

LPT and DA challenges anytime: an open web portal for continuous development and benchmarking of algorithms

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ABSTRACT

We introduce a web portal (<https://www.onera.fr/flow-benchmarks>) dedicated to automatic evaluation and benchmarking of Lagrangian Particle Tracking (LPT) and related Data Assimilation (DA) algorithms. Following a first prototype launched in 2022, with a single dataset of two-pulse LPT (i.e. Particle Tracking Velocimetry - PTV), the portal has been substantially completed, and now hosts all test cases of the First and Second LPT and DA Challenges. This constitutes a total of twelve different datasets, including an experimental one, addressing a large range of physical situations and parameters of influence. While datasets are free to download to everyone, the portal offers the possibility to a registered user to upload their result and automatically receive its evaluation in a fully private way. The user can then freely choose between publishing the evaluated result, or discarding it. The portal is thus intended as a development tool for the community, to help algorithmic development, as well as a way of providing easier access to established benchmarks, which otherwise are only accessible when challenges are organized. It can also be used to organize challenges themselves, as has been the case for the second LPT and DA challenges, whose results are presented in companion communications (Sciacchitano et al. 2026, Schröder et al. 2026). The objective of the present communication is to provide all necessary information to researchers interested by the portal, by presenting the datasets and describing in a practical way how to get an evaluation and possibly publish it. A second objective is to encourage the community to propose new datasets to be integrated to the portal, in order to keep it up-to-date with research progress.

1. Introduction

In the last decade, volumetric velocimetry approaches based on tracking the motion of individual particles have received considerable interest and achieved substantial progress, owing to their high accuracy in the measurement of 3D flows (see, e.g. Schanz et al. 2016). This is both the case of traditional, two-pulse acquisition (mostly referred to as Particle Tracking Velocimetry, PTV) and of time-resolved acquisition of sequences of up to hundred instants (Lagrangian Particle Tracking, LPT). Due to the scattered nature of the obtained result, at the particles positions only, significant

research efforts have also been directed towards the development of related Data Assimilation (DA) techniques, aiming at finally reconstructing full 3D fields of velocity (and possibly other physical quantities, such as pressure) on regular Cartesian grids (see, e.g., Schneiders et al. 2016). Similar to the development of planar or volumetric Particle Image Velocimetry (PIV) algorithms, implementing a new code for LPT or DA data requires evaluating its performance on synthetic data, which allows comparing against a ground truth and computing quantitative error metrics. To understand the behavior and performances of the various approaches available, the PIV community has adopted the tradition of regularly organizing challenges, in which synthetic and experimental datasets were made available. Organization relied on a defined schedule, with a deadline for result submission, and presentation of the results during a conference or a dedicated workshop, followed by a journal publication. Following challenges either on planar PIV (Stanislas et al. 2003, 2005, 2008) or both on planar and on volumetric PIV (Kähler et al. 2016), two challenges on LPT and DA were recently organized in the same spirit (see Leclaire et al. 2021, Sciacchitano et al. 2021a, 2021b for the first challenge, and Sciacchitano et al. 2026 and Schröder et al. 2026, submitted to the conference, for the second one). While such events are successful in triggering intense developments in the participating teams, and fostering scientific discussions during result presentation, their punctual nature in time limits the possible number of participants. Besides, the frequency of their occurrence is dependent on the availability of teams willing to organize them. In order to give a broader access to established datasets and to provide the ability to new teams to benchmark their algorithms, independent of the organization of a challenge, we recently introduced a web portal (Leclaire et al., 2022), which allows to upload a result and get its evaluation in an automated and private manner - with then the possibility to either publish the result on the website, or simply to erase it. One aim is to define a common standard to which newly developed methods should be measured against. This allows both the developers, as well as the readers of the resulting publications, to instantly judge the benefits and drawbacks in comparison to state-of-the-art. Such websites have in fact been introduced in the computer vision community more than a decade ago, and have since become essential development tools. While the version described in Leclaire et al. 2022 corresponded to an initial prototype, with a single dataset, the portal has since then been substantially completed. It has been used to organize the Second LPT and DA challenge (see the companion papers Sciacchitano et al. 2026 and Schröder et al. 2026 submitted to the conference), and presently gathers 12 different datasets, most of them synthetic and one of them experimental, all with the automatic evaluation capability.

