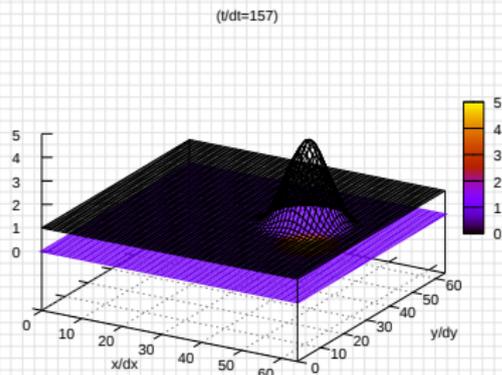
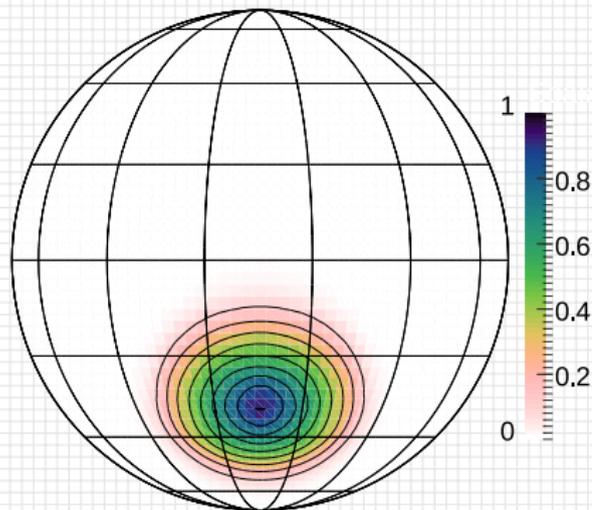
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user/test  
code

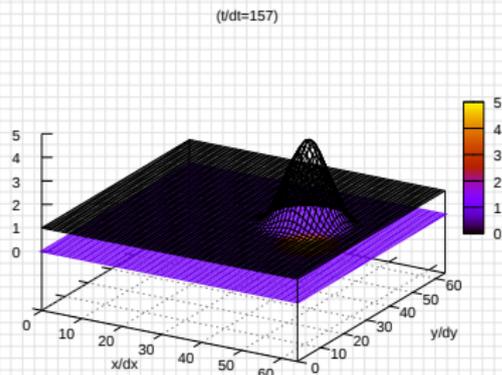
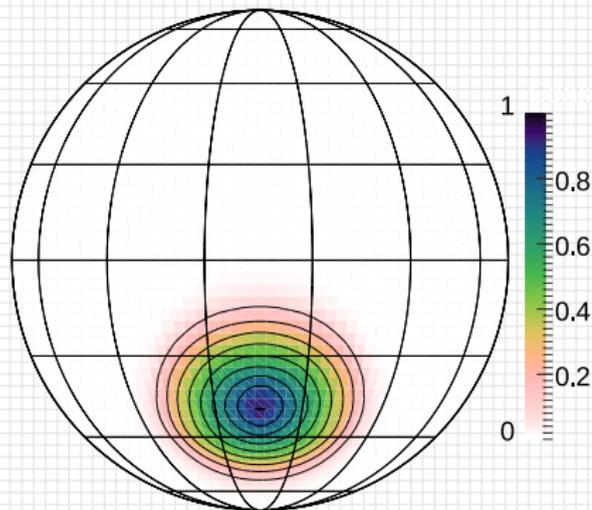


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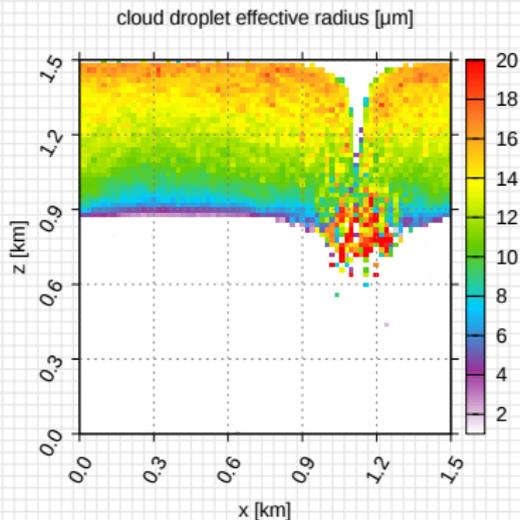
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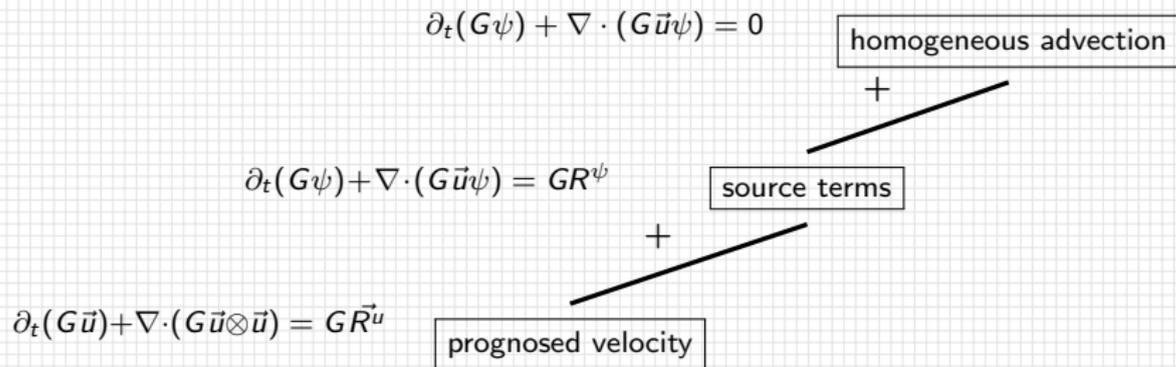
+

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

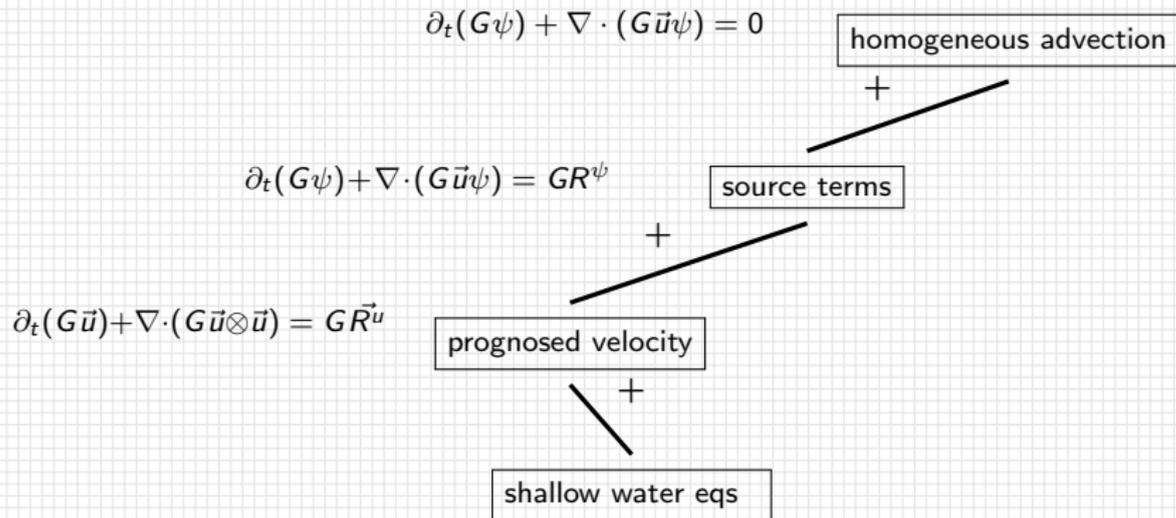
source terms



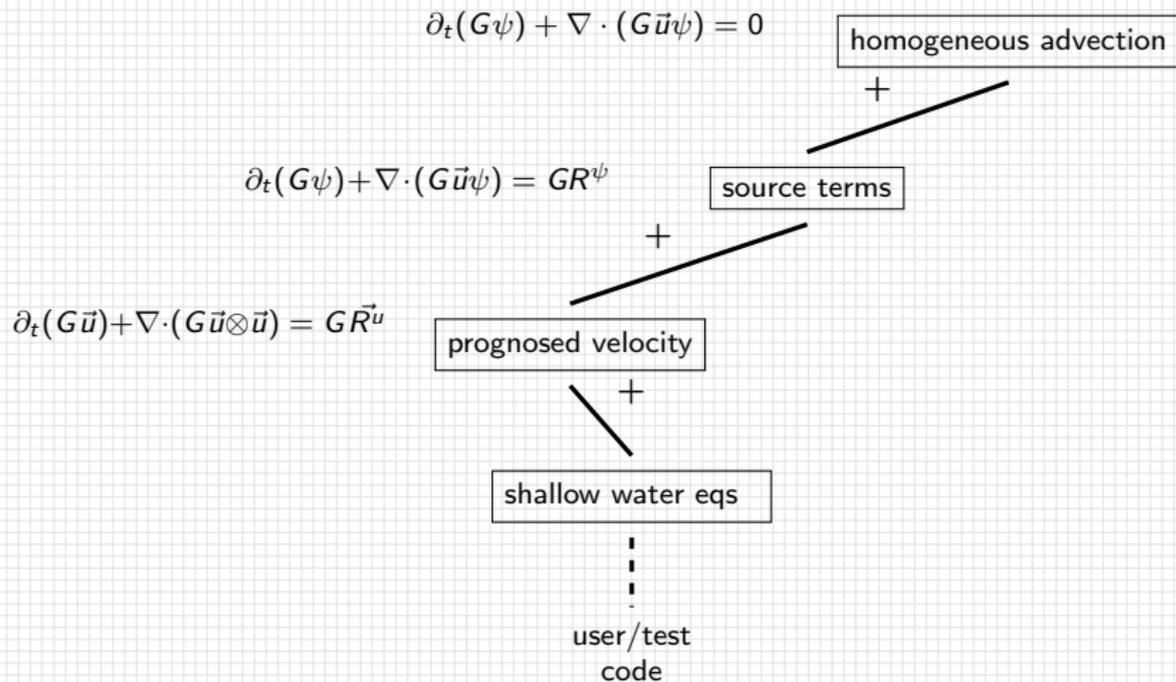
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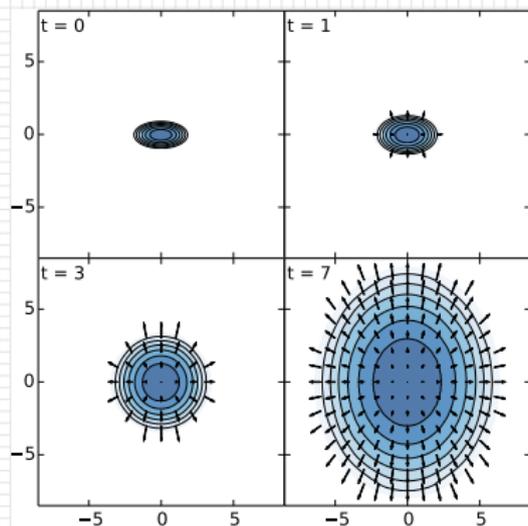
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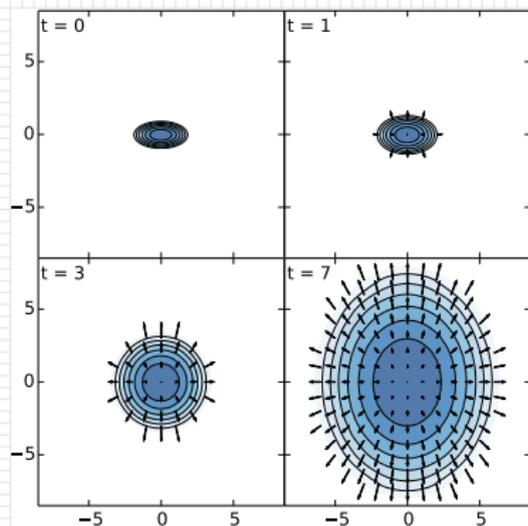


# libmpdata++: 3D shallow-water system example



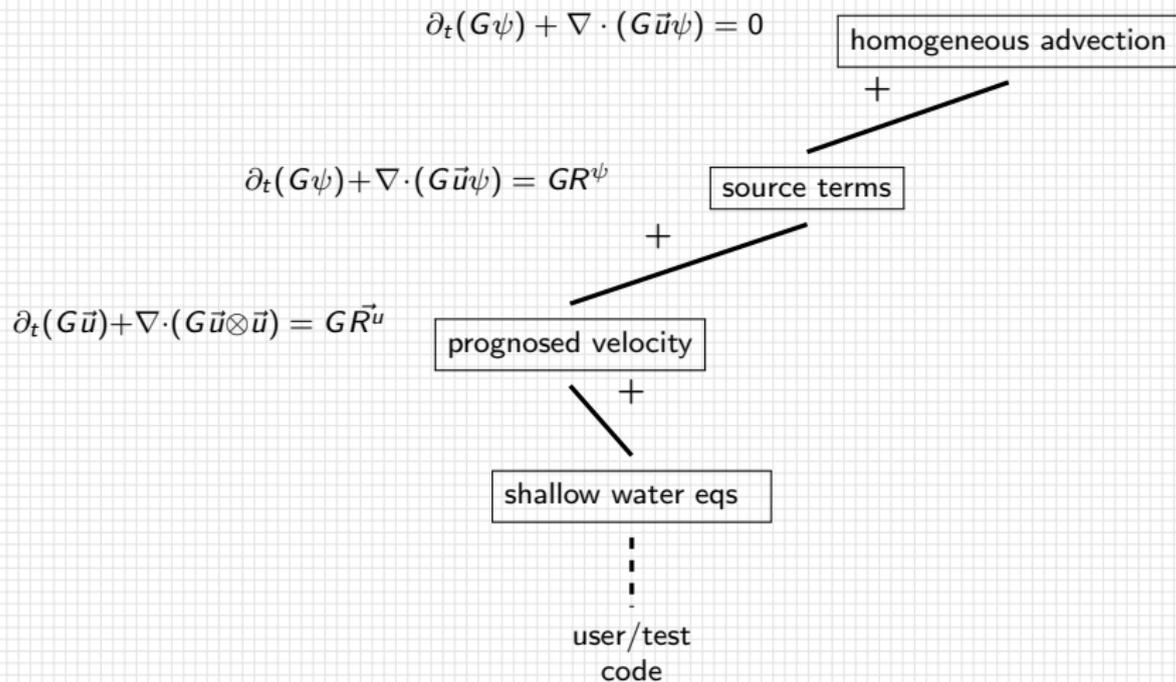
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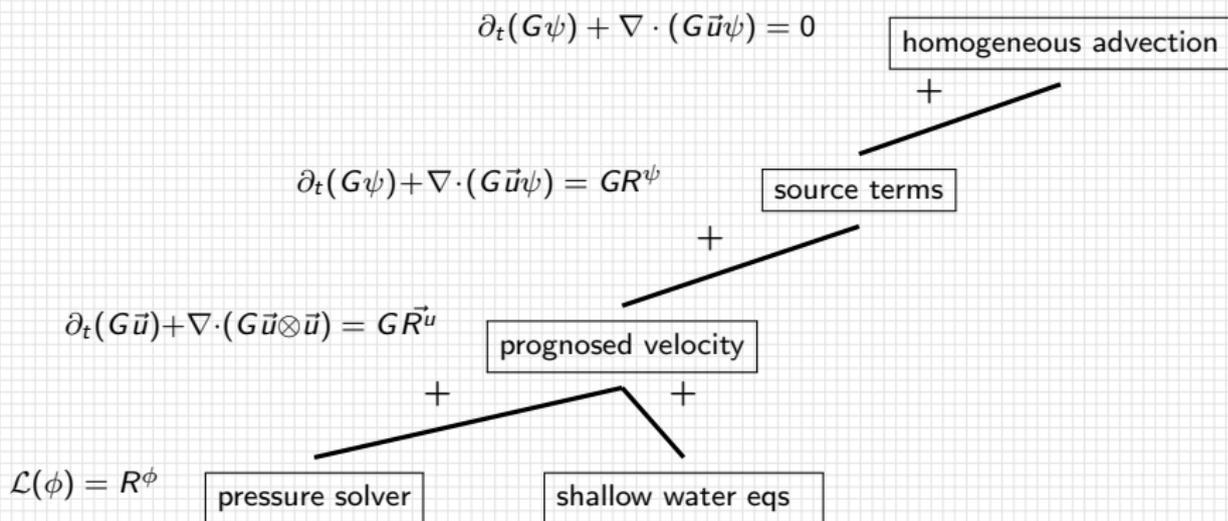


