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PIV Measurements of DCC-06 and DCC-07 PPOOLEX Experiments

Lauri Pyy
Joonas Telkkä

Lappeenranta University of Technology
Nuclear Safety Research Unit
Finland

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Abstract

This report summarizes the results of the DCC-06 and DCC-07 steam discharge experiments carried out with the scaled down PPOOLEX test facility designed and constructed at Lappeenranta University of Technology. Steam was blown through the vertical DN100 blowdown pipe to the condensation pool filled with sub-cooled water.

The main objective of the experiments was to use the PIV measurement system in different direct contact condensation situations in order to obtain velocity field data to be used in verification of CFD simulation results.

Both experiments consisted of several PIV measurement sequences, where different steam flow rates and pool water temperatures were used. Most of the time the steam/water interface moved up and down along the blowdown pipe as a result of rapid condensation taking place either inside the pipe or at the pipe outlet. There was only a short period of time in DCC-06, when the steam/water interface was quite calm at the blowdown pipe outlet.

Steam release into the pool water created major optical problems for the PIV measurements. The problems couldn't be avoided even with the new red band pass filters. Time-averaging of the PIV images did not work due to the fluctuating behaviour of the water phase. Therefore, the PIV results from the DCC-06 and DCC-07 experiments can be presented only as individual vector images from those measurement sequences where optically intact raw images are available. It is possible to measure the velocity field of the water phase, but only from areas where condensing does not occur.

The main finding from the DCC-06 and DCC-07 experiments is that PIV cannot be applied successfully for velocity measurements near the blowdown pipe outlet with the current PPOOLEX measuring set-up. The character of the flow in most steam discharge experiments is fluctuating and chaotic. These fluctuations make the time-averaging of PIV images impossible because there is no constant flow direction to be found. In addition, when there are optical distortions present, the PIV vector result is corrupted. At the moment there is not a way to get around these optical distortions even though the new filters succeeded well by cutting the reflections from the actual steam bubbles.

Key words

condensation pool, steam blowdown, PIV measurements

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e-mail nks@nks.org

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Lauri Pyy, Joonas Telkkä

Lappeenranta University of Technology
Faculty of Technology
LUT Energy
Nuclear Safety Research Unit
P.O. Box 20, FIN-53851 LAPPEENRANTA, FINLAND
Phone +358 5 621 11

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Research organization and address	**Customer**	
Lappeenranta University of Technology Nuclear Safety Research Unit P.O. Box 20 FIN-53851 LAPPEENRANTA, FINLAND	VYR / SAFIR2014 NKS	
Project manager Markku Puustinen	**Contact person** Jari Hämäläinen (SAFIR2014) Karin Andgren (NKS)	
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Both experiments consisted of several PIV measurement sequences, where different steam flow rates and pool water temperatures were used. Most of the time the steam/water interface moved up and down along the blowdown pipe as a result of rapid condensation taking place either inside the pipe or at the pipe outlet. There was only a short period of time in DCC-06, when the steam/water interface was quite calm at the blowdown pipe outlet. Despite of clear chugging the used steam flow rates were not high enough for strong internal circulation to develop and mix the pool. Therefore thermal stratification of the wetwell pool could be observed. Temperatures remained almost constant at the pool bottom but increased towards the surface layers.

Steam release into the pool water created major optical problems for the PIV measurements. The problems couldn't be avoided even with the new red band pass filters. Time-averaging of the PIV images did not work due to the fluctuating behavior of the water phase. Therefore, the PIV results from the DCC-06 and DCC-07 experiments can be presented only as individual vector images from those measurement sequences where optically intact raw images are available. It is possible to measure the velocity field of the water phase, but only from areas where condensing does not occur.

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Principal author or Project manager	**Reviewed by**
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PREFACE

Condensation pool studies started in Nuclear Safety Research Unit at Lappeenranta University of Technology (LUT) in 2001 within the Finnish Research Programme on Nuclear Power Plant Safety (FINNUS). The experiments were designed to correspond to the conditions in the Finnish boiling water reactors (BWR) and the experiment programme was partially funded by Teollisuuden Voima Oy (TVO). Studies continued in 2003 within the Condensation Pool Experiments (POOLEX) project as a part of the Safety of Nuclear Power Plants - Finnish National Research Programme (SAFIR). The studies were funded by the State Nuclear Waste Management Fund (VYR) and by the Nordic Nuclear Safety Research (NKS).

In these research projects, the formation, size and distribution of non-condensable gas and steam bubbles in the condensation pool was studied with an open scaled down pool test facility. Also the effect of non-condensable gas on the performance of an emergency core cooling system (ECCS) pump was examined. The experiments were modelled with computational fluid dynamics (CFD) and structural analysis codes at VTT.

A research project called Condensation Experiments with PPOOLEX Facility (CONDEX) started in 2007 within the SAFIR2010 - The Finnish Research Programme on Nuclear Power Plant Safety 2007–2010. The CONDEX project focused on several containment issues and continued further the work done in this area within the FINNUS and SAFIR programs. For the new experiments, a closed test facility modelling the drywell and wetwell compartments of BWR containment was designed and constructed. The main objective of the CONDEX project was to increase the understanding of different phenomena inside the containment during a postulated main steam line break (MSLB) accident. The studies were funded by the VYR, NKS and Nordic Nuclear Reactor Thermal-Hydraulics Network (NORTHNET).

A new research project called Experimental Studies on Containment Phenomena (EXCOP) started in 2011 within the national nuclear power plant safety research programme SAFIR2014. The EXCOP project focuses on gathering an extensive experiment database on condensation dynamics, heat transfer and structural loads, which can be used for testing and developing computational methods used for nuclear safety analysis. To achieve the above mentioned goals sophisticated measuring solutions i.e. a Particle Image Velocimetry (PIV) system and a modern high speed camera have been installed to the PPOOLEX facility in 2011. Networking among international research organizations is enhanced via participation in the NORTHNET framework and NKS/ENPOOL project. Analytical and numerical work of Kungliga Tekniska Högskolan (KTH) is combined to EXCOP, ELAINE, NUMPOOL and ESA projects of SAFIR2014. The studies are funded by the VYR, NKS and NORTHNET.

CONTENTS

NOMENCLATURE

A	area
f	frequency
N	number
P	power
p	pressure
q	flow rate
T	temperature
v	velocity

Greek symbols

Δ	change

Abbreviations

BWR	boiling water reactor
CCTV	closed circuit television
CFD	computational fluid dynamics
CONDEX	condensation experiments
DCC	direct contact condensation
DYN	experiment series focusing on dynamic loading
ECCS	emergency core cooling system
ELAINE	enhancement of Lappeenranta instrumentation of nuclear safety experiments project
EMS	effective momentum source
ENPOOL	NKS project
ESA	enhancement of safety evaluation tools project
EXCOP	experimental studies on containment phenomena project
FOV	field of view
KTH	Kungliga Tekniska Högskolan
LOCA	loss-of-coolant accident
LUT	Lappeenranta University of Technology
MSLB	main steam line break
MIX	mixing experiment series
NKS	Nordic nuclear safety research
NORTHNET	Nordic Nuclear Reactor Thermal-Hydraulics Network
NUMPOOL	numerical modelling of condensation pool project
PACTEL	parallel channel test loop
PAR	experiment series with parallel blowdown pipes
PIV	particle image velocimetry
POOLEX	condensation pool experiments project
PPOOLEX	pressurized condensation pool experiments project
PWR	pressurized water reactor
SAFIR	Safety of Nuclear Power Plants - Finnish National Research Programme
SLR	steam line rupture
SRV	safety/relief valve

TC	thermocouple
TRA	experiment series with transparent blowdown pipes
TVO	Teollisuuden Voima Oyj
VTT	Technical Research Centre of Finland
VYR	State Nuclear Waste Management Fund

1 INTRODUCTION

During a postulated main steam line break accident inside the containment a large amount of non-condensable (nitrogen) and condensable (steam) gas is blown from the upper drywell to the condensation pool through the blowdown pipes in the Olkiluoto type BWR, see Figure 1. The wetwell pool serves as the major heat sink for condensation of steam.

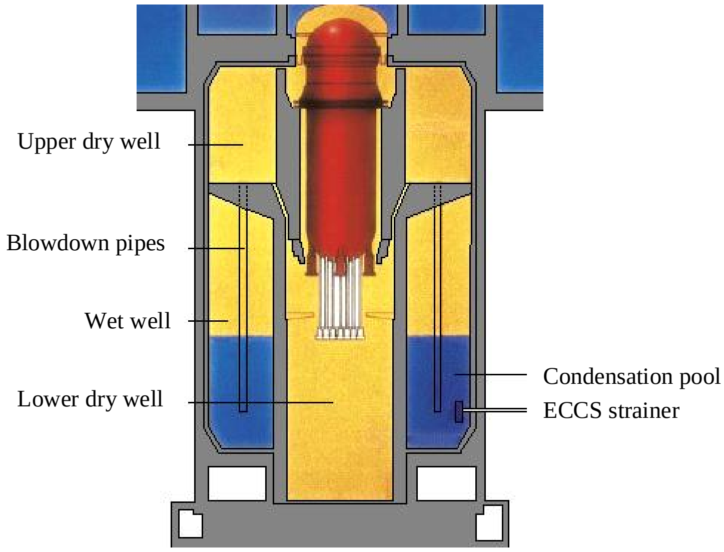

Figure 1. Schematic of the Olkiluoto type BWR containment.

The main objective of the EXCOP project is to improve understanding and increase fidelity in quantification of different phenomena inside the dry and wetwell compartments of BWR containment during steam discharge. These phenomena could be connected, for example, to bubble dynamics issues, thermal stratification and mixing, wall condensation, direct contact condensation (DCC) and interaction of parallel blowdown pipes. Steam bubbles interact with pool water by heat transfer, condensation and momentum exchange via buoyancy and drag forces. Pressure oscillations due to rapid condensation can occur frequently.

To achieve the project objectives, a combined experimental/analytical/computational study programme is being carried out. Experimental part at LUT is responsible for the development of a database on condensation pool dynamics and heat transfer at well controlled conditions. Analytical/computational part at VTT, KTH and LUT use the developed experiment database for the improvement and validation of models and numerical methods including CFD and system codes. Also analytical support is provided for the experimental part by pre- and post-calculations of the experiments. Furthermore, the (one-directional or bi-directional) coupling of CFD and structural analysis codes in solving fluid-structure interactions can be facilitated with the aid of load measurements of the steam blowdown experiments.

In 2006, a new test facility, called PPOOLEX, suitable for BWR containment studies was designed and constructed by Nuclear Safety Research Unit at LUT. It models both the dry and wetwell (condensation pool) compartments of the containment and withstands prototypical system pressures. Experience gained with the operation of the preceding open POOLEX facility was extensively utilized in the design and construction process of the new facility.

Experiments with the PPOOLEX facility started in 2007 by running characterizing tests where the general behaviour of the facility was observed and instrumentation and the proper operation of automation, control and safety systems was tested [1]. The SLR series focused on the initial period of a postulated MSLB accident inside the containment [2]. Air was used as the flowing substance in these experiments. The research program continued in 2008 with a series of thermal stratification and mixing experiments [3]. Stratification in the water volume of the wetwell during small steam discharge was of special interest. In December 2008 and January 2009 a test series focusing on steam condensation in the drywell compartment was carried out [4]. Experiments to study the effect of the Forsmark type blowdown pipe outlet collar design on loads caused by chugging phenomena were also done in 2009 [5]. Then the research programme continued with eleven experiments (TRA and PAR series) studying the effect of the number of blowdown pipes (one or two) on loads caused by chugging phenomenon [6]. In January 2010, experiments focusing on dynamic loading (DYN series) during steam discharge were carried out [7]. Stratification and mixing in the wetwell pool and the interaction of parallel blowdown pipes were investigated further in 2010 [8], [9]. In January–February 2011 a second series of the experiments with the Forsmark type blowdown pipe outlet collar was carried out [10]. First tests with the new PIV measurement system were executed at the end of 2011 [11]. In June–October 2012 a series of thermal stratification and mixing experiments (labeled as MIX-01…06) were carried out [12]. The main purpose of the experiments was to generate data for the development of the Effective Momentum Source (EMS) and Effective Heat Source (EHS) models to be implemented in GOTHIC code by KTH [13]. To generate more data for the development of the EMS and EHS models a second series of thermal stratification and mixing experiments was carried out in October–November 2013 (labeled as MIX-07…12) [14].

Work with the PPOOLEX facility continued in 2014 with a series of DCC experiments. A smaller diameter blowdown pipe (DN100 vs. earlier DN200) than before was used in the experiments. The main objective was to gather PIV measurement data from the vicinity of the blowdown pipe outlet in order to define flow fields for the verification of CFD simulation results. In this report, the results of the DCC-06 and DCC-07 experiments are presented. First, chapter two gives a short description of the test facility and its measurements as well as of the data acquisition system used. The experiments in question are introduced in chapter three. The PIV measurement results are presented and discussed in chapter four. Chapter five summarizes the findings of the experiments.

2 PPOOLEX TEST FACILITY

The PPOOLEX test facility was taken into use at LUT in the end of 2006. PPOOLEX models the containment of a BWR plant. During the years the facility has gone through several modifications and enhancements as well as improvements of instrumentation. The PPOOLEX facility is described in more detail in reference [15]. However, the main features of the facility and its instrumentation are introduced below.

2.1 TEST VESSEL

The PPOOLEX facility consists of a wetwell compartment (condensation pool), drywell compartment, inlet plenum and air/steam-line piping. An intermediate floor separates the compartments from each other. A route for gas/steam flow from the drywell to the wetwell is created by a vertical blowdown pipe attached underneath the floor.

The main component of the facility is the ~31 m^3 cylindrical test vessel, 7.45 m in height and 2.4 m in diameter. It is constructed from three plate cylinder segments and two dome segments. The test facility is able to withstand considerable structural loads caused by rapid condensation of steam. The dry and wetwell sections are volumetrically scaled according to the compartment volumes of the Olkiluoto containment (ratio approximately1:320). There are several windows for visual observation in both compartments. A DN100 (∅ 114.3 x 2.5 mm) drain pipe with a manual valve is connected to the vessel bottom. A relief valve connection is mounted on the vessel head. The removable vessel head and a man hole (DN500) in the wetwell compartment wall provide access to the interior of the vessel for maintenance and modifications of internals and instrumentation. The drywell is thermally insulated.

A sketch of the test vessel is shown in Figure 2. Table 1 lists the main dimensions of the test facility compared to the conditions in the Olkiluoto plant.

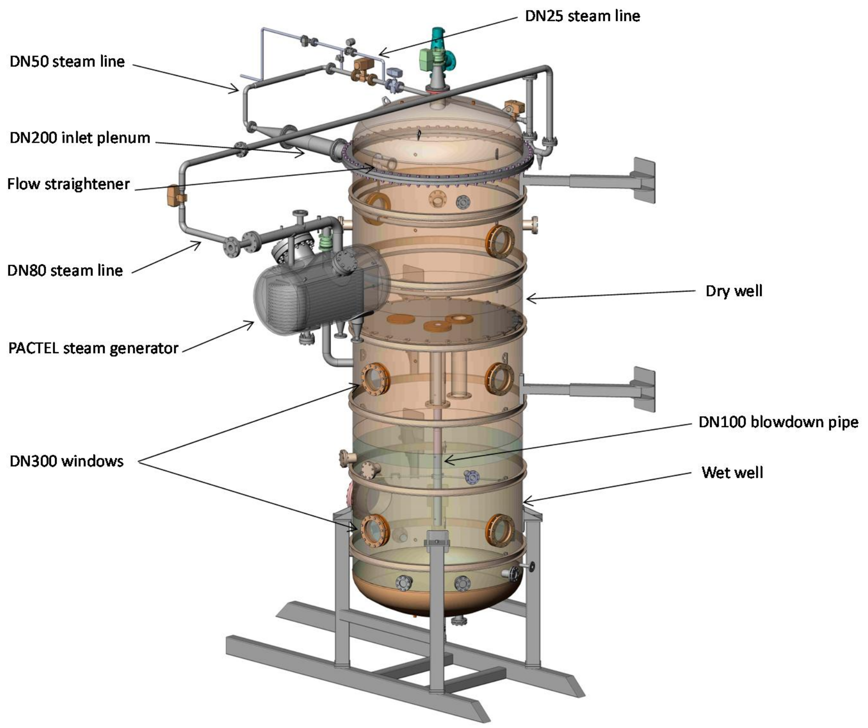

Figure 2. PPOOLEX test vessel.

Table 1. Test facility vs. Olkiluoto 1 and 2 BWRs.

	PPOOLEX test facility	Olkiluoto 1 and 2
Number of blowdown pipes	1-2	16
Inner diameter of the blowdown pipe [mm]	214.1	600
Suppression pool cross-sectional area [m^2]	4.45	287.5
Drywell volume [m^3]	13.3	4350
Wetwell volume [m^3]	17.8	5725
Nominal water volume in the suppression pool [m^3]	8.38*	2700
Nominal water level in the suppression pool [m]	2.14*	9.5
Pipes submerged [m]	1.05	6.5
A_{pipes}/A_{pool}x100%	0.8 / 1.6**	1.6

* Water volume and level can be chosen according to the experiment type in question. The values listed in the table are based on the ratio of nominal water and gas volumes in the plant.
** With one / two blowdown pipes.

2.2 PIPING

Steam needed in the experiments is produced with the nearby PACTEL [16] test facility, which has a core section of 1 MW heating power and three horizontal steam generators. Steam is led through a thermally insulated steam line, made of sections of standard DN80 (Ø88.9x3.2) and DN50 (Ø60.3x3.0) from the PACTEL steam generators towards the test vessel. The steam line is connected to the DN200 inlet plenum with a 0.47 m long cone section.

2.3 BLOWDOWN PIPE

The DN100 (∅ 114.3 x 2.5 mm) blowdown pipe, made from austenitic stainless steel EN 1.4301 (AISI 304), is positioned inside the pool in a non-axisymmetric location, i.e. the pipe is 420 mm away from the centre of the condensation pool. To enable better conditions for the PIV-measurements the total length of the blowdown pipe was decreased from 3209 mm to 2917 mm. Thus the outlet of the DN100 pipe is located 292 mm higher than the outlet of the DN200 pipe in earlier experiments. The water level of the condensation pool was increased accordingly in order to keep the submergence depth of the blowdown pipe the same as in the preceding experiments.

2.4 AIR REMOVAL SYSTEM

For the sparger experiments the PPOOLEX facility was equipped with an air removal system. The system consists of a filter unit and an air removal device. Air is removed in a vacuum chamber by a vacuum pump. With the help of the air removal system oxygen content of PPOOLEX water could be decreased from 6 mg/l to 3 mg/l during the preparation period for the experiments. However, the system was not used in all experiments because it was still being tested.

2.5 MEASUREMENT INSTRUMENTATION

The applied instrumentation depends on the experiments in question. Normally, the test facility is equipped with several thermocouples (T) for measuring steam, pool water and structure temperatures and with pressure transducers (P) for observing pressures in the drywell, inside the blowdown pipes, at the condensation pool bottom and in the gas space of the wetwell. Steam flow rate is measured with a vortex flow meter (F) in the steam line. Additional instrumentation includes, for example, strain gauges (S) on the pool outer wall and steam line valve position sensors.

Figures in Appendix 1 show the locations of the PPOOLEX measurements during the DCC-06 and DCC-07 experiments and the table in Appendix 1 lists their identification codes and other details.

2.6 PIV MEARUREMENT SYSTEM

The PIV measurement system for the PPOOLEX facility was purchased from LaVisionUK Ltd.

The system’s laser is a Neodym-YAG double-cavity laser. The two pulsed lasers are mounted on a single baseplate. The lasers emit the beam in infrared range at 1064 nm and they are polarization combined. A second harmonic generator is used to convert the beam to visible range at 532 nm. Dichroic mirrors separate the visible light from the residual infrared light and direct the beam to the experiment.

System's light sheet optics uses a combination of two spherical lenses and one cylindrical divergence lens. The appropriate thickness of the light sheet is achieved with the two spherical lenses. The aperture and the height of the light sheet are controlled by the focal length of the divergence lens and the diameter of the laser.

The system's cameras are Imager Pro X 4M CCD cameras. The camera type has progressive-scan technology with a dual frame-technique for cross correlation. The CCD sensors are cooled with Peltier element to +10°C to reduce background noise. With remote controlled focus rings the focus and aperture of the camera lenses can be controlled with computer software. The system has also a remote controlled Scheimpflug mount which allows all areas of the image plane to be in focus.

For collecting PIV recording and other data the equipment has a system computer. The system utilizes DaVis software solution for image acquisition and analysis of flow fields in both 2D and 3D cases.

2.7 CCTV SYSTEM

Standard video cameras with 25 fps and a digital videocassette recorder were used for visual observation of the test vessel interior during the test series.

2.8 DATA ACQUISITION

National Instruments PXIe PC-driven measurement system was used for data acquisition. The system enables high-speed multi-channel measurements. The maximum number of measurement channels is 64 with additional eight channels for strain gauge measurements. The maximum recording capacity depends on the number of measurements and is in the region of three hundred thousand samples per second. Measurement software was LabView 2013. The data acquisition system is discussed in more detail in reference [17].

Self-made software using the National Instruments FieldPoint measurement system was used for monitoring and recording the essential measurements of the PACTEL facility generating the steam. Both data acquisition systems measure signals as volts. After the experiments, the voltage readings are converted to engineering units with conversion software.

The used measurement frequency of LabView was 1 kHz for pressures and strains and 20 Hz for temperatures. The rest of the measurements (for example temperature, pressure and flow rate in the steam line) were recorded by the self-made software with the frequency of 0.67 Hz.

3 DCC-06 AND DCC-07 EXPERIMENTS

The objective of the DCC-06 and DCC-07 experiments was to study direct contact condensation both in a semi stable situation when there are no large collapsing steam bubbles at the blowdown pipe outlet as well as in a more violent situation (chugging) when water is sucked back into the blowdown pipe after the collapse of a steam bubble at the pipe outlet.. For this reason the used steam flow rates ranged from very small values to such values that produced chugging.

Before the experiments, the wetwell pool was filled with isothermal water (about 20 °C) to the level of 2.44 m i.e. the blowdown pipe outlet was submerged by 1.0 m. The experiments were started from atmospheric conditions in PPOOLEX. After the correct initial steam generator pressure (0.6 MPa) had been reached, the remote-controlled cut-off valve (X2100) in the DN50 steam line was opened. The steam discharge rate into the PPOOLEX vessel was controlled with the help of the pressure level of the steam source (PACTEL steam generator) and a remote-operated control valve (S2002) in the DN50 steam line. During the clearing phase the steam flow rate was about 300 g/s. As a result, the drywell compartment was soon filled with steam that mixed there with the initial air content. Part of the steam condensed on the drywell walls until the structures had heated up. Pressure build-up in the drywell then pushed water in the blowdown pipe downwards and after a while the pipe cleared and air/steam flow into the wetwell compartment started. After air was displaced from the drywell into the gas space of the wetwell the steam flow rate was reduced to the desired level. The main parameters of the DCC-06 and DCC-07 experiments are listed in Table 2.

Table 2. Parameter values of the DCC-06 and DCC-07 tests.

Exp.	Initial water level [m]	Initial water temperature [°C]	Steam source pressure [MPa]	Steam flow rate [g/s]	Comments
DCC-06	2.4	20	0.6	47–152	Ten PIV measurement sequences
DCC-07	2.4	20	0.6	34–415	Four PIV measurement sequences

Figures 3 shows the pressure behaviour in the steam line and in the PPOOLEX facility during the DCC-06 experiment. The pressure curves are very much the same for the DCC-07 experiment and are therefore not presented here.