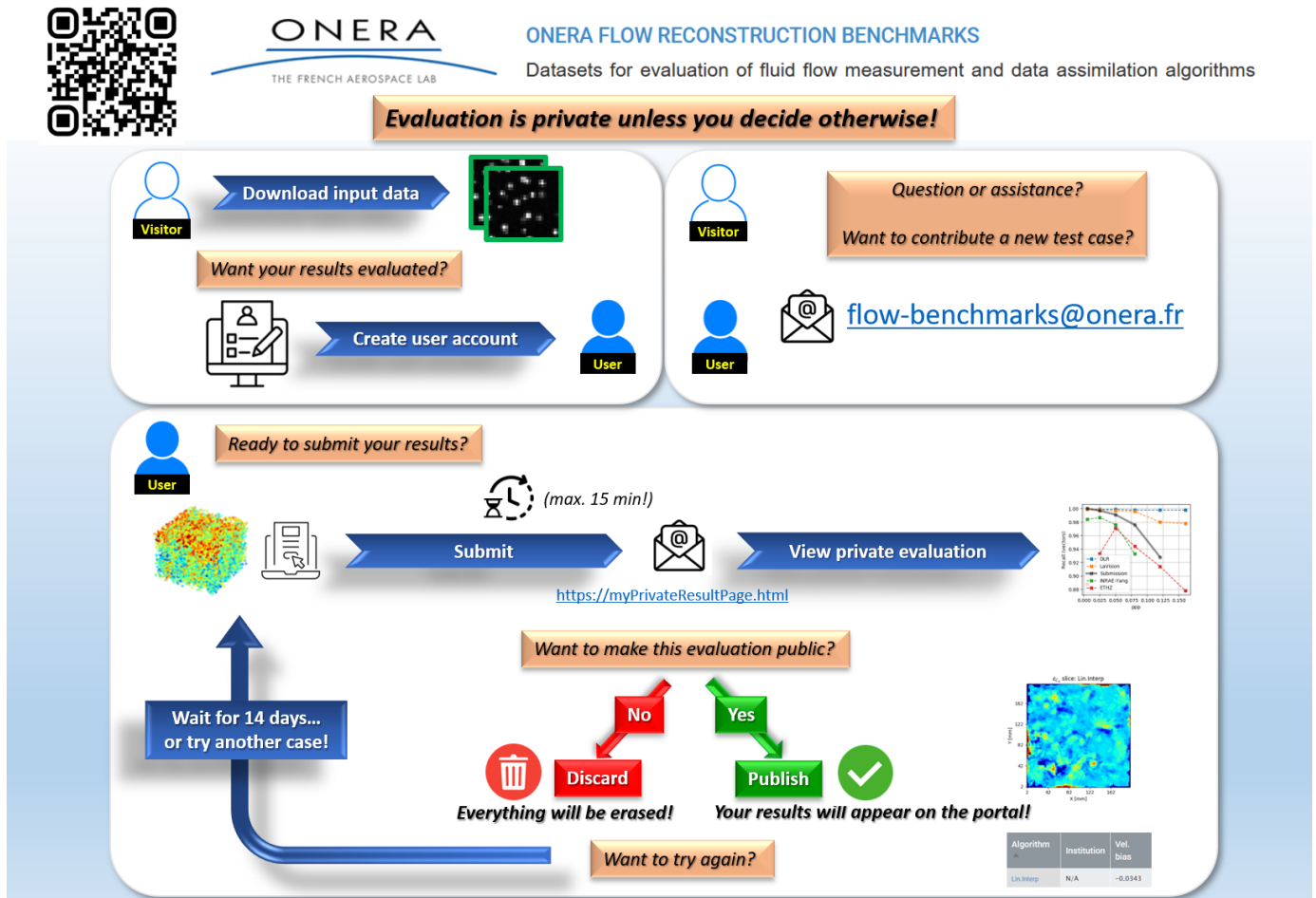


Figure 1 – Portal's working principle

The purpose of the present communication is to describe the available datasets and the principles of use of the portal, in order to encourage as widely as possible its use by the scientific community. The portal's working principle is schematized in Figure 1, where we stress that data can be downloaded freely, and that evaluation, accessible to logged-in users, is private unless they decide to make it public. We also encourage the community to suggest what the next datasets should be. In this article, a general presentation of the webpage structure, followed by a description of the datasets, is exposed in section 2. Remaining sections are then built as a "how-to" practical guide, explaining how to submit a result (section 3), and then either publishing it or erasing it (section 4). Section 4 also outlines what is presented on the dataset pages gathering the published results.

2. Presentation and available datasets

2.1. Website principle and structure

The portal is accessible at the URL address <https://www.onera.fr/flow-benchmarks>, which then redirects towards <https://onera-flow-benchmarks.fr/> (also accessible directly). As shown in

Figure 2, it comprises pages describing the datasets and their published results (as detailed in sections 2 and 4), as well as a page detailing the submission and publication process (see section 3). As seen on the top right part, it includes the possibility of creating an account and then logging in. This functionality is necessary for uploading a result in order to obtain its evaluation, as detailed in section 3. However, it is not for accessing the datasets: visitors to the website can freely download any of them. Data download and result upload links are accessible on each dataset's page.

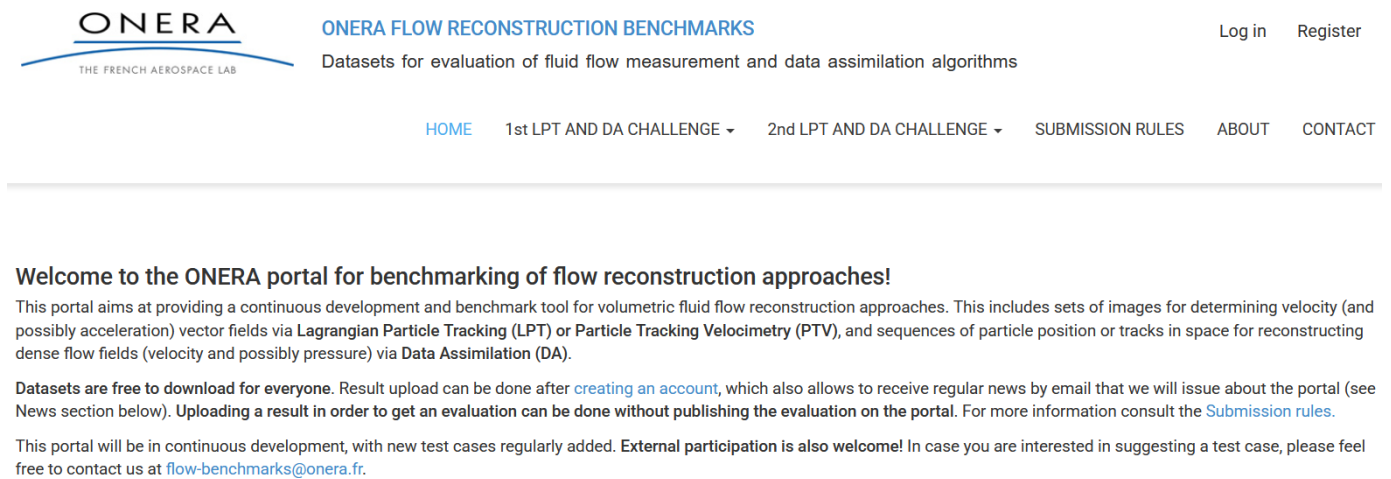


Figure 2 – Homepage screenshot, featuring the different sections

2.2 Available test cases

We here provide only a short description of the datasets, since a full description can be found on the portal itself, as well as in the publications on the first and second LPT and DA challenges (Leclaire et al. 2021, Sciacchitano et al. 2021a, b for the first one, Sciacchitano et al. 2026 and Schröder et al. 2026 for the second one).