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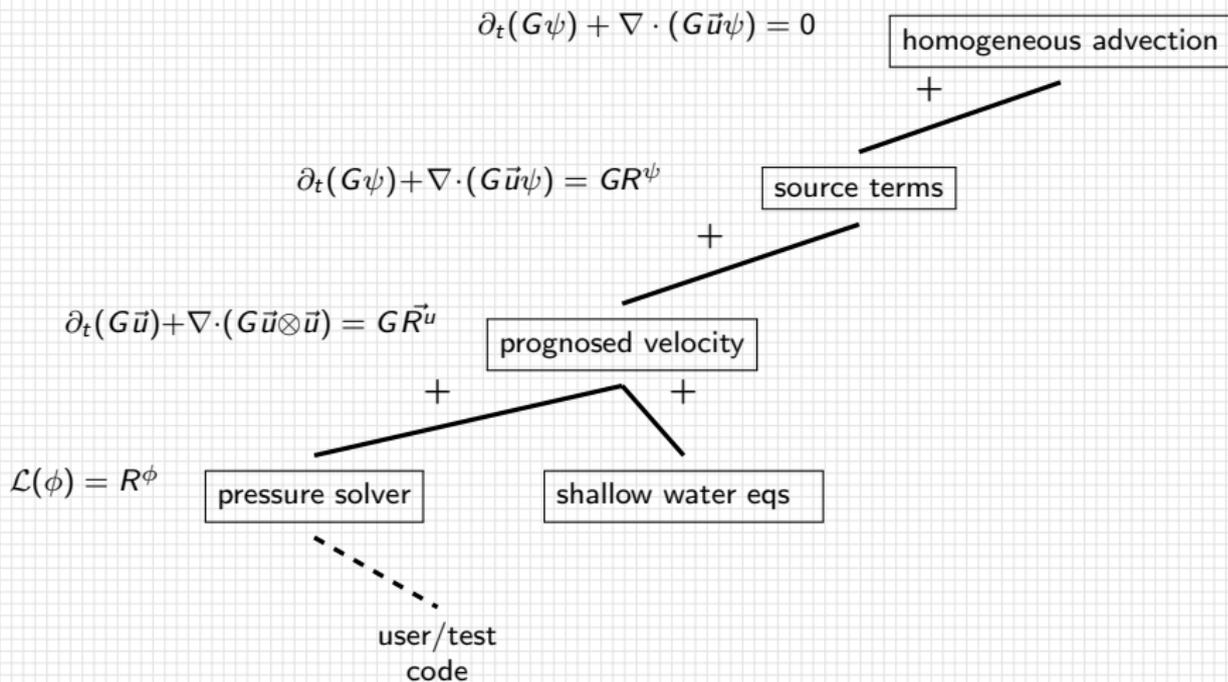
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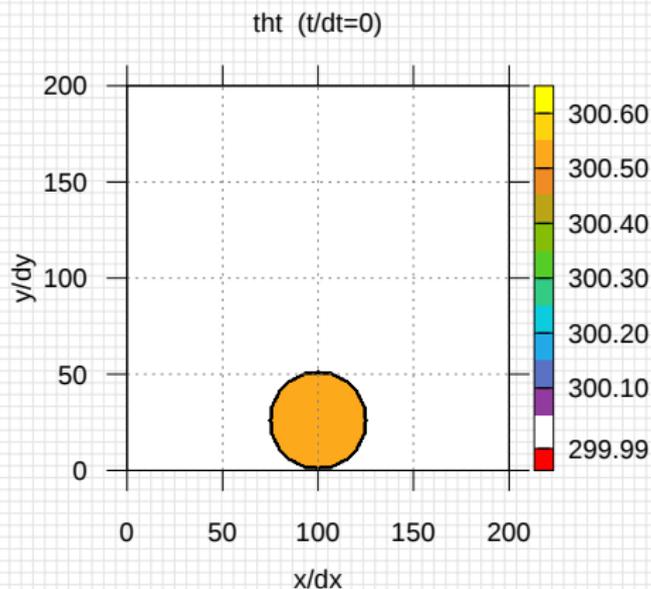
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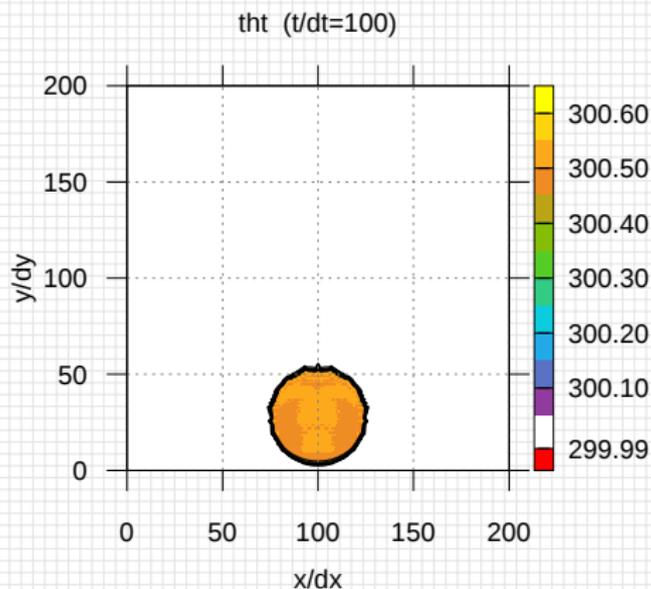
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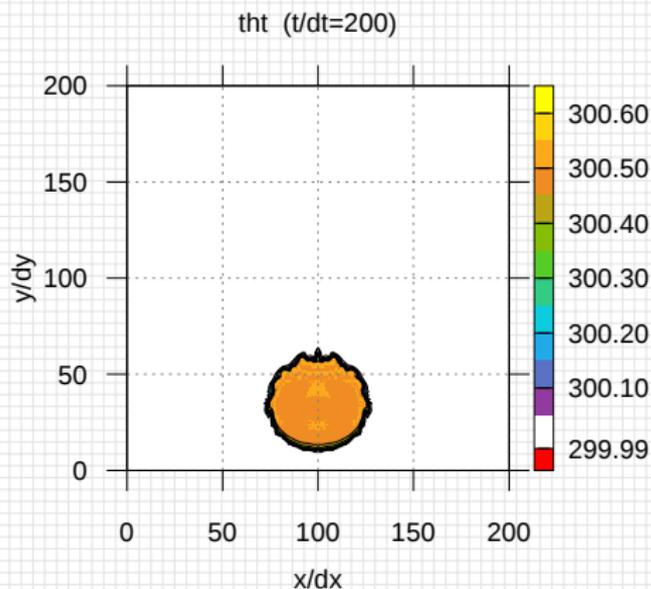
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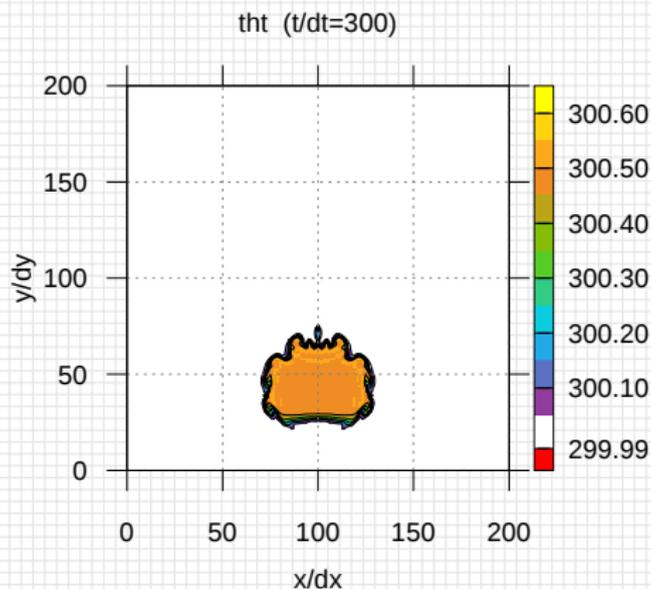
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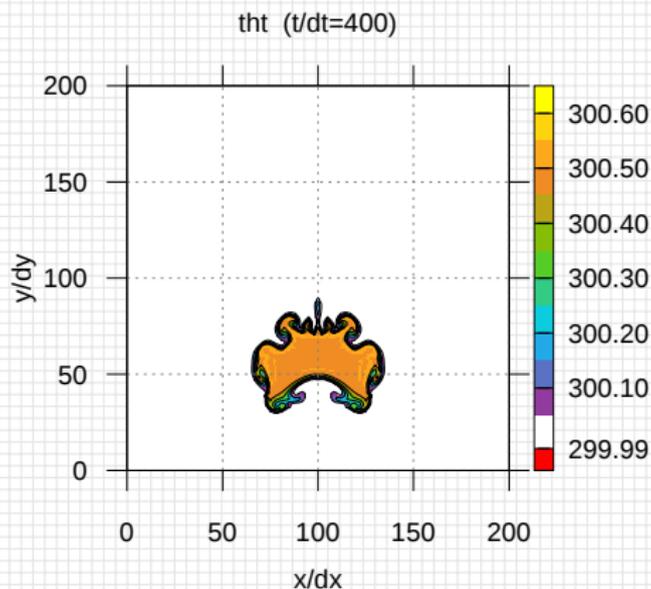
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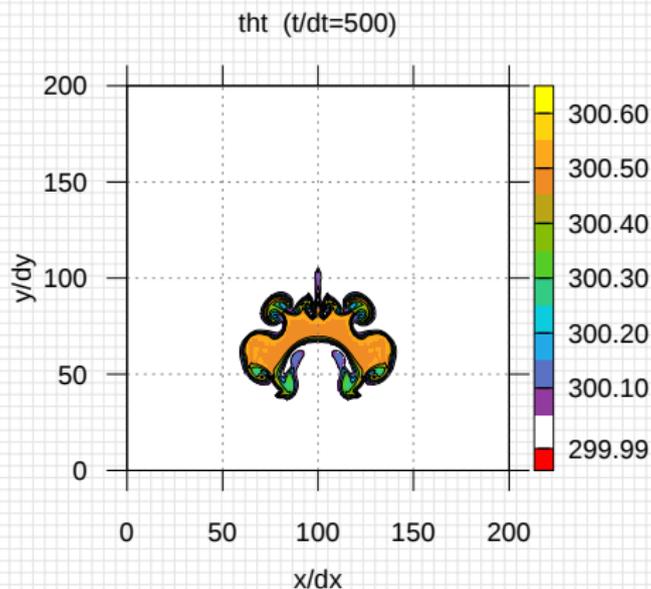
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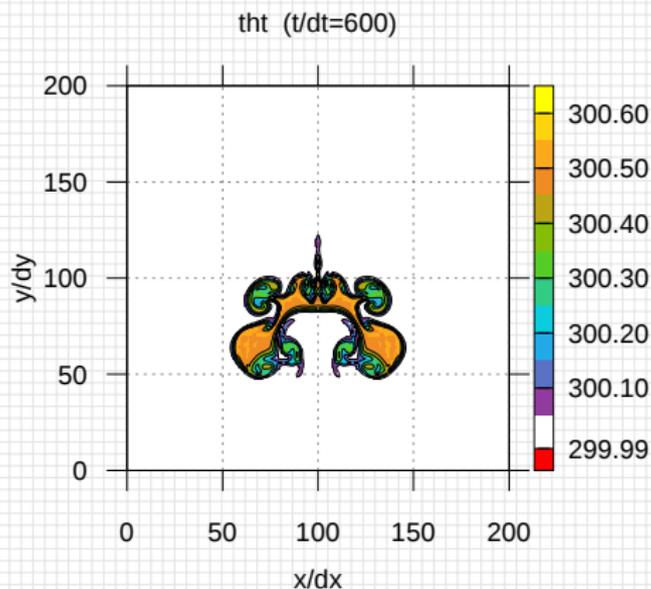
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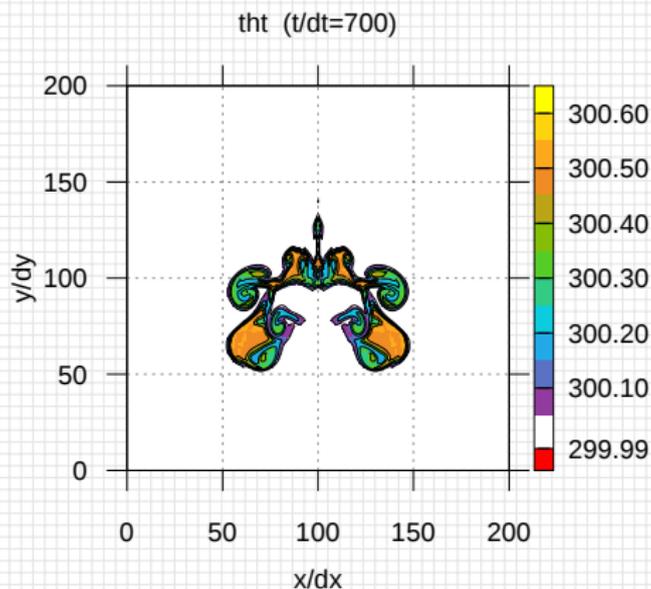
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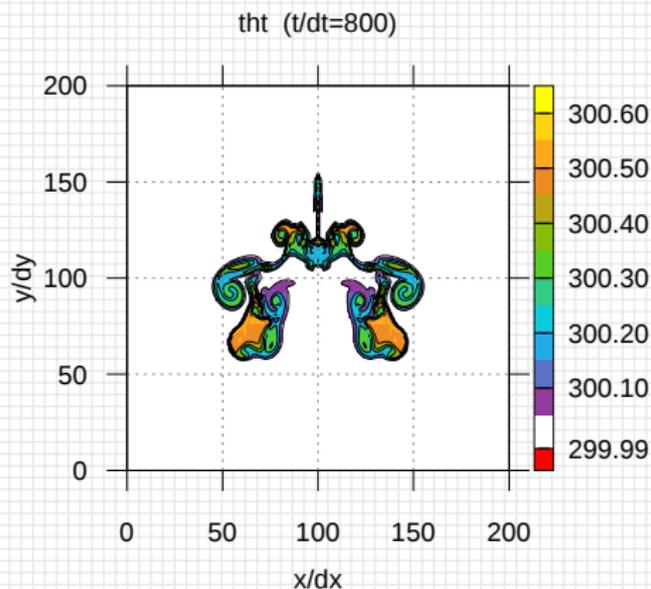
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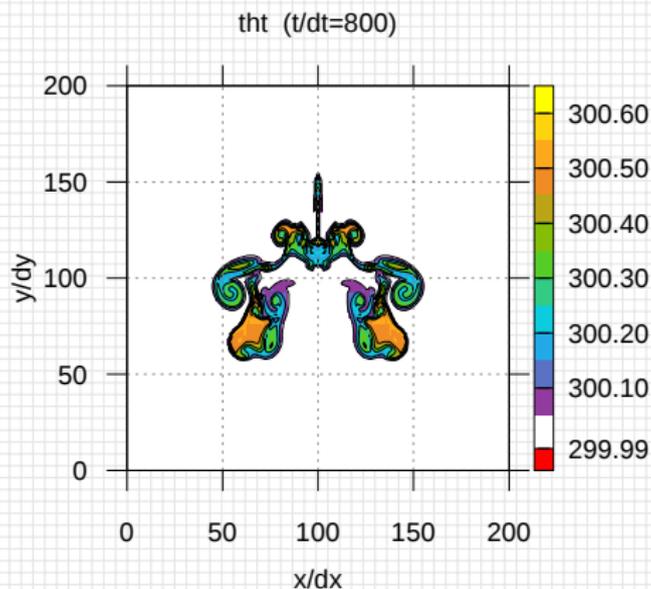
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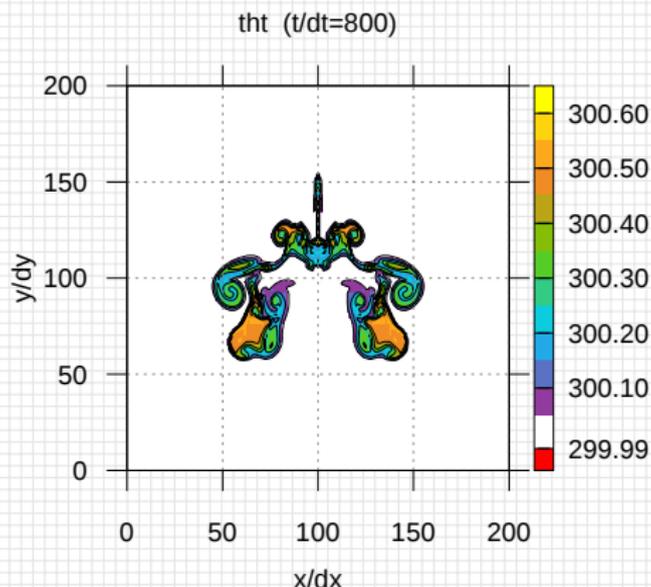
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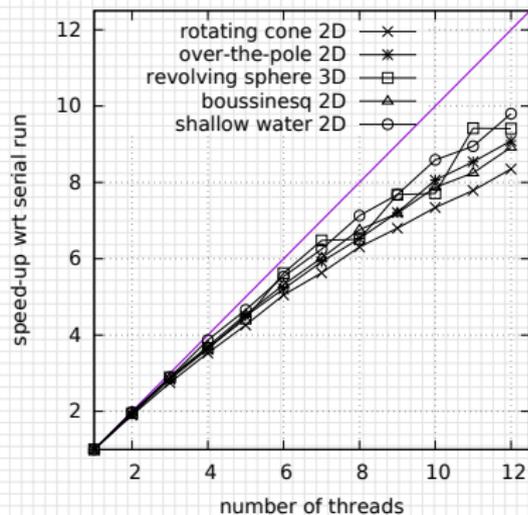


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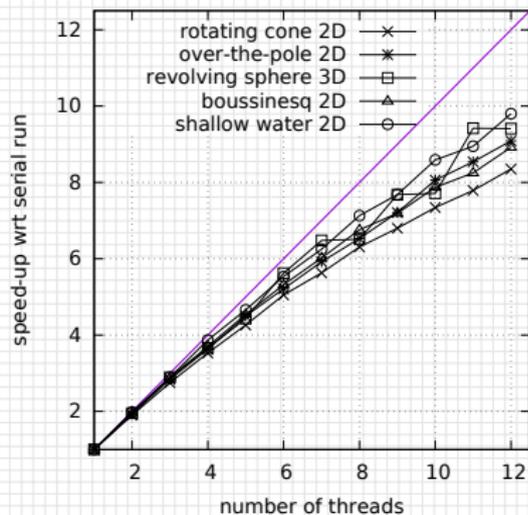


(3D, homogeneous  
advection, serial)

grid	ratio
$59^3$	4.8
$(2 \times 59)^3$	2.0
$(4 \times 59)^3$	1.4
$(6 \times 59)^3$	0.9

Analysis performed by Maciek Waruszewski, computational time granted by the Center for Cooperative Work on Computational Science of the University of Hyogo

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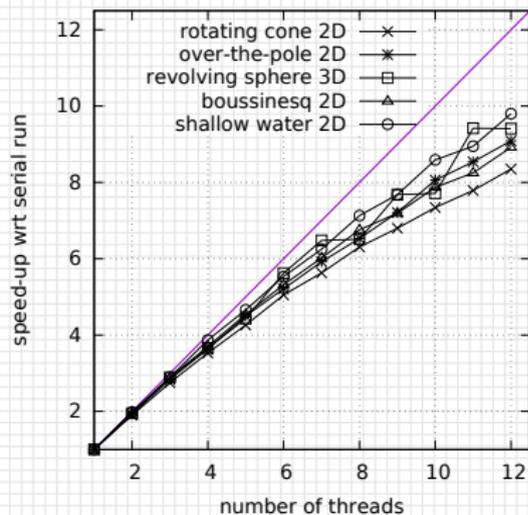


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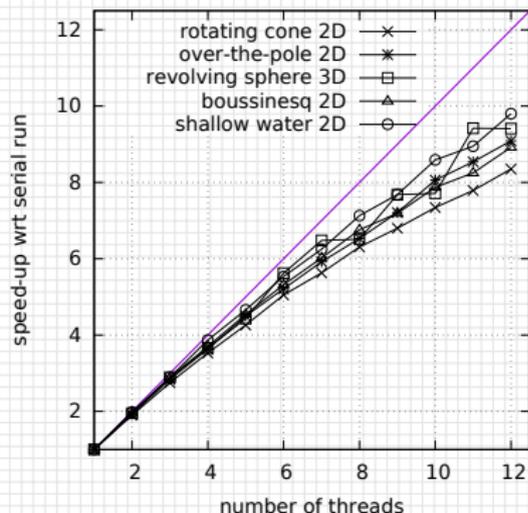
libmpdata++ / F77  
CPU-time ratios