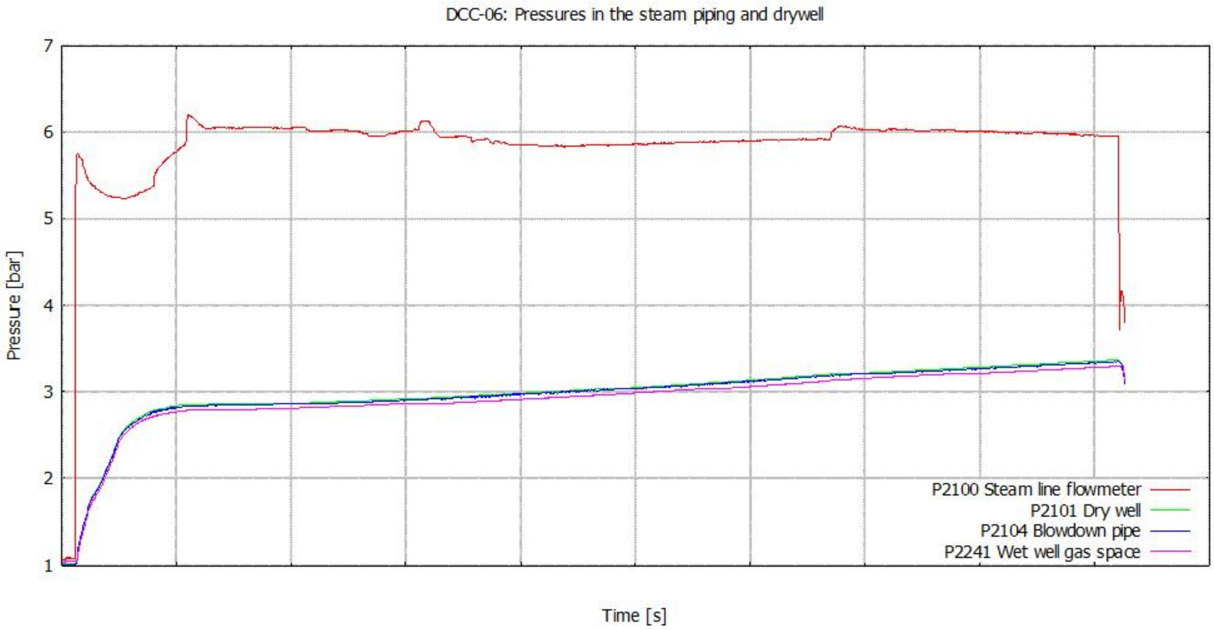

Figure 3. Development of pressure during the DCC-06 experiment.

Figures 4 and 5 show the used steam mass flow rates in DCC-06 and DCC-07, respectively. Measured values from the flow meter F2100 are valid for flow rates above 100 g/s and measured values from the flow meter F2102 for flow rates below 100 g/s.

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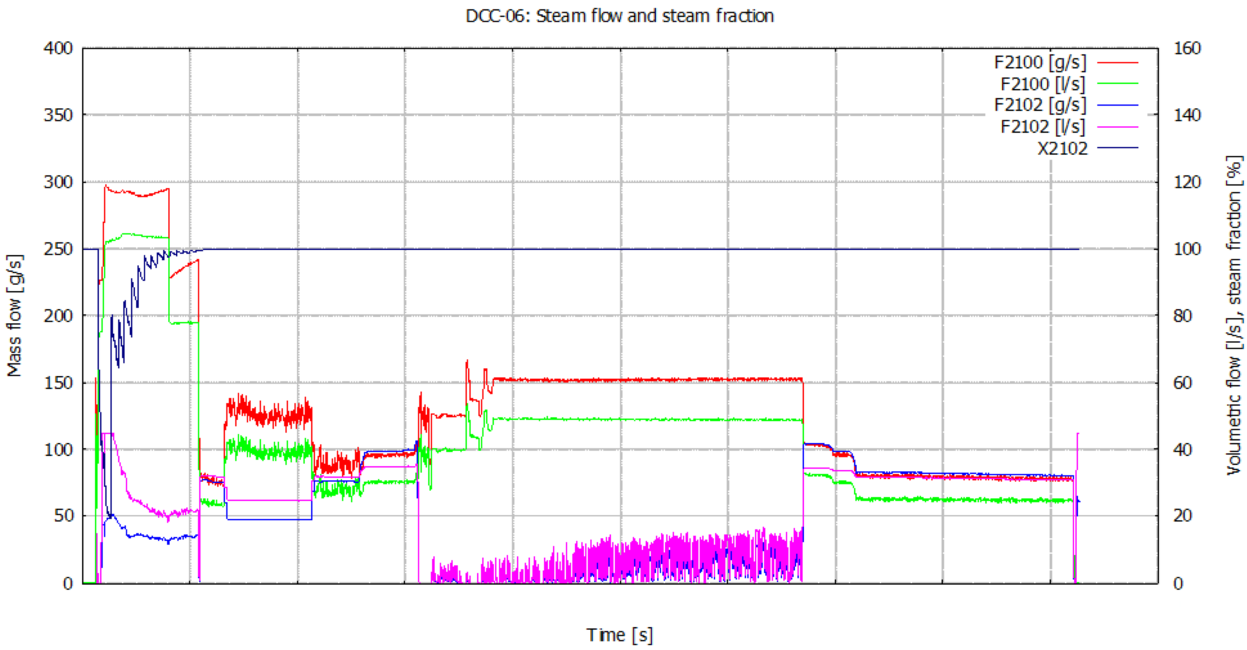

Figure 4. Steam flow rate in the DCC-06 experiment.

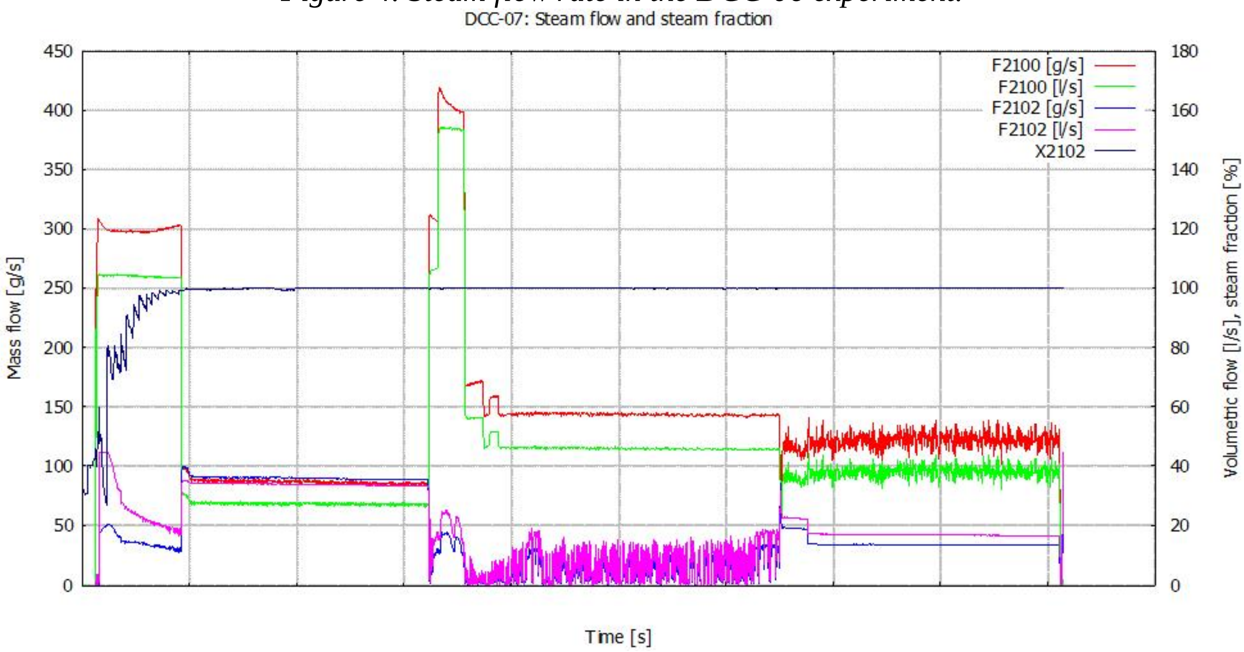

Figure 5. Steam flow rate in the DCC-07 experiment.

The behaviour of the steam/water interface in DCC-06 and DCC-07 can be concluded on the basis of temperatures measured from inside the blowdown pipe (Figure 6 and 7). It can be seen that only in DCC-06 there was a short period of time when the steam/water interface was quite calm at the pipe outlet. This was between 700 and 1050 seconds with the 47 g/s mass flow rate. Otherwise the interface moved up and down along the blowdown pipe as a result of rapid condensation taking place either inside the pipe or at the pipe outlet.

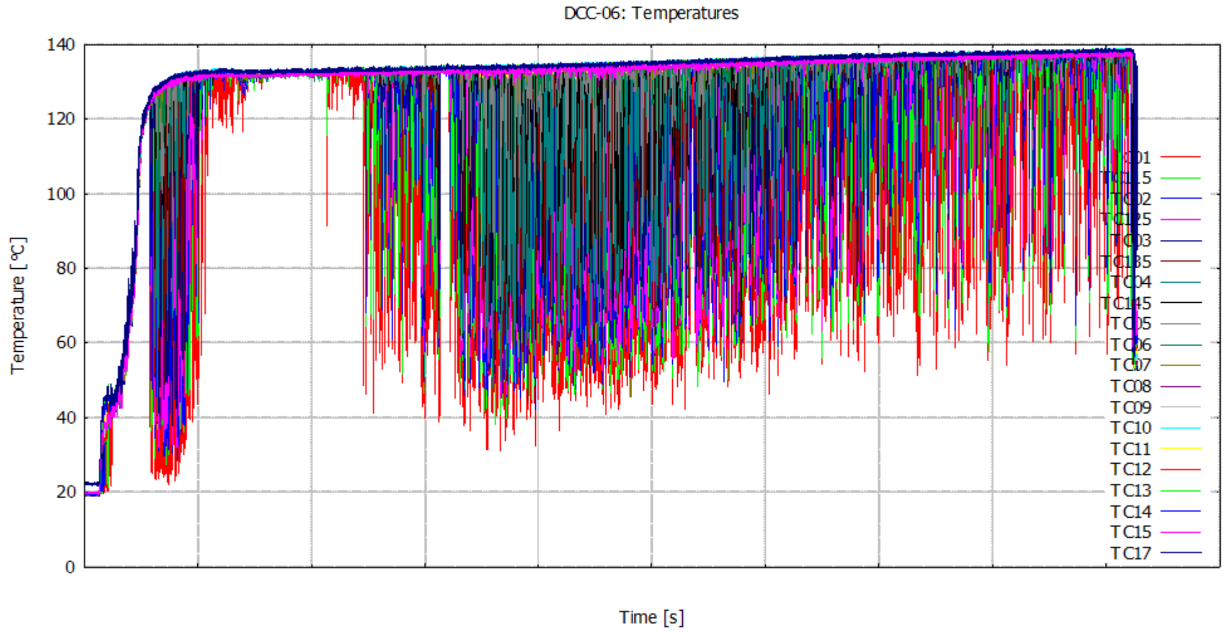

Figure 6. Temperature inside the blowdown pipe in the DCC-06 experiment.

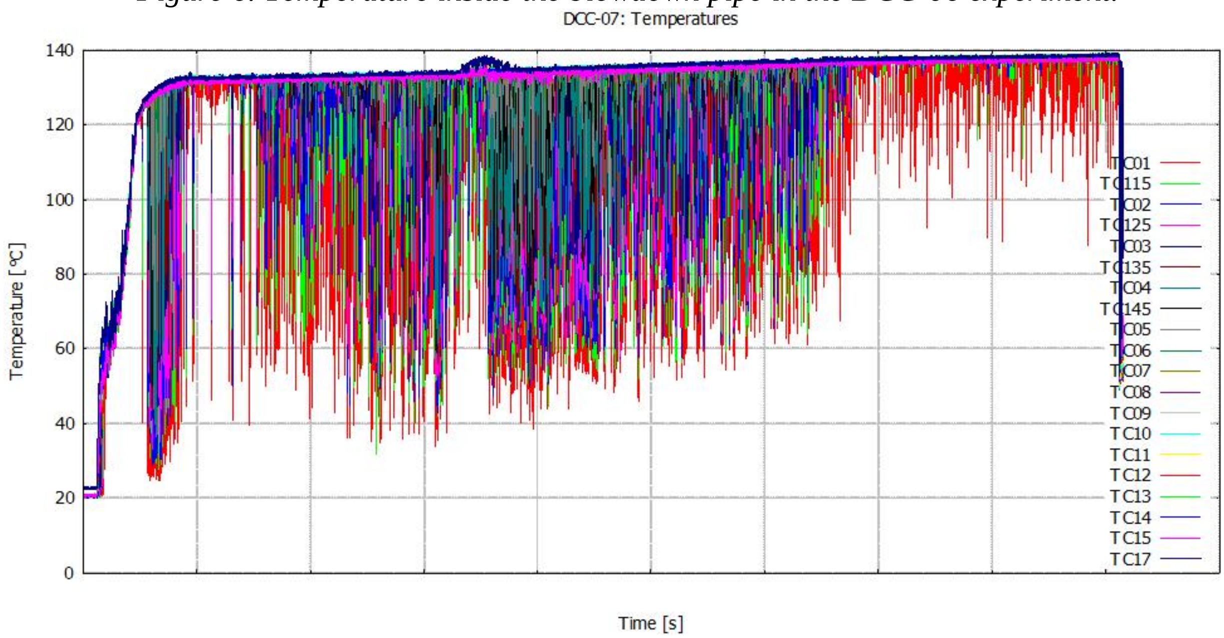

Figure 7. Temperature inside the blowdown pipe in the DCC-06 experiment.

Both experiments were so long that the pool water warmed up considerably due to heat input by steam discharge. Despite of chugging the used steam flow rates were not so high that strong internal circulation would have developed and mixed the pool. Therefore strong thermal stratification of the wetwell pool could be observed. The heat-up process was driven by flow of warm condensed water upwards from the blowdown pipe outlet as well as by conduction through the pipe wall. Those elevations, which were clearly below the pipe outlet, remained at the initial temperature. The elevations just below the pipe outlet heated up slightly and the elevations above the outlet heated up considerably. The final temperature difference between the pool bottom and water surface was almost 40 °C, Figure 8.

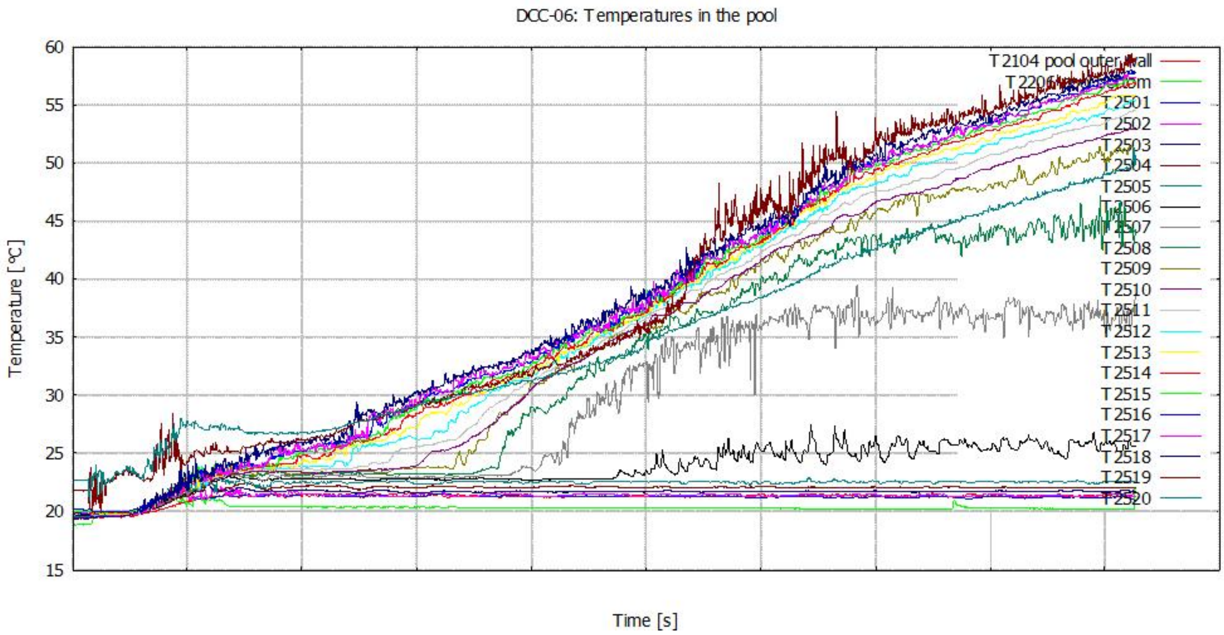

Figure 8. Temperatures in the pool in the DCC-06 experiment.

4 PIV MEASUREMENTS

4.1 BACKGROUND

In the previous DCC experiments with PIV measurements it was found out that even with the use of fluorescent tracer particles and short pass filters the reflections from steam bubbles created huge problems in the field-of-view, FOV. The reflective properties were too weak compared to the huge reflections. With a big steam release to the FOV the reflections oversaturated the particle image so much that it was unusable. An example of such a situation is presented in the Figure 9.

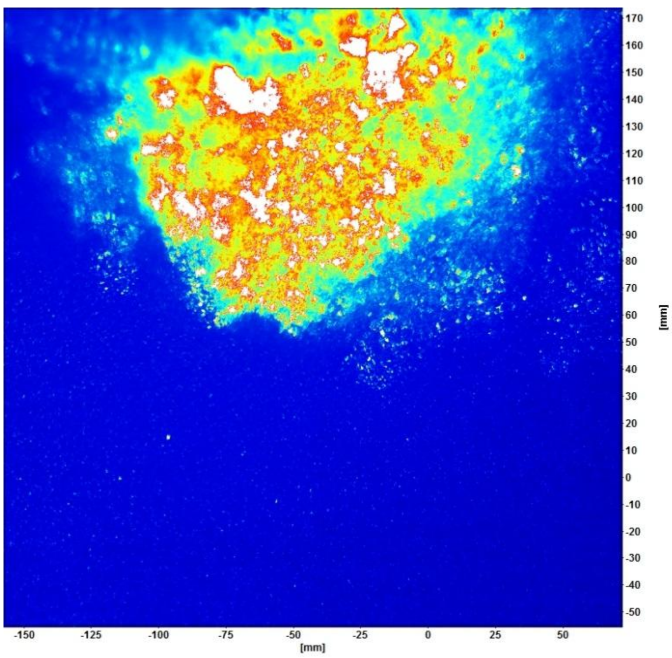

Figure 9. An example of oversaturated particle image caused by a huge steam release to the FOV.

The white color in Figure 1 represents full intensity in the CCD chip meaning that the corresponding pixels are fully saturated with light. The means to overcome this problem were thought of and a decision was made to purchase new filters with better filtering properties. The previous long pass filters were replaced with common red band pass filters which let through only 0.4 % of 532 nm wavelength compared to the old long pass filters. In the fluorescent region, the new filters were filtering more as well, but still let 34 % of the fluorescent light through compared to the old filters. The ratio between the blocked 532 nm light and let through fluorescent light was improved drastically compared to the previous long pass filters. In addition to better filtering, the FOV was lower (below the blowdown pipe outlet) in the DCC-06 and DCC-07 experiments compared to the previous experiments to avoid big steam releases to the FOV.

4.2 MEASURED PIV SEQUENCES

In the DCC-06 and DCC-07 tests the top edge of the FOV was about 300 mm below the blowdown pipe outlet. The calibration for DCC-06 and DCC-07 was conducted in a new manner by taking images of the calibration plate with only one side lighted up. In the previous experiments an optimal lighting condition for both calibration plate sides were hard to achieve. This was mainly because the lights in the opposite side of the calibration plate would sometime create unwanted reflections and oversaturation. The attributes of the PIV measurement sequences in the DCC-06 and DCC-07 experiments are presented in the Table 3.

Table 3. Attributes of PIV measurement sequences in DCC-06 and DCC-07

Sequence No.	N [-]	f [Hz]	P_{laser1} [%]	P_{laser2} [%]	dt [µs]	q_{msteam} [g/s]	Comment
DCC-06-1	100	1	90	70	65000	47	
DCC-06-2	100	1	90	70	65000	76	
DCC-06-3	100	1	90	70	65000	98	
DCC-06-4	100	1	90	70	65000	125	
DCC-06-5	100	1	90	70	65000	152	
DCC-06-6	1024	1	90	70	65000	152	
DCC-06-7	100	1	90	70	65000	98	Failure
DCC-06-8	100	1	90	70	65000	83	
DCC-06-9	1024	2	90	70	65000	83	
DCC-06-10	1024	1	90	70	65000	0	”non-DCC”
DCC-07-1	1024	1	90	70	65000	91	
DCC-07-2	1024	1	90	70	65000	145	
DCC-07-3	1024	1	90	70	65000	34	
DCC-07-4	512	2	90	70	65000	0	”non-DCC”

The DCC-06 experiment started with sequences of 100 raw image pairs to evaluate when there is enough movement in the water phase to get particle movement of around 5 pixels. The first longer set was taken with the steam mass flow rate of 152 g/s. The reason for a long set is to get statistical reliability when time-averaging the vector images. In the sequence DCC-06-7 all recorded images were lost due to an error. There are two sequences marked “non-DCC” which are without a steam release. The goal of these two PIV measurement sequences was to see if there is any movement through the FOV caused by the temperature difference between the bottom of the pool and the surface.

4.3 AIM OF PIV MEASUREMENTS

The primary goal of the experiments was to test out the new filters and their performance in direct contact condensation situations. As the time-averaging of images taken from the blowdown pipe outlet is impossible due to the fluctuating character of the water phase, the FOV was lowered to see if an area with stable flow could be found. In addition, the aim was to see whether there would be any optical disturbance left from smaller steam bubbles that travel further than the main bubble in the exit of the blowdown pipe. An example of a steam release to the water phase is presented in the Figure 10. As it can be seen there are a lot of reflective steam bubbles also beneath the “main” steam bubble. In addition, there are bubbles of incondensable gases alongside with steam bubbles creating optical distractions.

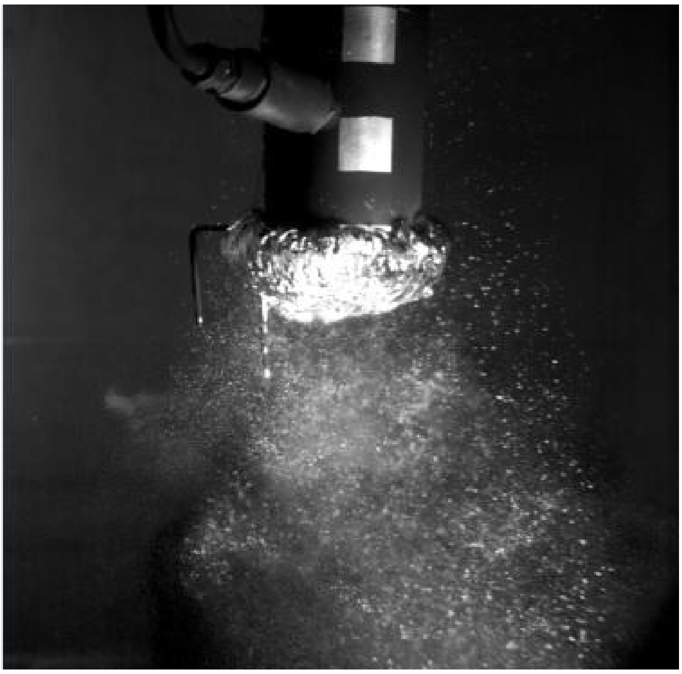

Figure 10. Steam release into subcooled water in the PPOOLEX test facility.