The purpose of the LPT datasets is to assess the ability of algorithms to reconstruct volumetric fields of velocity vectors, or even complete trajectories over a sequence of instants, of particles seeding a flow. The input datasets consist of sequences of particle images, together with a file containing a grid of points in the object space and the related 2D projection coordinates on each camera, in order to allow calibration. Depending on the test case, either two-pulse (TP), four-pulse (FP) and/or time-resolved (TR) datasets can be provided. For the TP cases, the requested result consists of positions of matched particles at the two instants, and for the other cases, of both raw and fitted positions of the found particles, together with their velocity and acceleration.

The DA datasets consist of individual files containing particle positions at each instant of a sequence. Each particle has an ID, allowing to reconstruct the trajectories from the files.

Participants should provide, on a prescribed 3D Cartesian grid, the components of the velocity vector, of the velocity gradient tensor, and of static pressure. Depending on the test case, other physical quantities, such as density or temperature, can be requested.

2.2.1. First LPT and DA Challenge

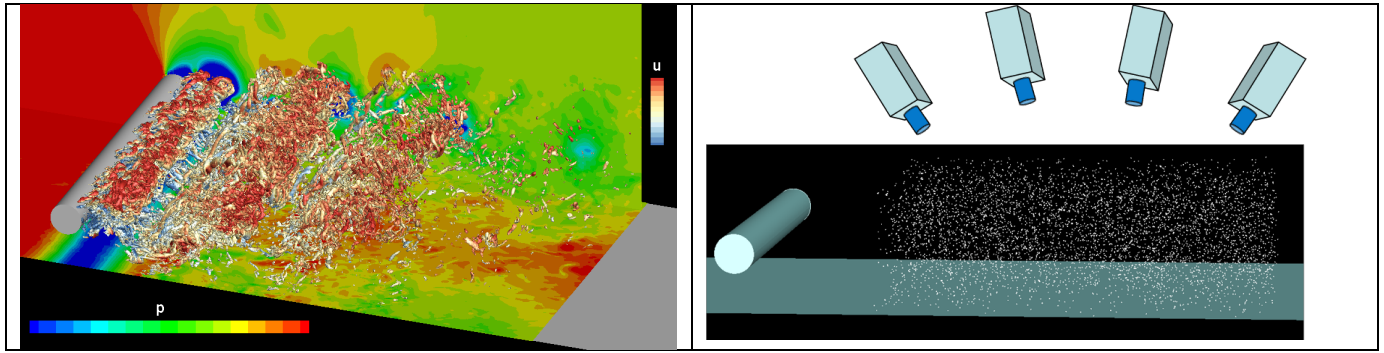


Figure 3 – First LPT and DA Challenge datasets: snapshot of the flow (left), featuring pressure at the bottom and side walls and Q-criterion colored by streamwise velocity; principle sketch of the virtual domain seeded with particles and observed by a multi-camera setup (right).

The First LPT and DA challenges (Leclaire et al. 2021, Sciacchitano et al. 2021a, b) considered synthetic datasets designed from the LES of the wake flow of a cylinder in ground effect. As depicted in Figure 3, the zone of interest has been chosen a few diameters downstream of the cylinder, in contact to the lower wall and with a thickness equal to three cylinder diameters. The LPT test case gathers two datasets, one for TP and one for TR acquisition, and explores the influence of increasing seeding density. The virtual multi-camera setup corresponds to a situation where all cameras view the whole measurement domain. The DA dataset also explores the influence of seeding density.

2.2.2. Second LPT and DA Challenge

2.2.2.1. LPT Cases

As described in Sciacchitano et al. (2026), three different LPT cases are available, each having a specific objective:

- Case 1, provided by the Delft University of Technology, aims at evaluating the impact of the time separation dt between subsequent instants in a time-resolved acquisition. It has been designed using a canonical situation of turbulent flow in a square channel, investigated by direct numerical simulation (DNS) by Pirozzoli et al. (2018). This simulation has also been used for Case 1 of the DA challenge (see section 2.2.2.2 and Figure 5).

- Case 2, provided by ONERA, aims at exploring the influence of increasing seeding density, of Mie scattering and of geometrical effects linked to the multi-camera setup (situations where the volume of interest is not fully viewed by each camera). It is based on the LES of two cylindrical pillars in a turbulent boundary layer.
- Case 3, provided by DLR, originates from an experiment that explores the flow in a Rayleigh-Bénard convection cell (Bosbach et al. 2021, Godbersen et al. 2021, Weiss et al. 2024). As depicted in Figure 4, the cylindrical cell (of 1.1 m diameter and height) is seeded with helium-filled soap bubbles, illuminated with an LED array, and viewed by a six-camera setup. Images of only the four central cameras are provided, while the whole set of images is used to form the ground truth. In addition to providing a true experimental signal-to-noise ratio, the test case explores the influence of seeding density for TP and TR acquisition.