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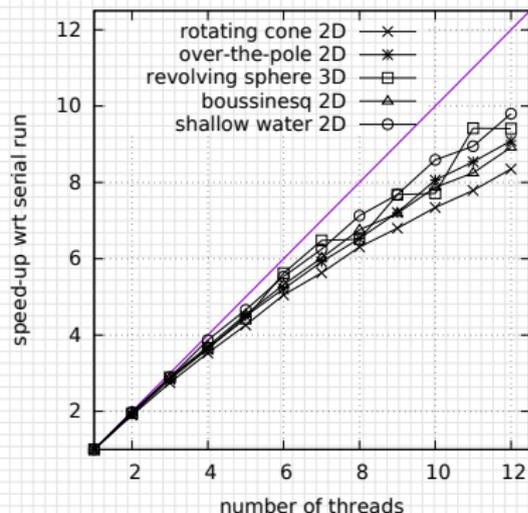
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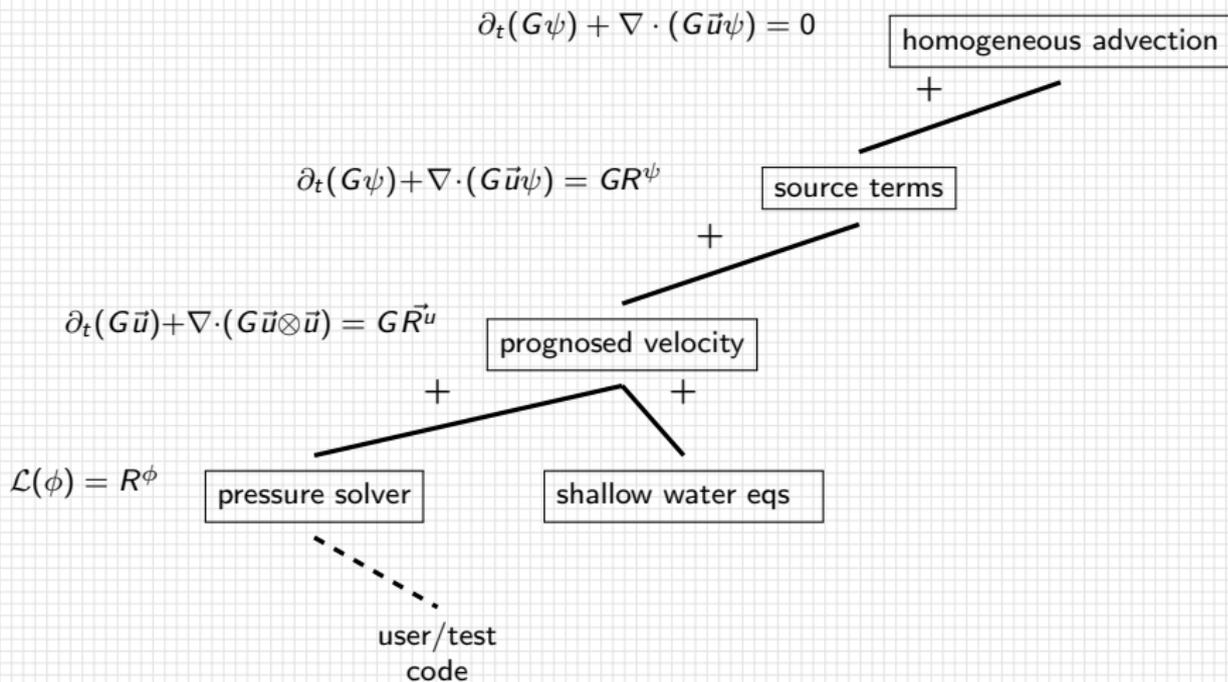
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- 2 libmpdata++: a hello-world program
- 3 libmpdata++ 1.0: summary of features
- 4 libmpdata++ 2.0: new features under development
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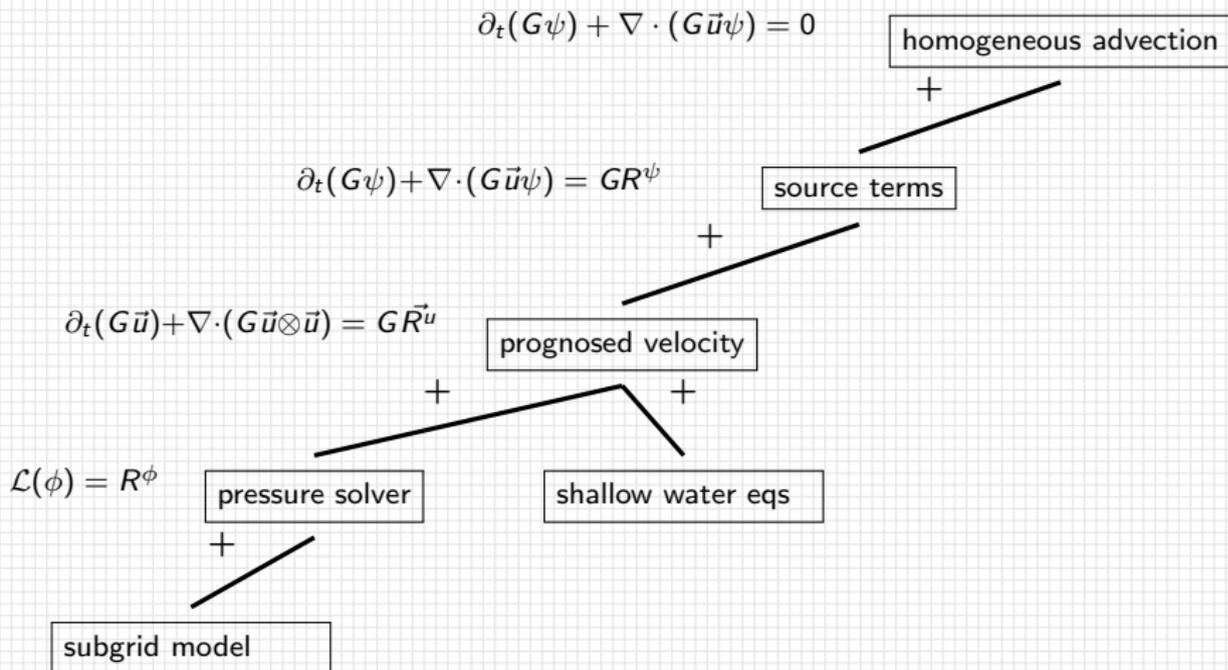
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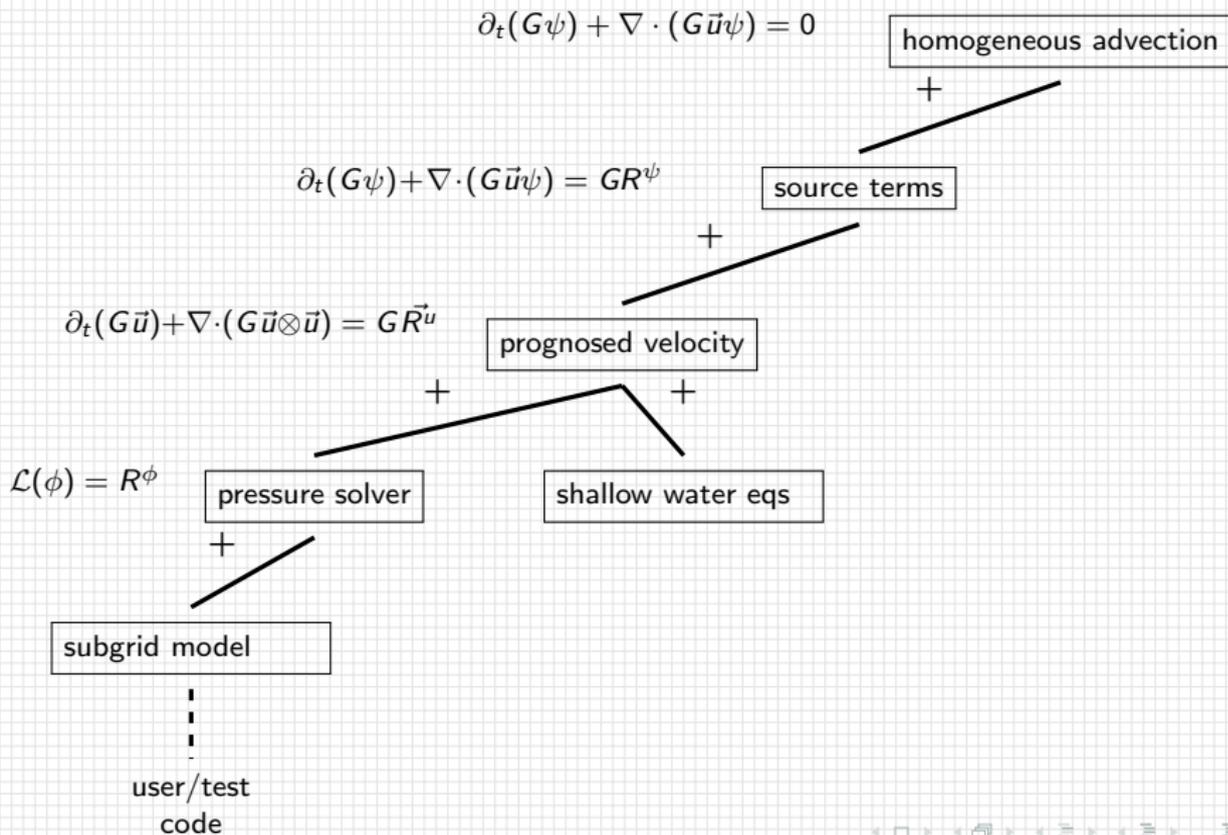
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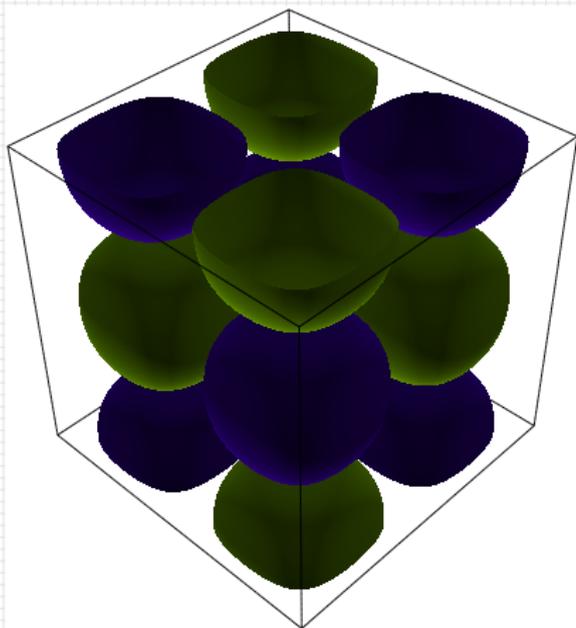
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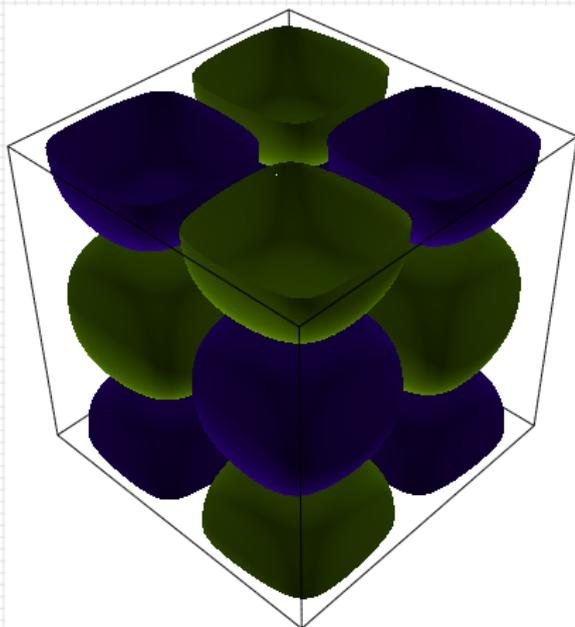
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- inspired by spectral calculations of Brachet et al., 1983
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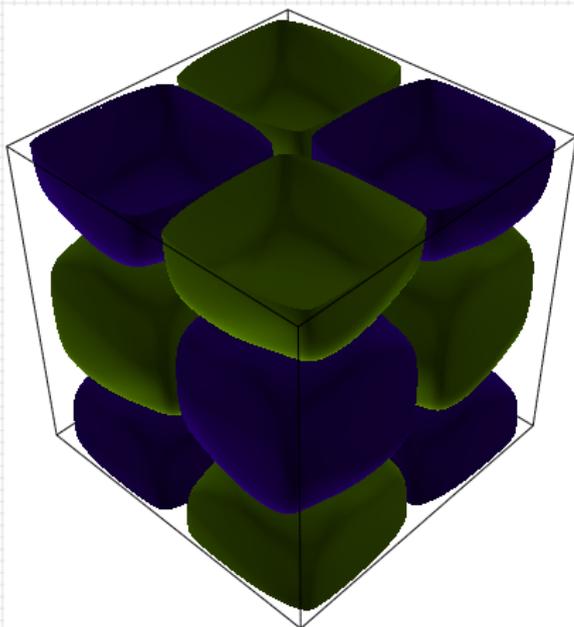
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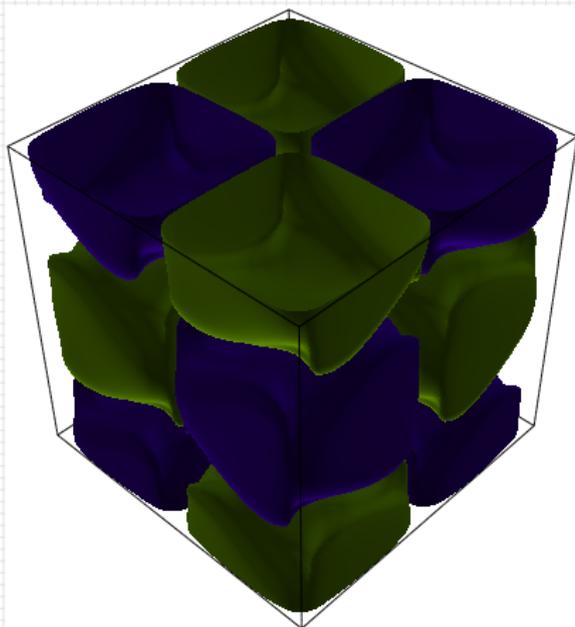
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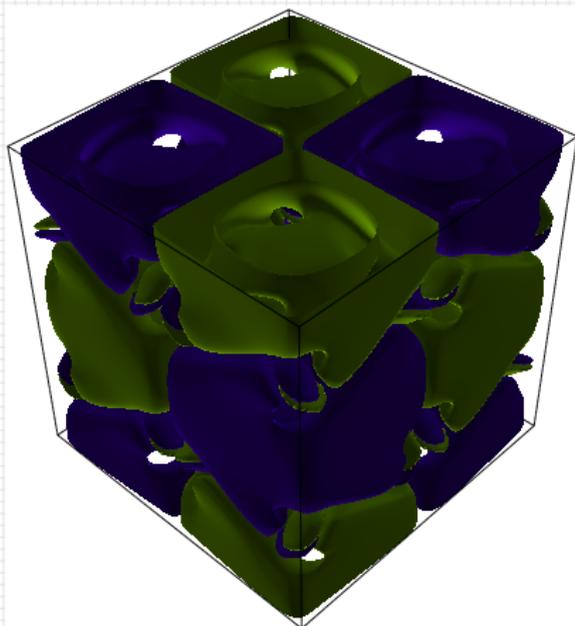
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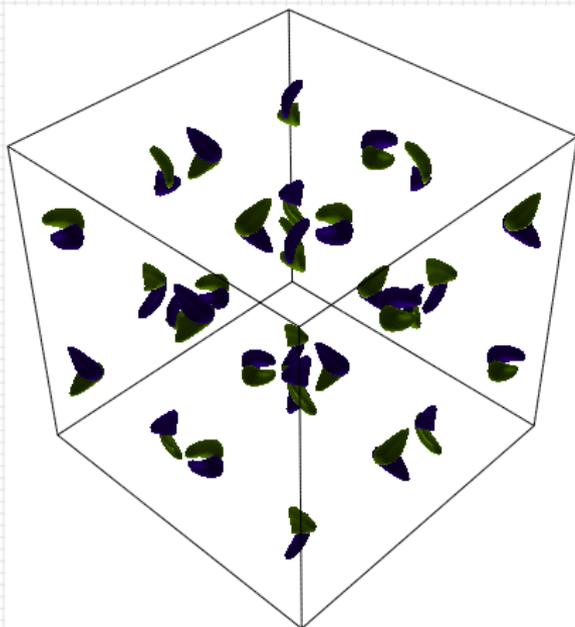
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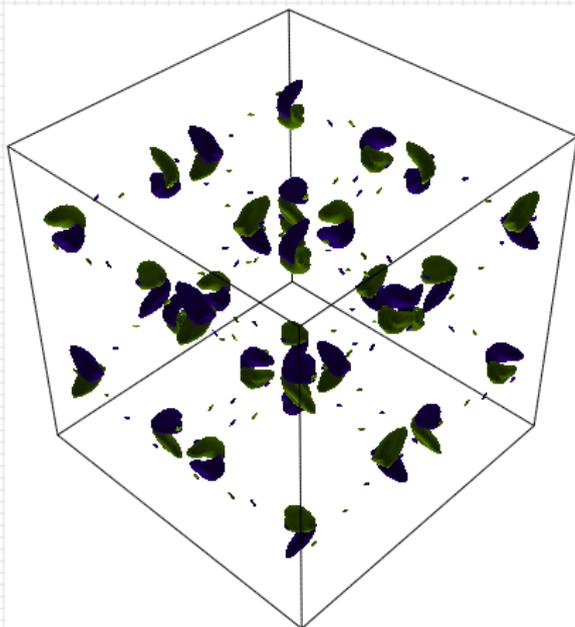
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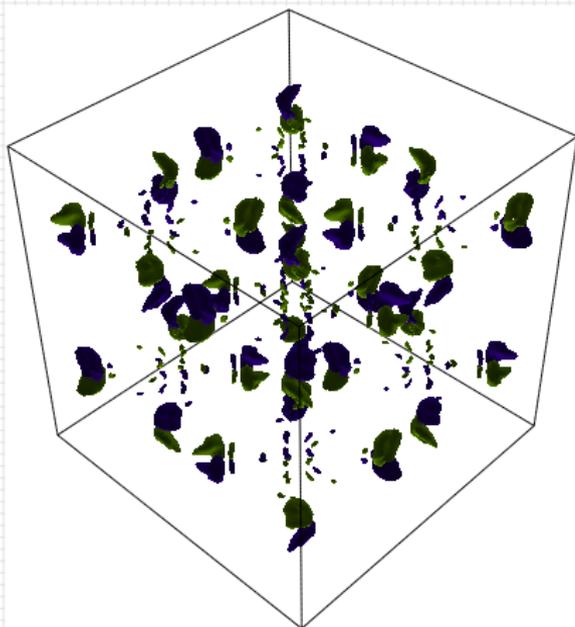
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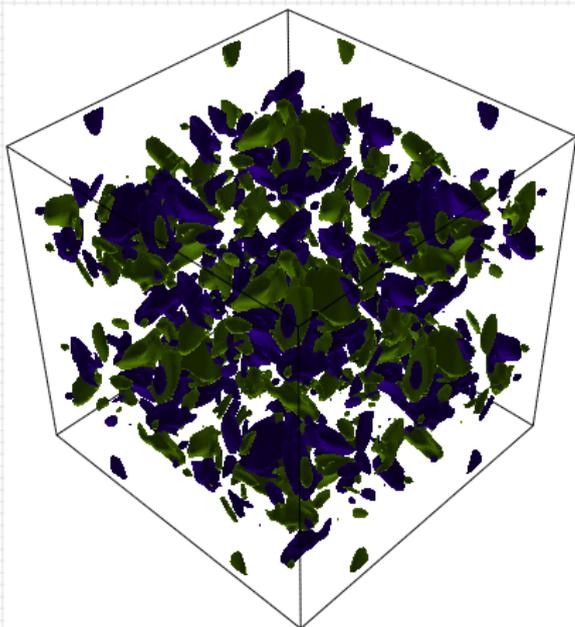
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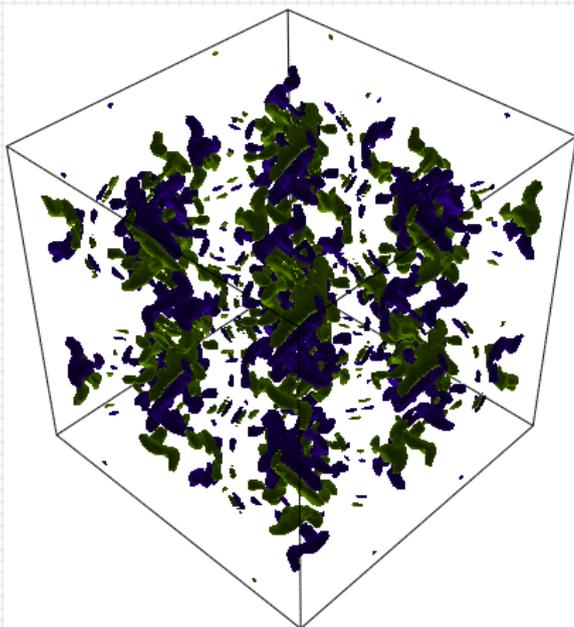
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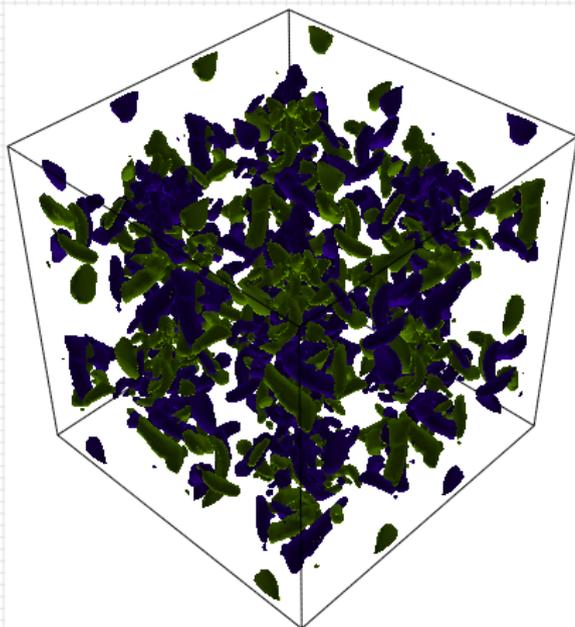
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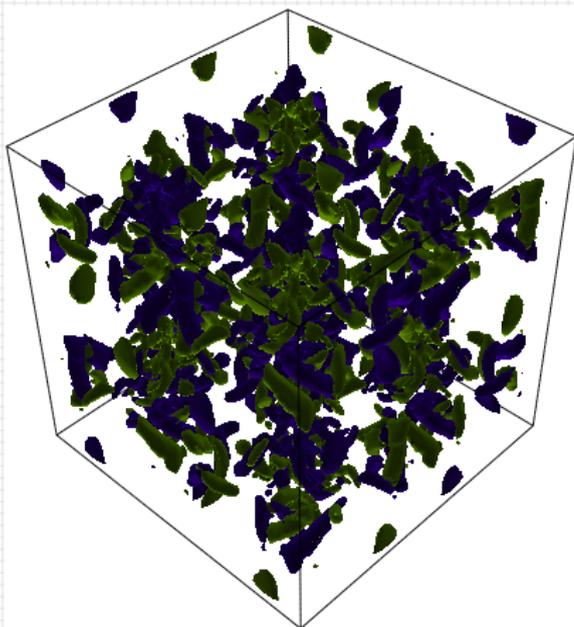
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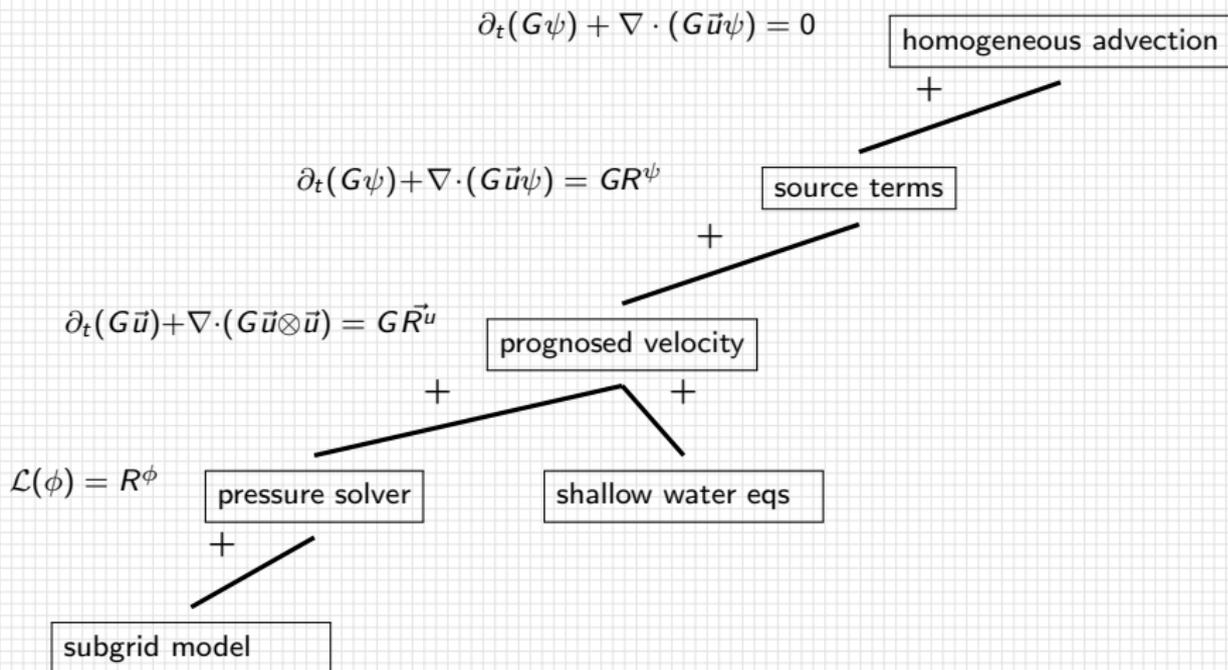
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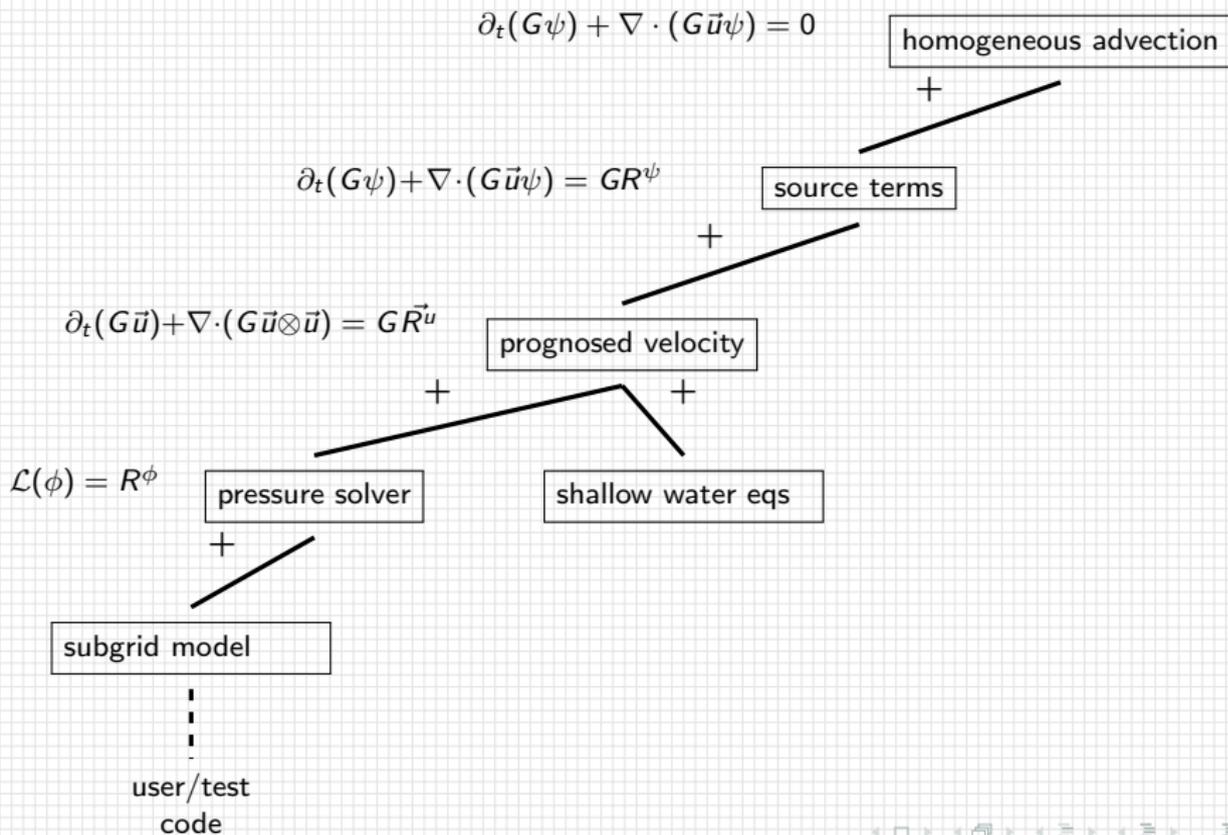
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<https://github.com/igfuw/libmpdataxx/tree/master/tests/sandbox/turbulence>

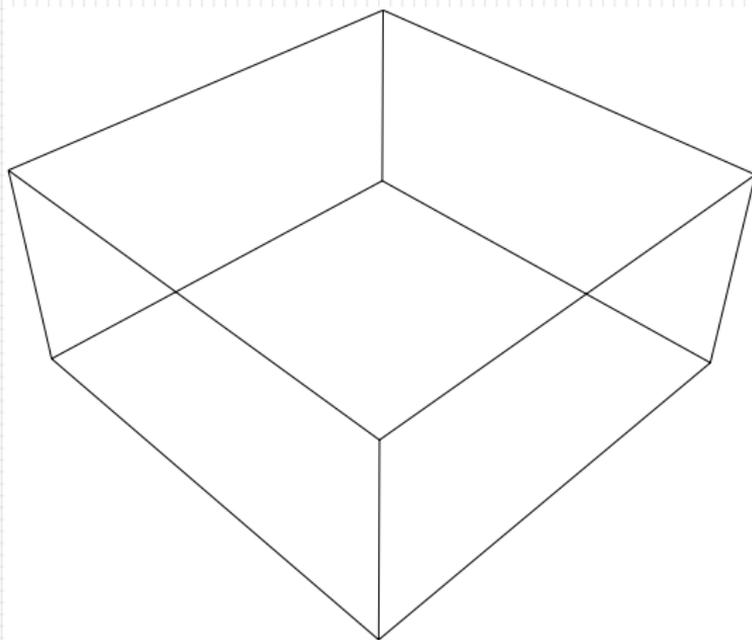
# libmpdata++ 2.0: solver/algorithm hierarchy