4.4 VISUAL INSPECTION OF RAW PARTICLE IMAGES

It is needless to say that for the PIV measurement system to work correctly, high quality raw particle images need to be recorded. One emphasis with the new filters was to see whether there will be optical aberrations in the FOV. Also a lower FOV position was used in order to prevent steam bubbles and incondensable gas from entering it.

The following sub-chapters present observations related to the PIV measurement sequences in the DCC-06 and DCC-07 experiments. The steam mass flow rate and the change of pool temperature during the PIV measurement sequence are presented in the Tables 4 to 16. The pool temperatures are from thermo-couple T2510, which is situated 700 mm away from the blowdown pipe in horizontal direction and about 60 mm below the vertical elevation of the pipe outlet. The pool bottom temperature is taken form thermo-couple T2206.

4.4.1 DCC-06-1

There was not a single steam release to the FOV.

Table 4. Experiment values for PIV measurement sequence DCC-06-1

$q_{m,steam}$ [g/s]	47
$T_{pool,start}$ / $T_{pool,end}$ [°C]	23.5 / 23.5
ΔT_{pool} [°C]	0

4.4.2 DCC-06-2

There was not a single steam release to the FOV.

Table 5. Experiment values for PIV measurement sequence DCC-06-2

$q_{m,steam}$ [g/s]	76
$T_{pool,start}$ / $T_{pool,end}$ [°C]	23.4 / 23.5
ΔT_{pool} [°C]	0.1

4.4.3 DCC-06-3

12 out of 100 raw images were with a steam release to the water.

Table 6. Experiment values for PIV measurement sequence DCC-06-3

$q_{m,steam}$ [g/s]	98
$T_{pool,start}$ / $T_{pool,end}$ [°C]	23.6 / 24.0
ΔT_{pool} [°C]	0.4

4.4.4 DCC-06-4

81 out of 100 images were with steam release to the FOV.

Table 7. Experiment values for PIV measurement sequence DCC-06-4

$q_{m,steam}$ [g/s]	125
$T_{pool,start}$ / $T_{pool,end}$ [°C]	25.6 / 26.8
ΔT_{pool} [°C]	1.2

4.4.5 DCC-06-5

97 out of 100 images were with steam release to the FOV.

Table 8. Experiment values for PIV measurement sequence DCC-06-5

$q_{m,steam}$ [g/s]	152
$T_{pool,start}$ / $T_{pool,end}$ [°C]	29.5 / 31.3
ΔT_{pool} [°C]	1.8

4.4.6 DCC-06-6

Inspection of raw particle images revealed that there was not a single particle image without steam disturbance in the FOV. Throughout the measurement sequence bubbles ruined the major area of the FOV. With steam mass flow rate values of this degree the use of the PIV measurement system is optically too challenging even with the lowered FOV.

Table 9. Experiment values for PIV measurement sequence DCC-06-6

$q_{m,steam}$ [g/s]	152
$T_{pool,start}$ / $T_{pool,end}$ [°C]	34.1 / 45.2
ΔT_{pool} [°C]	11.1

4.4.7 DCC-06-7

No data available.

4.4.8 DCC-06-8

All raw images were with steam release to the FOV.

Table 10. Experiment values for PIV measurement sequence DCC-06-8

$q_{m,steam}$ [g/s]	83
$T_{pool,start}$ / $T_{pool,end}$ [°C]	47.9 / 48.1
ΔT_{pool} [°C]	0.2

4.4.9 DCC-06-9

Like in the DCC06-6 sequence also the majority of the raw images of DCC06-9 were optically disturbed with steam bubbles. Only 20 raw images out of 1024 were found to be intact and without disruption of steam bubbles. Even with smaller steam mass flow rate values steam creates major optical problems if the pool water has risen so much that condensing efficiency has decreased and steam bubbles travel in the water further.

Table 11. Experiment values for PIV measurement sequence DCC-06-9

$q_{m,steam}$ [g/s]	83
$T_{pool,start}$ / $T_{pool,end}$ [°C]	49.0 / 52.6
ΔT_{pool} [°C]	3.6

4.4.10 DCC-06-10

The sequence DCC-06-10 was different from the previous measurement sequences of the DCC-06 experiment as there were no steam discharge into the pool water. The driving force and possible velocity field was created by the 31.6 °C temperature difference between the pool bottom and top layer. The raw images for camera 2 were slightly out of focus on the far side of laser sheet. For camera 1 the top part was as well slightly out of focus. As the calibration plate dots are bigger than the tracer particles the focus is harder to inspect during the calibration process. Scheimpflug adjustment is applied to achieve sharp focus throughout the measurement plane by tilting the camera in comparison to the camera lens. In other words the Scheimpflug adjustment is used to tilt the focal plane to match the measurement plane and thus achieving sharp focus throughout the measurement plane. It seems that with growing angle between the observation window of the pool and the camera lens, the Scheimpflug adjustment is not able to match the need after some degree. This applies clearly both vertically and horizontally. This leaves out of focus particles in the far regions of the measurement plane(s). Out-of-focus particles are bigger in size than the in-focus particles. This creates problems in the sense that the out-of-focus regions need bigger interrogation windows. It is recommended to have 5-15 tracer particles inside an interrogation window. The same kind of defocusing problems occurred in the previous DCC-06-1, -2, -3 and -4 sequences. For sequences DCC 06-5, -6 and -8 the steam release to the FOV was a bigger optical problem.

Table 12. Experiment values for PIV measurement sequence DCC-06-10

$q_{m,steam}$ [g/s]	0
T_{pool} [°C]	52.6
$T_{pool\ bottom}$ [°C]	21

4.4.11 DCC-07-1

The steam mass flow rate in measurement sequence DCC-07-1 is similar to DCC-06-9. There were 118 raw images out of 1024 with steam bubbles in the FOV. Only two bigger steam releases penetrated the FOV and mostly just the upper region of the FOV was disturbed with steam bubbles. When comparing DCC-07-1 and DCC-06-9 the only difference is the pool temperature. The penetration power of a single steam release is drastically smaller when the water is at room temperature. It is noticeable that the first 604 images were completely without steam bubbles in the FOV. When the pool temperature reached 25 °C the bubbles started to penetrate the FOV. Only two steam releases penetrated the whole FOV and at that point the temperature was between 28-28.5 °C.

Table 13. Experiment values for PIV measurement sequence DCC-07-1

$q_{m,steam}$ [g/s]	91
$T_{pool,start}$ / $T_{pool,end}$ [°C]	23.5 / 28.5
ΔT_{pool} [°C]	5.0

4.4.12 DCC-07-2

In DCC-07-2, the steam mass flow rate and pool water temperature were higher. Steam release penetrated the whole FOV for the whole duration of the measurement sequence and therefore too much optical distortions were created.

Table 14. Experiment values for PIV measurement sequence DCC-07-2

$q_{m,steam}$ [g/s]	145
$T_{pool,start}$ / $T_{pool,end}$ [°C]	37.7 / 48.1
ΔT_{pool} [°C]	10.4

4.4.13 DCC-07-3

Sequence DCC-07-3 had the smallest steam mass flow rate of those cases where direct contact condensing occurred. Even with such a low steam mass flow rate optical distortions were present. This time there were no distinctive steam releases penetrating the FOV during the measurement sequence. Instead, the particles created streak patterns in the beginning of the sequence. This stopped after the first 75 raw images. The reason for this phenomenon is unknown yet.

Table 15. Experiment values for PIV measurement sequence DCC-07-3

$q_{m,steam}$ [g/s]	34
$T_{pool,start}$ / $T_{pool,end}$ [°C]	50.0 / 50.6
ΔT_{pool} [°C]	0.6

4.4.14 DCC-07-4

In DCC-07-4, the attributes were similar to DCC-06-10. Also the raw images were similar with the exception that there was a 50 second period of huge steam release because of accidentally opened steam line valve.

Table 16. Experiment values for PIV measurement sequence DCC-07-4

$q_{m,steam}$ [g/s]	0
T_{pool} [°C]	50.6
$T_{pool\ bottom}$ [°C]	21

4.5 DIFFERENT OPTICAL DISTORTION TYPES

A typical undisrupted particle image had defocusing problems for both cameras in the DCC-06 and DCC-07 experiments. Even though the calibration was successful the angle between the camera and the observation window of the pool makes focusing the whole measurement plane difficult. The viewing angles for the cameras are adverse. This is mainly due to the fact that the observation windows are small in size and when the FOV is moved horizontally or vertically the cameras are out of their “sweet spot”. It seems that this problem cannot be solved even with the Scheimpflug adjustment. The defocusing occurs both horizontally and vertically. Examples of typical disrupted particle images are shown in Figures 11 to 14.

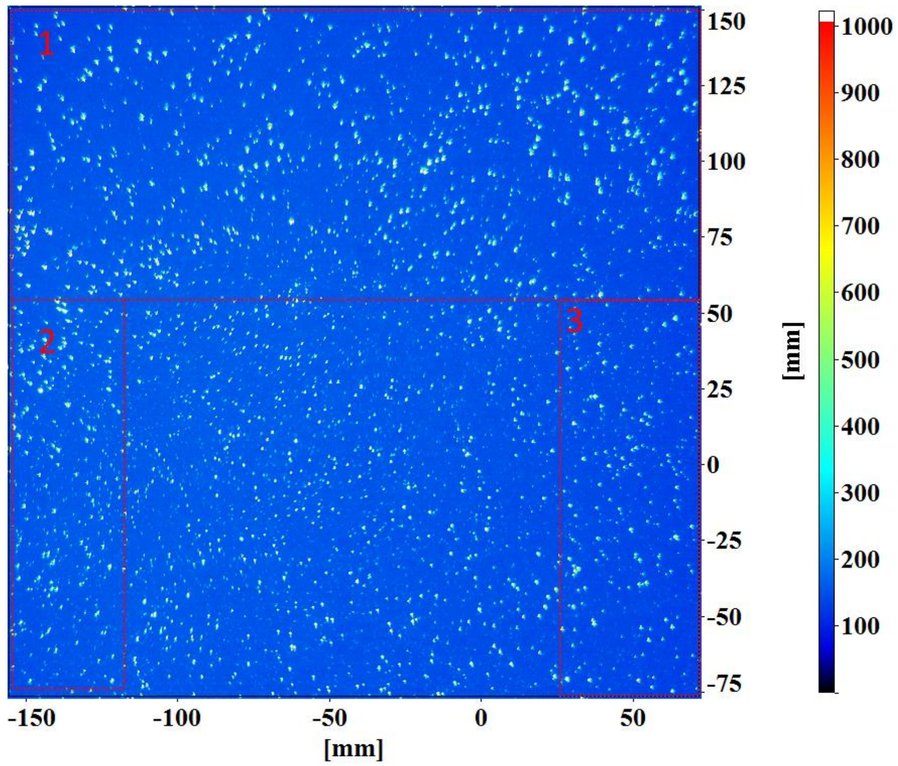

Figure 11. Particle image with highlighted defocused areas (DCC-07-4, image 69, camera 1).

In the top region (1) of Figure 10 the particles are clearly different in size compared to the middle. Also there is defocusing in the outer regions (2 and 3). Defocusing itself is not a major issue but having regions with different particle sizes need to be taken into account when choosing a proper interrogation window. Particles can also agglomerate so they appear bigger in size but in the DCC-06 and DCC-07 experiments the problem is defocusing because the phenomenon is present in all particle images.

Streak patterns also appeared, especially in the DCC-07-3 measurement sequence. A likely reason for this is temperature stratification. An example of the streaking phenomenon is presented in the Figure 12. The streaking is strongest between 0 mm and 75 mm in vertical direction.

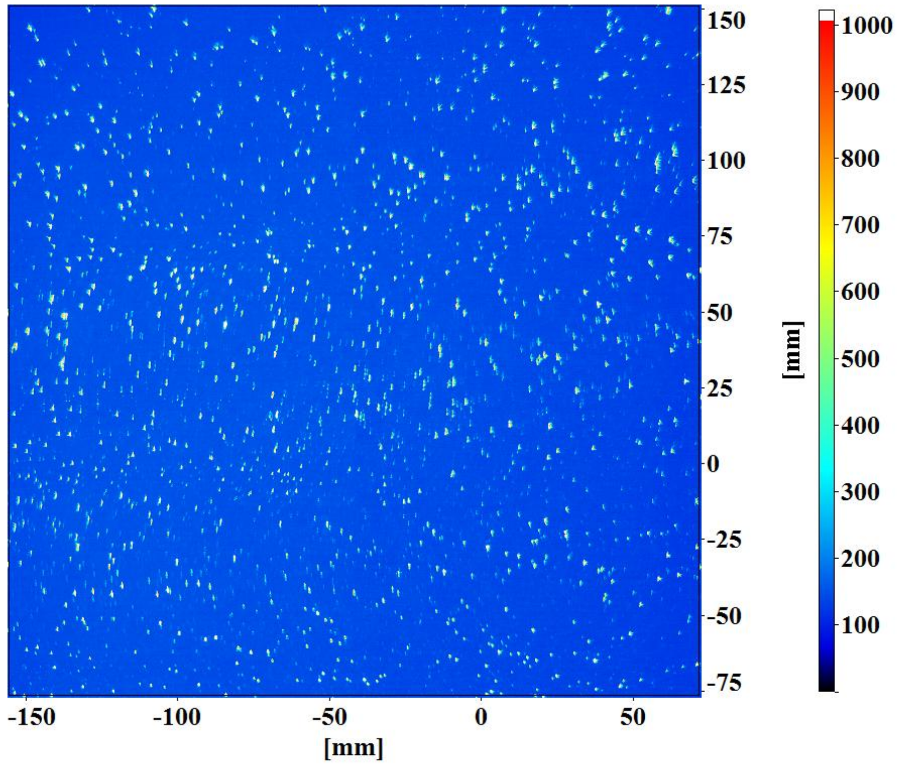

Figure 12. Streaks in the particle image (DCC-06-8, image 33, camera 1).

The biggest optical problem occurs when a steam release penetrates the FOV. Naturally the penetration power depends on the pool water temperature and the steam mass flow rate. An example of a minor steam release to the FOV is presented in the Figure 13.

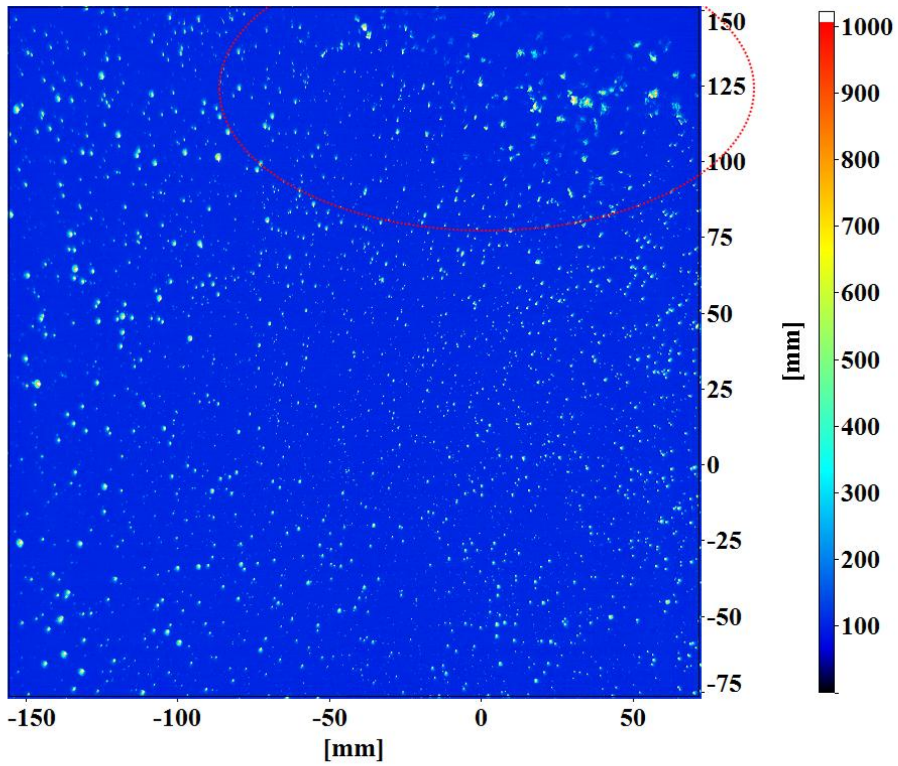

Figure 13. A minor steam release (DCC-06-4, image 28, camera 2).

A steam release differs from defocused particles and streaks as the particle behind the steam grows in size and diminishes in intensity level. Steam release is easy to observe from the images. A major steam release disrupts the whole particle image. An example of this is shown in Figure 14. The particles are dim and the size is around the size of a single interrogation window.

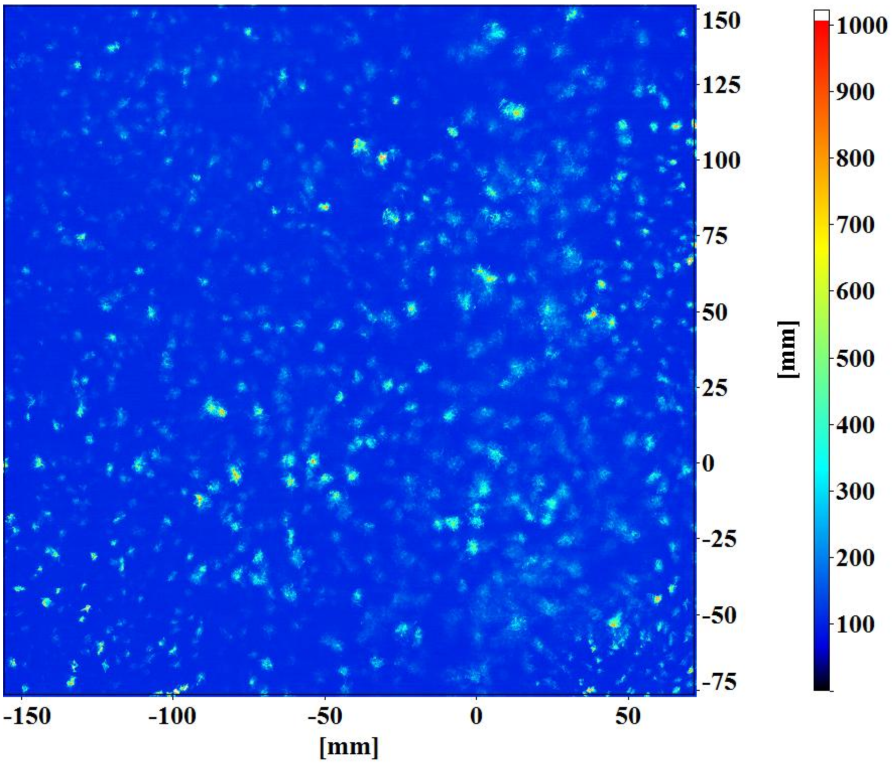

Figure 14. A major steam release (DCC-06-6, image 69, camera 2).

4.6 VELOCITY ANALYSIS

For time-averaging purposes close to a constant velocity field should exist. Otherwise the fluctuations will diminish average velocity field close to zero depending on the characteristics of the flow. Time-averaging is a way to increase the precision of the measurement. A good example of a fluctuating behavior can be seen in the Figures 15 to 17.

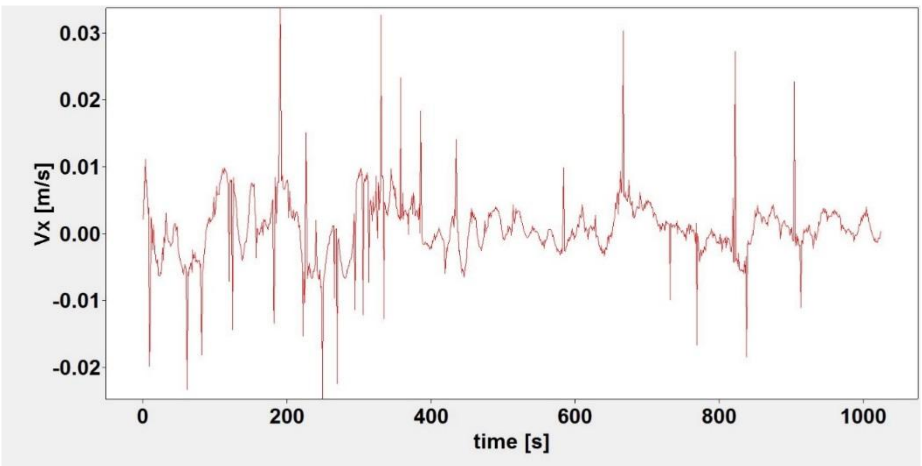

Figure 15. Velocity in x-direction in DCC-07-3 at the point 0,0 on the measurement plane.

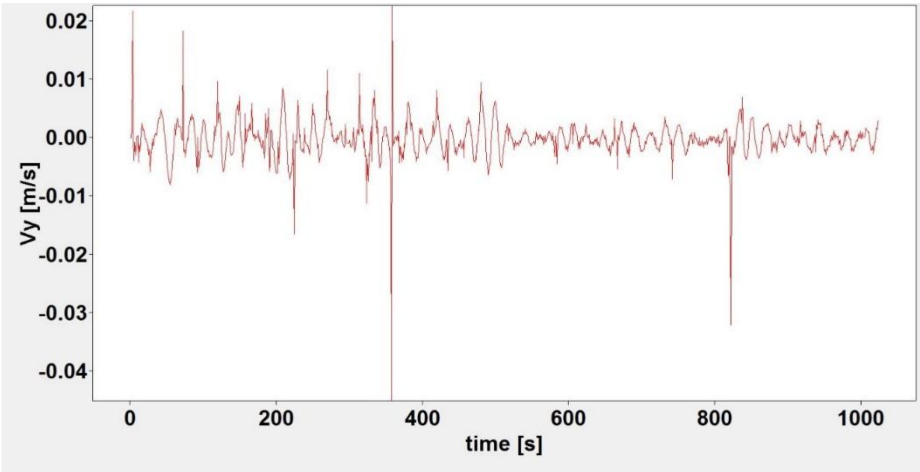

Figure 16. Velocity in y-direction in DCC-07-3 at the point 0,0 on the measurement plane.

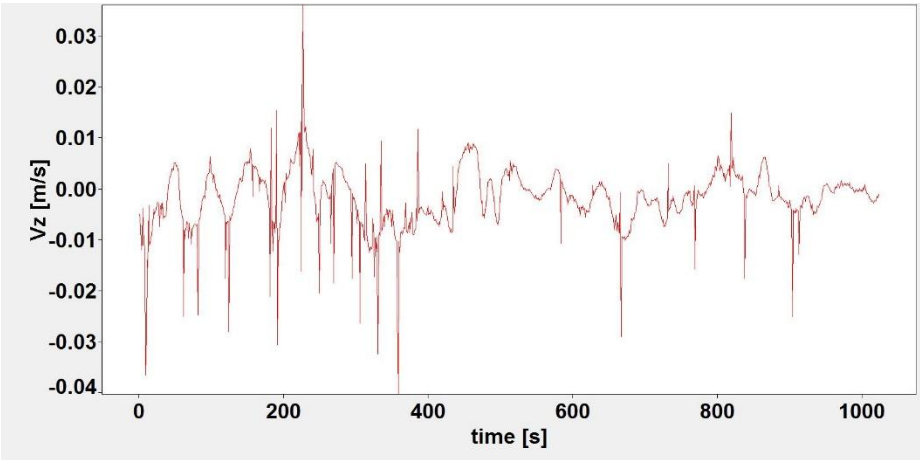

Figure 17. Velocity in z-direction in DCC-07-3 at the point 0,0 on the measurement plane.