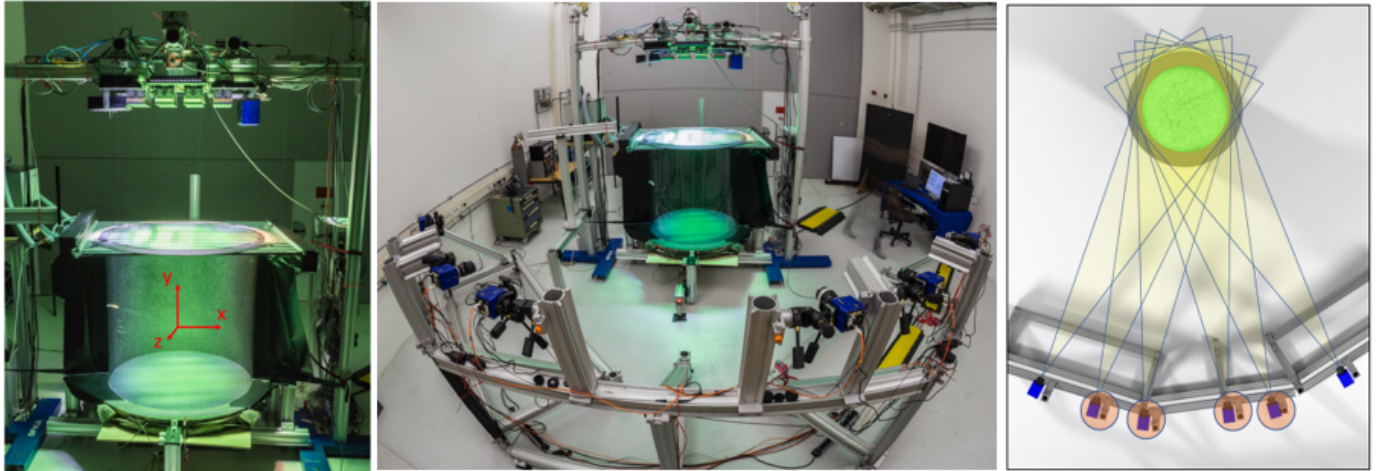


Figure 4 – Experimental setup of Case 3 of the second LPT Challenge. Rayleigh-Bénard convection in a cylindrical cell is studied by seeding the flow with helium-filled soap bubbles, illuminating them with an LED array and imaging them with a six-camera setup. In the dataset, images of the four central cameras are provided, while the ground truth is obtained by LPT processing of all six cameras.

2.2.2.2. DA Cases

In the three DA cases (Schröder et al. 2026), the following objectives are pursued:

- In Case 1, provided by the Delft University of Technology: assessing the ability of algorithms to reconstruct the velocity and pressure of a canonical turbulent flow (turbulent flow in a square duct, DNS simulations of Pirozzoli et al., also used in LPT Case 1, see Figure 5), at various seeding densities, in the case of TP, FP and TR acquisitions

- In Case 2 (yet to be included in the portal), provided by the Pennsylvania State University: exploring the influence of inertial tracers compared to ideal ones, as well as of seeding density. The dataset is built from the DNS of a high Mach number turbulent boundary layer replicating conditions in the National Aerothermochemistry Laboratory (NAL) at Texas A&M University (Huang et al., 2022).
- In Case 3, provided by the DLR: assessing the accuracy of DA algorithms in reconstructing velocity, pressure and optionally temperature from TR sequences in a Rayleigh-Bénard convection flow. The case has been designed using DNS provided gratefully by Mohammad Shah Emran and Olga Shishkina at MPI-DS Göttingen, and explores the influence of seeding density.

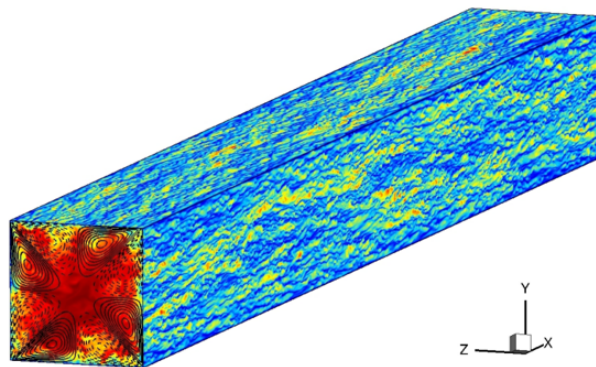


Figure 5 – Snapshot of the square duct flow DNS simulations from Pirozzoli et al. (2018)

3. How to get an evaluation

We now describe the way users can get an evaluation of a result with the portal. As a first important notice, we recall that submitting a result does not imply publishing it on the portal: this choice is left to the user, who can either decide to indeed publish it, or to erase both the uploaded result and its evaluation (see section 3.5.1).

3.1. Account creation

As mentioned above, submitting a result is accessible to logged-in users. Creating an account is accessible with the "Register" link on top right of the home page (see Figure 2). In the related form (see Figure 6), we request the following information:

- Username
- Identity (first and family name)
- Email, which should be preferentially a professional / institutional email
- Professional information: affiliated institution, and possibly research team

Part of this information is used to identify results which have been published (see section 3.2 for more details).

Email address *

A valid email address. All emails from the system will be sent to this address. The email address is not made public and will only be used if you wish to receive a new password or wish to receive certain news or notifications by email.

Username *

Several special characters are allowed, including space, period (.), hyphen (-), apostrophe ('), underscore (_), and the @ sign.

First name *

Your first name, e.g. "John"

Family name *

Your family name, e.g. "Doe"

Institution *

e.g. "ONERA" (no comma)

Department/Team

e.g. "Department of Fluid Mechanics / LPT and DA team" (no commas)

Figure 6 – User account creation form

3.2. Result upload

3.2.1. Upload form and formatting rules

Each of the dataset pages contains, on the left part, buttons allowing to download the data, and to upload a result. When clicking on the latter, a registered user gets access to a form allowing to provide information about the result. As shown in Figure 7, at this step we request the following information:

- List of authors
- Corresponding list of institutions
- Corresponding list of teams
- The short name or acronym of the algorithm used to generate the result
- The full name of the algorithm
- If available, a link to a publication describing the algorithm

At form opening, the first three fields are pre-filled with the user account information. They can be freely modified, in particular if the result was obtained by a team and not by the user alone. In case the result is finally published, the information above will be accessible in the corresponding webpage, via the result tables (see section 4.2.1).