# libmpdata++ 2.0: solver/algorithm hierarchy

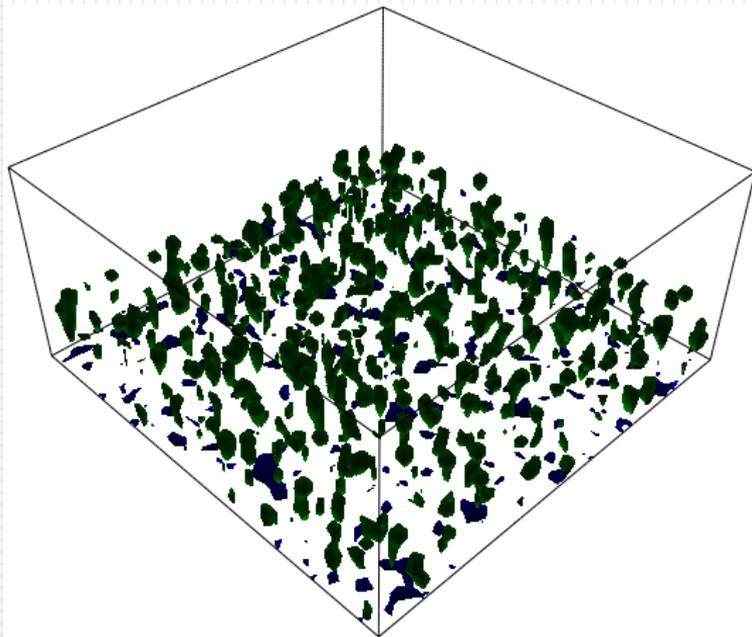


## libmpdata++ 2.0: convective boundary layer example



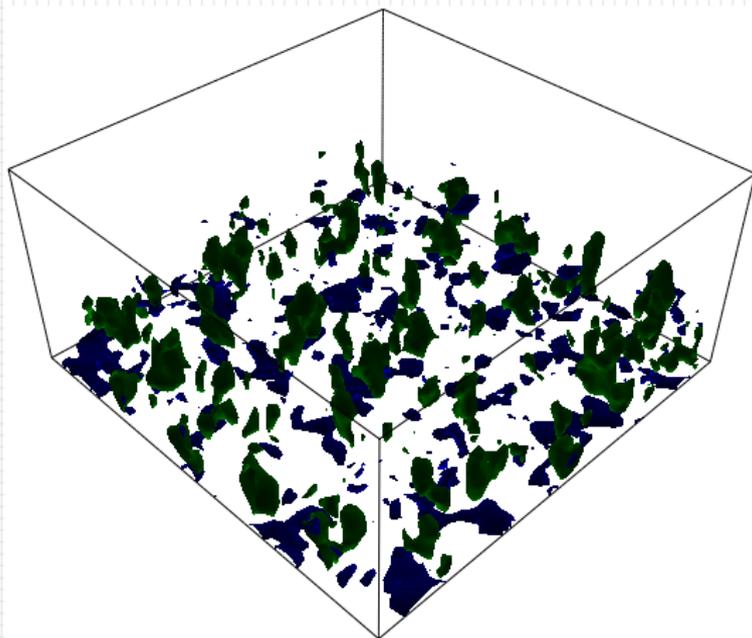
- iLES setup following Margolin et al., 1999
- <250 lines of code with libmpdata++

# libmpdata++ 2.0: convective boundary layer example



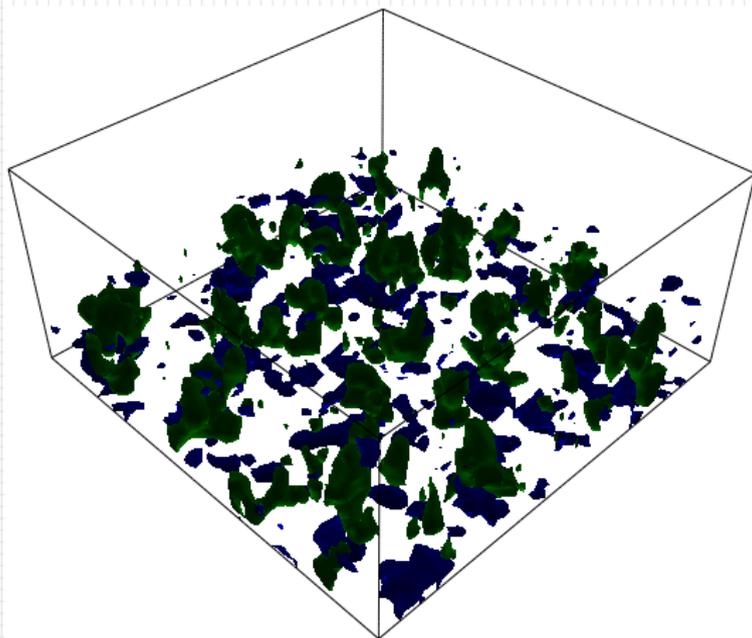
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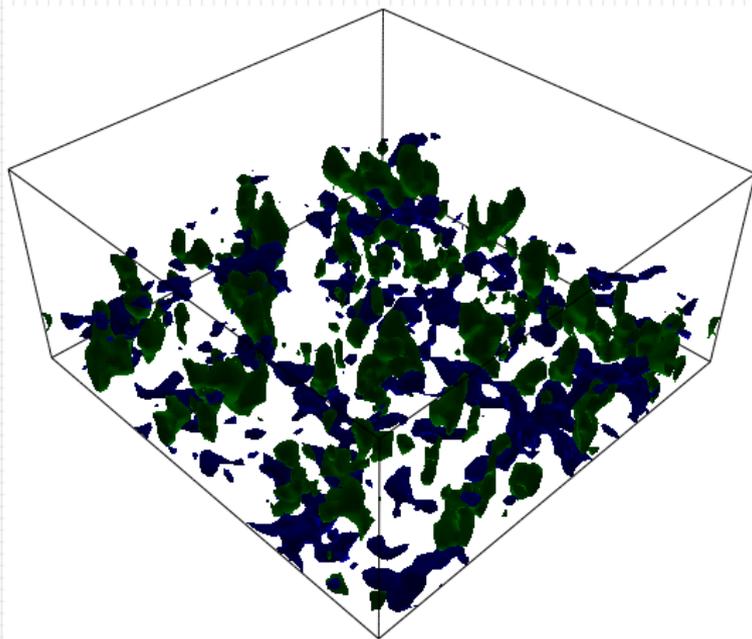
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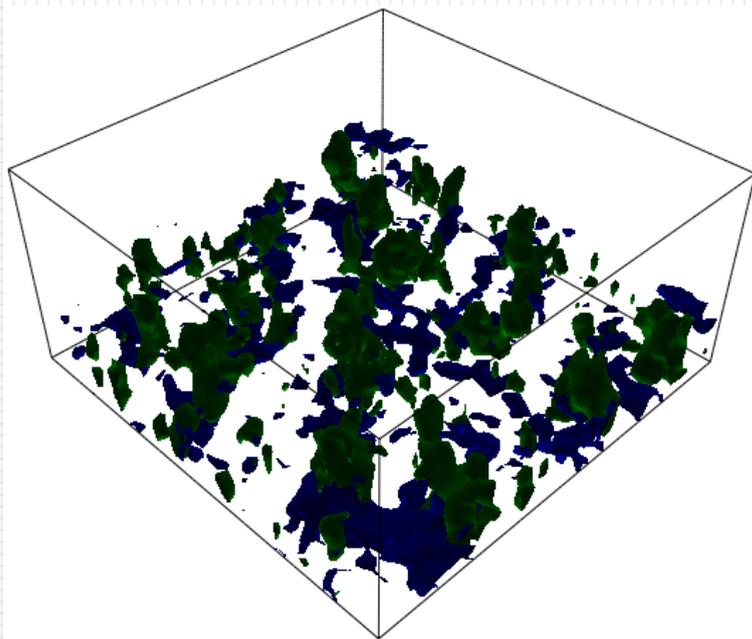
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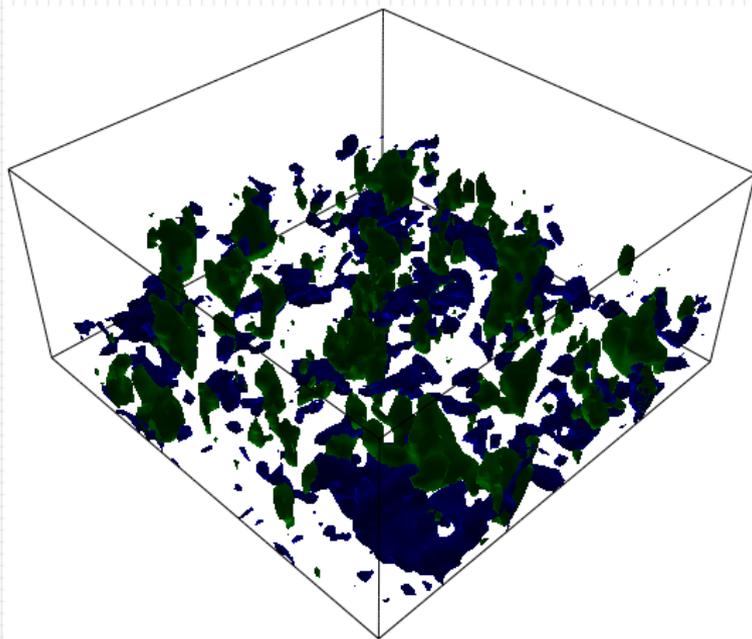
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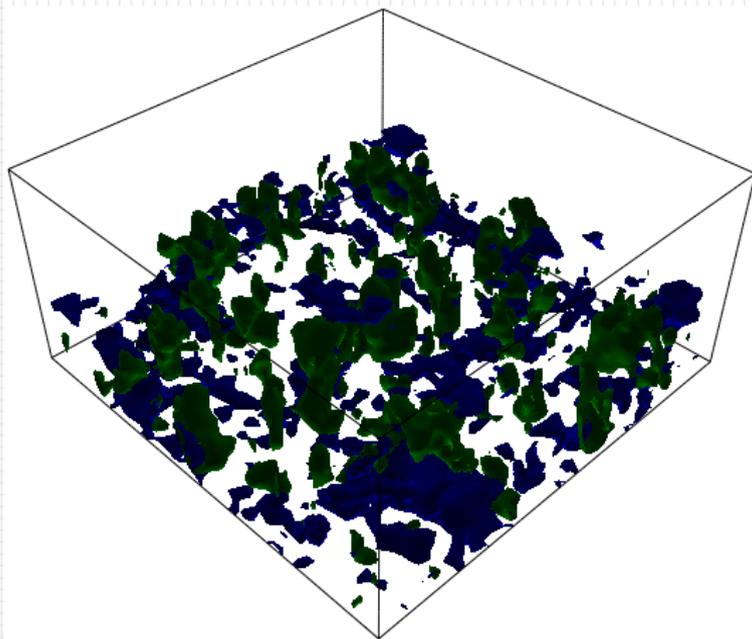
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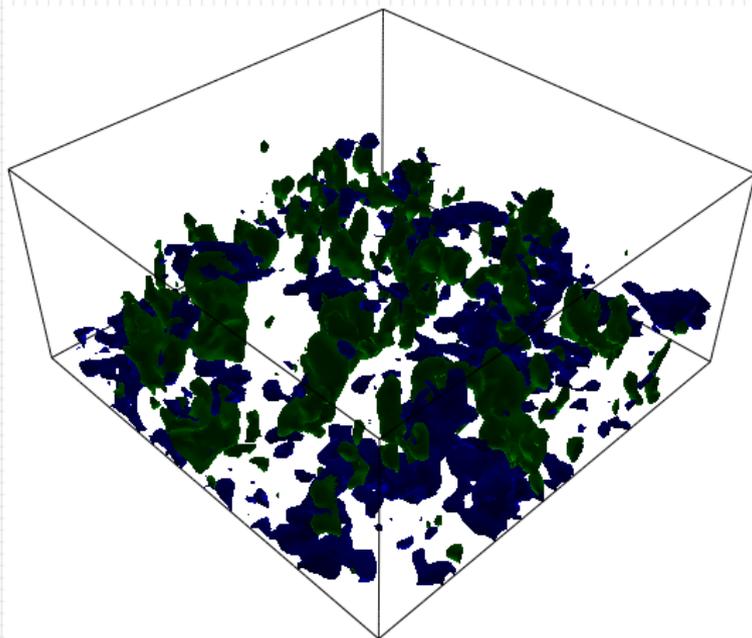
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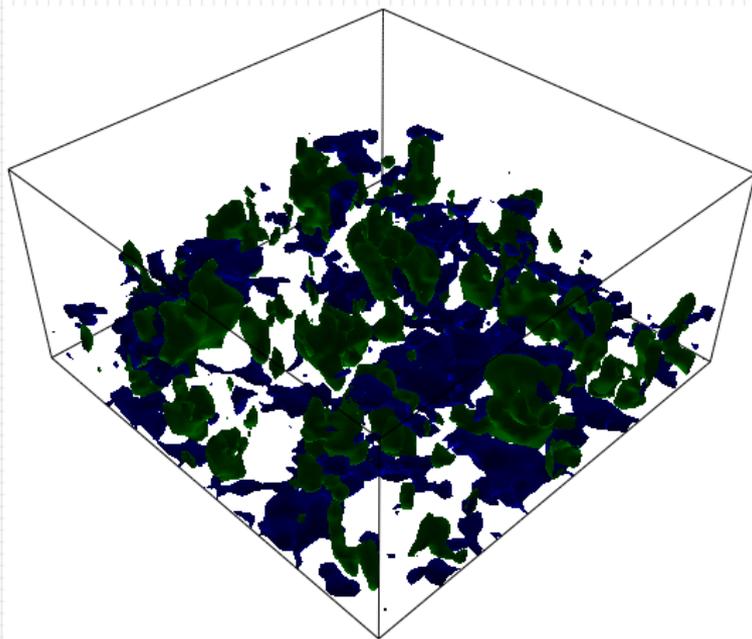
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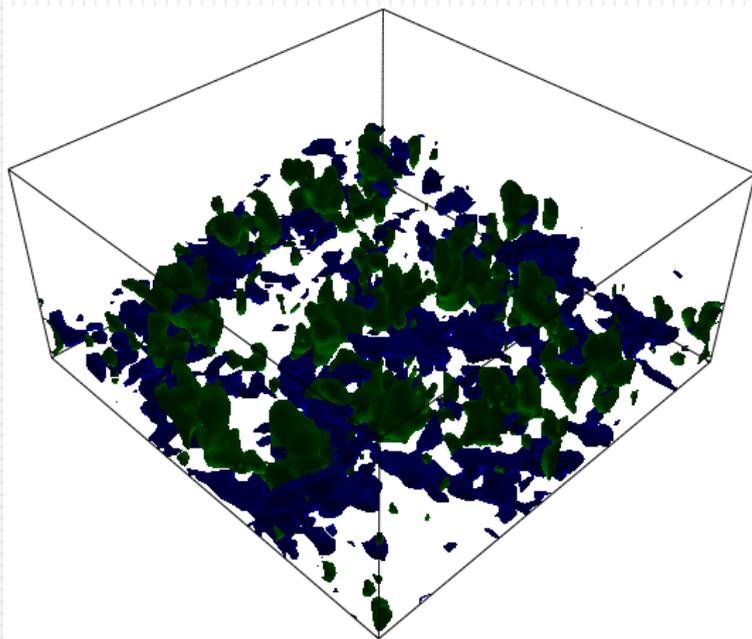
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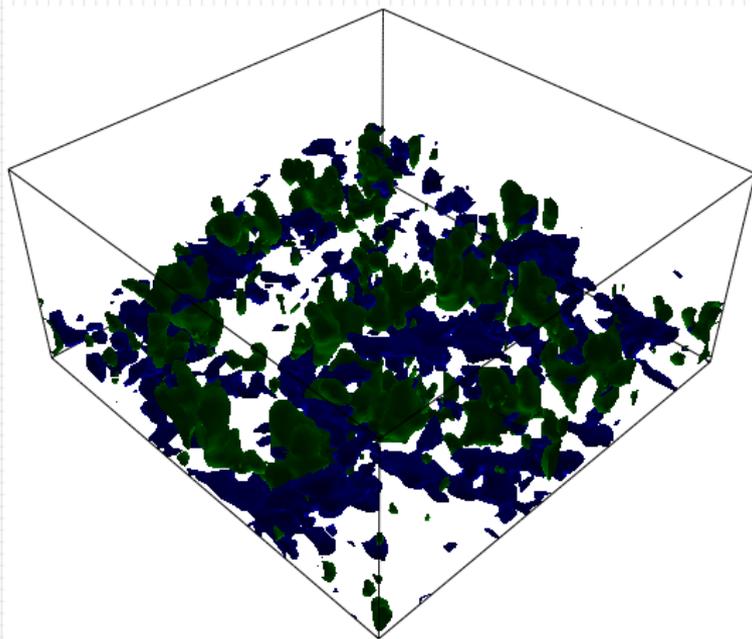
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# libmpdata++ 2.0: convective boundary layer example



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- <250 lines of code with libmpdata++

# libmpdata++ 2.0: summary of features under development

- **Support for 32-bit architectures**  
(`libmpdata++` will be able to compile on 32-bit systems)
- **Support for 64-bit floating point numbers**  
(`libmpdata++` will be able to compile on 64-bit systems)
- **Support for 64-bit integers**  
(`libmpdata++` will be able to compile on 64-bit systems)
- **Support for 64-bit pointers**  
(`libmpdata++` will be able to compile on 64-bit systems)



coded by  
Maciej Waruszewski

# libmpdata++ 2.0: summary of features under development

- higher-order operators  
(for DNS/ILES simulations)
- adaptive timestepping
- implicit treatment of absorbers  
(for immersed-boundary method)
- distributed-memory parallelisation  
(using Boost.MPI & HDF5/MPI-IO)