Mass flow rate during the DCC-07-3 measurement sequence was 34 g/s being the smallest in the whole experiment series. Even with such a small mass flow rate the fluctuations are high thus making time-averaging impossible. The only way to present the results is as velocity fields from a single time-step. To measure a single steam release one would need a PIV measurement system with a much higher measuring frequency.

4.7 RESULTS

The visual inspection of the raw images gave indication that even with the lowered position of the FOV steam creates major optical problems that cannot be overcome with the new red band pass filters. When the steam mass flow rate was 98 g/s in DCC-06-3 around 12 % of the raw images were with the steam release. In DCC-07-1 the mass flow rate was 91 g/s and around 11.5 % were with similar situation. For these sequences the pool water temperature was between 23.5-28.5 °C. When the water temperature gets higher the penetrating power of the steam release is bigger. For example in DCC-06-8 the steam mass flow rate was 83 g/s and the pool water temperature above 47.9 °C and the steam release distorted 100% of the raw images. Different optical distortions are presented in Figures 11 to 14.

As it was expressed in the Chapter 4.6 time-averaging will not work for the DCC-06 and DCC-07 experiments because of the fluctuating behavior of the water phase. Not even the lowered position of the FOV helped. The only way to present any PIV results from DCC-06 and DCC-07 is with individual vector images when there are optically intact raw images available.

All the vector images were analyzed with the DaVis 8.2 software. An adaptive PIV algorithm was used for the analysis. The algorithm changes the size and the shape of the interrogation windows depending on the local tracer particle density and flow gradients. The final size of the interrogation window was chosen to be 64x64 pixels in all the cases. The individual vector images are presented in Appendix 2. The red vector indicates the xy-velocity and the background color z-velocity. The main attributes of the measurement sequences are also presented next to the vector field.

LaVision started to offer a new tool called "Uncertainty Quantification", UQ, for individual vector fields using Correlation Statistics method [18] in the end of 2014. The quantification should give indications for experimental and processing parameters such as seeding density, out-of-plane-motion, interrogation window size and etc. The new tool offers the uncertainty for the velocity components as well as the bias error for each velocity component. The update for software, called DaVis 8.2.2., with the new UQ tool was released in the end of November. In Appendix 2, there are also the new uncertainty quantification fields for each velocity direction presented as well as the bias error. In general, it can be said that the overall bias error is around 1% of the respective velocity. Uncertainties for the velocity vectors are roughly from 10 % to 50 % depending on the region. This also indicates that the present measuring set-up is optically too challenging and the results are not robust.

In Appendix 2, the spurious vectors are left in the velocity vector fields. Usually spurious vectors are deleted and replacing vector is interpolated from the neighboring vectors. That is possible when the amount of spurious vectors is small and they are not stacked in groups. There are spurious vectors present in all of the results. The amount of spurious vectors is clearly dependent on the temperature of the pool water. In DCC-06-1, there are only few spurious vectors present whereas in DCC-07-3 the amount of spurious vectors is drastically larger even with a smaller mass flow rate of the steam.

4.8 DISCUSSION AND FUTURE IMPROVEMENTS

There are many challenges when executing PIV measurements in the PPOOLEX test facility. Due to the structural restrictions of PPOOLEX installing of bigger observation windows is out of question. There is a support rim going around PPOOLEX just there where the optimal place for observing windows would be. The existing observation windows are also directed towards the centerline of the blowdown pipe and moving the PIV camera in relation to window creates optical distortions on the outermost regions of the camera image. Due to that moving camera sideways directly underneath the pipe is problematic although possible. There was also an alternative experiment labelled DCC-08, where the upper observing windows were used. Because of the angle for the camera 2 steam bubbles and incondensable gases blurred out the whole view. Even with a small steam mass flow rate this did not turn out to be a feasible way to measure.

The character of the flow in most steam discharge experiments is fluctuating and chaotic. These fluctuations make the time-averaging of PIV images impossible. There is no constant flow direction to be found in the DCC experiments. The only way to obtain data, that could be time-averaged, would be by triggering the system on the basis of some pressure or temperature value that then would correspond to a constant flow situation in the measurement area. This would mean developing a novel pre-triggering system for PIV. This can be considered very challenging to build. Even this option does not exclude the fact that when there are optical distortions present, the PIV vector result is corrupted. At the moment there is not a way to get around these optical distortions. However, the new filters succeeded well by cutting the reflections from the actual steam bubbles.

The main finding from the DCC-06 and DCC-07 experiments is that PIV cannot be applied successfully for velocity measurements with the current measuring set-up. In general, it is challenging to measure two-phase flow with a lot of condensing from steam phase to water phase. It is possible to measure the velocity of the water phase, but only from areas where condensing does not occur. Taking this into consideration with the fact that the optical set-up is restricted heavily, the overall feasibility of the PIV in its current experimental set-up is under question. An optical measurement system naturally needs good optical data to be applied successfully. Point measurement with a Laser Doppler Velocimetry (LDV) system might work better because the need for optical access is not as crucial as it is for PIV. The loss of wide spatial resolution would be substituted with better temporal resolution (in kilohertz range).

5 CONCLUSIONS

This report summarizes the results of the DCC-06 and DCC-07 experiments in 2014 with the scaled down PPOOLEX test facility designed and constructed at Lappeenranta University of Technology. The test facility is a closed stainless steel vessel divided into two compartments, drywell and wetwell. The main objective of the experiments was to use the PIV measurement system in different direct contact condensation situations in order to obtain velocity field data to be used in verification of CFD simulation results.

Both experiments consisted of several PIV measurement sequences, where different steam flow rates and pool water temperatures were used. Most of the time the steam/water interface moved up and down along the blowdown pipe as a result of rapid condensation taking place either inside the pipe or at the pipe outlet. There was only a short period of time in DCC-06, when the steam/water interface was quite calm at the blowdown pipe outlet. Despite of clear chugging the used steam flow rates were not high enough for strong internal circulation to develop and mix the pool. Therefore thermal stratification of the wetwell pool could be observed. Temperatures remained almost constant at the pool bottom but increased towards the surface layers. The final temperature difference between the pool bottom and water surface was about 40 °C.

Steam release into the pool water created major optical problems for the PIV measurements. The problems couldn’t be avoided even with the new red band pass filters. Time-averaging of the PIV images did not work due to the fluctuating behavior of the water phase. Therefore, the PIV results from the DCC-06 and DCC-07 experiments can be presented only as individual vector images from those measurement sequences where optically intact raw images are available. It is possible to measure the velocity field of the water phase, but only from areas where condensing does not occur.

The main finding from the DCC-06 and DCC-07 experiments is that PIV cannot be applied successfully for velocity measurements near the blowdown pipe outlet with the current PPOOLEX measuring set-up. The character of the flow in most steam discharge experiments is fluctuating and chaotic. These fluctuations make the time-averaging of PIV images impossible because there is no constant flow direction to be found. In addition, when there are optical distortions present, the PIV vector result is corrupted. At the moment there is not a way to get around these optical distortions even though the new filters succeeded well by cutting the reflections from the actual steam bubbles.

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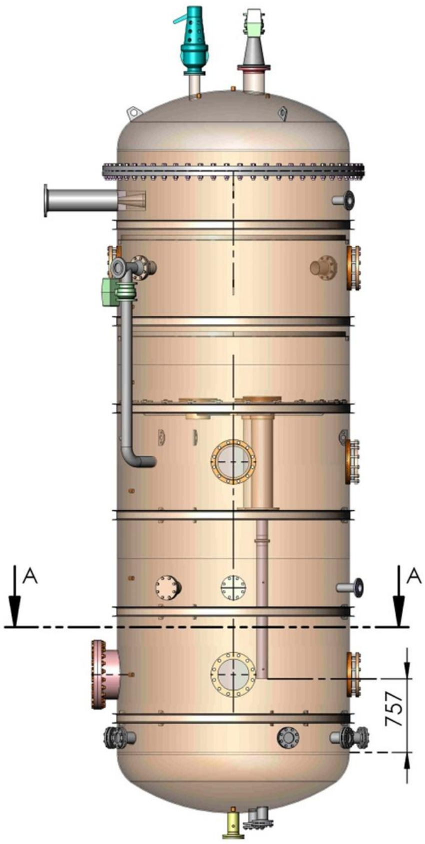
APPENDIX 1: PPOOLEX INSTRUMENTATION



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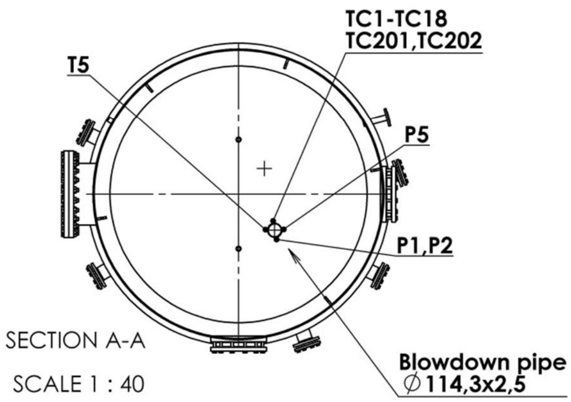
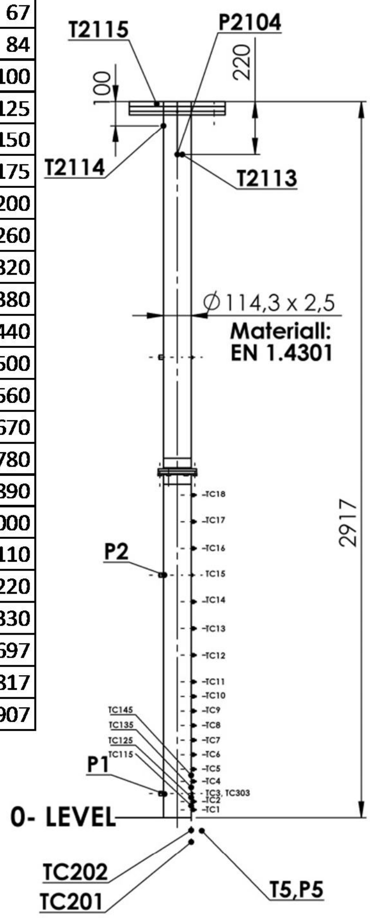
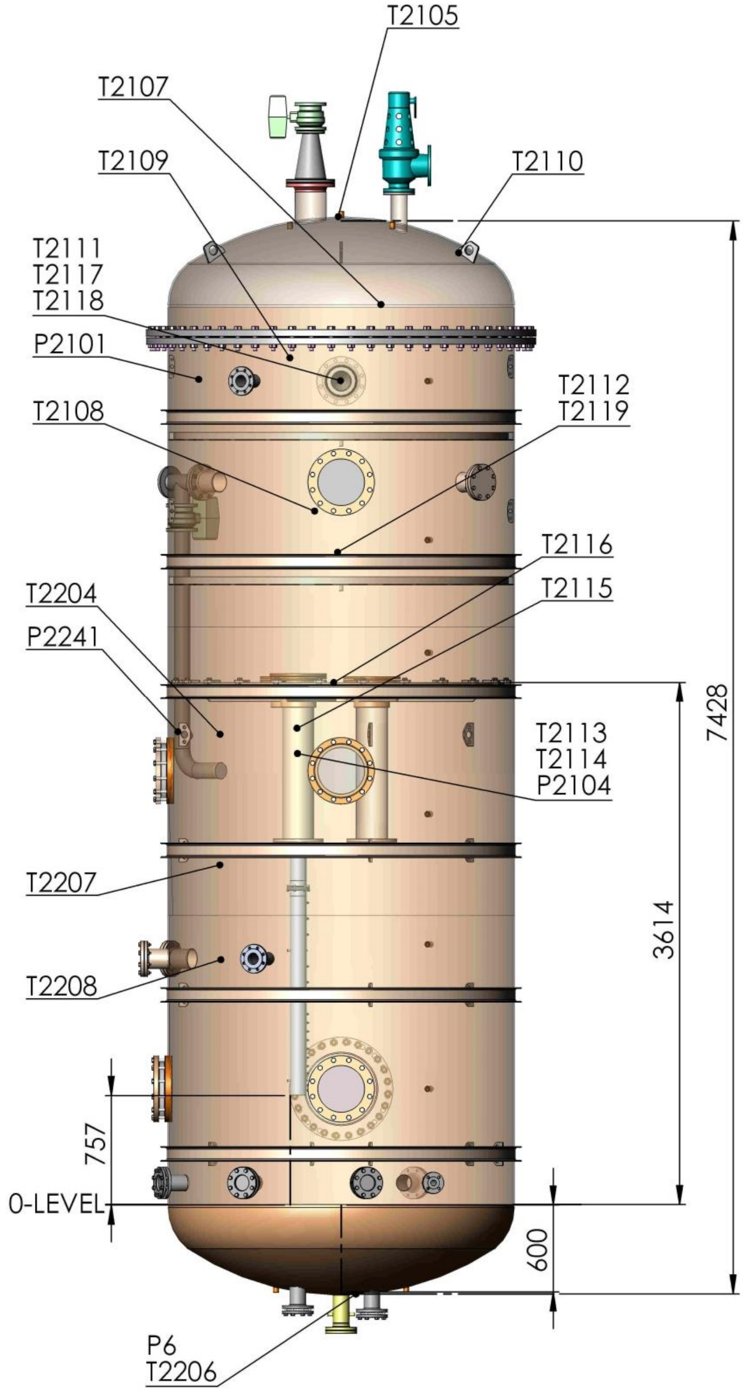
TC202, T5, P5	-50
TC1	33
TC115	50
TC2	67
TC125	84
TC3, TC303, P1	100
TC135	125
TC4	150
TC 145	175
TC5	200
TC6	260
TC7	320
TC8	380
TC9	440
TC10	500
TC11	560
TC12	670
TC13	780
TC14	890
TC15, P2	1000
TC16	1110
TC17	1220
TC18	1330
T2113, P2104	2697
T2114	2817
T2115	2907

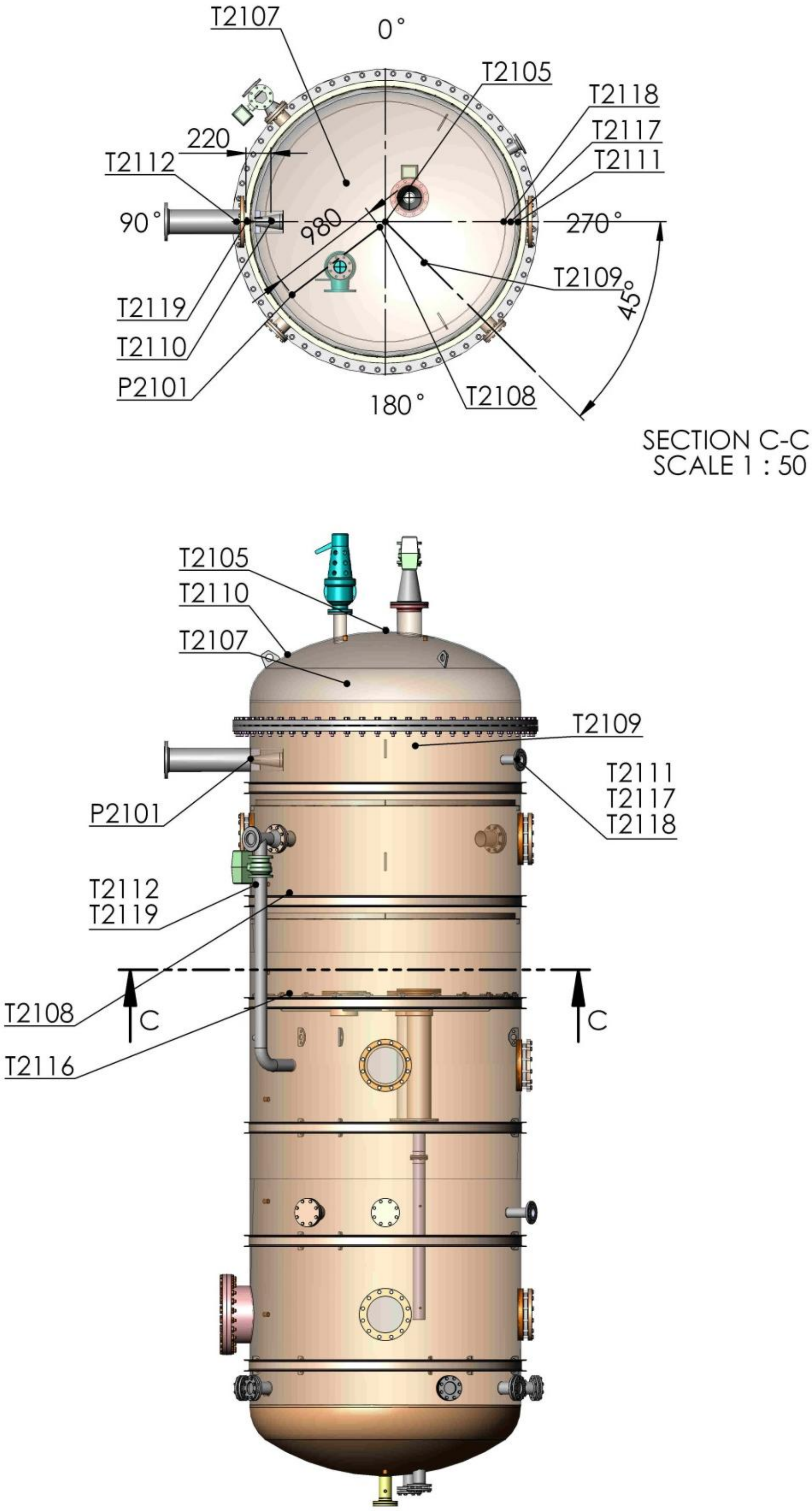




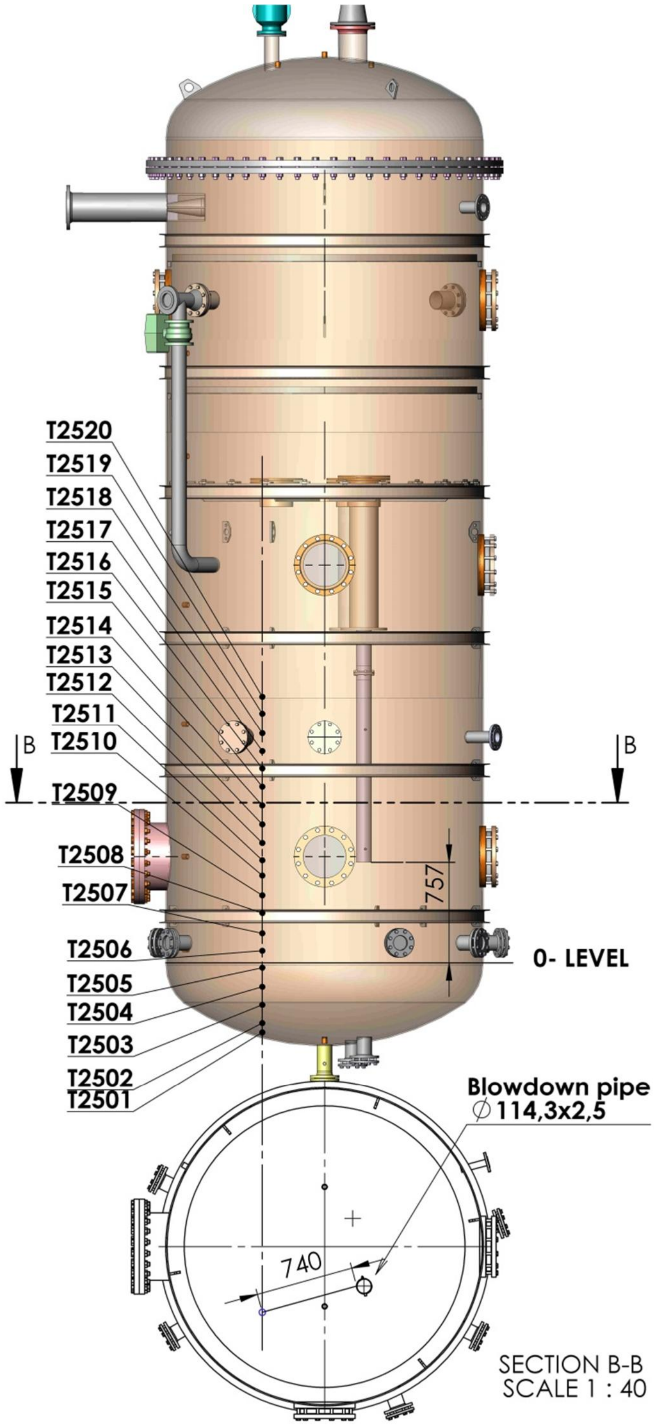
Blowdown pipe measurements in the DCC-06 and DCC-07 tests.



Test vessel measurements.

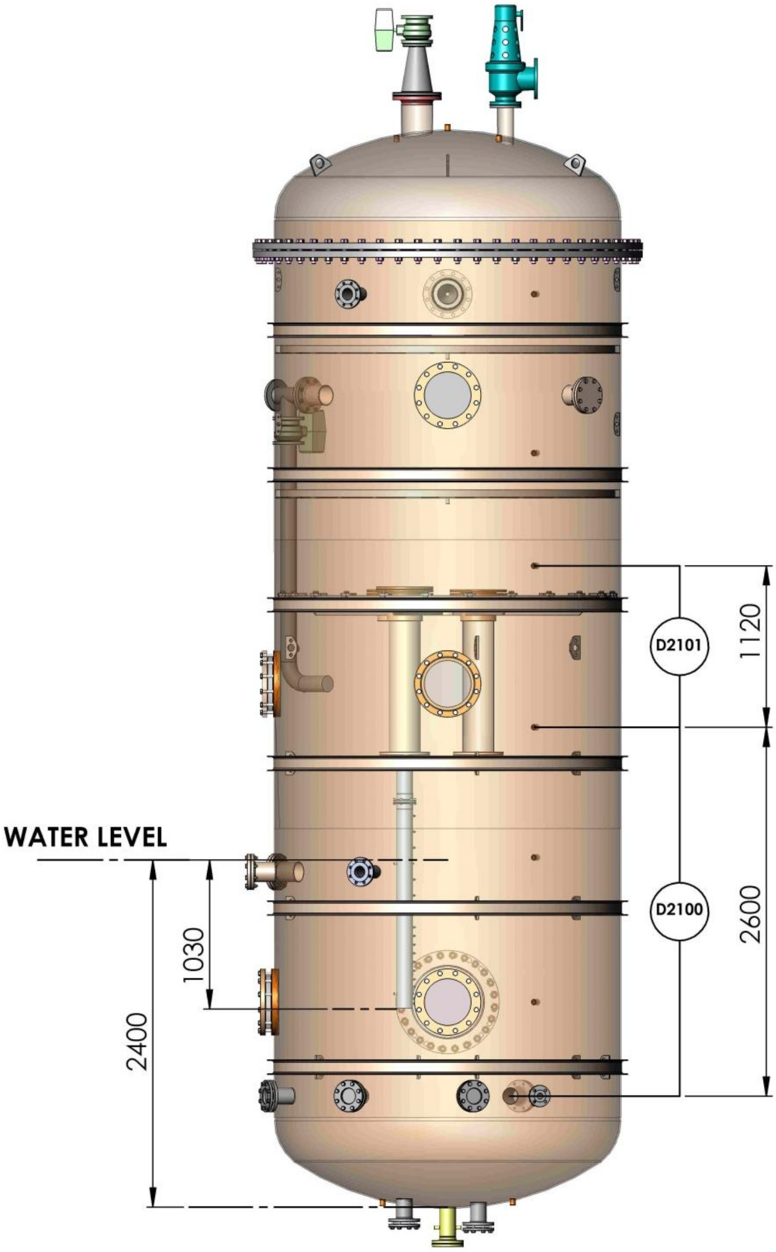


Drywell measurements.