As mentioned in the explanatory help in Figure 7, the result should be provided in the form of a single zip archive directly containing all requested files of the dataset (with no intermediate folder). While no convention holds for naming this zip file, each dataset has rules pertaining to: the naming of each result file, their number (to guarantee that all mandatory points of the dataset have been provided), as well as to formatting of the data inside the files. Data formatting rules have been systematized as much as possible, separately for the LPT cases (ASCII format) and the DA cases (HDF5 format). Each dataset page recalls all necessary instructions.

Data File *

[Parcourir...](#) Aucun fichier sélectionné.

Zip extension. Max size 500 MB

Author(s) *

Benjamin Leclaire

Author names. Use ";" as a separator, e.g.: First Author; Second Author; Third Author. Max 255 char.

Institution(s) *

ONERA

Institution(s) of the author(s). Use ";" as a separator to enter several of them (e.g. Institution1; Institution2). Max 50 chars.

Department/Team

DAAA/MAPE

Département or team name (e.g. LPT and DA team). Max 50 chars.

Algorithm short name or acronym *

Between 2 and 20 chars - No space - only [A-Z0-9a-z]_@+## chars

Algorithm full name *

Between 3 and 100 chars.

Reference (optional)

URL of publication or webpage describing your algorithm - one link only

☐ I accept the submission rules

Please read and accept the [submission rules](#)

Submit

Figure 7 – Result upload form

3.2.2. Submission rules

While the upload feature of the portal is free of use to any registered user, we designed a set of rules to help maintain the soundness and interest of the published benchmarks. The following three rules are enforced in an automated way, meaning that if they are not respected, either the upload form is not accessible, or the user will receive an error message at submission.

1. In order to avoid excessive overfitting of methods to the computed performances, the number of submissions per user and per dataset is limited to 1 every 14 days. In case this

duration is not met yet, the upload form is not accessible, and the user is informed of the remaining waiting duration.

2. As long as a user has not decided between accepting or discarding publication of their results on a dataset, no further submission is possible for the dataset, even after the 14 days waiting time. However, the user still keeps the possibility to upload results to other datasets.
3. To avoid conflicts in the case of publication, it is not possible to submit a result with the same algorithm short name as an already published result for the considered dataset. An exception to that is if both the algorithm short name and the institution list coincide with the published result: this situation is intended to allow a team to overwrite their published results with updated ones, if desired (see section 4.1.1).

3.3. Evaluation provided

After the submission form has been sent, the automatic evaluation is run on the dataset, at the latest 15 minutes after submission. If a formatting error is detected, the user receives an email providing minimal information to help fixing it. Should problems persist, contact address flow-benchmarks@onera.fr can be used to get assistance.

If no formatting error is detected, the evaluation is launched; once terminated, the user receives an email with a link to a private page summarizing it. As shown in the example in Figure 8, it contains several sets of curves, showing the same performance metrics as in the public pages, as well as, possibly, more detailed diagnostics. In the example of Figure 8, relative to the 1st LPT challenge TP dataset, a first series of plots compares the submission of the user with a selection of already published results (see Leclaire et al. 2022 for how this selection is performed). This type of comparison is systematically presented, whatever the dataset (LPT or DA). For this LPT TP dataset, the remaining two groups of figures then show histograms of positional error and subzones of the volume featuring true and reconstructed particles, for all seeding densities.