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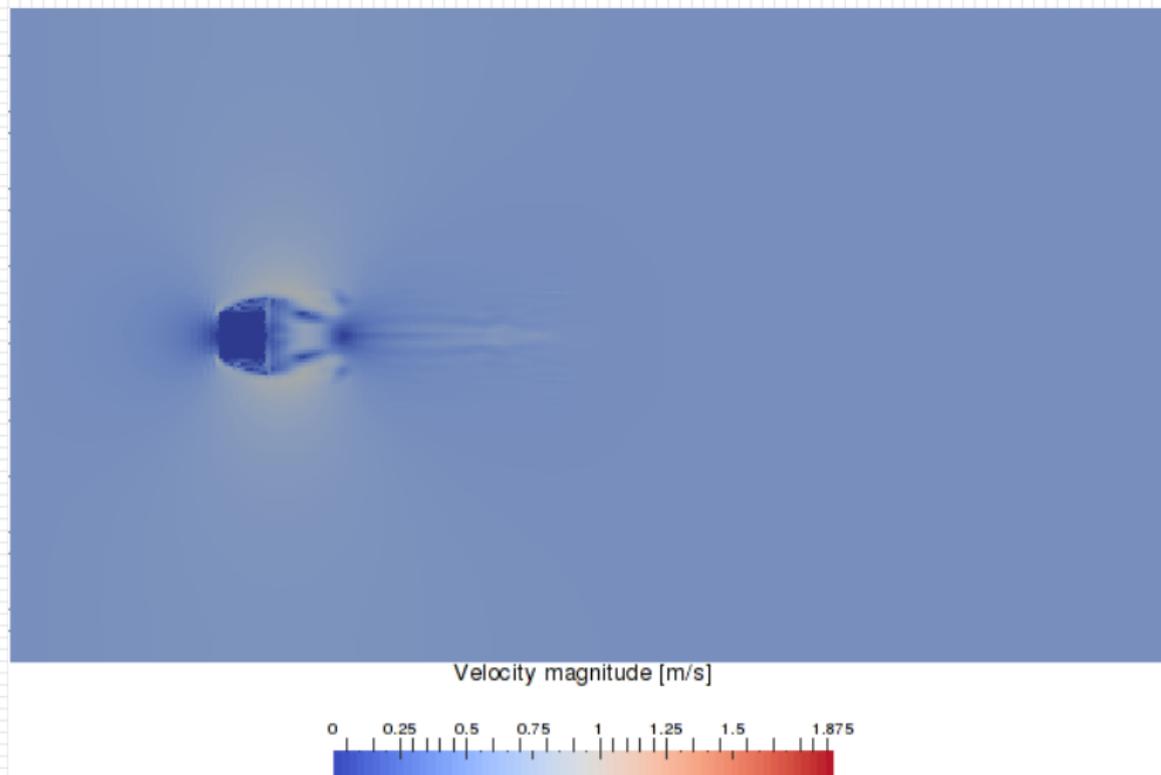
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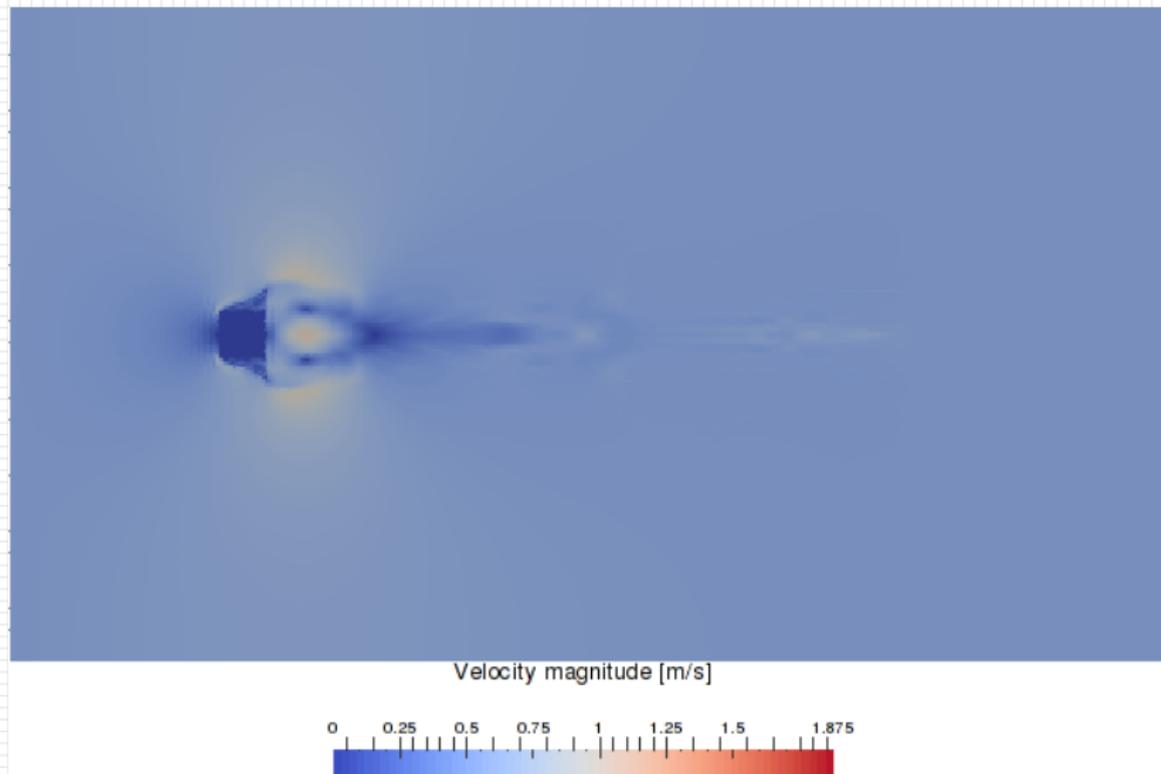
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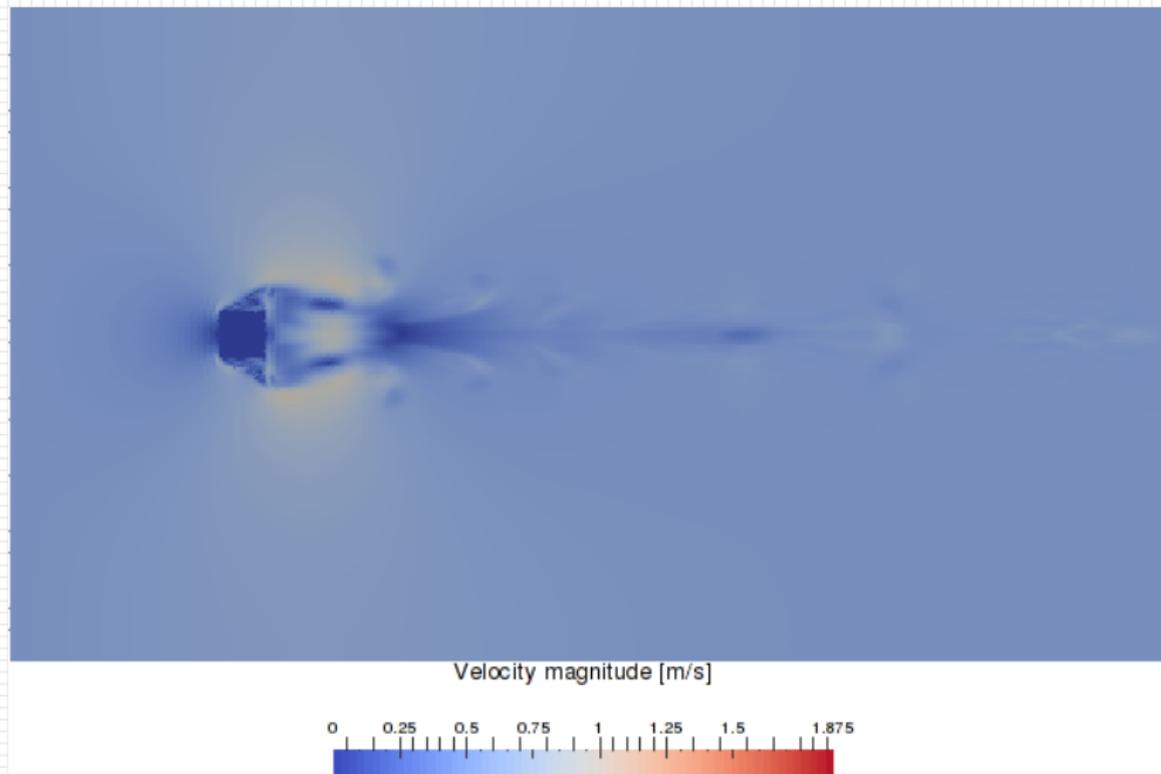
# libmpdata++ 2.0: immersed boundary teaser