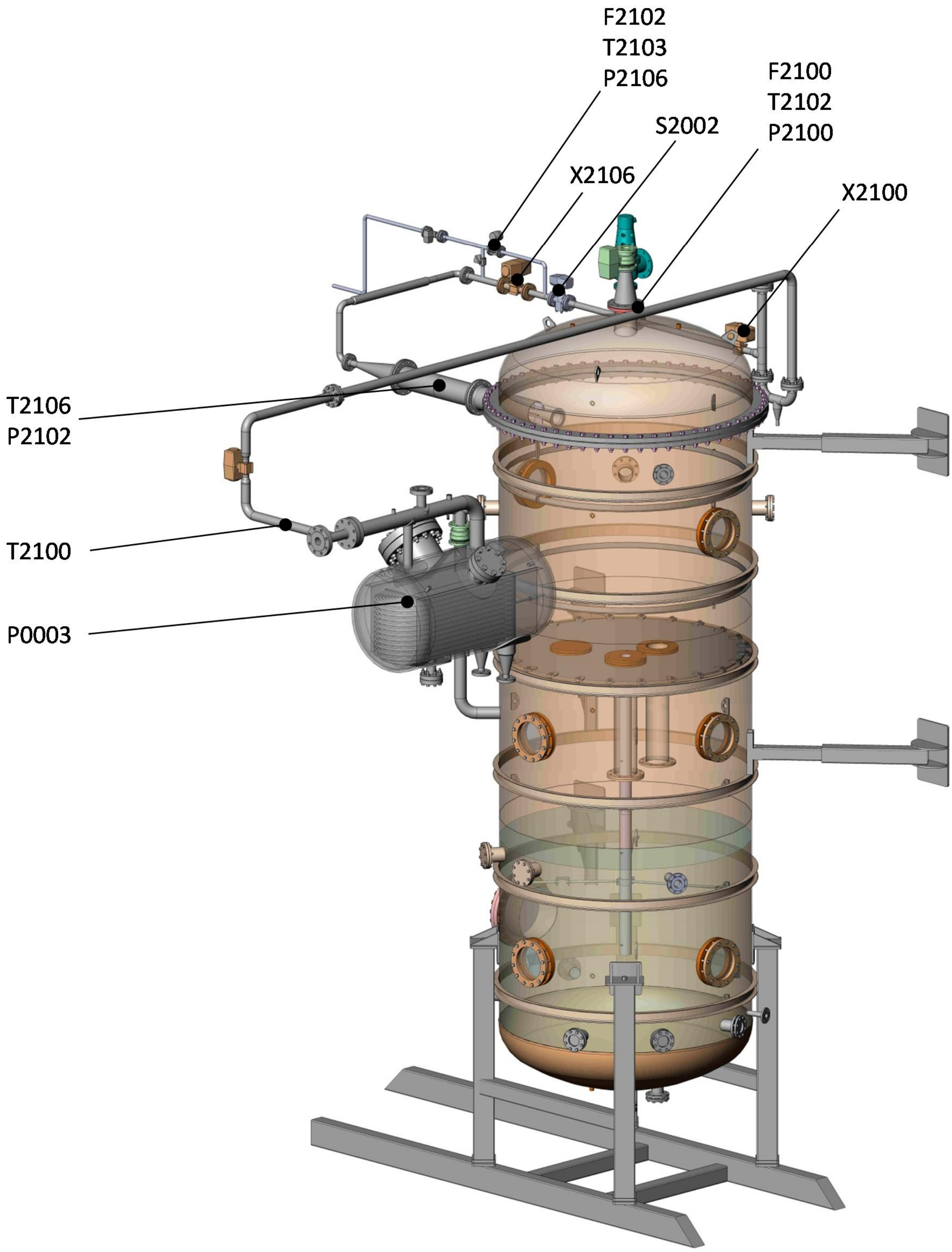


Code	Level
T2501	-530
T2502	-390
T2503	-260
T2504	-125
T2505	10
T2506	150
T2507	287
T2508	427
T2509	560
T2510	695
T2511	830
T2512	965
T2513	1103
T2514	1236
T2515	1369
T2516	1505
T2517	1640
T2518	1775
T2519	1910
T2520	2045

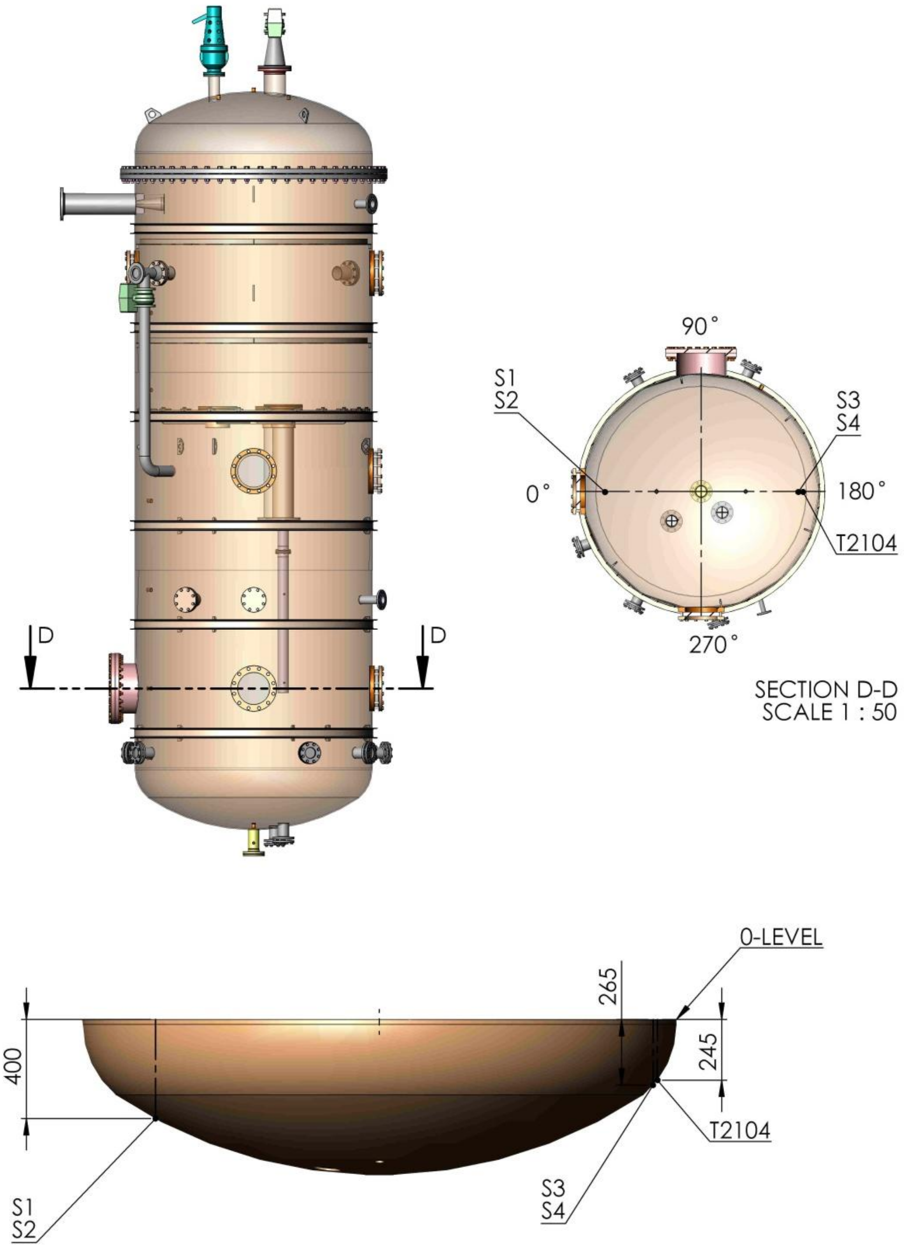
Temperature measurements in the wetwell pool for the detection of thermal stratification.



Pressure difference measurements. Nominal water level is 2.4 m.



Measurements in the steam line.



Strain gauges and thermocouple T2104 on the outer wall of the pool bottom.

Measurement	Code	Elevation	Location	Error estimation	Measurement software
High speed camera trigger	C1	-	Wetwell	Not defined	LabView
Pressure difference	D2100	100–2700	Wetwell	±0.05 m	FieldPoint
Pressure difference	D2101	2700–3820	Across the floor	±4000 Pa	FieldPoint
Flow rate	F2100	-	DN50 Steam line	±4.9 l/s	FieldPoint
Flow rate	F2102	-	DN25 Steam line	±0.7 l/s	FieldPoint
Pressure	P1	857	Blowdown pipe	±0.7 bar	LabView
Pressure	P2	1757	Blowdown pipe	±0.7 bar	LabView
Pressure	P5	707	Blowdown pipe outlet	±0.7 bar	LabView
Pressure	P6	-615	Wetwell bottom	±0.5 bar	LabView
Pressure	P2100	-	DN50 Steam line	±0.2 bar	FieldPoint
Pressure	P2101	5700	Drywell	±0.03 bar	FieldPoint
Pressure	P2102	-	Inlet plenum	±0.03 bar	FieldPoint
Pressure	P2104	3454	Blowdown pipe	±0.03 bar	FieldPoint
Pressure	P2106	-	DN25 Steam line	±0.06 bar	FieldPoint
Pressure	P2241	3600	Wetwell gas space	±0.05 bar	FieldPoint
Control valve position	S2002	-	DN50 Steam line	Not defined	FieldPoint
Strain	S1	-400	Bottom segment	Not defined	LabView
Strain	S2	-400	Bottom segment	Not defined	LabView
Strain	S3	-265	Bottom segment	Not defined	LabView
Strain	S4	-265	Bottom segment	Not defined	LabView
Temperature	T5	707	Blowdown pipe outlet	±1.8 °C	LabView
Temperature	T1279	-3860	Laboratory	±1.8 °C	FieldPoint
Temperature	T1280	-1860	Laboratory	±1.8 °C	FieldPoint
Temperature	T1281	140	Laboratory	±1.8 °C	FieldPoint
Temperature	T1282	2140	Laboratory	±1.8 °C	FieldPoint
Temperature	T1283	4140	Laboratory	±1.8 °C	FieldPoint
Temperature	T1284	6140	Laboratory	±1.8 °C	FieldPoint
Temperature	T1285	8140	Laboratory	±1.8 °C	FieldPoint
Temperature	T2100	-	Steam line beginning	±3.5 °C	FieldPoint
Temperature	T2102	-	DN50 Steam line	±1.8 °C	FieldPoint
Temperature	T2103	-	DN25 Steam line	±1.8 °C	FieldPoint
Temperature	T2104	-245	Wetwell outer wall	±1.8 °C	FieldPoint
Temperature	T2105	6780	Drywell top	±1.8 °C	FieldPoint
Temperature	T2106	-	Inlet plenum	±1.8 °C	FieldPoint
Temperature	T2107	6085	Drywell middle	±1.8 °C	FieldPoint
Temperature	T2108	4600	Drywell bottom	±1.8 °C	FieldPoint
Temperature	T2109	5790	Drywell lower middle	±1.8 °C	FieldPoint
Temperature	T2110	6550	Drywell outer wall	±1.8 °C	FieldPoint
Temperature	T2111	5700	Drywell outer wall	±1.8 °C	FieldPoint
Temperature	T2112	4600	Drywell outer wall	±1.8 °C	FieldPoint
Temperature	T2113	3454	Blowdown pipe	±1.8 °C	LabView
Temperature	T2114	3574	Blowdown pipe	±1.8 °C	FieldPoint
Temperature	T2115	3664	Blowdown pipe	±1.8 °C	FieldPoint
Temperature	T2116	3600	Drywell floor	±1.8 °C	FieldPoint
Temperature	T2117	5700	Drywell inner wall	±1.8 °C	FieldPoint
Temperature	T2118	5700	Drywell, 10 mm from the wall	±1.8 °C	FieldPoint
Temperature	T2119	4600	Drywell inner wall	±1.8 °C	FieldPoint

Temperature	T2204	3410	Wetwell gas space	±1.8 °C	FieldPoint
Temperature	T2206	-615	Wetwell bottom	±1.8 °C	FieldPoint
Temperature	T2207	2585	Wetwell gas space	±1.8 °C	FieldPoint
Temperature	T2208	1760	Wetwell gas space	±1.8 °C	FieldPoint
Temperature	T2501	-530	Wetwell	±1.8 °C	FieldPoint
Temperature	T2502	-390	Wetwell	±1.8 °C	FieldPoint
Temperature	T2503	-260	Wetwell	±1.8 °C	FieldPoint
Temperature	T2504	-125	Wetwell	±1.8 °C	FieldPoint
Temperature	T2505	10	Wetwell	±1.8 °C	FieldPoint
Temperature	T2506	150	Wetwell	±1.8 °C	FieldPoint
Temperature	T2507	287	Wetwell	±1.8 °C	FieldPoint
Temperature	T2508	427	Wetwell	±1.8 °C	FieldPoint
Temperature	T2509	560	Wetwell	±1.8 °C	FieldPoint
Temperature	T2510	695	Wetwell	±1.8 °C	FieldPoint
Temperature	T2511	830	Wetwell	±1.8 °C	FieldPoint
Temperature	T2512	965	Wetwell	±1.8 °C	FieldPoint
Temperature	T2513	1103	Wetwell	±1.8 °C	FieldPoint
Temperature	T2514	1236	Wetwell	±1.8 °C	FieldPoint
Temperature	T2515	1369	Wetwell	±1.8 °C	FieldPoint
Temperature	T2516	1505	Wetwell	±1.8 °C	FieldPoint
Temperature	T2517	1640	Wetwell	±1.8 °C	FieldPoint
Temperature	T2518	1775	Wetwell	±1.8 °C	FieldPoint
Temperature	T2519	1910	Wetwell	±1.8 °C	FieldPoint
Temperature	T2520	2045	Wetwell	±1.8 °C	FieldPoint
Temperature	TC01	790	Blowdown pipe	±1.8 °C	LabView
Temperature	TC115	807	Blowdown pipe	±1.8 °C	LabView
Temperature	TC02	824	Blowdown pipe	±1.8 °C	LabView
Temperature	TC125	841	Blowdown pipe	±1.8 °C	LabView
Temperature	TC03	857	Blowdown pipe	±1.8 °C	LabView
Temperature	TC135	882	Blowdown pipe	±1.8 °C	LabView
Temperature	TC04	907	Blowdown pipe	±1.8 °C	LabView
Temperature	TC145	932	Blowdown pipe	±1.8 °C	LabView
Temperature	TC05	957	Blowdown pipe	±1.8 °C	LabView
Temperature	TC06	1017	Blowdown pipe	±1.8 °C	LabView
Temperature	TC07	1077	Blowdown pipe	±1.8 °C	LabView
Temperature	TC08	1137	Blowdown pipe	±1.8 °C	LabView
Temperature	TC09	1197	Blowdown pipe	±1.8 °C	LabView
Temperature	TC10	1257	Blowdown pipe	±1.8 °C	LabView
Temperature	TC11	1317	Blowdown pipe	±1.8 °C	LabView
Temperature	TC12	1427	Blowdown pipe	±1.8 °C	LabView
Temperature	TC13	1537	Blowdown pipe	±1.8 °C	LabView
Temperature	TC14	1647	Blowdown pipe	±1.8 °C	LabView
Temperature	TC15	1757	Blowdown pipe	±1.8 °C	LabView
Temperature	TC16	1867	Blowdown pipe	±1.8 °C	LabView
Temperature	TC17	1977	Blowdown pipe	±1.8 °C	LabView
Temperature	TC18	2087	Blowdown pipe	±1.8 °C	LabView
Temperature	TC201	657	Below blowdown pipe	±1.8 °C	LabView
Temperature	TC202	707	Below blowdown pipe	±1.8 °C	LabView
Temperature	TC303	857	Blowdown pipe outer surface	±1.8 °C	LabView
Cut-off valve position	V1	-	DN50 Steam line	Not defined	LabView

Cut-off valve position	X2100	-	DN50 Steam line	Not defined	FieldPoint
Steam partial pressure	X2102	4600	Drywell	Not defined	FieldPoint
High speed camera trigger	X2103	-	Wetwell	Not defined	FieldPoint
Cut-off valve position	X2106	-	DN50 Steam line	Not defined	FieldPoint

Measurements of the PPOOLEX facility in the DCC-06 and DCC-07 test.

APPENDIX 2: SELECTED VECTOR IMAGES FROM DCC-06 AND DCC-07 EXPERIMENTS

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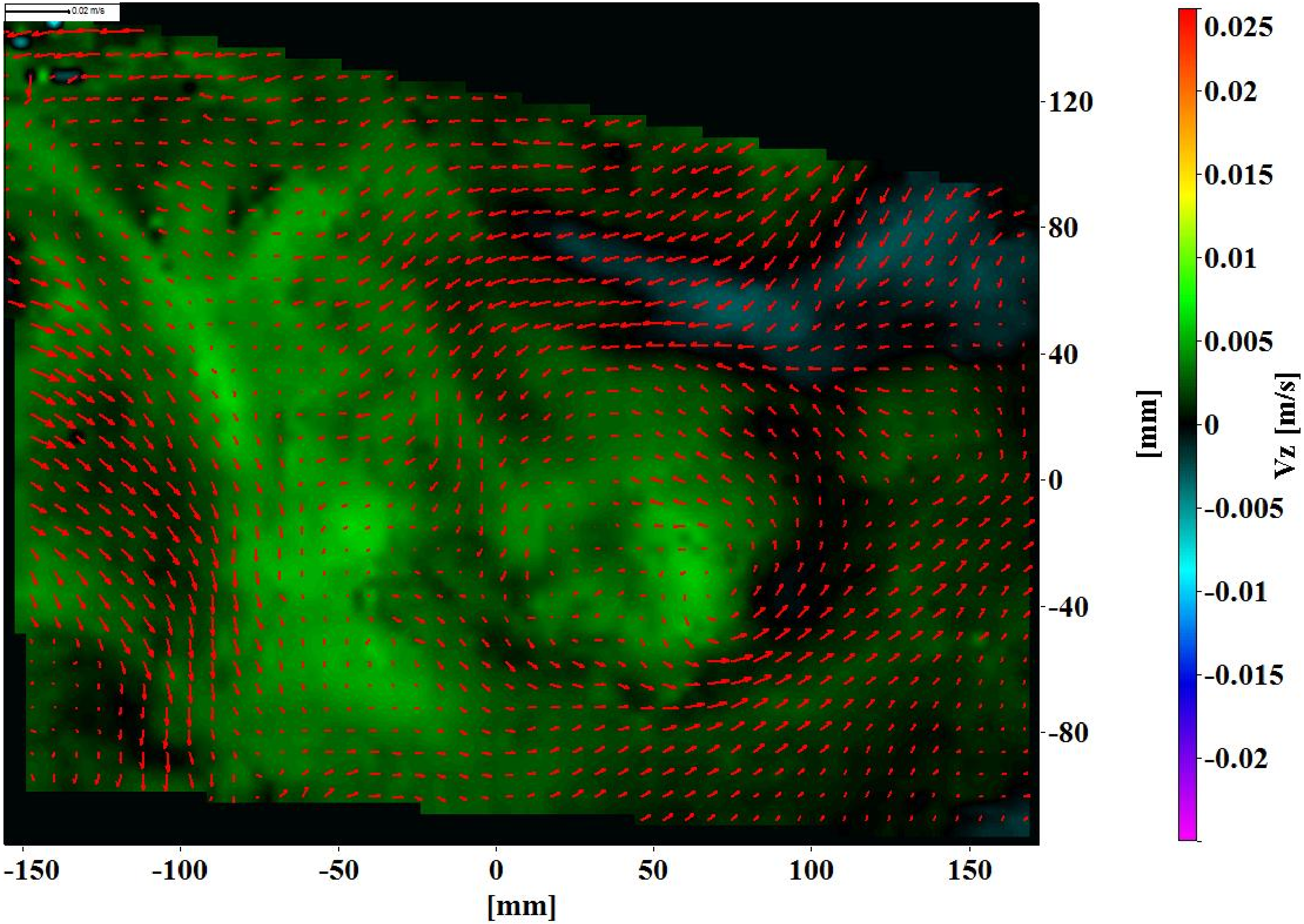
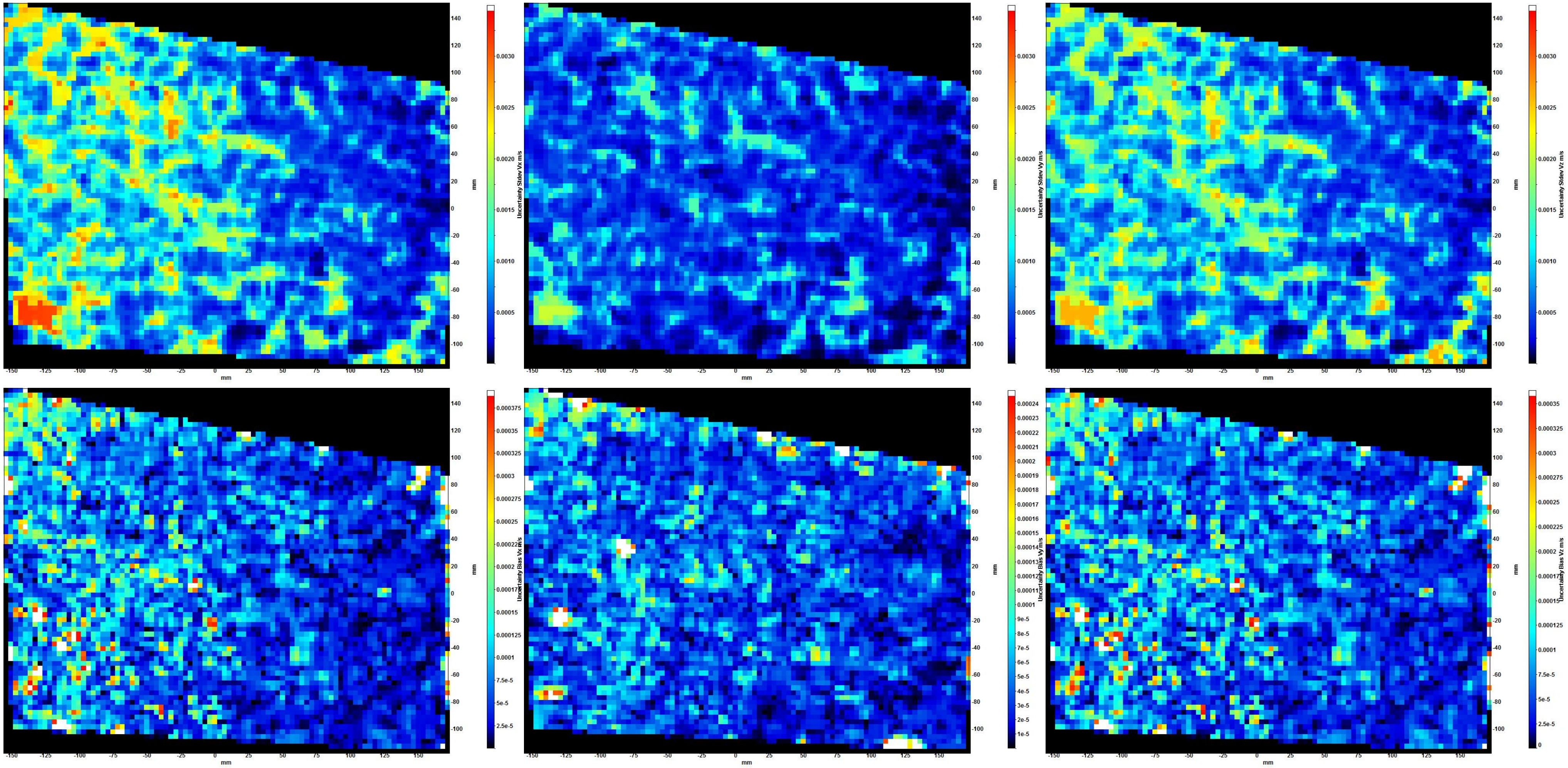
DCC06-1
t = 941 s
T_{pool} = 23,479 °C
$P_{blowdown}$ = 2,8526 bar
P_{pool} = 2,8039 bar
$q_{m,steam}$ = 47 g/s