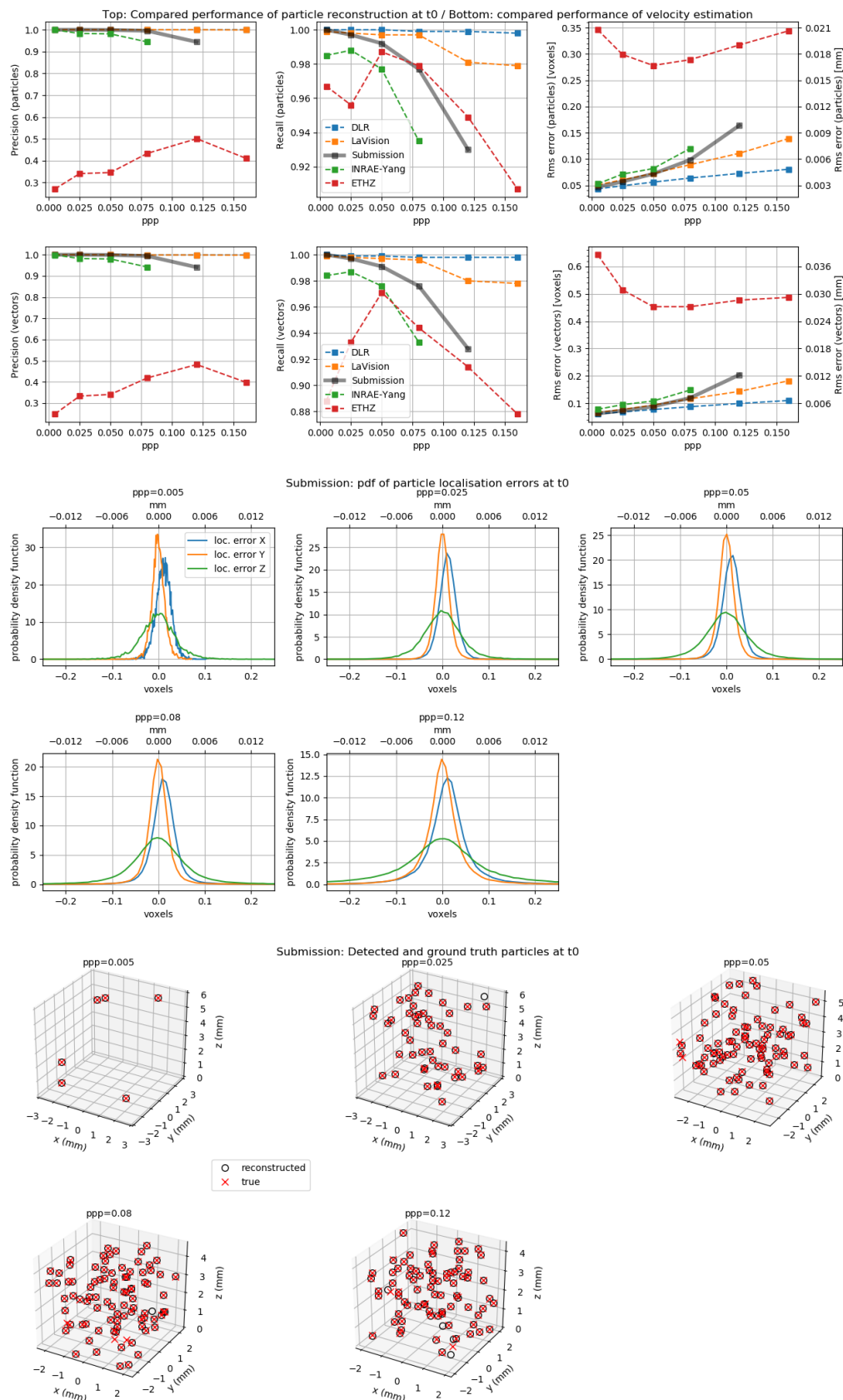


Figure 8 – Figures contained in the evaluation of an LPT TP dataset, here of the 1st LPT Challenge. The exemplary upload is denoted by “Submission” in the first series of plots.

4. How to publish an evaluated result (or not)

4.1. Publishing or discarding: choosing with the evaluation form

The private webpage presenting the evaluation to the user is in fact a form for deciding what should be done next, either publishing the result on the portal, or erasing it. This is simply accessible by radio button choices at the bottom of the form ("Publish" and "Discard"). We next describe where each of these choices precisely leads to.

4.1.1. Publishing

If the "Publish" option is selected, then the evaluation will be integrated in the results presented in the dataset page. The updated pages are then visible on the portal shortly after publishing (maximum 1hr after). There are no automated rules pertaining for publication itself, other than the rules already in effect at submission phase. In particular, as mentioned above, if a team re-submits and re-publishes an algorithm that they have already published, then the results will be replaced.

While publishing their result, we also ask the users to respect the following two rules:

- A user may publish the results of up to 5 different algorithms on a given dataset
- In case several publications on the same dataset have been done with too few differences in the algorithm name (i.e. differences only in parameter setting), only one of them will be kept.

In case deviations from these rules should be observed, the users will be contacted individually in order to apply the necessary corrections.

4.1.2. Discarding

If the user selects the "Discard" option on the evaluation form, then all information regarding the submission is erased from the server, i.e. both the uploaded files and those corresponding to the evaluation. The only remaining information stored, which is only accessible to the portal developers, is the date of the submission, as it is necessary to ensure that a new submission will be possible only 14 days after (see section 3.2.2).

Note that if, by 30 days after evaluation, the user has not chosen between discarding or publishing their result, then they will be automatically discarded, with the same consequences.

4.2. Published information: dataset result pages

4.2.1. Common structure

Each result page follows a three-part structure, with first the presentation of the performance metrics used, and then results, first gathered in groups of tables, and then in groups of figures. Both the tables and figures present the same quantities, and are shown to provide either exact quantitative data, or visual trends.

Irrespective of the LPT or DA type of the dataset, the tables all exhibit a similar form, an example of which is shown in Figure 9 (top). These tables can be sorted according to any of the evaluation metrics / columns, with the velocity random error chosen in the example. Clicking on one of the algorithm names in the first column shows a page (Figure 9 bottom) gathering the information provided at submission, together with the numerical result values appearing in the table.

ppp: 0.005

Algorithm	Institution	Vel. bias	Vel. random error ▲	Vort. bias	Vort. random error	Pres. bias	Pres. random error	Pres. corr. coef.
VIC#-4D	LaVision GmbH	-0.0216	0.0852	-1.08	2.03	-0.0044	0.0341	0.947
Lin.Interp	N/A	-0.02	0.0904	-1.21	2.44	-0.000266	0.0345	0.945
FlowFit2	DLR	-0.00677	0.0933	-1.15	2.07	-0.0207	0.0355	0.933
VIC#-3D	LaVision GmbH	-0.00949	0.0946	-1.1	2.06	-0.0153	0.0394	0.934
VIC+	TU Delft	-0.0111	0.101	-1.2	2.34	0.0014	0.179	0.599

Author(s): S. Gesemann; F. Huhn; D. Schanz; A. Schröder
Institution(s): DLR
Department/Team: AS-EXV
Algorithm short name: FlowFit2
Algorithm full name: FlowFit2
Reference: http://ltces.dem.ist.utl.pt/lxaser/lxaser2016/finalworks2016/papers/04.5_4_18...
Publication date: Fri Jul 17 12:00:00 2020
Submitter name: Sebastian Gesemann
ppp: 0.005
Vel. bias: -0.00677
Vel. random error: 0.0933
Vort. bias: -1.15
Vort. random error: 2.07
Pres. bias: -0.0207
Pres. random error: 0.0355
Pres. corr. coef.: 0.933

Figure 9 – Top: example of table appearing in the result pages, here ordered as a function of velocity random error. Bottom: information displayed when clicking on an algorithm name in the first column. First DA Challenge dataset, https://onera-flow-benchmarks.fr/en/First_DA_Results?order=field_vel_random_error&sort=asc.