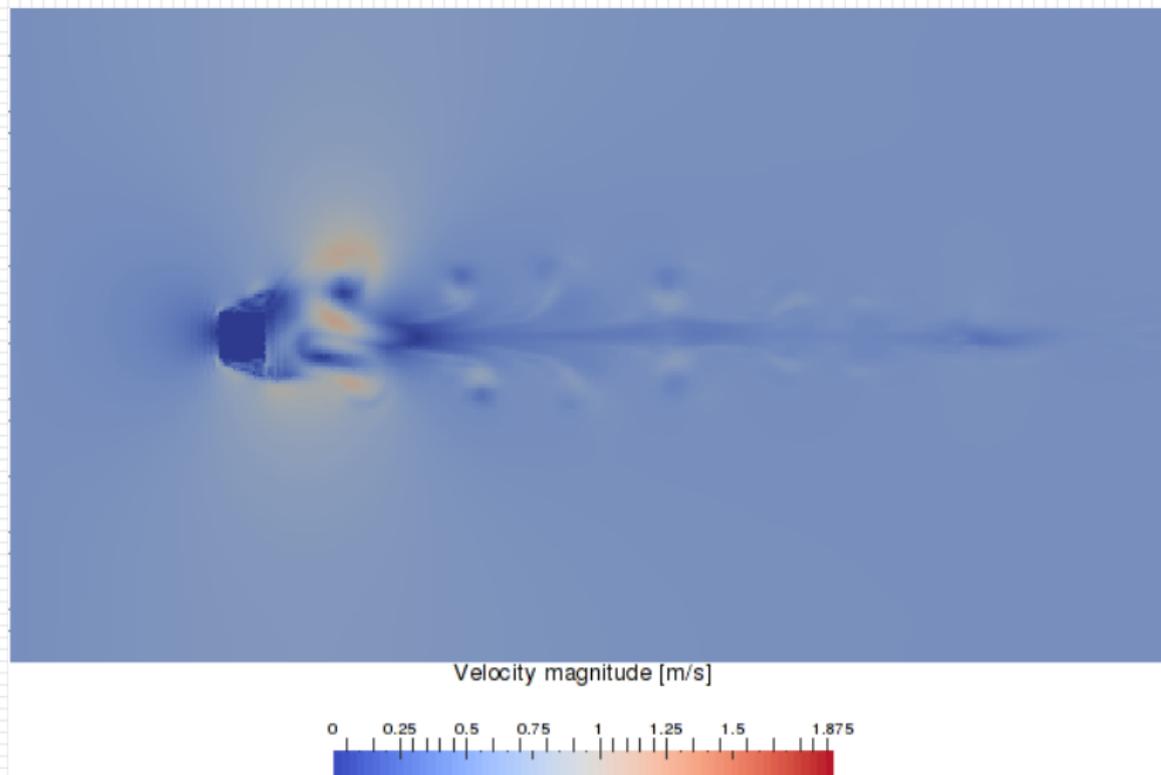
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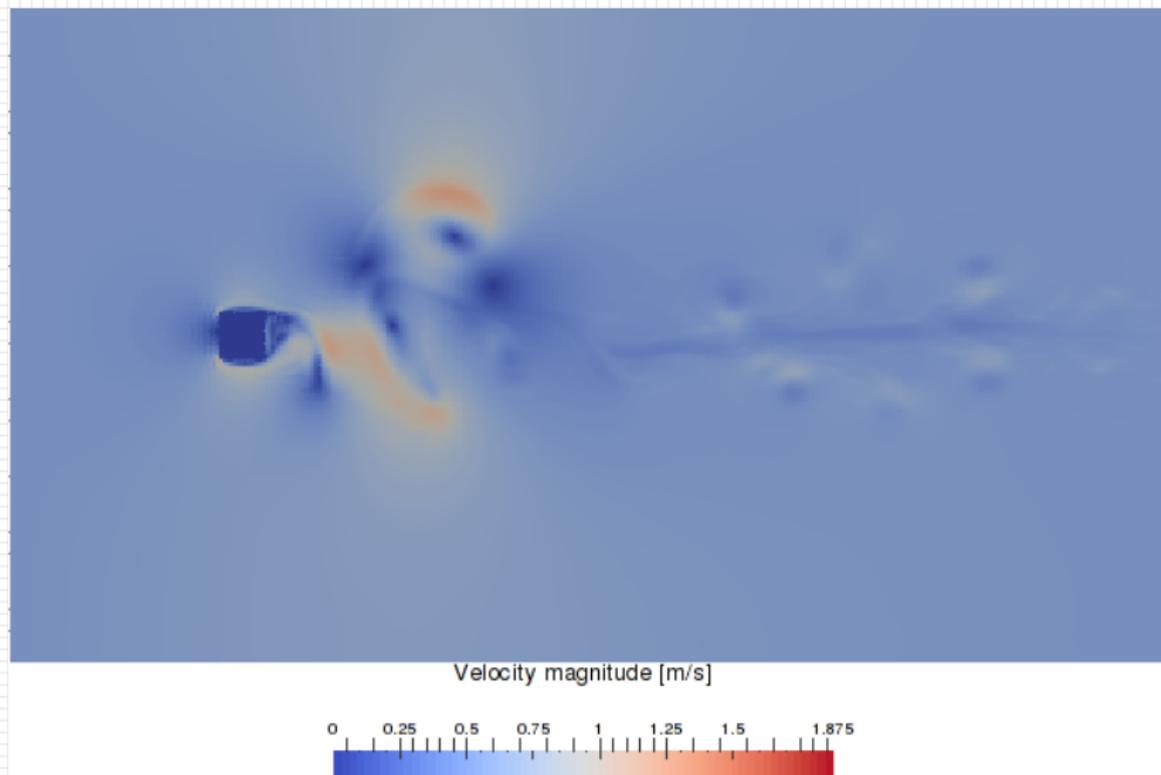
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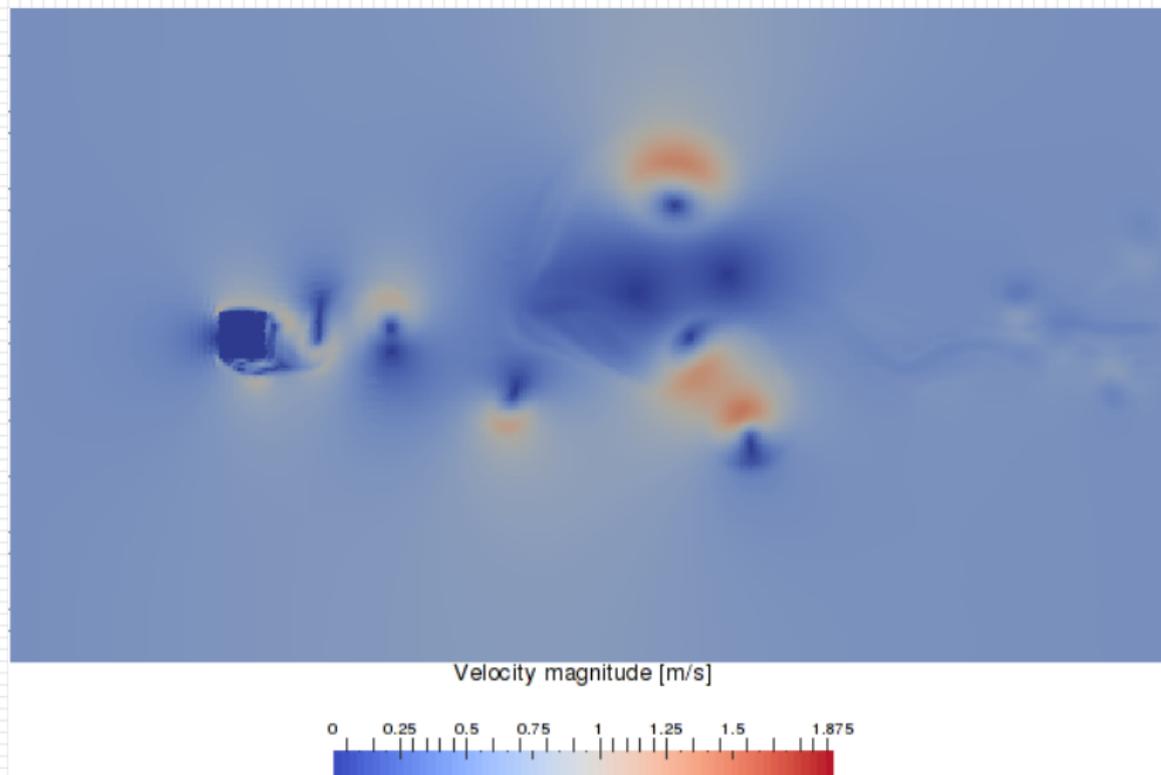
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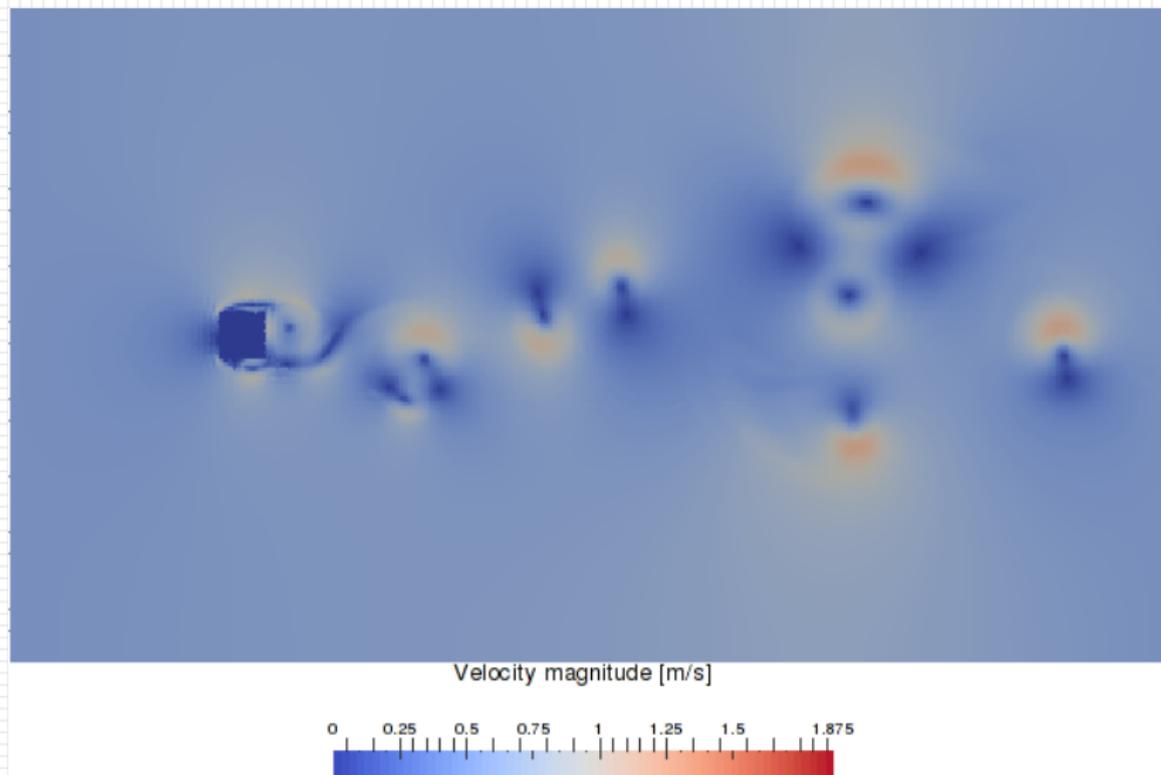
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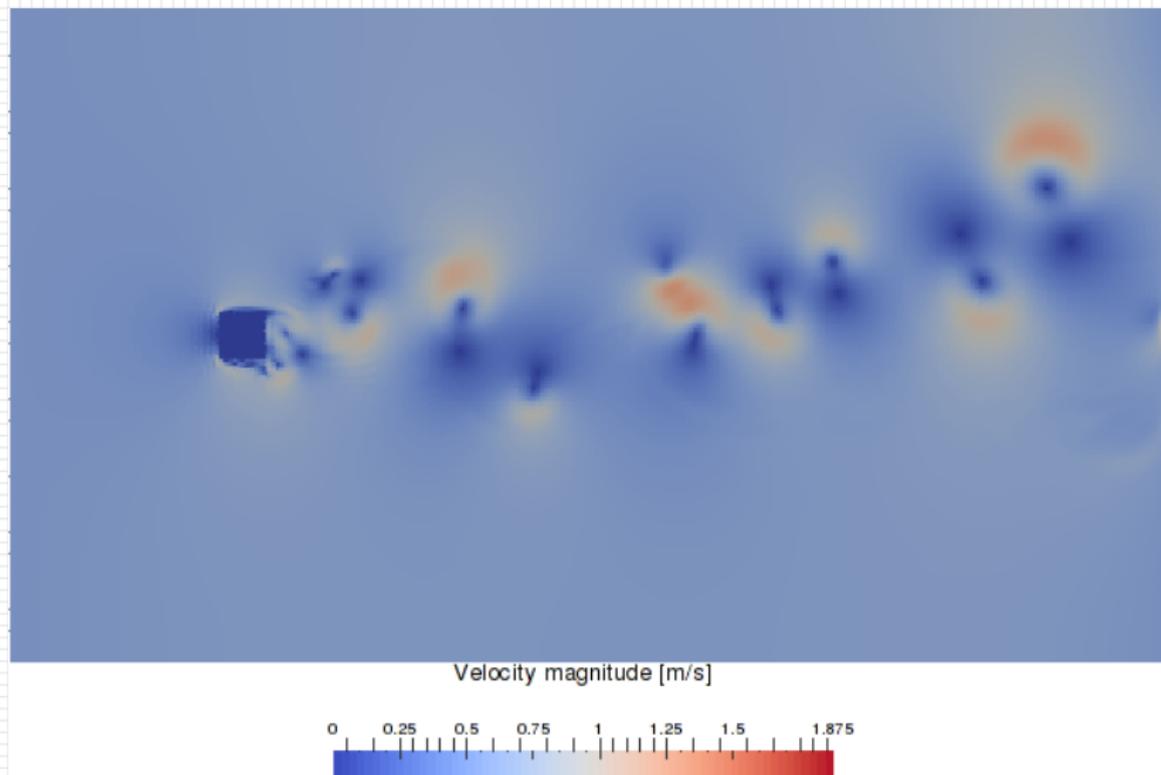
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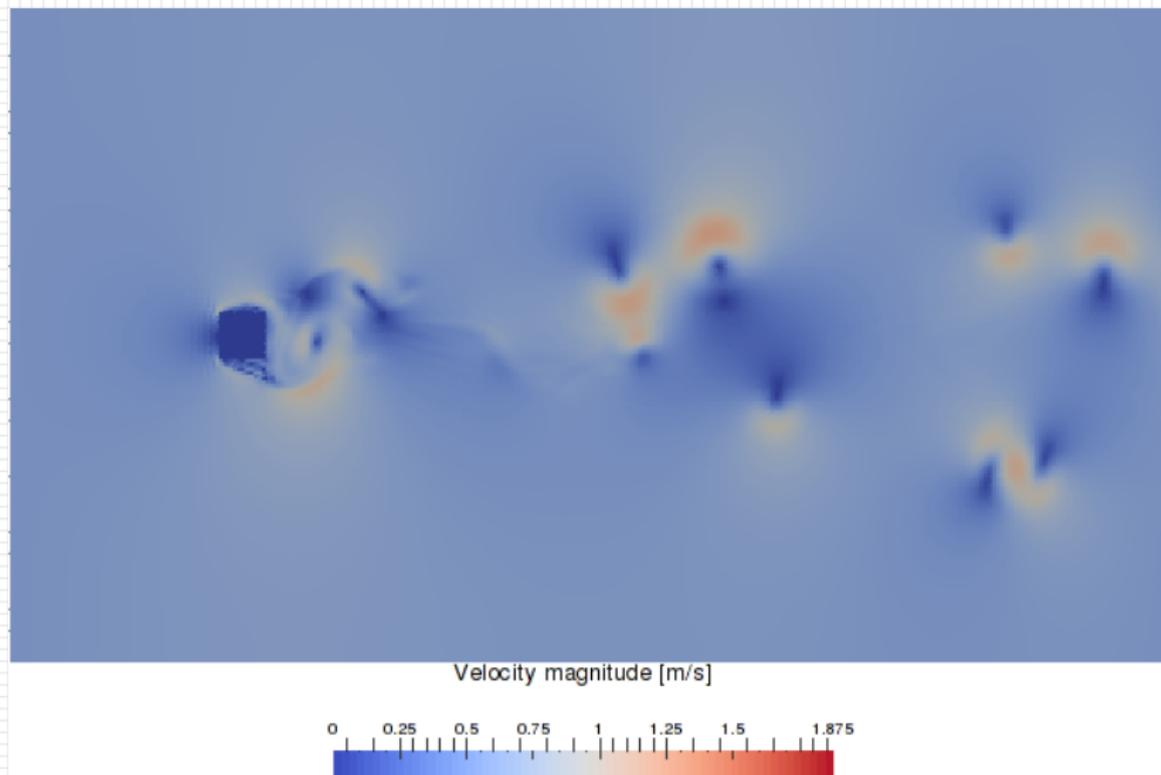
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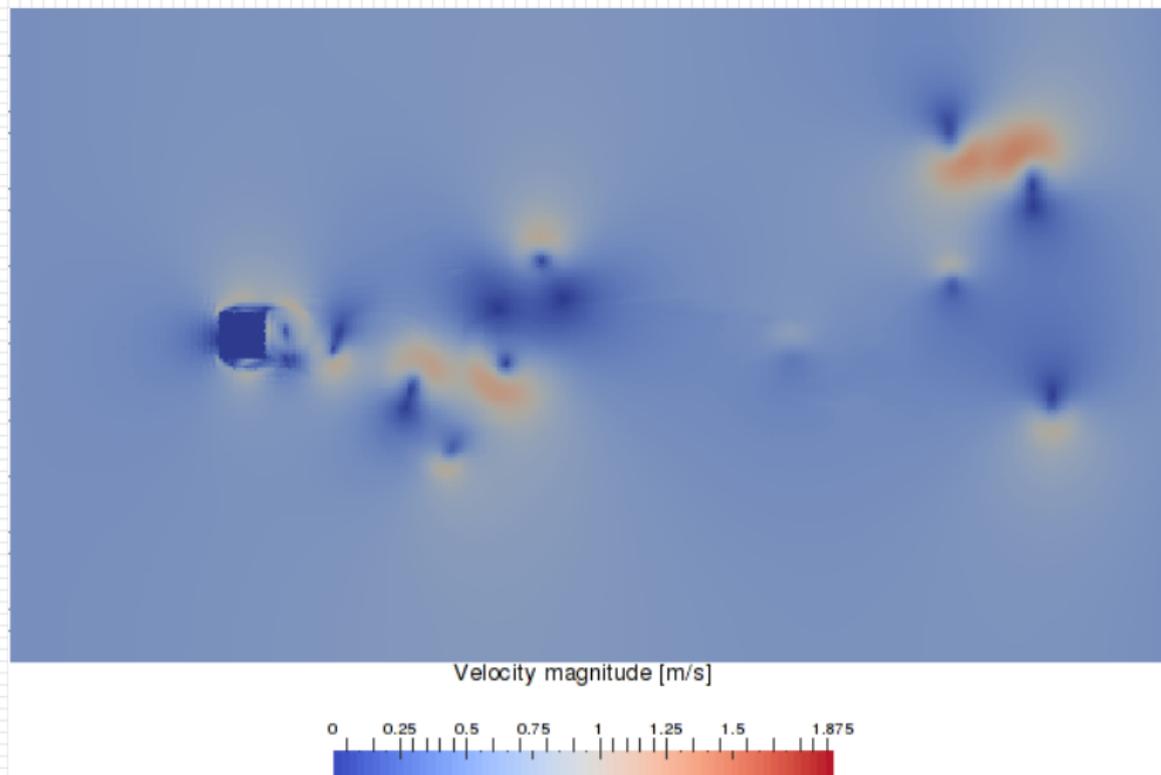
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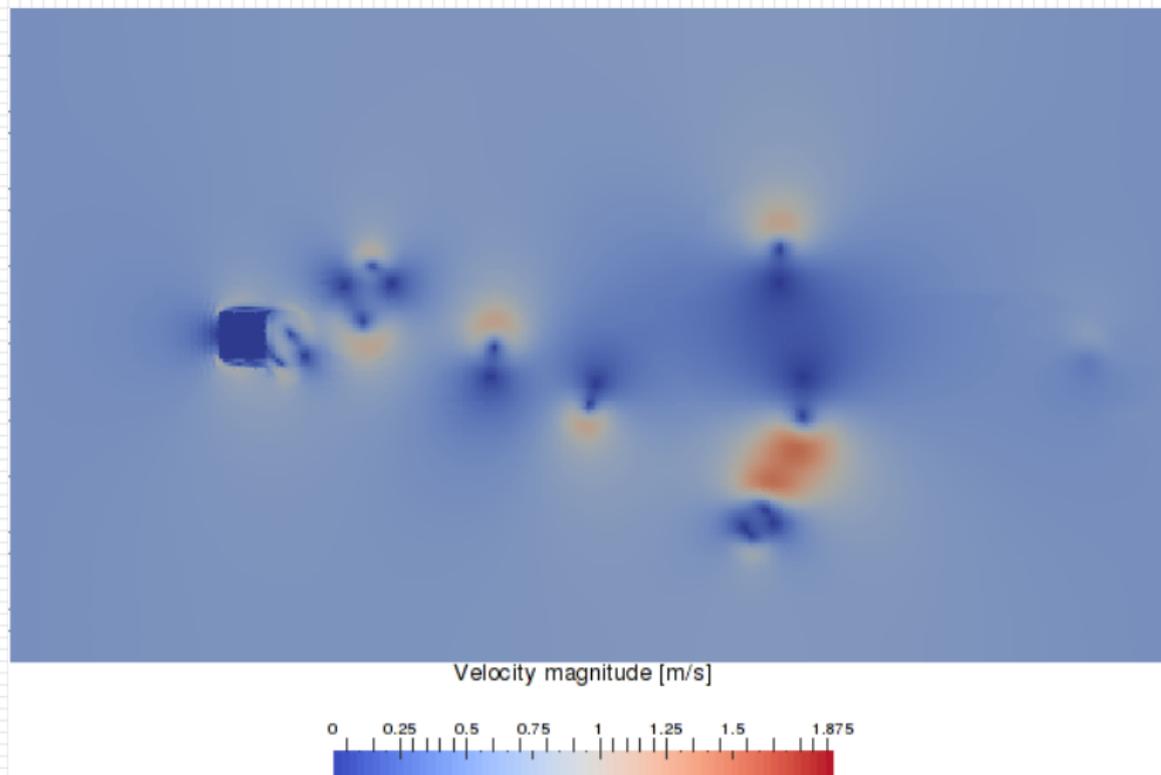
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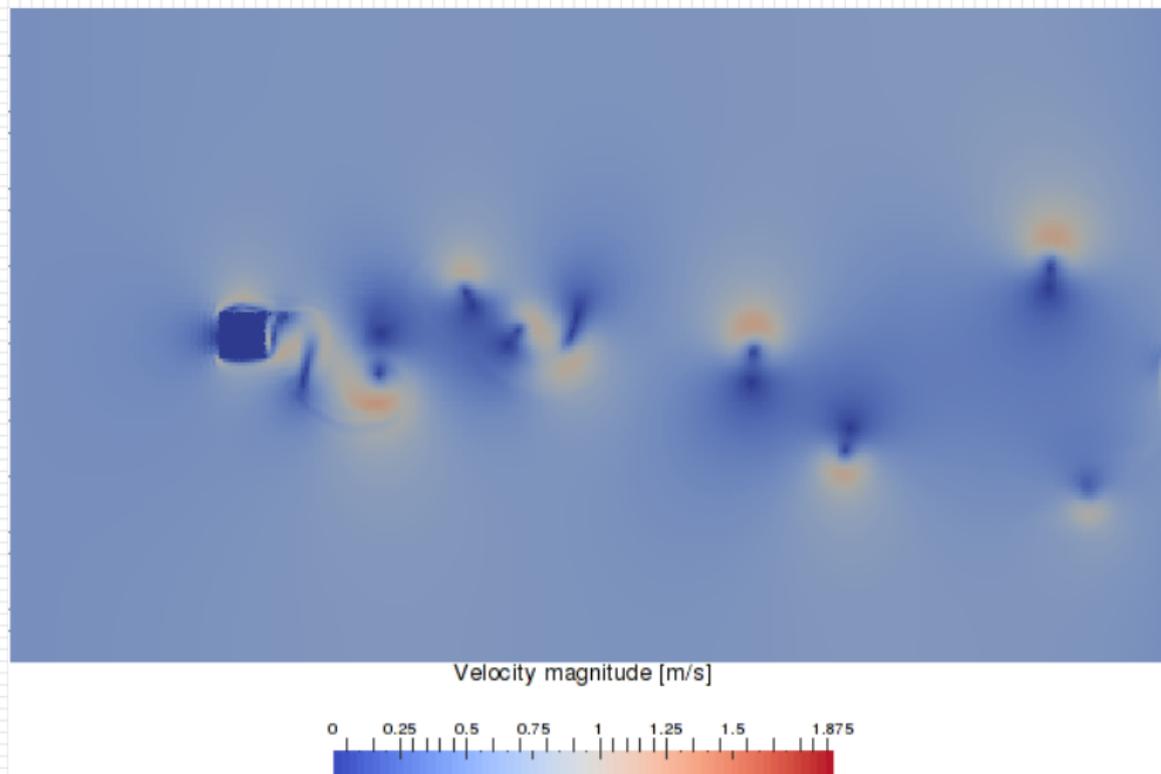
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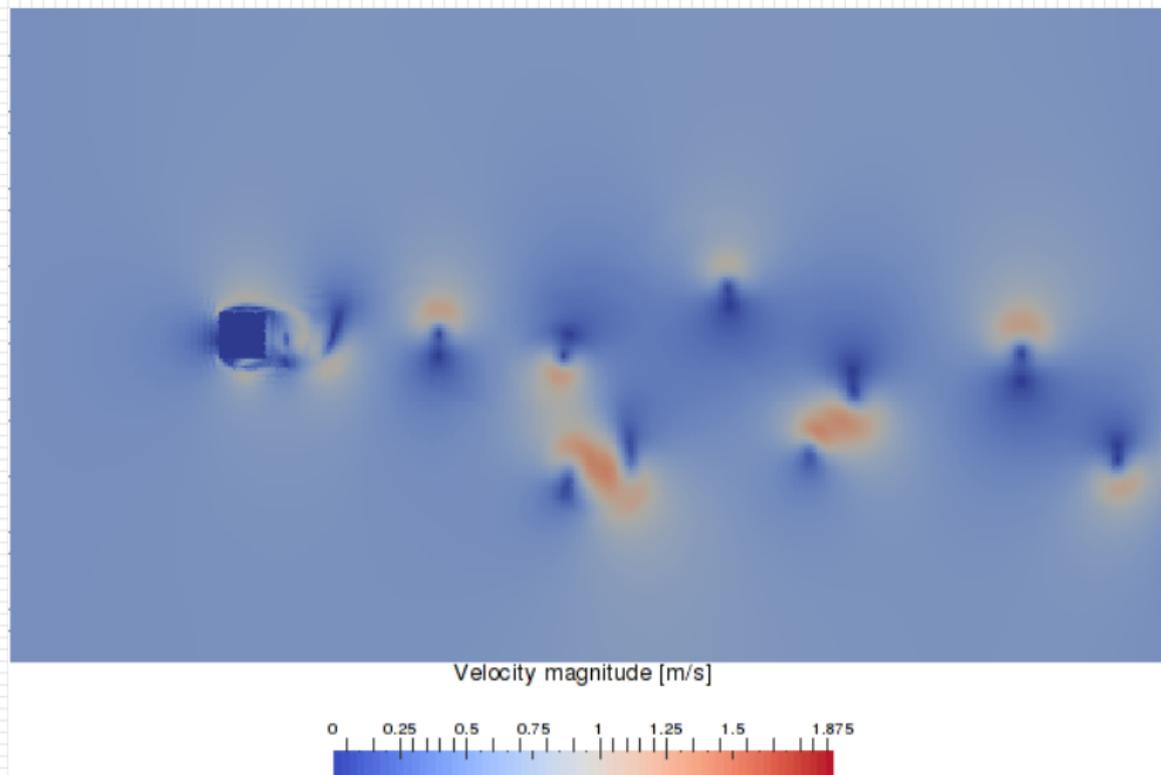
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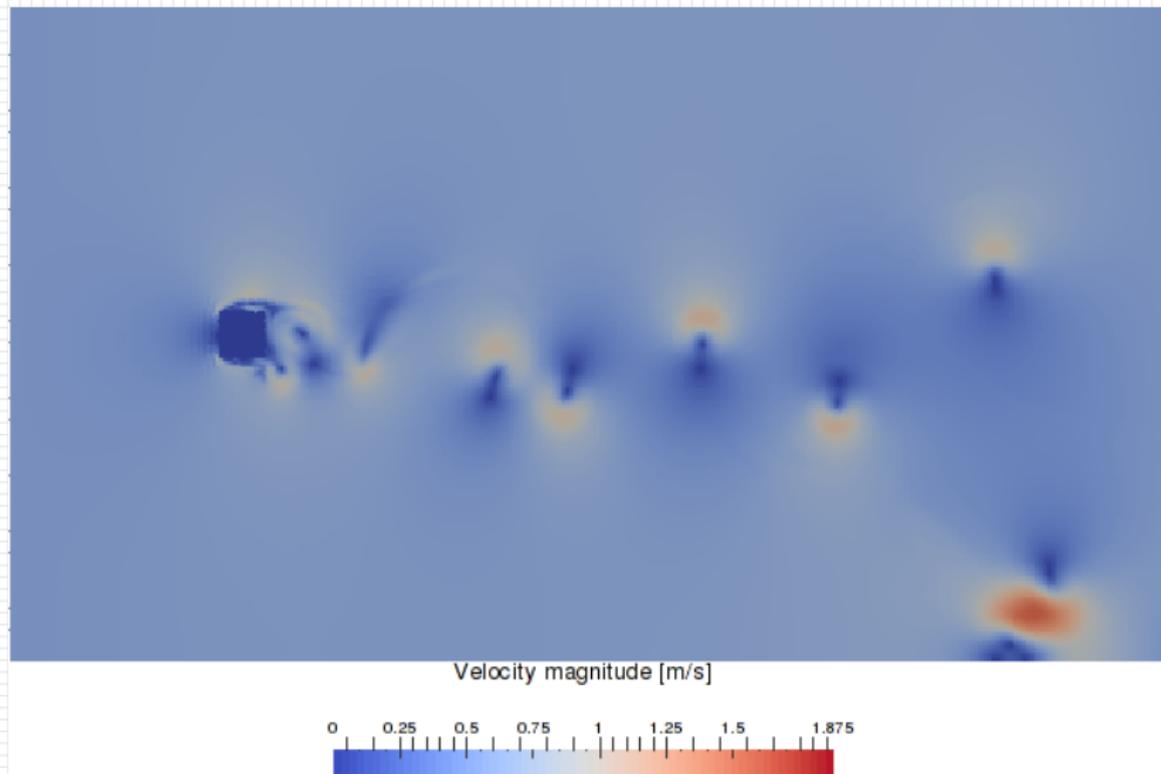
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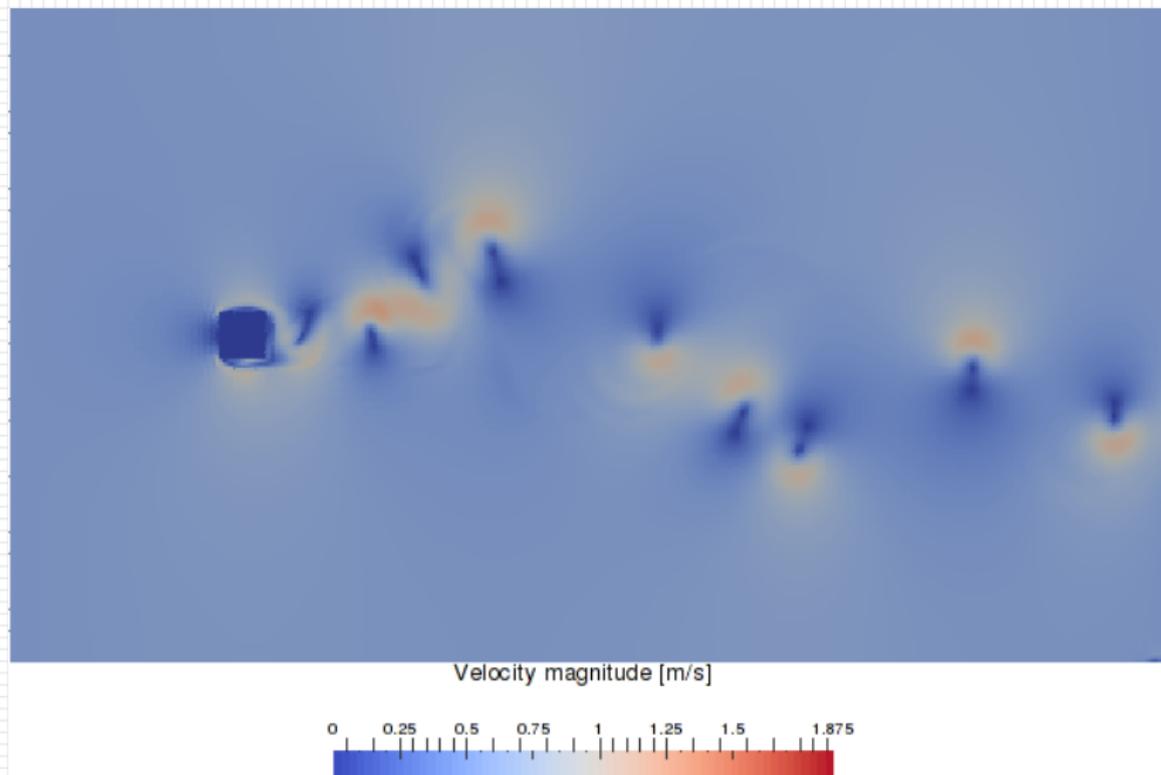
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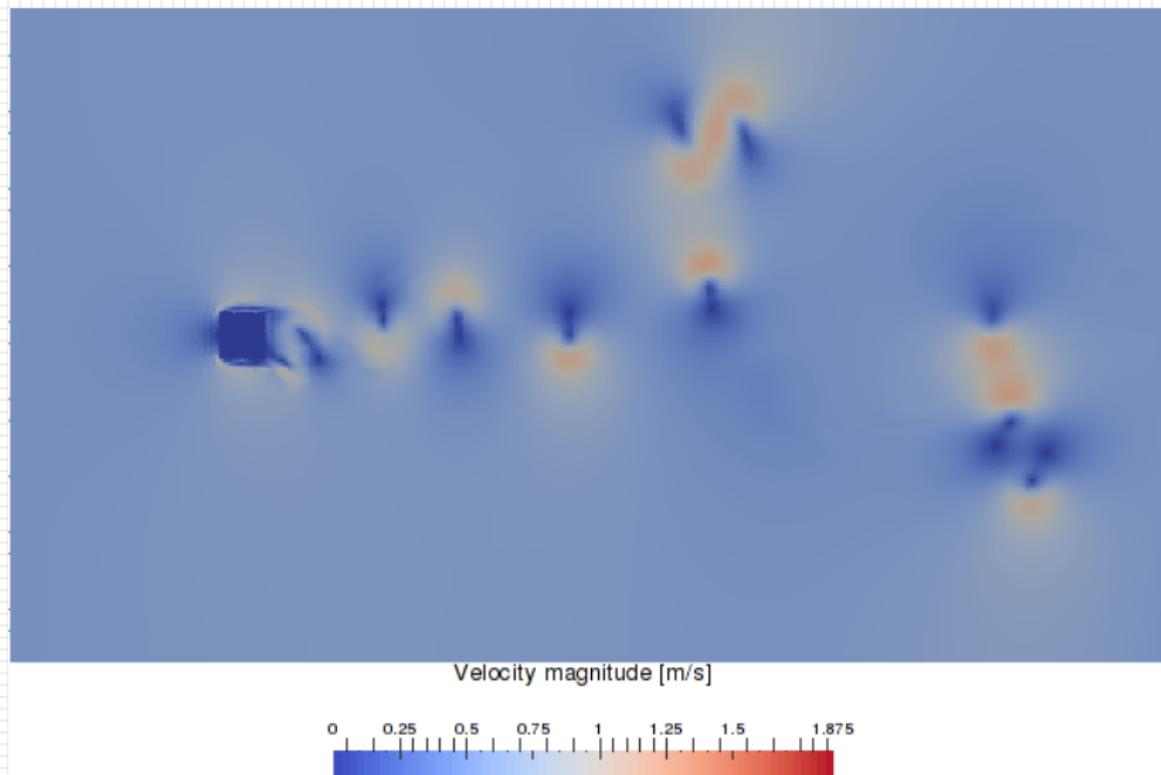
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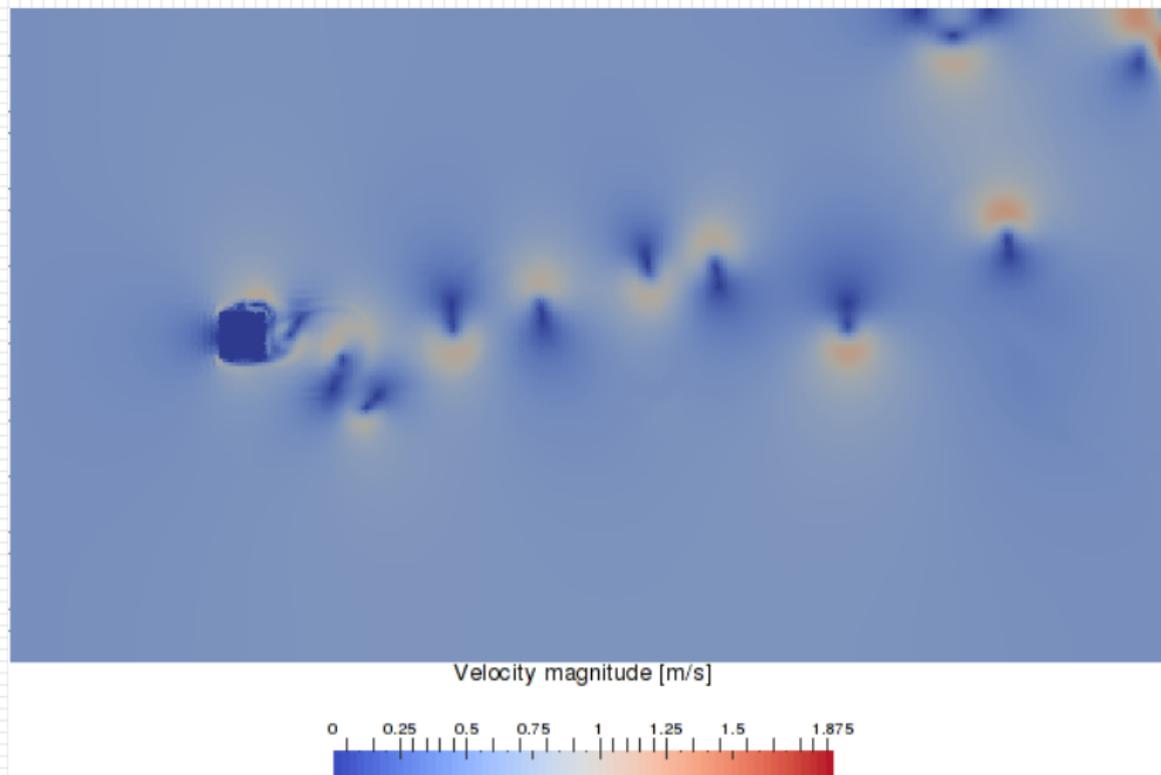
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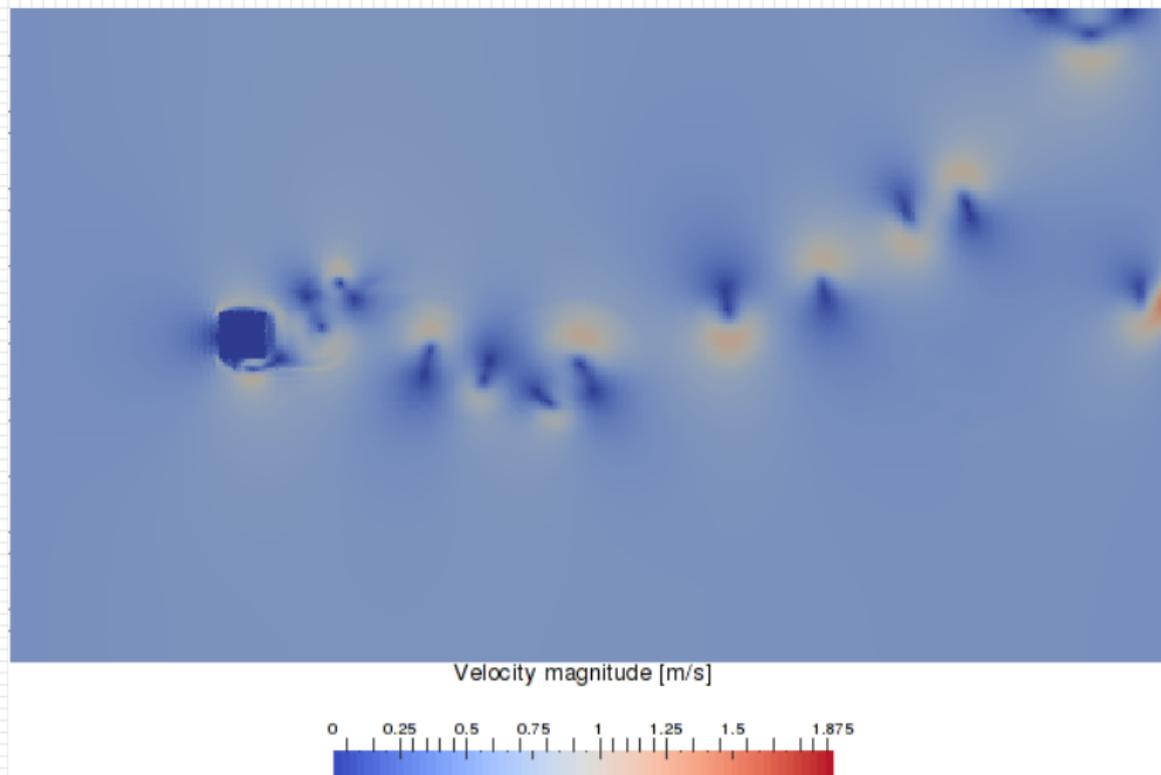