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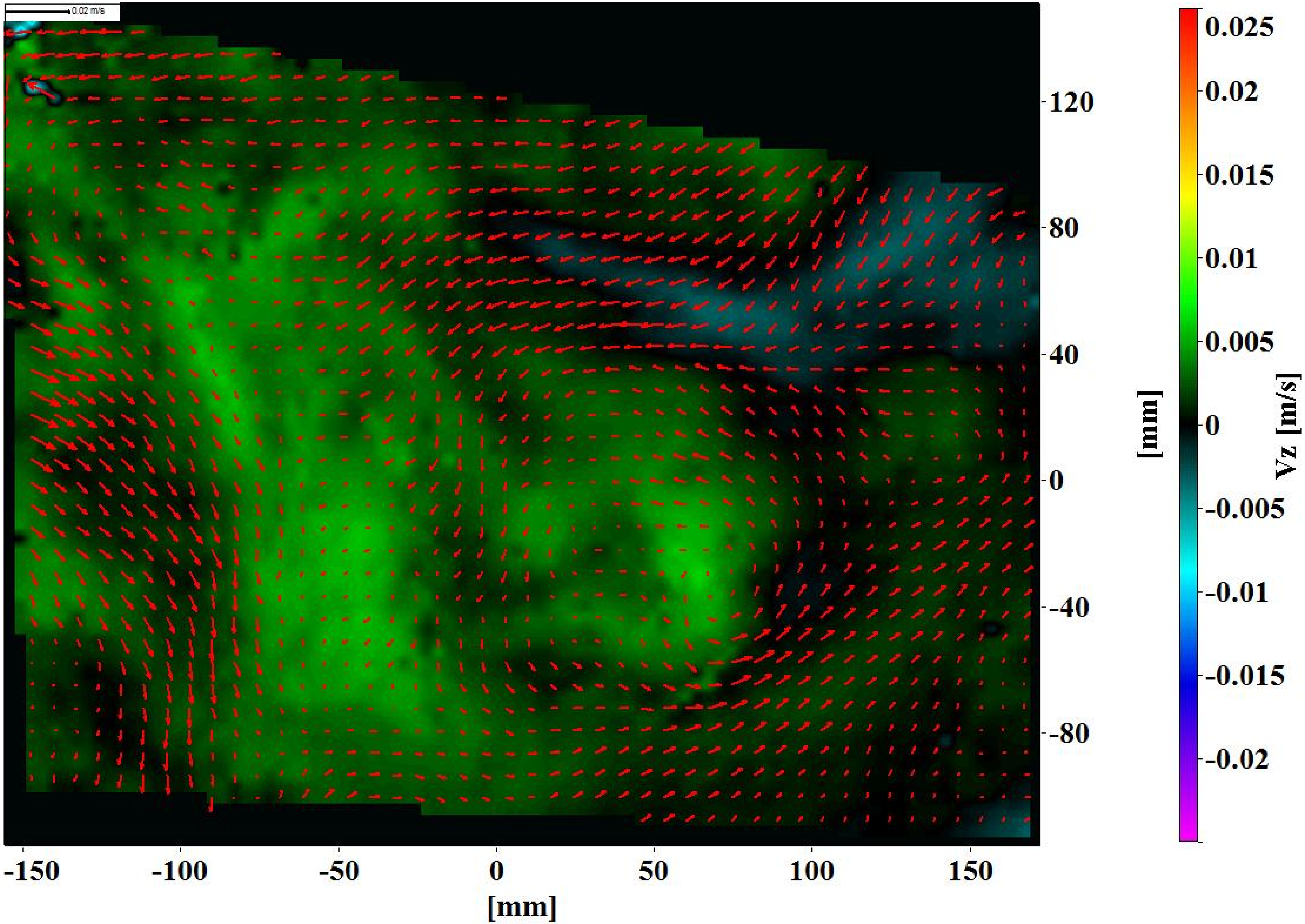
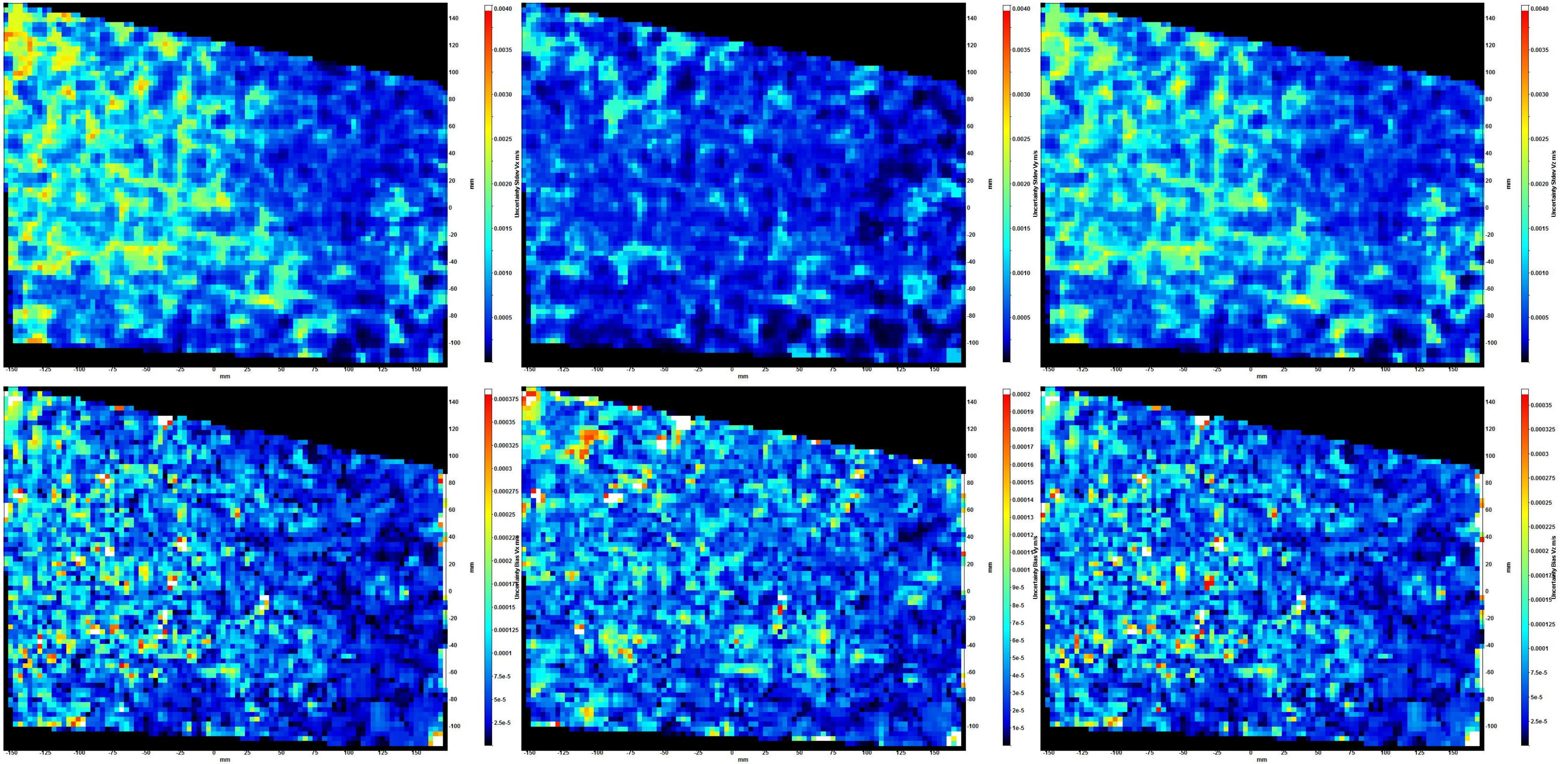
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC06-1
t = 942 s
T_{pool} = 23,479 °C
P_{blowdown} = 2,8526 bar
P_{pool} = 2,8039 bar
$q_{\text{m,steam}}$ = 47 g/s

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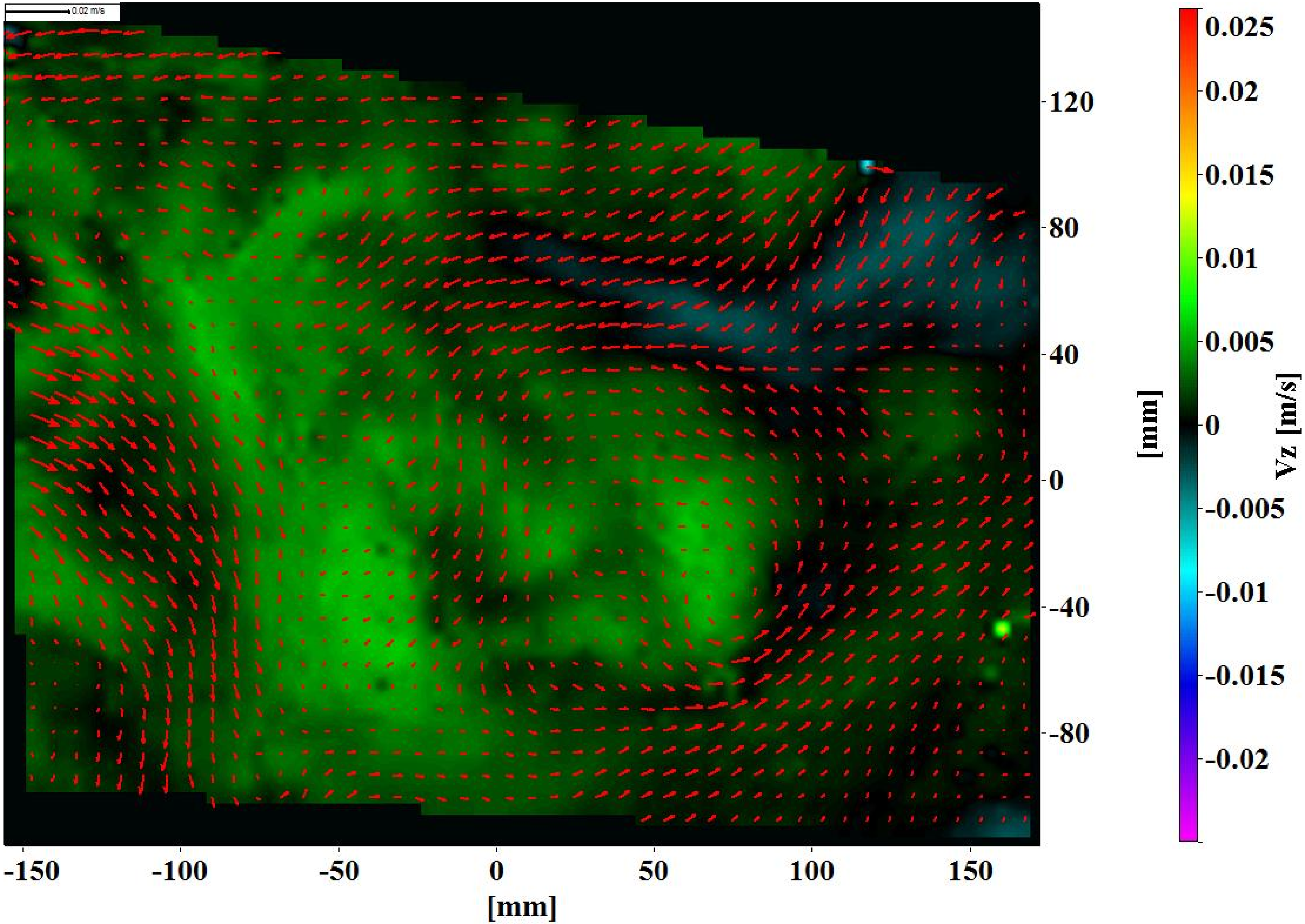
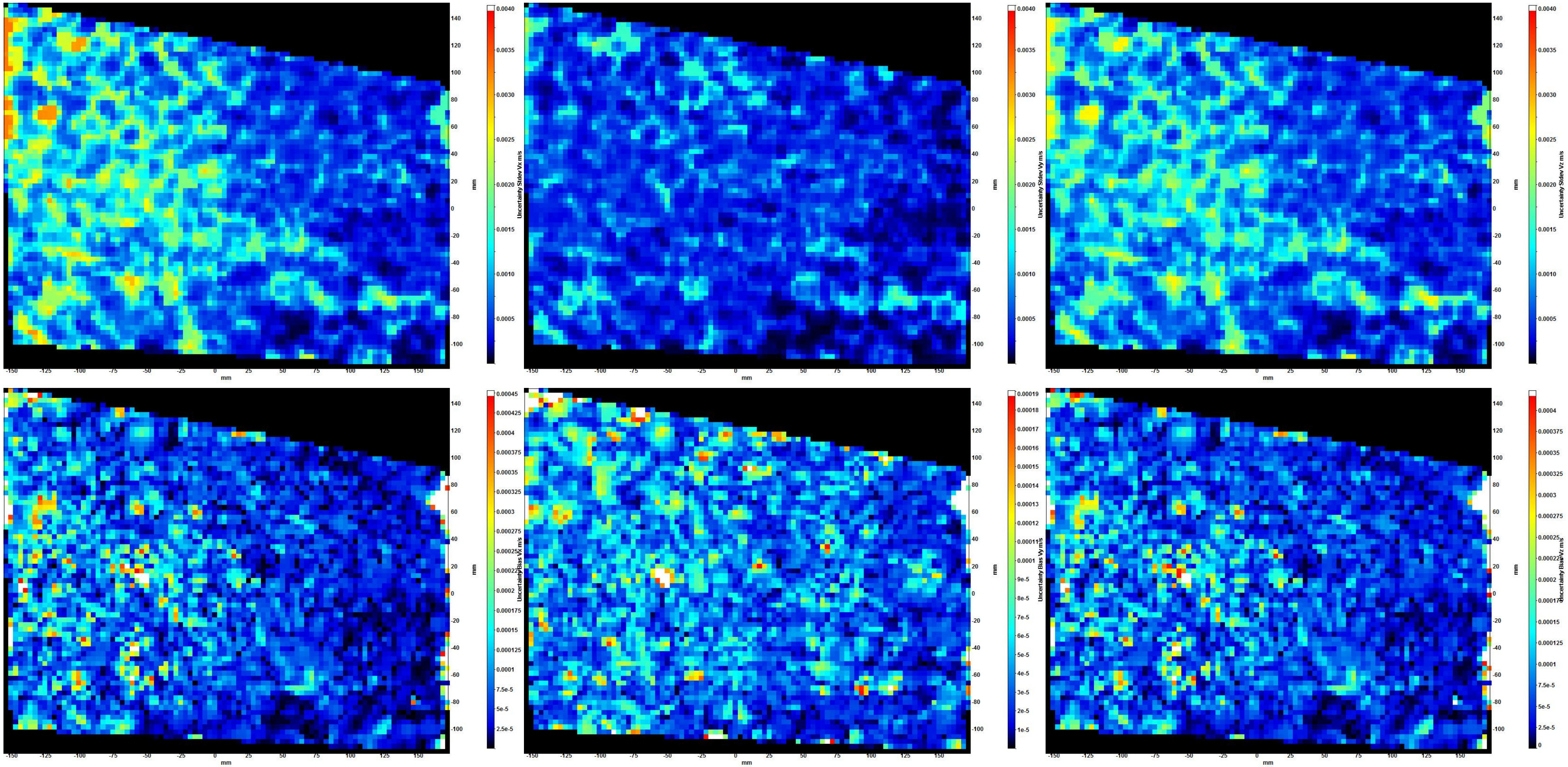
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC06-1
t = 943 s
T_{pool} = 23,479 °C
$P_{blowdown}$ = 2,8526 bar
P_{pool} = 2,8039 bar
$q_{m,steam}$ = 47 g/s

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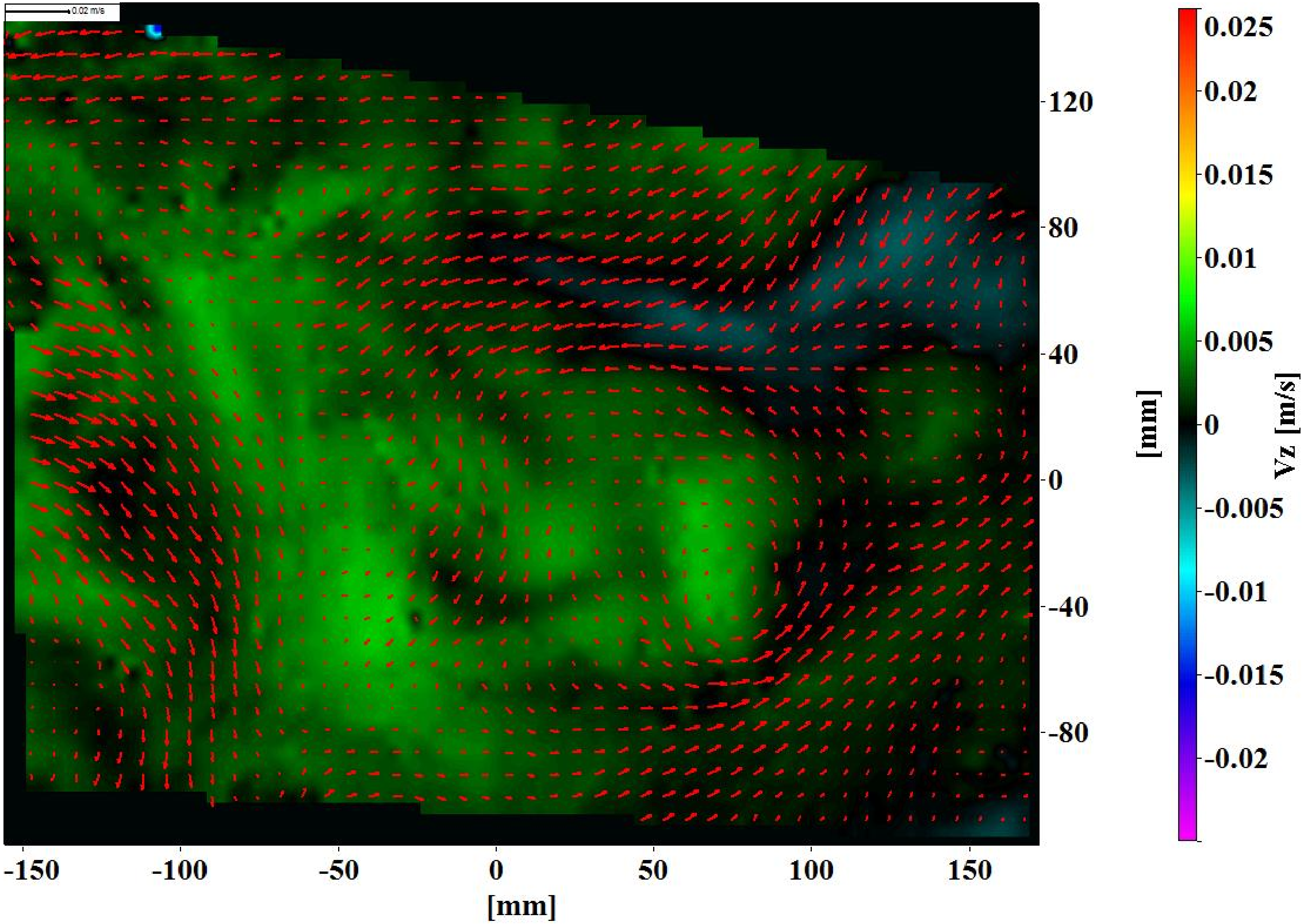
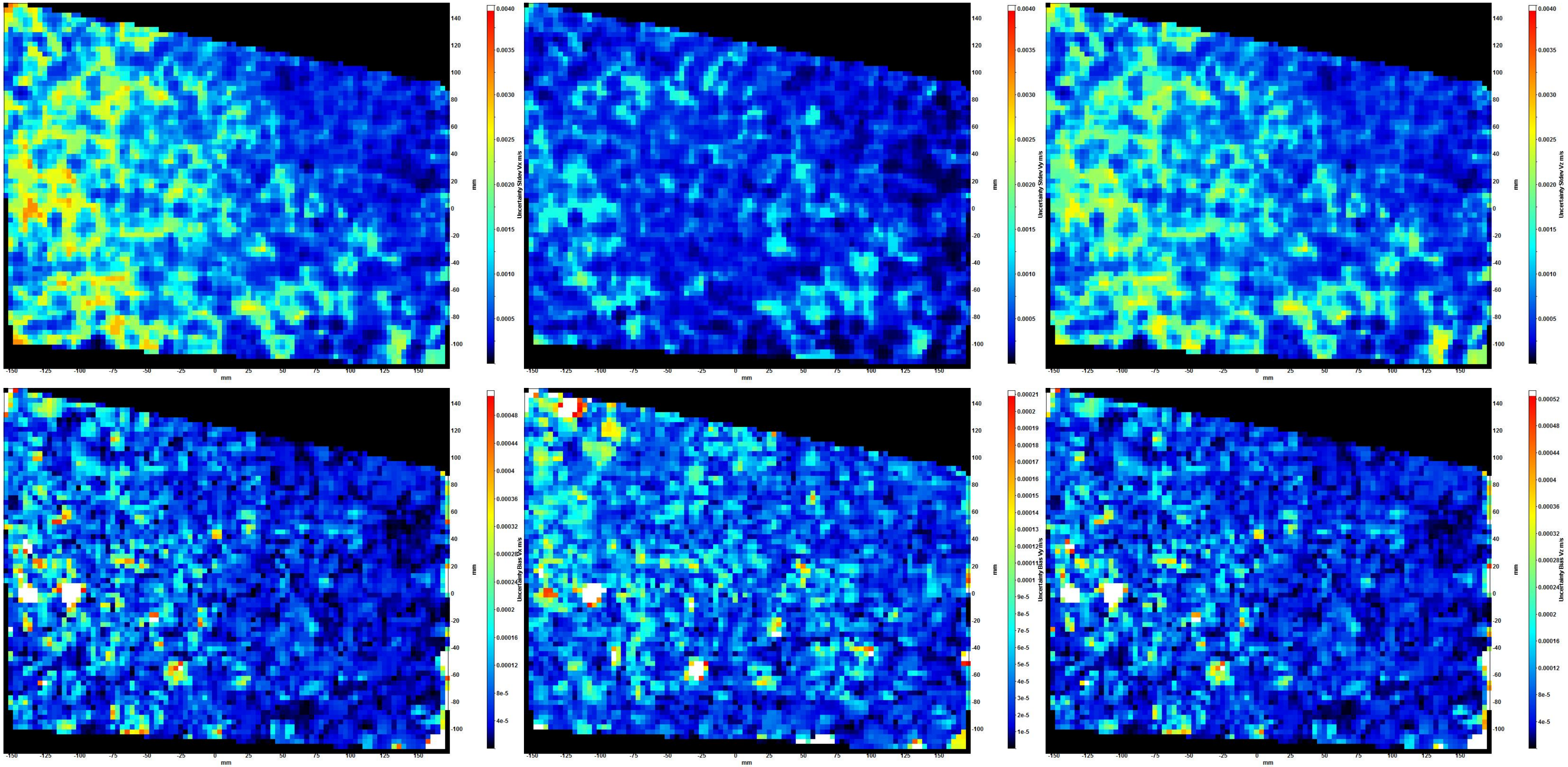
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC06-1
t = 944 s
T_{pool} = 23,479 °C
$P_{blowdown}$ = 2,8526 bar
P_{pool} = 2,8039 bar
$q_{m,steam}$ = 47 g/s