4.2.2. LPT cases

For the LPT datasets, evaluation pertains to particle detection on the one hand, and on accuracy of their position, velocity and acceleration (the latter for time-resolved datasets) on the other hand. To quantify the detection performance, on the particles or on the velocity vectors (in the case of a TP dataset), we count:

- a True Positive (TP) if a ground truth particle / vector is found in the neighborhood of a detection (i.e. if the maximum componentwise distance is less than a back-projected pixel)
- a False Negative (FN, missed particle) if there is no detection in the neighborhood of a ground truth particle
- a False Positive (FP, ghost particle) if there is no ground truth particle in the neighborhood of a detection.

Precision and Recall are then derived quantities:

$$Precision = \frac{\#TP}{\#TP + \#FP}$$

and

$$Recall = \frac{\#TP}{\#TP + \#FN}$$

respectively providing the fraction of true particles among all detected particles (Precision), and the proportion of true particles retrieved (Recall).

Considering the set of true particles, we then compute the rms error of positions, velocities and accelerations. In the case of time-resolved datasets, in order to assess the possible effect of the track fitting schemes, we show the errors in both raw and fitted positions.

Figure 10 shows an example of how these quantities are plotted in the result pages, here of the TR dataset of Case 2 of the 2nd Challenge.

4.2.3. DA cases

As shown in Figure 11, for the DA cases we compute, for the velocity, vorticity and pressure (and possibly other quantities depending on the case), the bias and random errors. In the case of pressure, we also provide the correlation coefficient with respect to the ground truth. Since the task of data assimilation is a matter of reconstructing missing scales, smaller than the inter-particle distance, we also plot spatial spectra, compared to that of the ground truth. In the tables as well as in the plots, we also include a submission (denoted by Lin. interp) obtained by performing a linear interpolation of the ground truth data at the particles position.

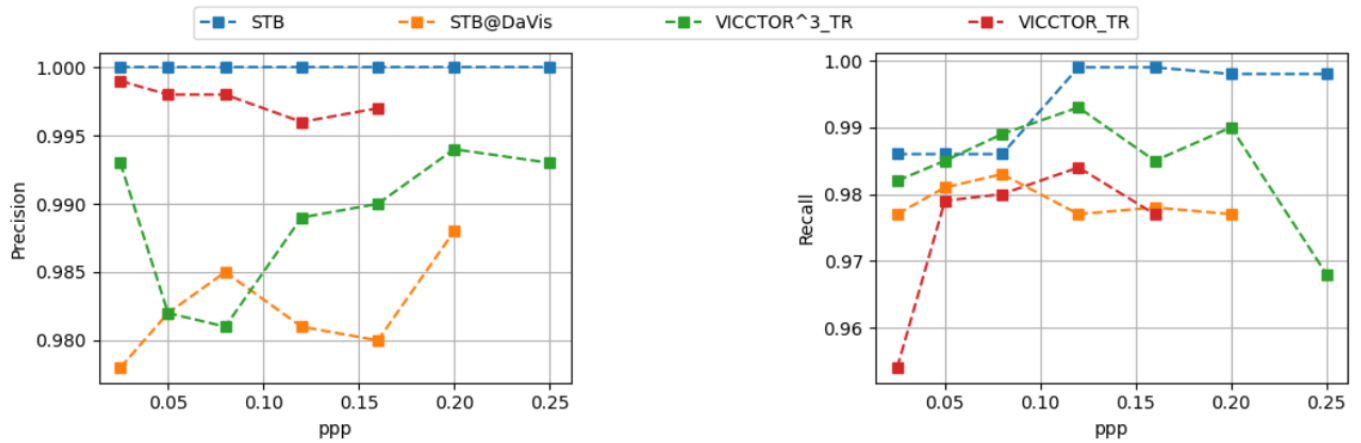
5. Perspectives

As the web portal is now fully operational with a significant number of datasets available, adding new datasets will be possible at marginal cost only. We thus encourage any interested researcher or team to contact us at flow-benchmarks@onera.fr to propose their test case for inclusion in our web portal, in order to help extend the variety of situations addressed and make the benchmarks as reflective as possible of current research.

Acknowledgments

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ppp sweep, $I/U = 0.99$, $Mie = 0$: particle reconstruction at t_0