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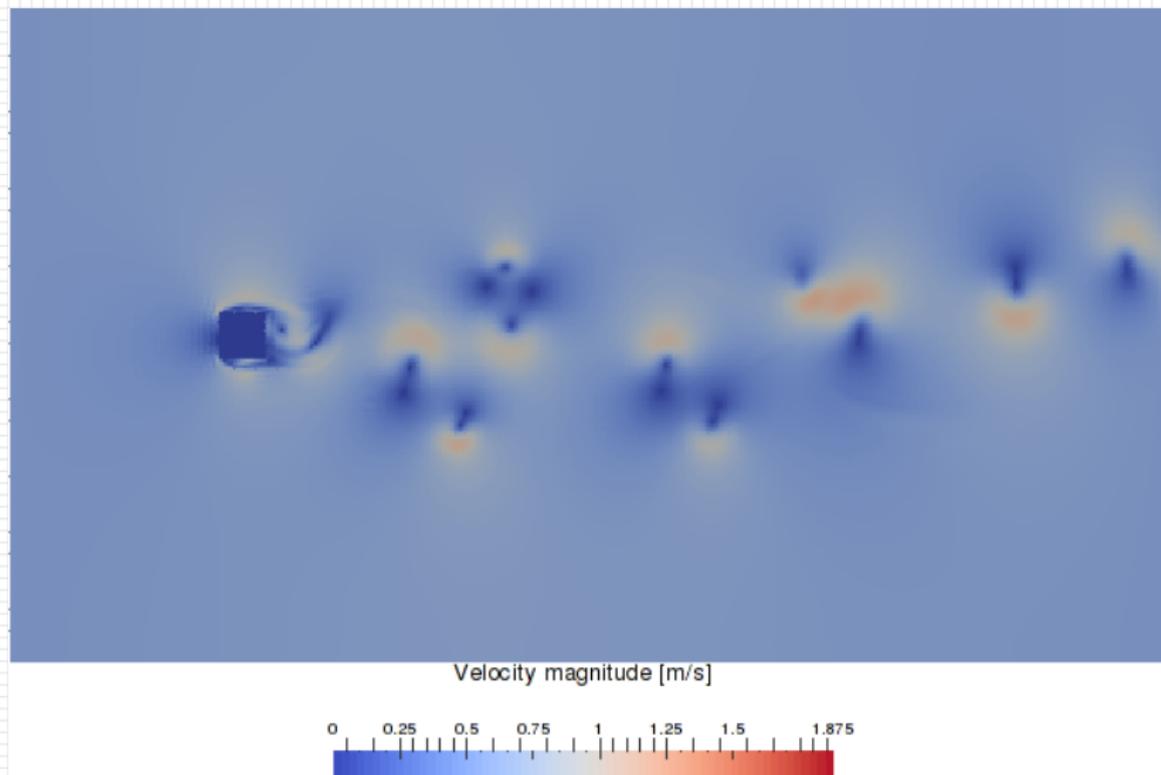
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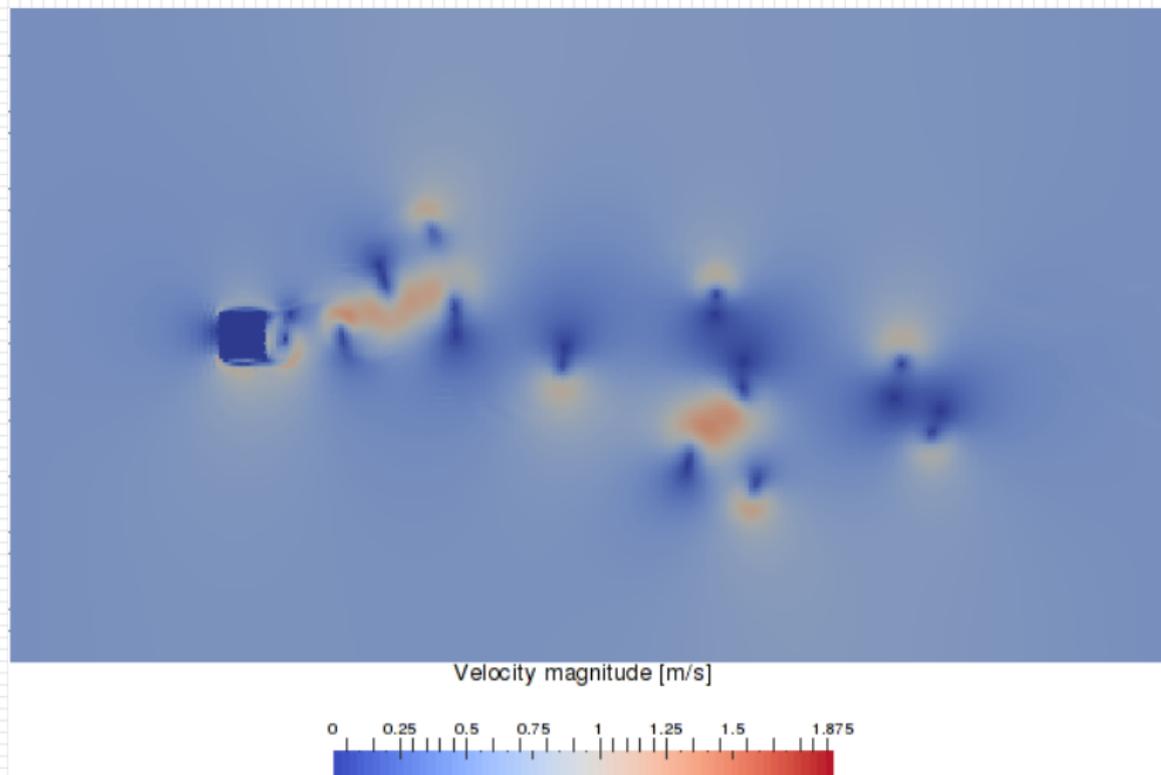
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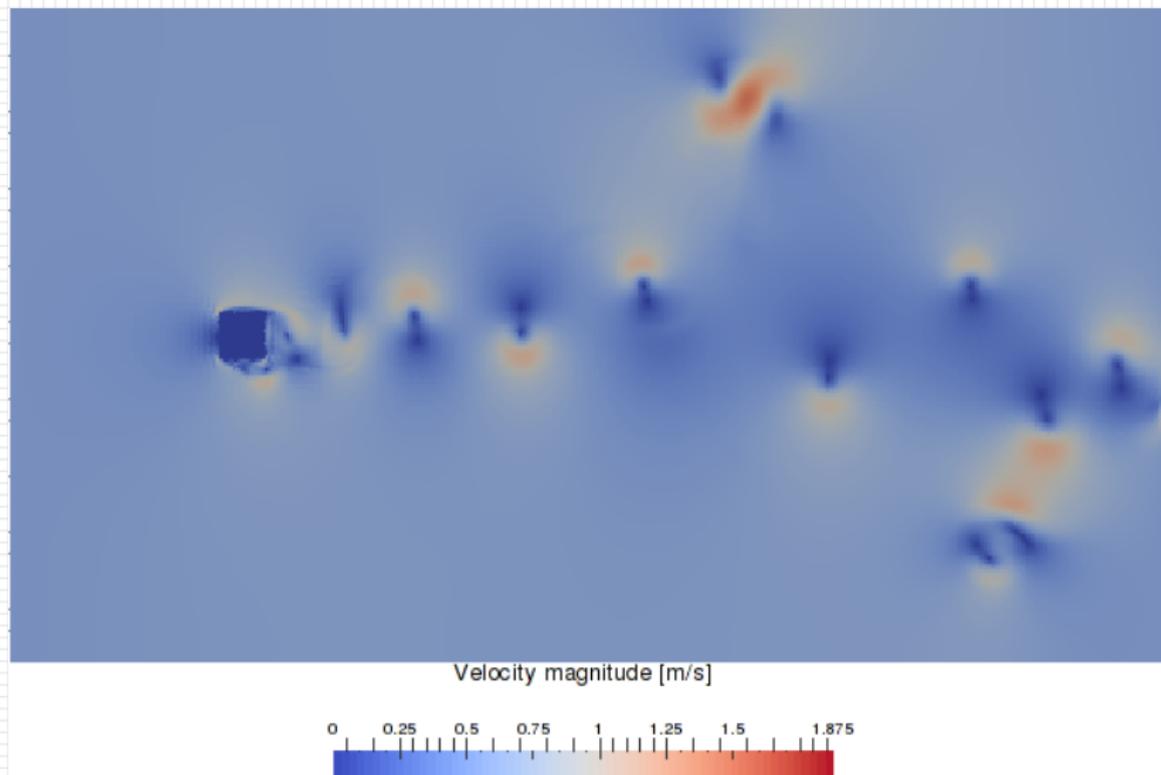
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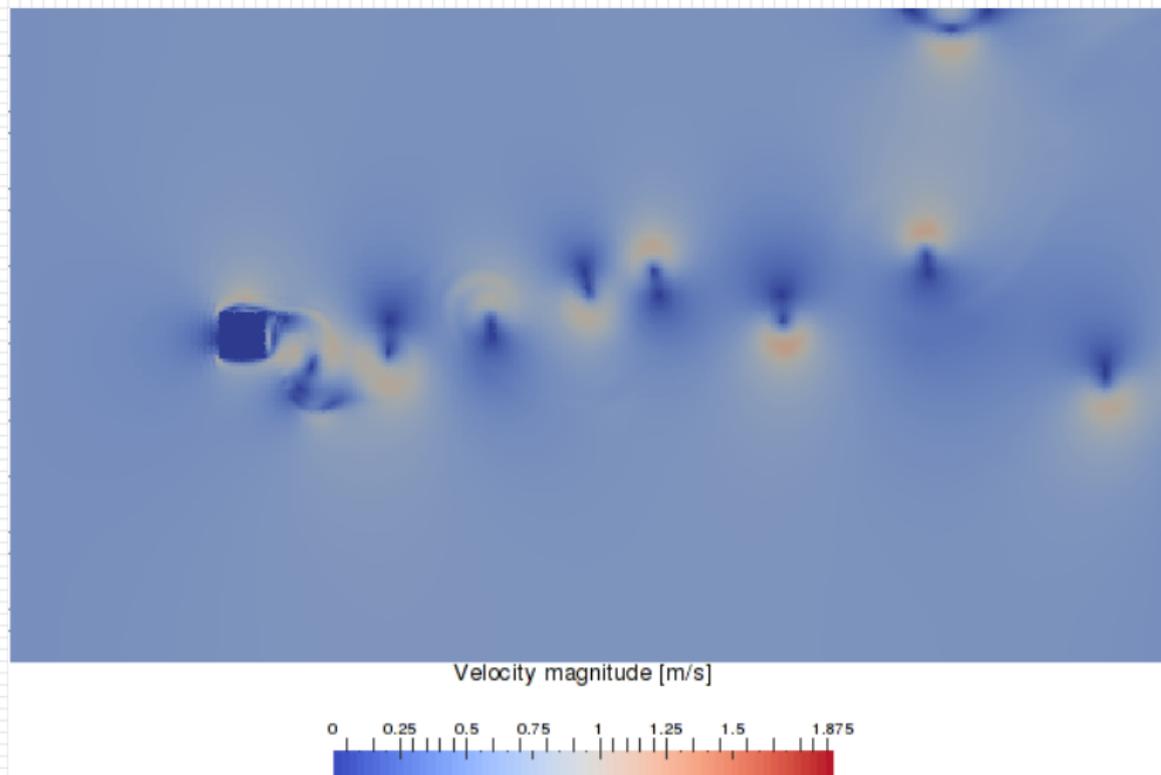
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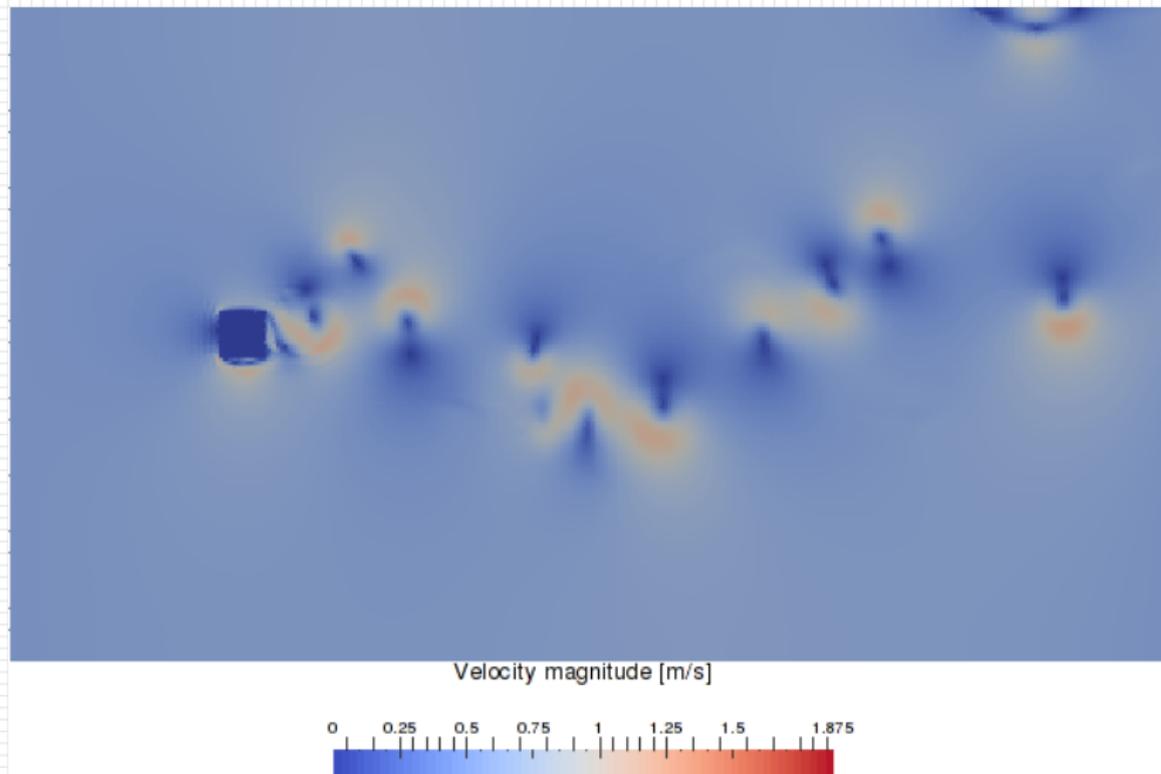
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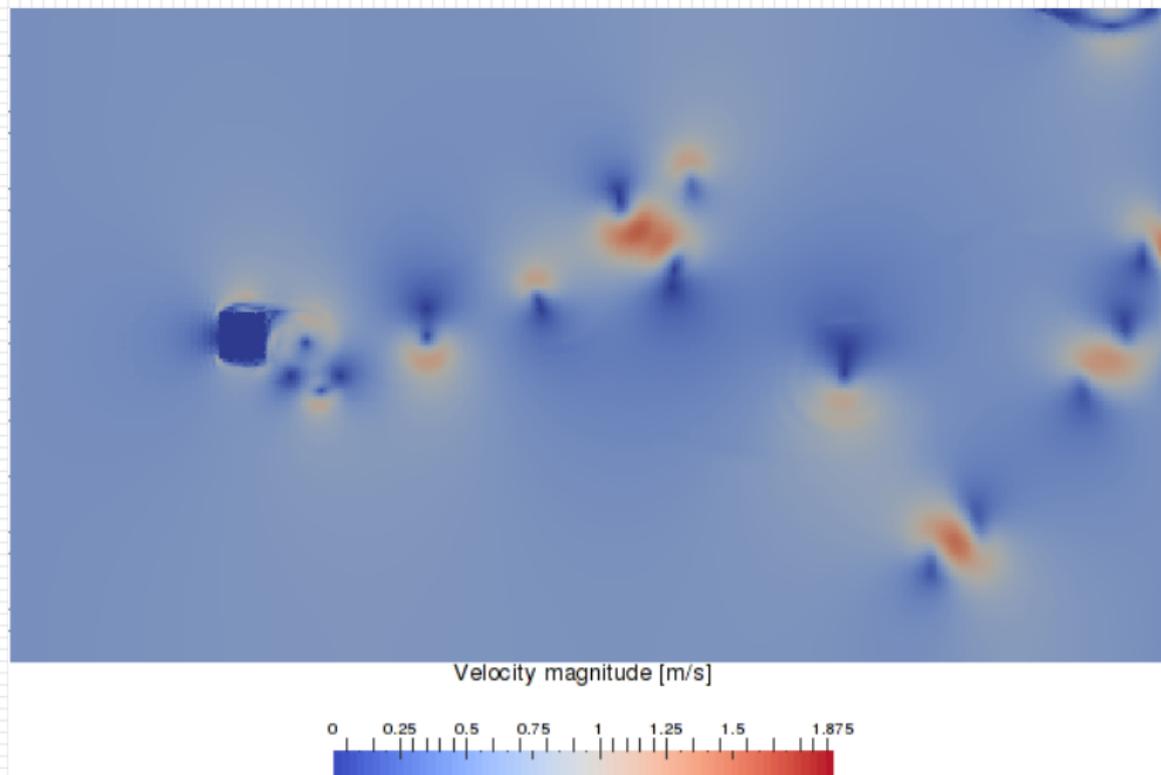
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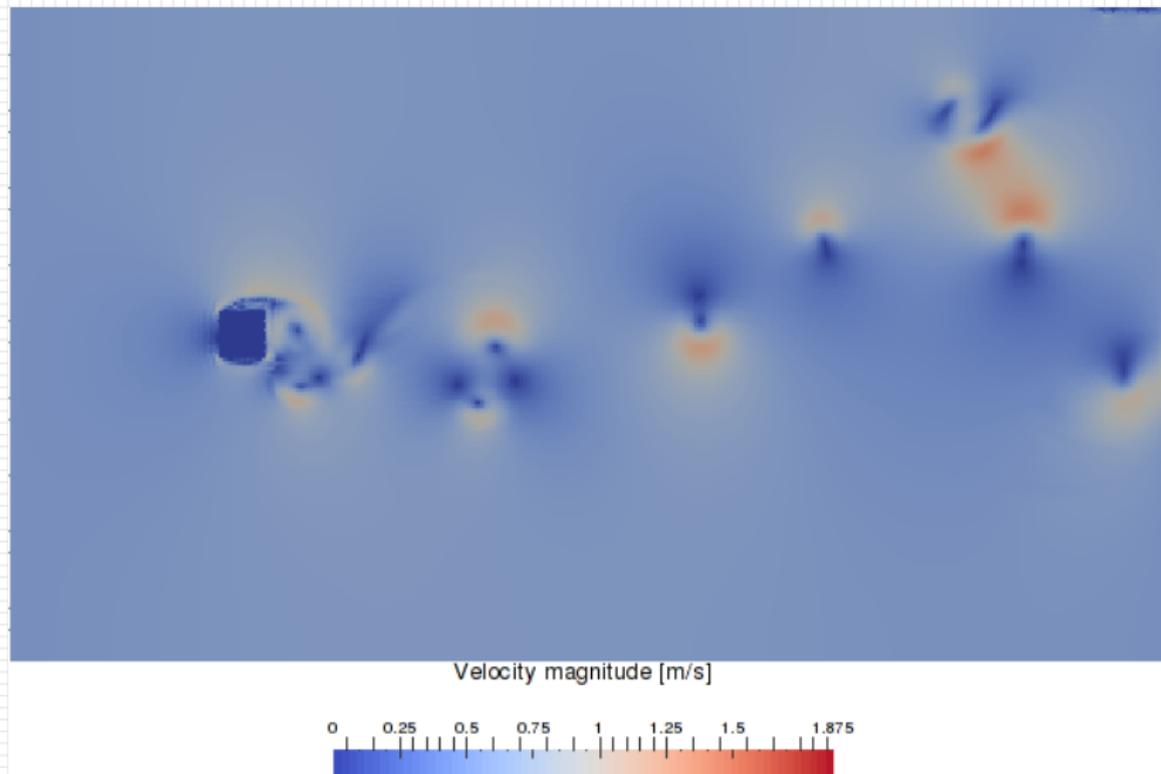
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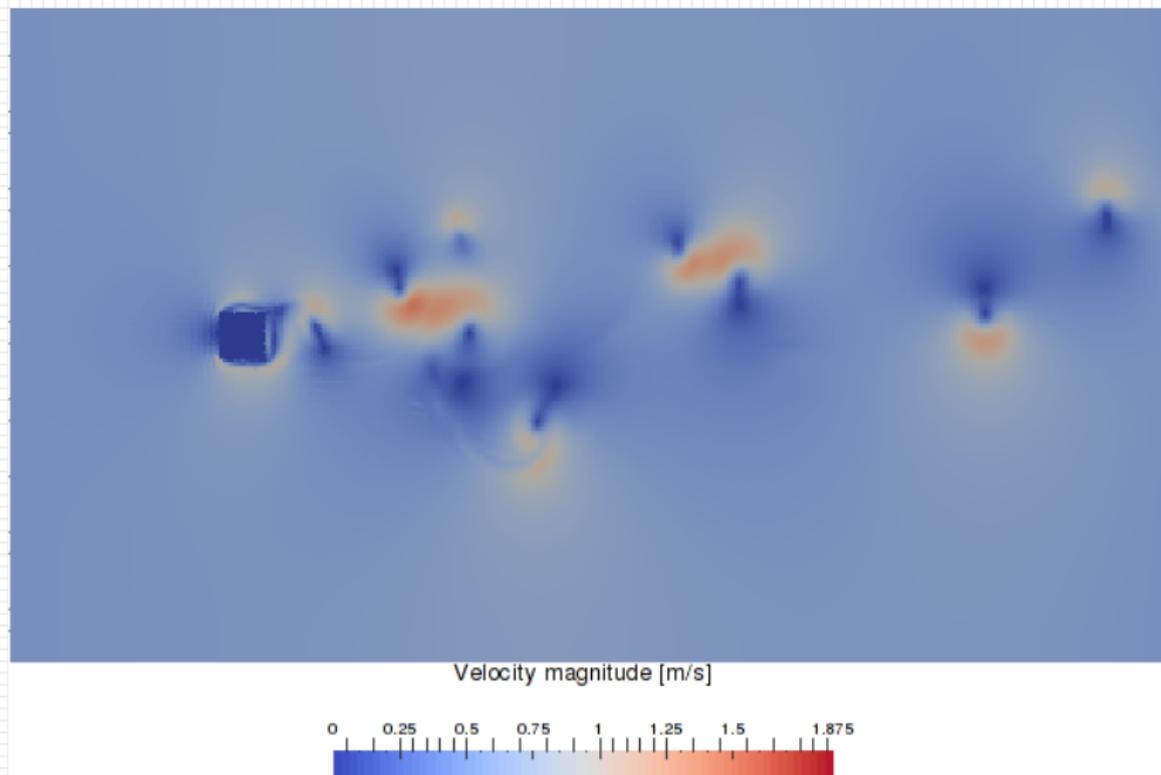
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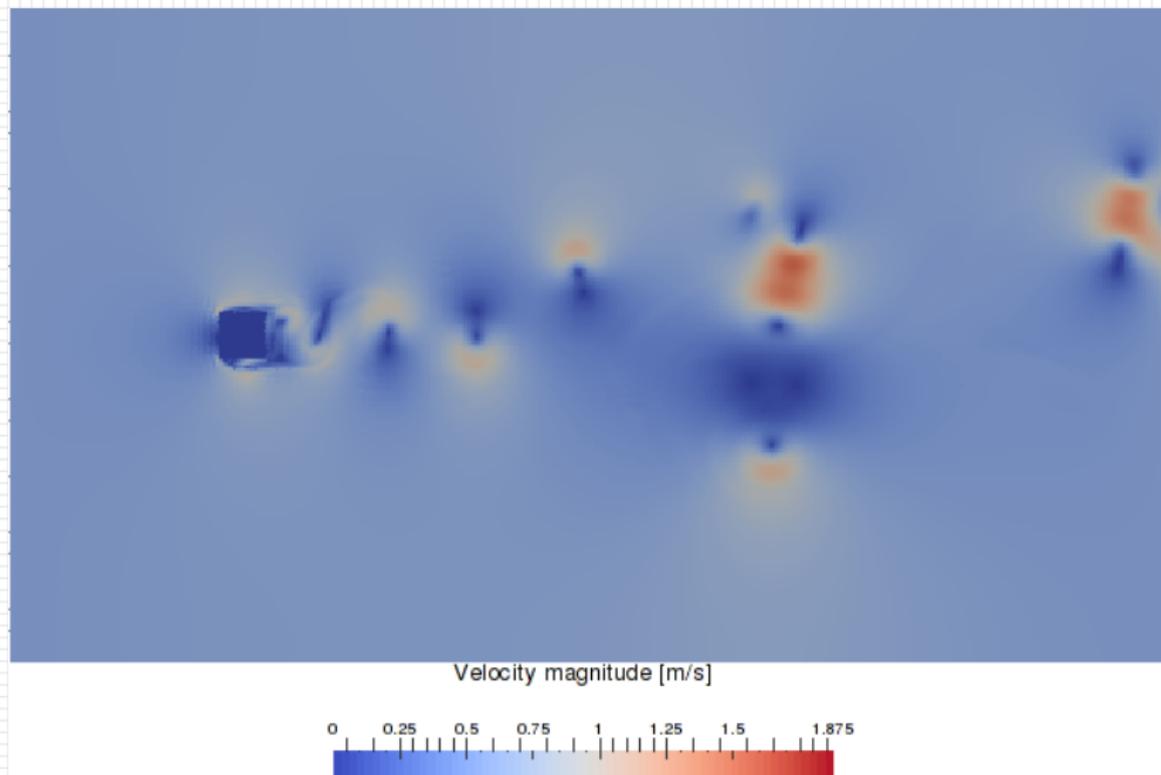
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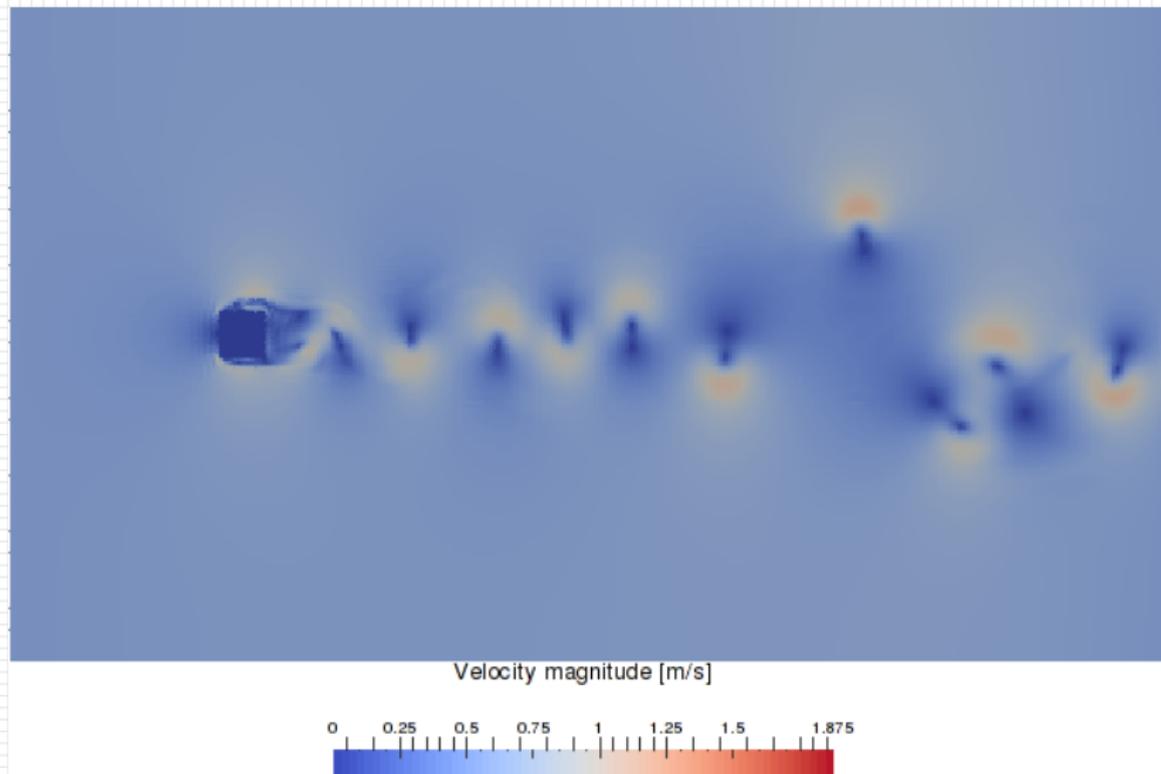
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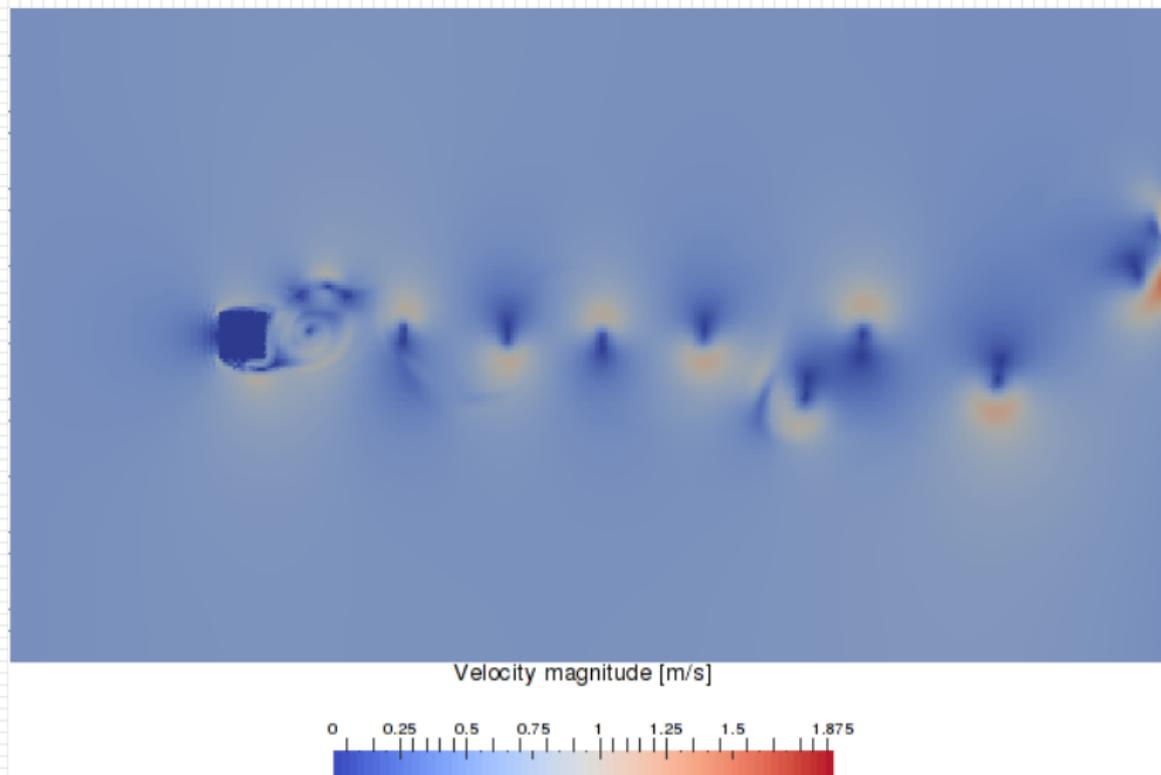
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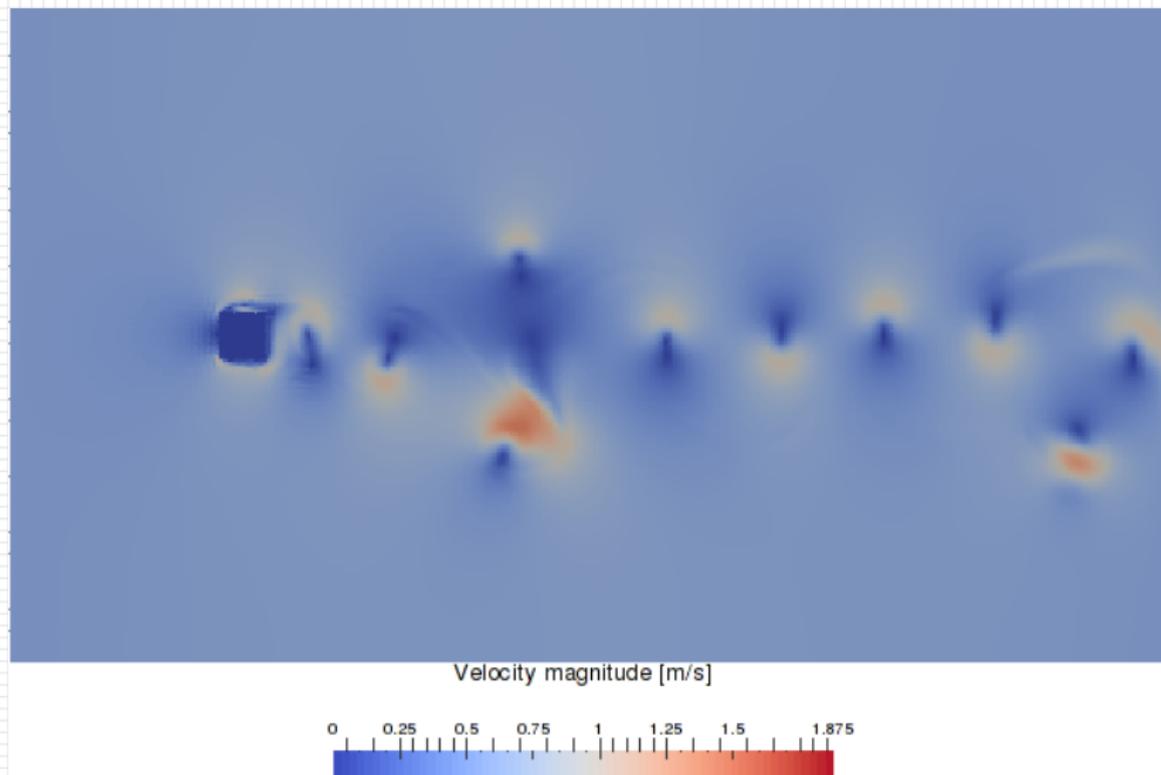
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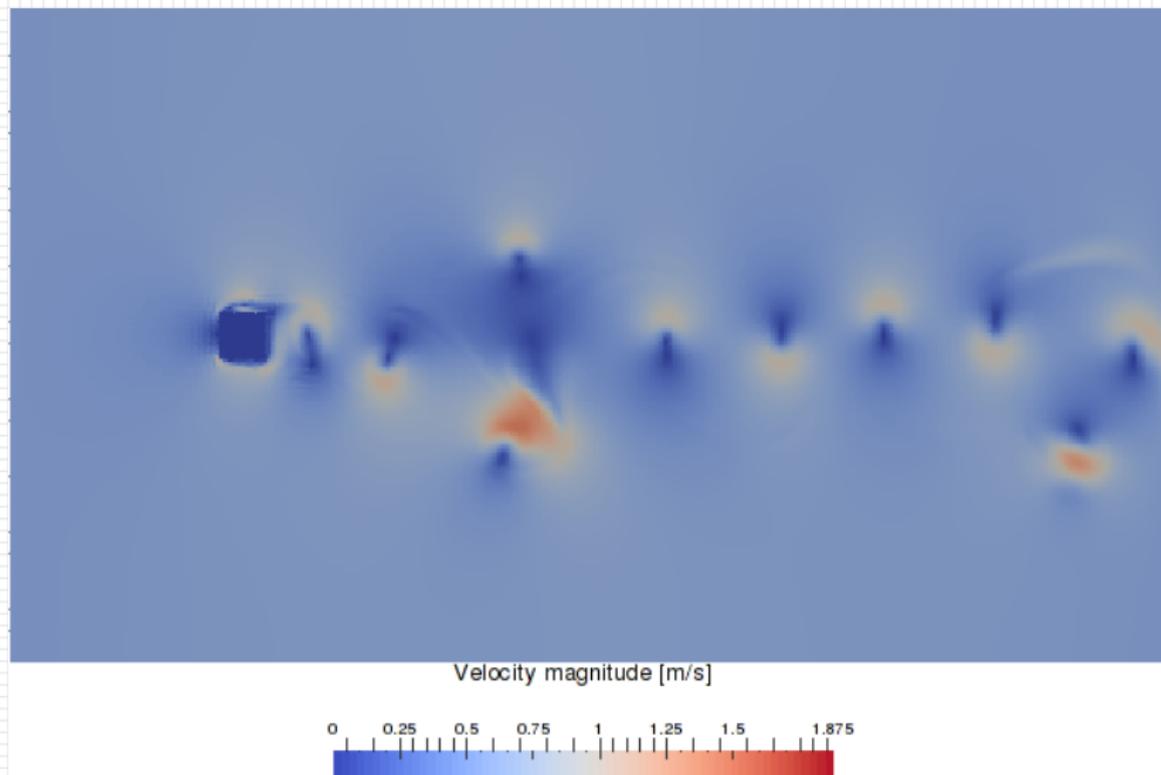
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# libmpdata++ 2.0: immersed boundary teaser