Velocity error norm slices, ppp: 0.08, I/U : 0.99, Mie : 0

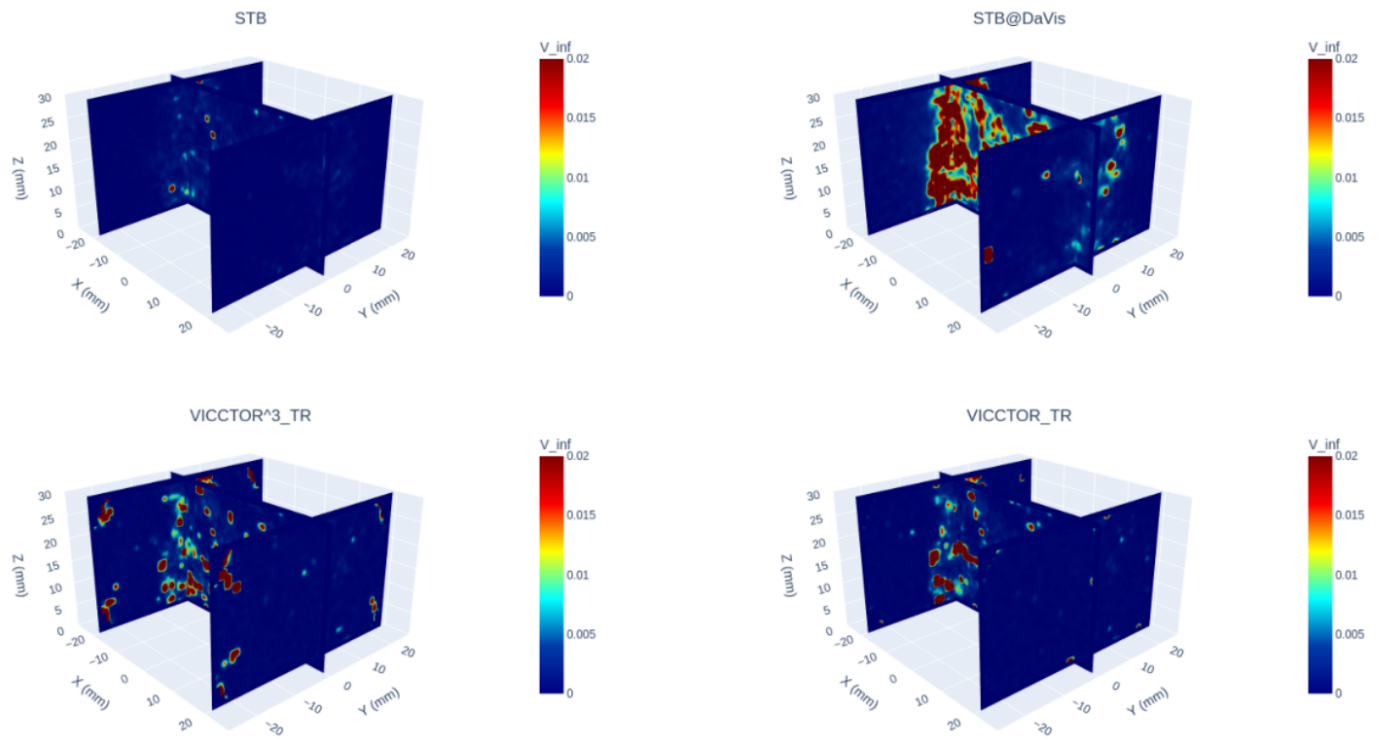


Figure 10 – Result figures (extracts) of the TR dataset LPT Challenge Case 2

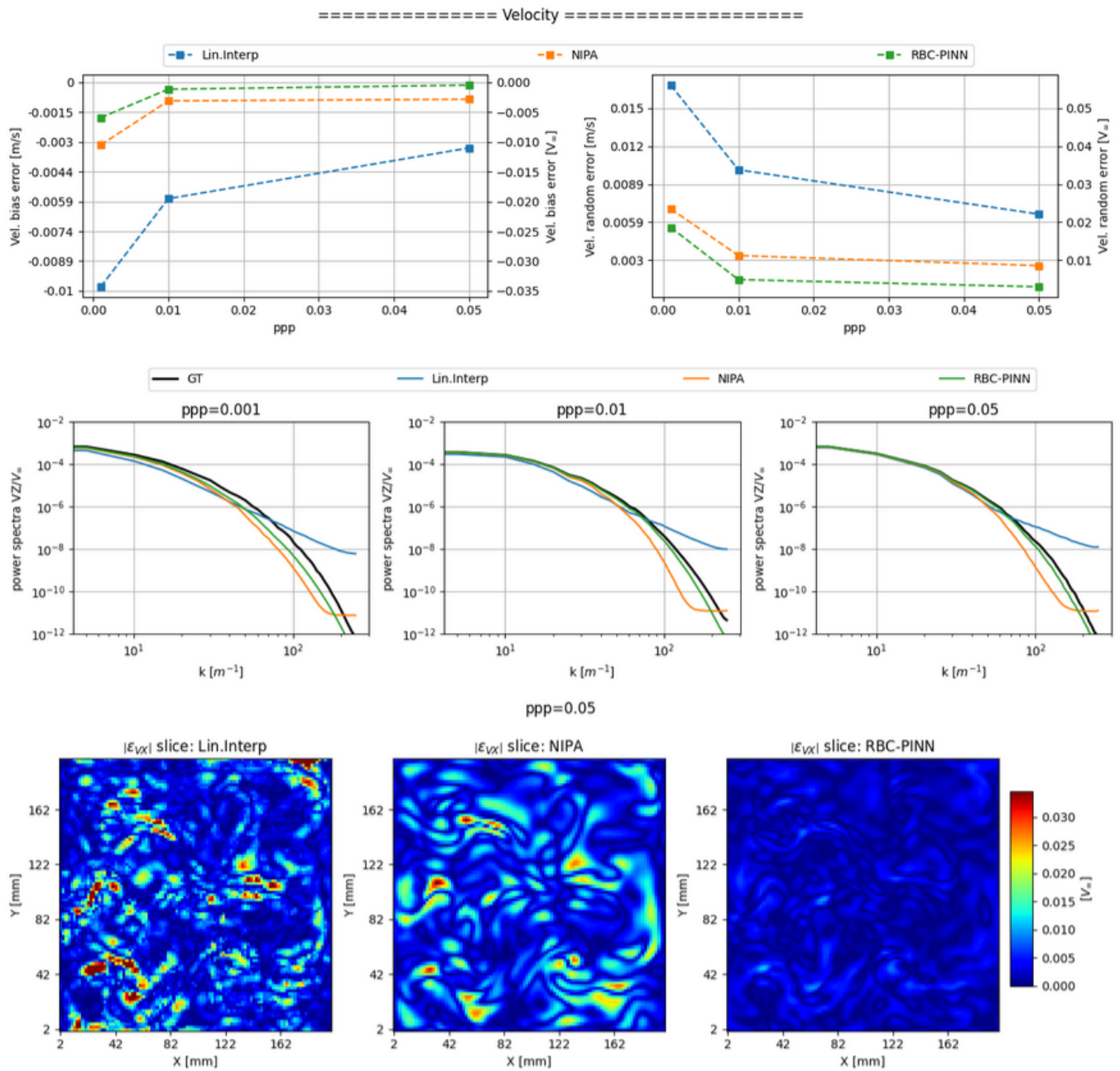


Figure 11 – Result figures (extracts) of Case 3 of the 2nd DA challenge

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