# libmpdata++ 2.0: immersed boundary teaser



# Plan of the talk

- 1 what's libmpdata++
- 2 libmpdata++: a hello-world program
- 3 libmpdata++ 1.0: summary of features
- 4 libmpdata++ 2.0: new features under development
- 5 closing remarks

# Plan of the talk

- 1 what's libmpdata++
- 2 libmpdata++: a hello-world program
- 3 libmpdata++ 1.0: summary of features
- 4 libmpdata++ 2.0: new features under development
- 5 closing remarks**

# libmpdata++: some design choices

## legal

- MIT license
- <https://github.com/mtrojanowski/libmpdata++>

## library components

- `libmpdata++`
- `libmpdata++-api`
- `libmpdata++-api-headers`
- `libmpdata++-api-headers-headers`
- `libmpdata++-api-headers-headers-headers`
- `libmpdata++-api-headers-headers-headers-headers`

## architectural components

- `libmpdata++-api-headers-headers-headers-headers-headers`
- `libmpdata++-api-headers-headers-headers-headers-headers-headers`
- `libmpdata++-api-headers-headers-headers-headers-headers-headers-headers`

## dependencies

- `libmpdata++`
- `libmpdata++-api`
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- `libmpdata++-api-headers-headers-headers`
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## API

- header-only library
- header-based component headers
- header-based component headers headers
- header-based component headers headers headers

# libmpdata++: some design choices

## legal

- license: GPL
- repo: [github.com/igfuw/](https://github.com/igfuw/)

## library components

- solvers/algorithms:
  - Cvxopt
  - Ipopt
- boundary conditions:
  - Dirichlet
  - Neumann
  - Robin
- output handlers:
  - HDF5/ADAM (MPI-IO)
  - graphs
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
- distributed-mem concurr.:
  - MPI

## dependencies

- C++11
- Boost
- Eigen
- GMP
- Intel MKL
- MPI
- HDF5

## API

- header-only library
- template-based component mixing
- interfaces over component boundaries
- user exposed to C++ API

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- solvers/algorithms:
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- output handlers:
  - HDF5/ADAM/MPFI/IO
  - graphs
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
- distributed-mem concurr.:
  - MPI

## dependencies

- C++11
- Boost
- Eigen
- CMake/CXZ
- MPI
- HDF5

## API

- header-only library
- template-based component interfaces
- interfaces based on constant expressions
- user exposed to C++11 API

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## library components

- solvers/algorithms:
  - Cvxopt
  - IPOPT
- boundary conditions:
  - Dirichlet
  - Neumann
- output handlers:
  - VTK5/VTK4 (MPI-IO)
  - gnuplot
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
- distributed-mem concurr.:
  - MPI

## dependencies

- C++11
- Boost
- Eigen
- CMake/CXZ
- MPI
- VTK5

## API

- header-only library
- template-based component interfaces
- interfaces based on component abstractions
- user exposed to C++-11 API



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## library components

- solvers/algorithms:
  - ...
- boundary conditions:
  - ...
- output handlers:
  - HDF5/XDMF (MP-I/O)
  - gnuplot
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
- distributed-mem concurr.:
  - MPI

## dependencies

- Eigen3
- Boost
- MPI
- MPIIO
- OpenMP
- gnuplot
- HDF5

## API

- header-only library
- template-based component interfaces
- interfaces to other component libraries
- user exposed to MPI++ API

# libmpdata++: some design choices

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- solvers/algorithms:
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- boundary conditions:
  - ...
- output handlers:
  - HDF5/XDMF (MP-I/O)
  - gnuplot
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
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## dependencies

- Eigen
- Boost
- MPI
- MPIIO
- OpenMP
- gnuplot
- MPI
- HDF5

## API

- header-only library
- template-based component interfaces
- inheritance-based component structure
- user exposed to full C++ API

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  - Boost.Thread
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## dependencies

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- Boost
- MPI
- MPIIO
- OpenMP
- gnuplot
- HDF5

## API

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- template-based component interfaces
- inheritance-based component organization
- user exposed to C++ API

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- repo: [github.com/igfuw/](https://github.com/igfuw/)

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  - ...
- output handlers:
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  - gnuplot
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
- distributed-mem concurr.:
  - MPI

## dependencies

- Eigen
- Boost
- Boost.Fiber
- Boost.Thread
- MPI
- XDMF

## API

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- templated-based component interfaces
- inheritance-based component abstraction
- user-exposed to HLL++ API

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## library components

- solvers/algorithms:
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- boundary conditions:
  - ...
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## dependencies

- Eigen
- Boost
- MPI
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## API

- header-only library
- templated-based component interfaces
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- distributed-mem concurr.:
  - MPI

## dependencies

```
libmpdata++ depends on  
libmpdata++ requires  
libmpdata++ recommends  
libmpdata++ suggests  
libmpdata++ provides
```

## API

- header-only library
- templated-based component interfaces
- interfaces-based component separation
- user-exposed to C++ API

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## library components

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  - ...
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  - gnuplot
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
- distributed-mem concurr.:
  - MPI

## dependencies

```
libmpdata++ depends on:
- Boost
- Eigen
- GMP
- HDF5
- MPI
- OpenMP
- gnuplot
- libxdmf
- libxdmf2
- libxdmf3
- libxdmf4
- libxdmf5
- libxdmf6
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- libxdmf92
- libxdmf93
- libxdmf94
- libxdmf95
- libxdmf96
- libxdmf97
- libxdmf98
- libxdmf99
- libxdmf100
```

## API

```
libmpdata++ is a:
- header-only library
- multiplatform, compiled, multi-arch
- independent from component dependencies
- user-exposed to MPI++ API
```















# libmpdata++: some design choices

## legal

- license: GPL
- repo: [github.com/igfuw/](https://github.com/igfuw/)

## library components

- solvers/algorithms:
  - ...
- boundary conditions:
  - ...
- output handlers:
  - HDF5/XDMF (MPI-IO)
  - gnuplot
- shared-mem concurrency:
  - OpenMP
  - Boost.Thread
  - C++11 threads
- distributed-mem concurr.:
  - MPI

## dependencies

- C++11
- Blitz++
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