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Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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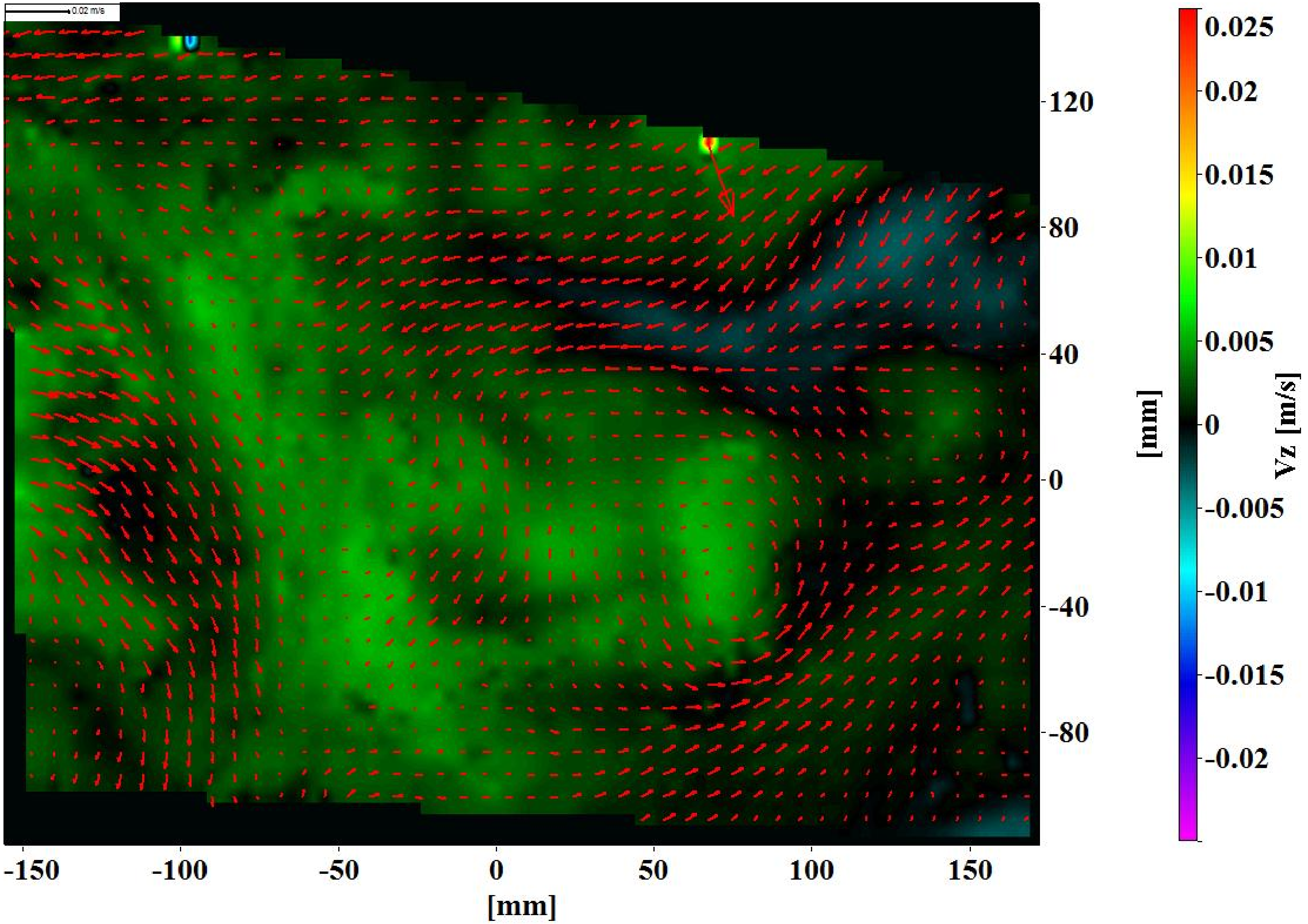
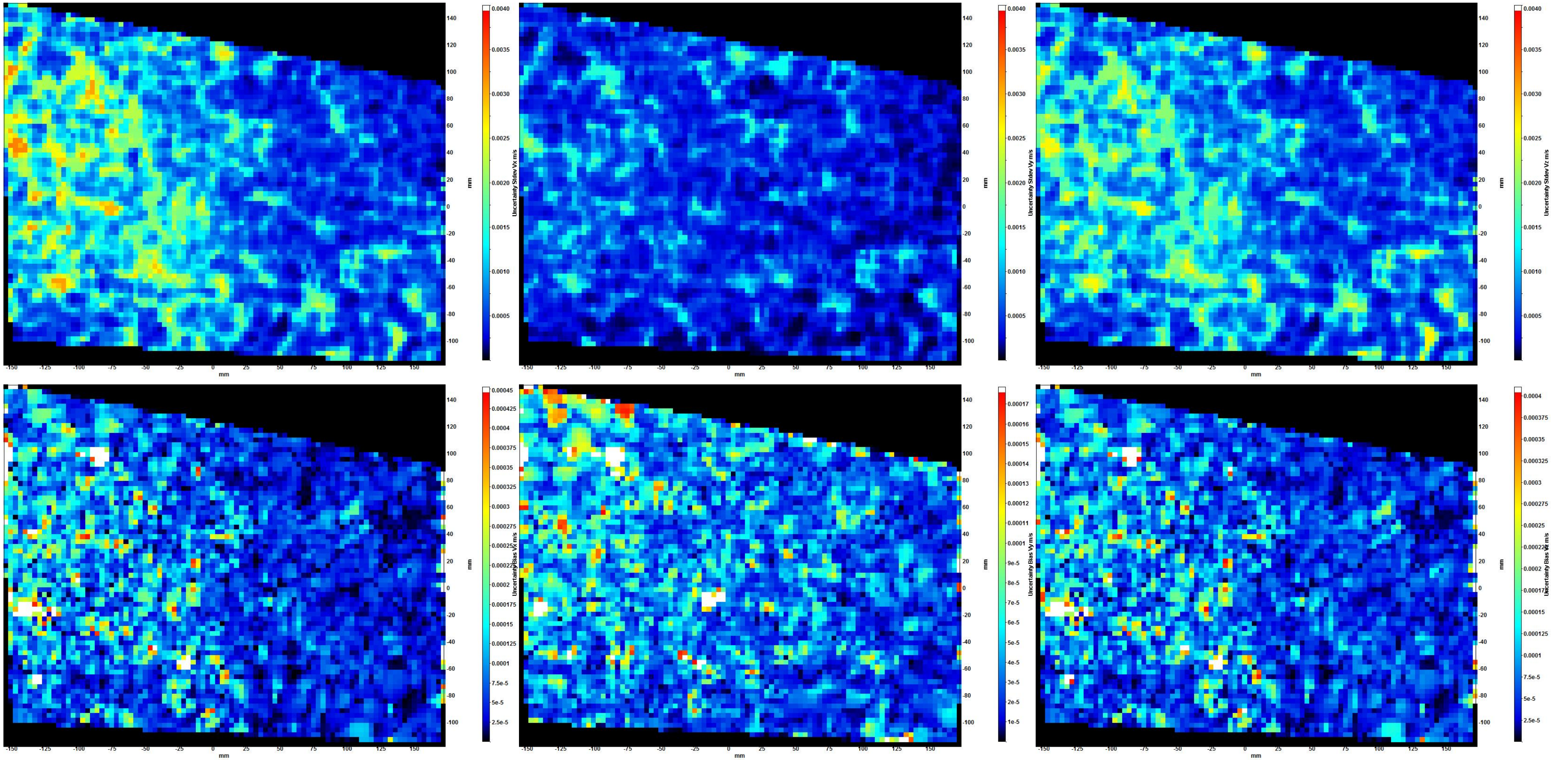
DCC06-1
t = 945 s
T_{pool} = 23,479 °C
$P_{blowdown}$ = 2,8526 bar
P_{pool} = 2,8039 bar
$q_{m,steam}$ = 47 g/s

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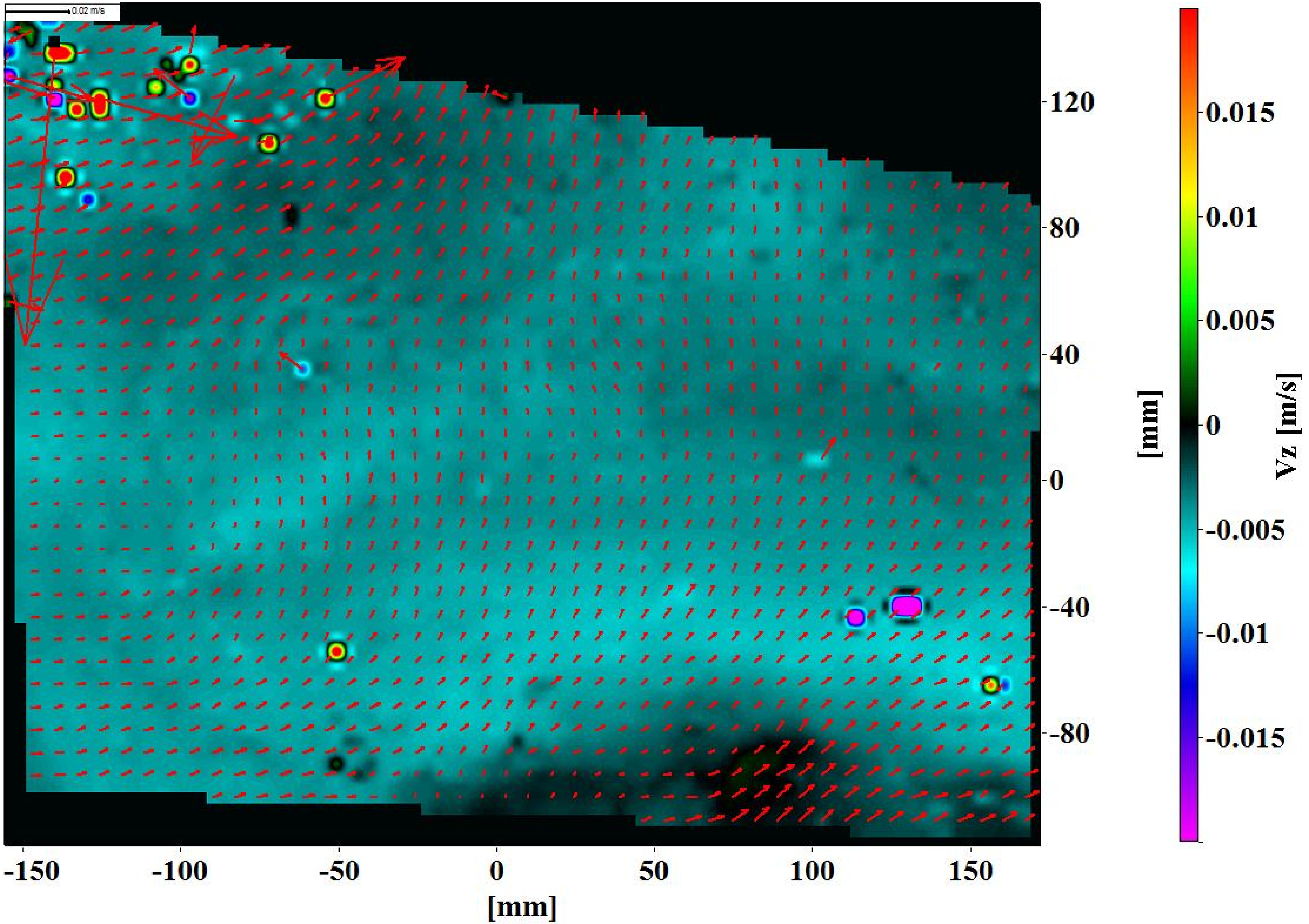
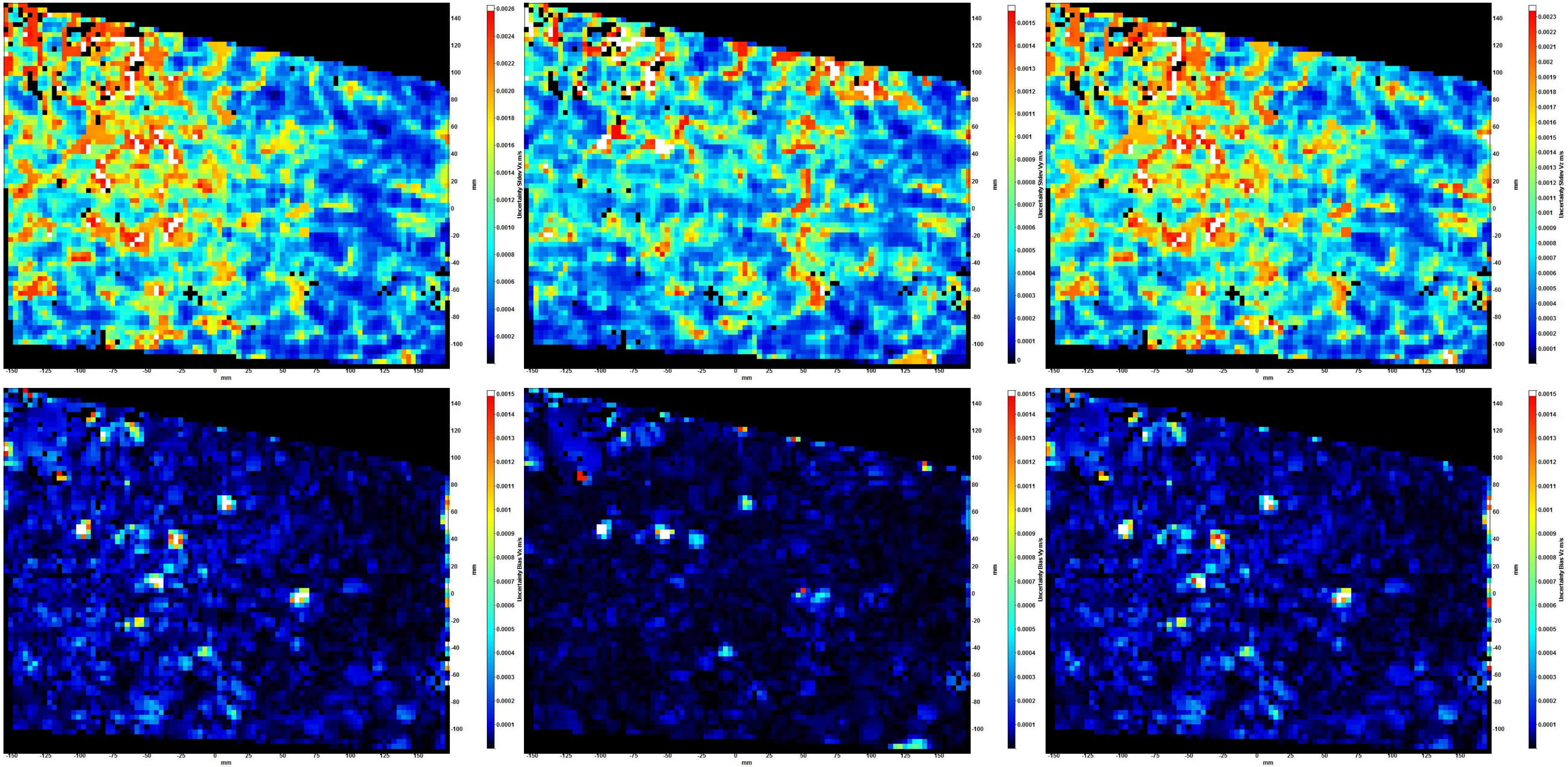
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC06-2
t = 1160 s
T_{pool} = 23,416 °C
$P_{blowdown}$ = 2,8731 bar
P_{pool} = 2,8236 bar
$q_{m,steam}$ = 76 g/s





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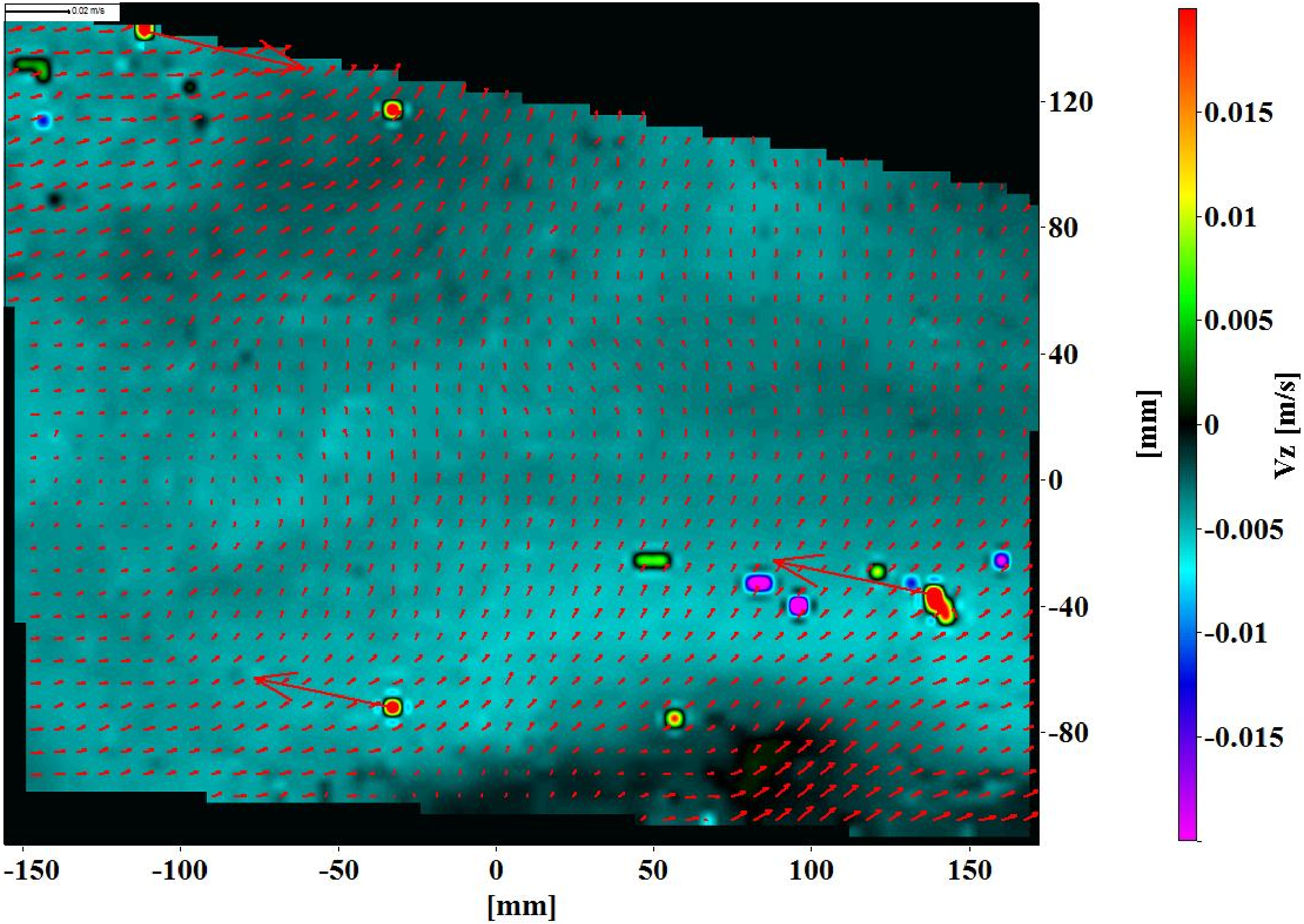
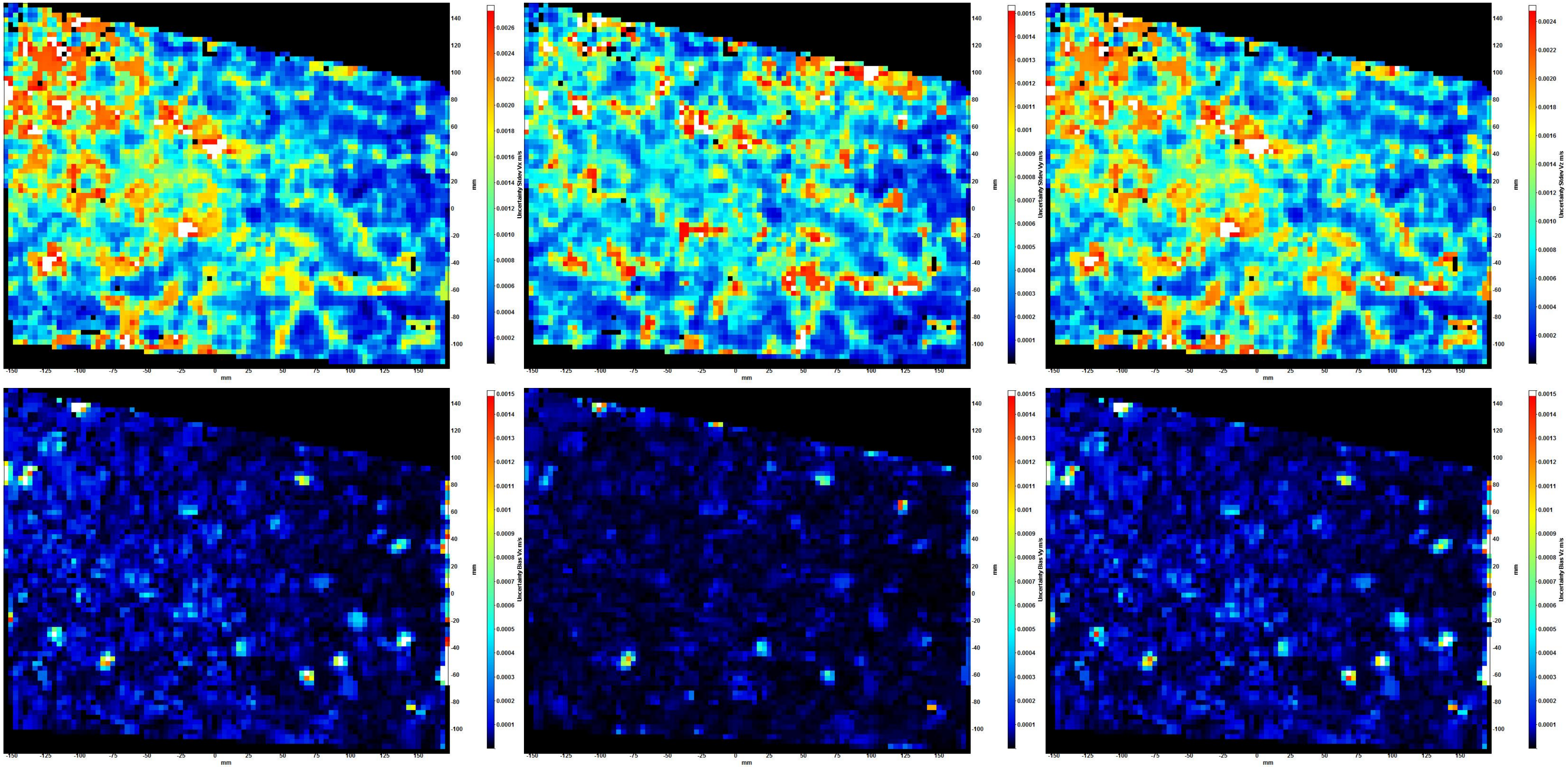
DCC06-2
t = 1161 s
T_{pool} = 23,416 °C
$P_{blowdown}$ = 2,8731 bar
P_{pool} = 2,8236 bar
$q_{m,steam}$ = 76 g/s




mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

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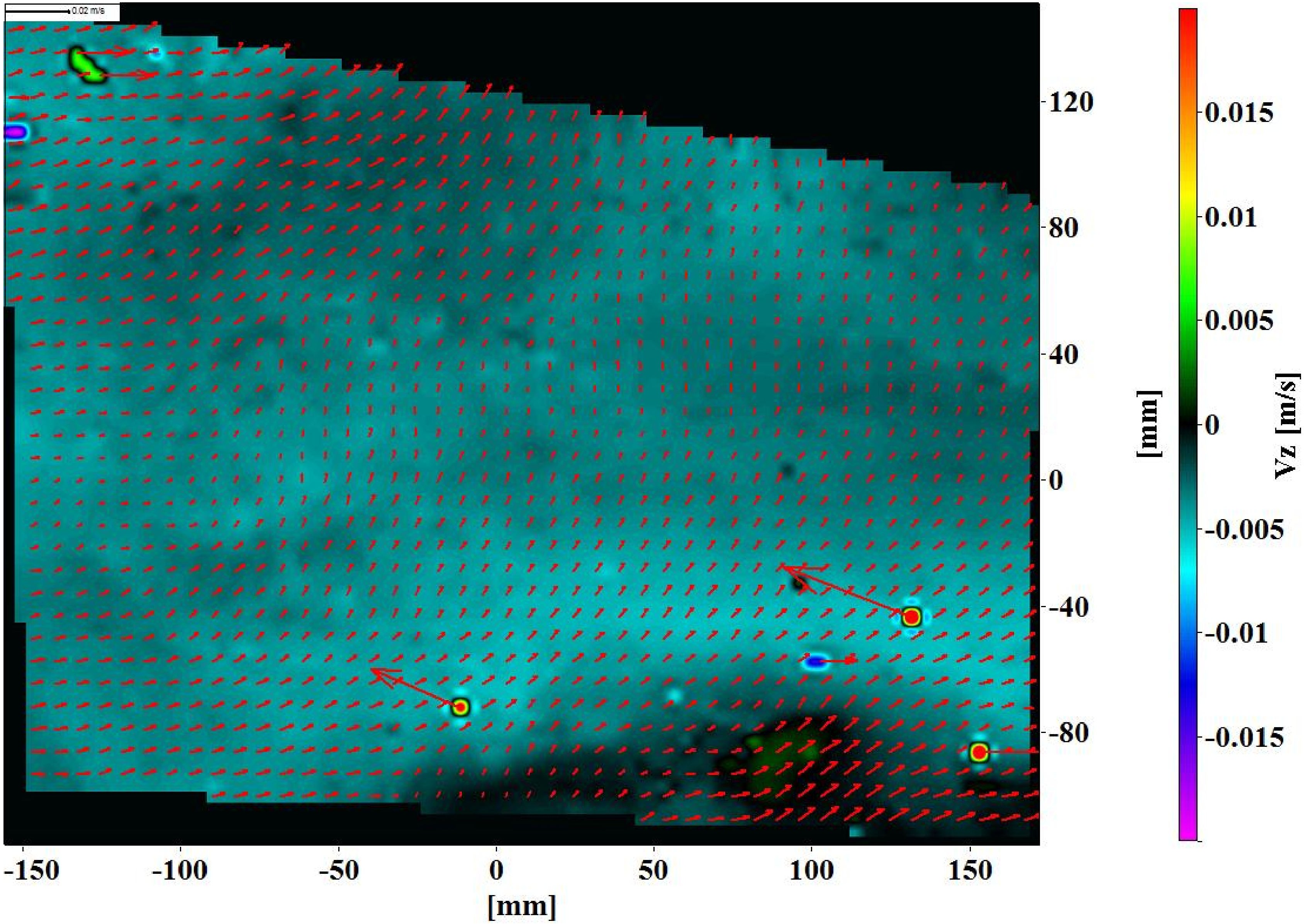
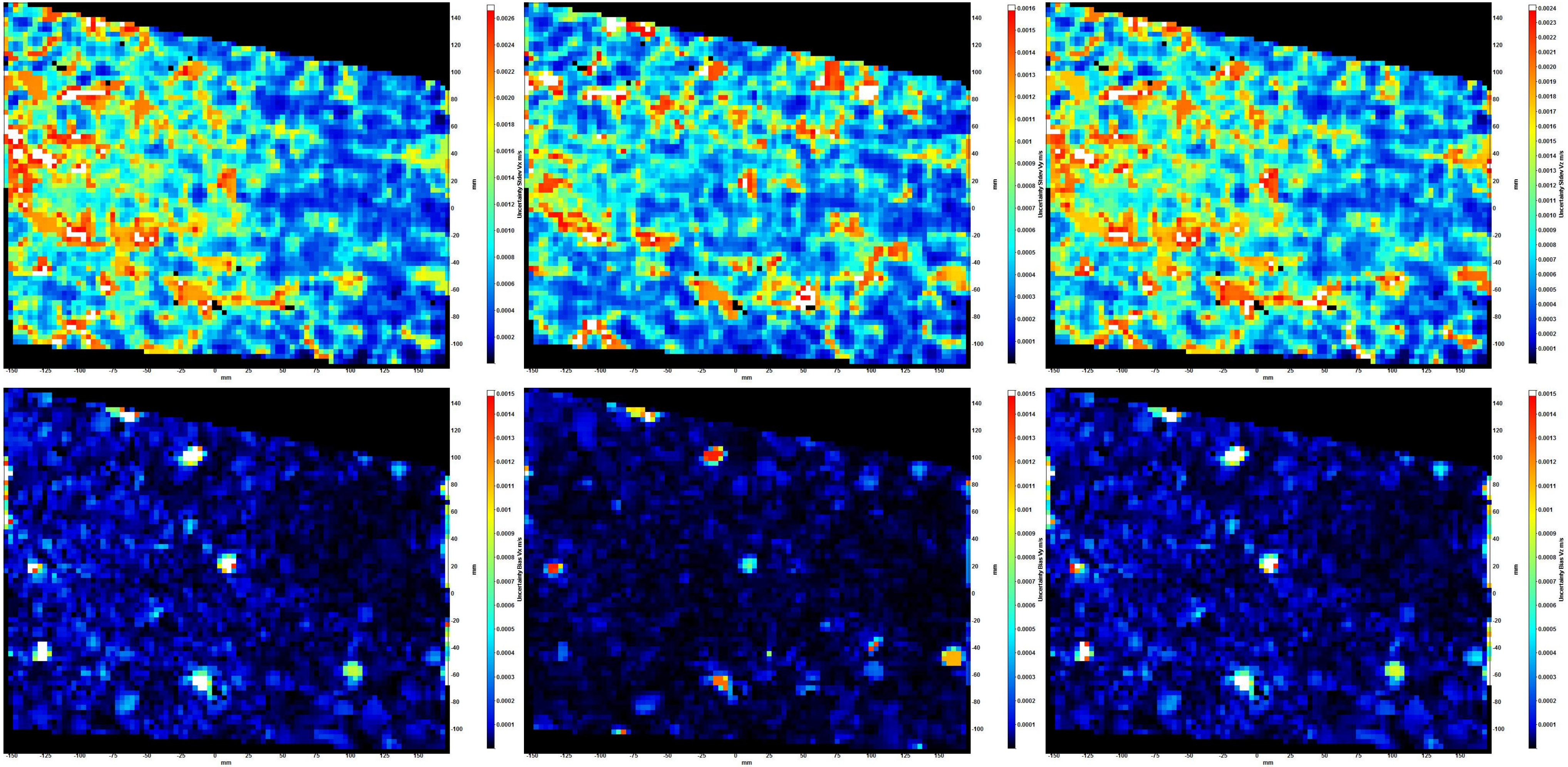
DCC06-2
t = 1162 s
T_{pool} = 23,416 °C
$P_{blowdown}$ = 2,8731 bar
P_{pool} = 2,8236 bar
$q_{m,steam}$ = 76 g/s




mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

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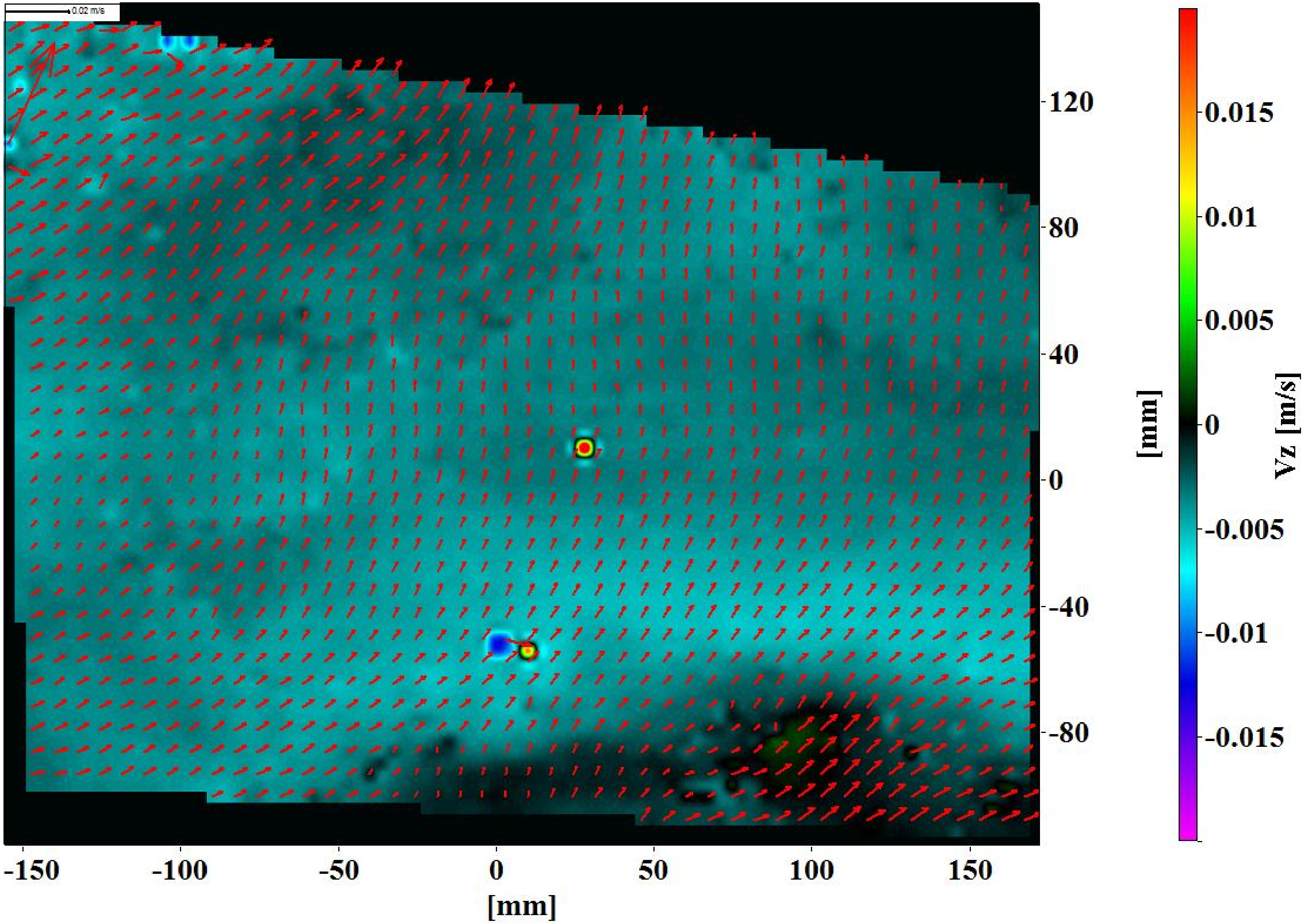
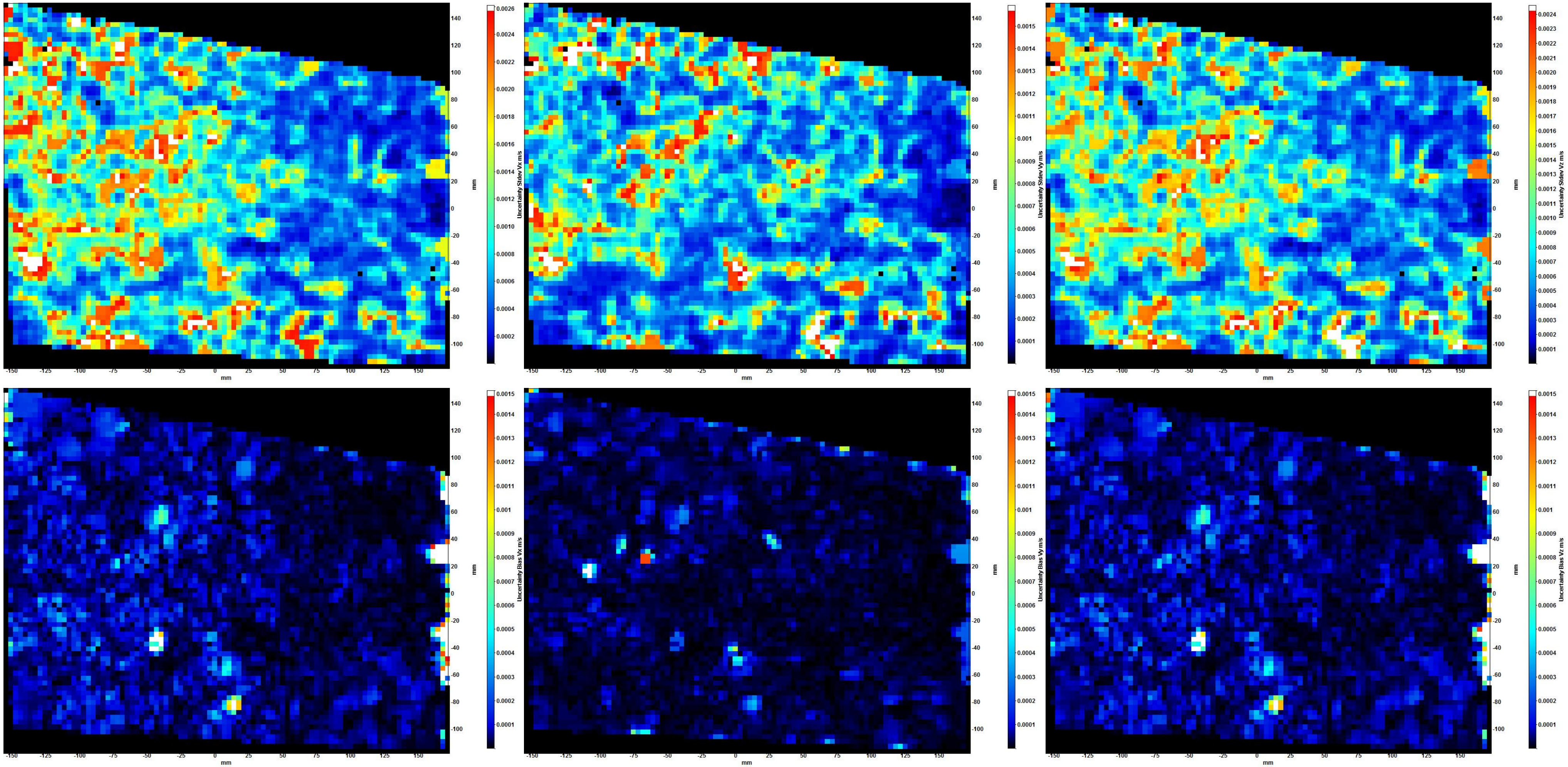
DCC06-2
t = 1163 s
T_{pool} = 23,416 °C
$P_{blowdown}$ = 2,8731 bar
P_{pool} = 2,8236 bar
$q_{m,steam}$ = 76 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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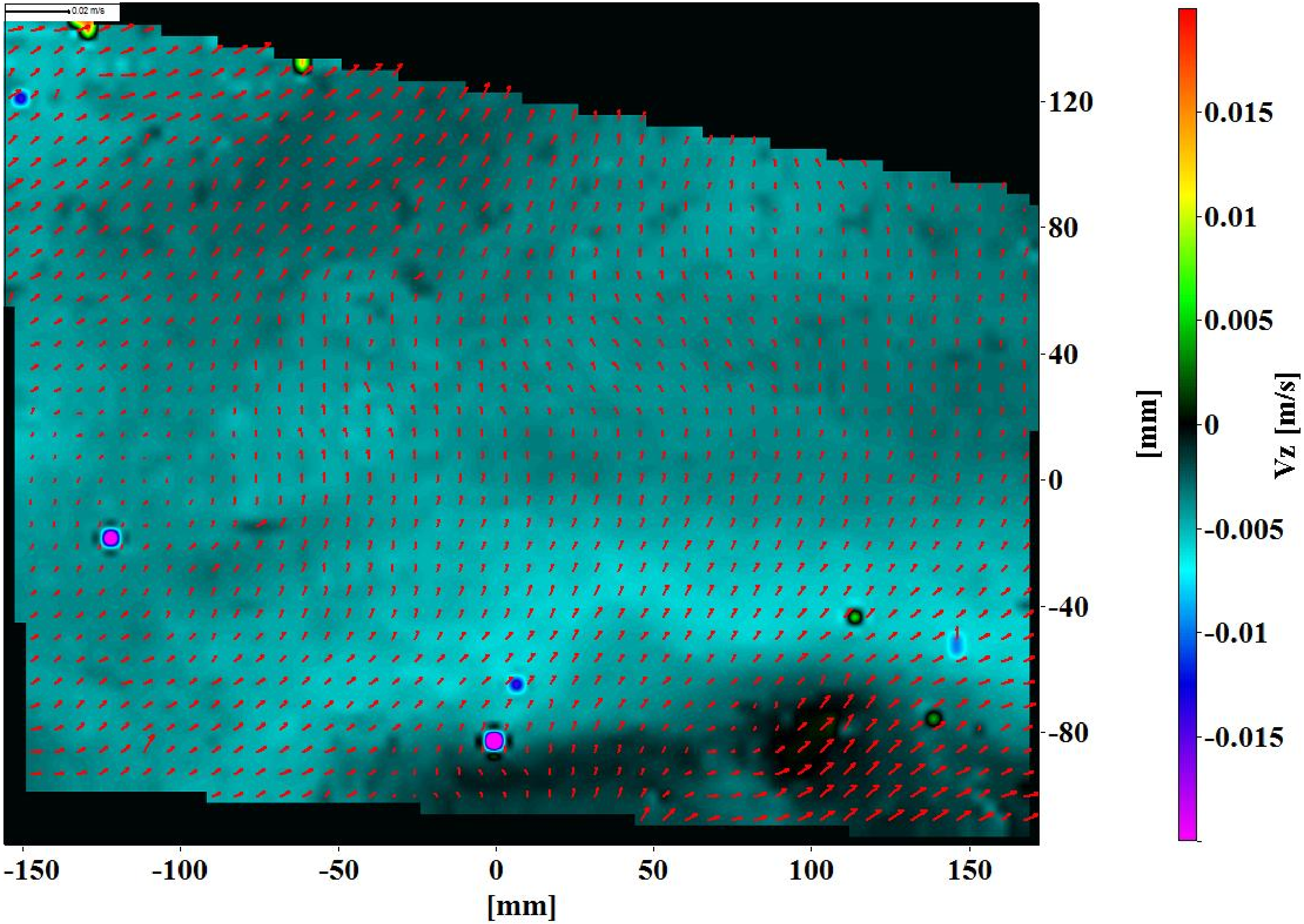
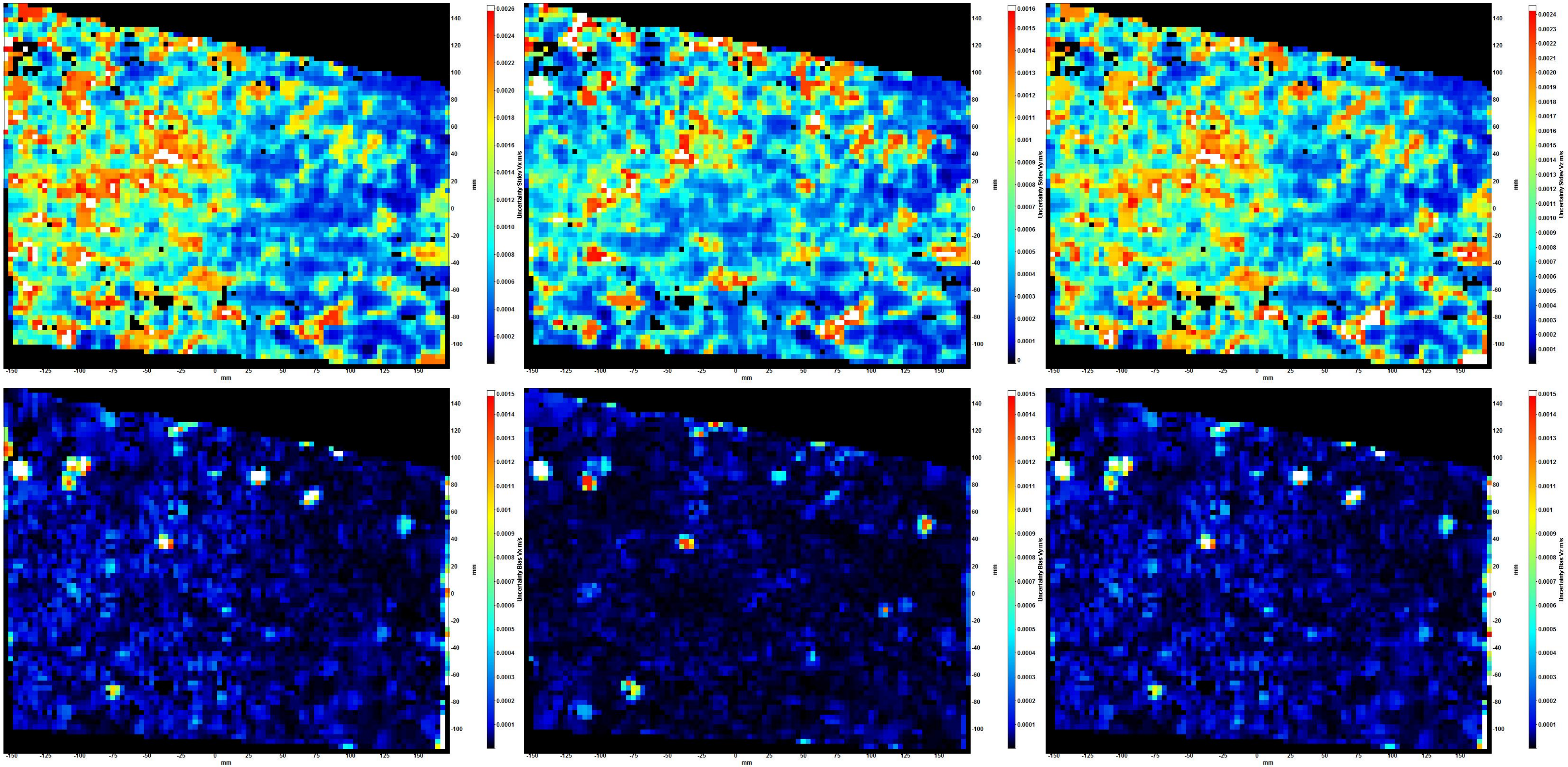
DCC06-2
t = 1164 s
T_{pool} = 23,416 °C
$P_{blowdown}$ = 2,8731 bar
P_{pool} = 2,8236 bar
$q_{m,steam}$ = 76 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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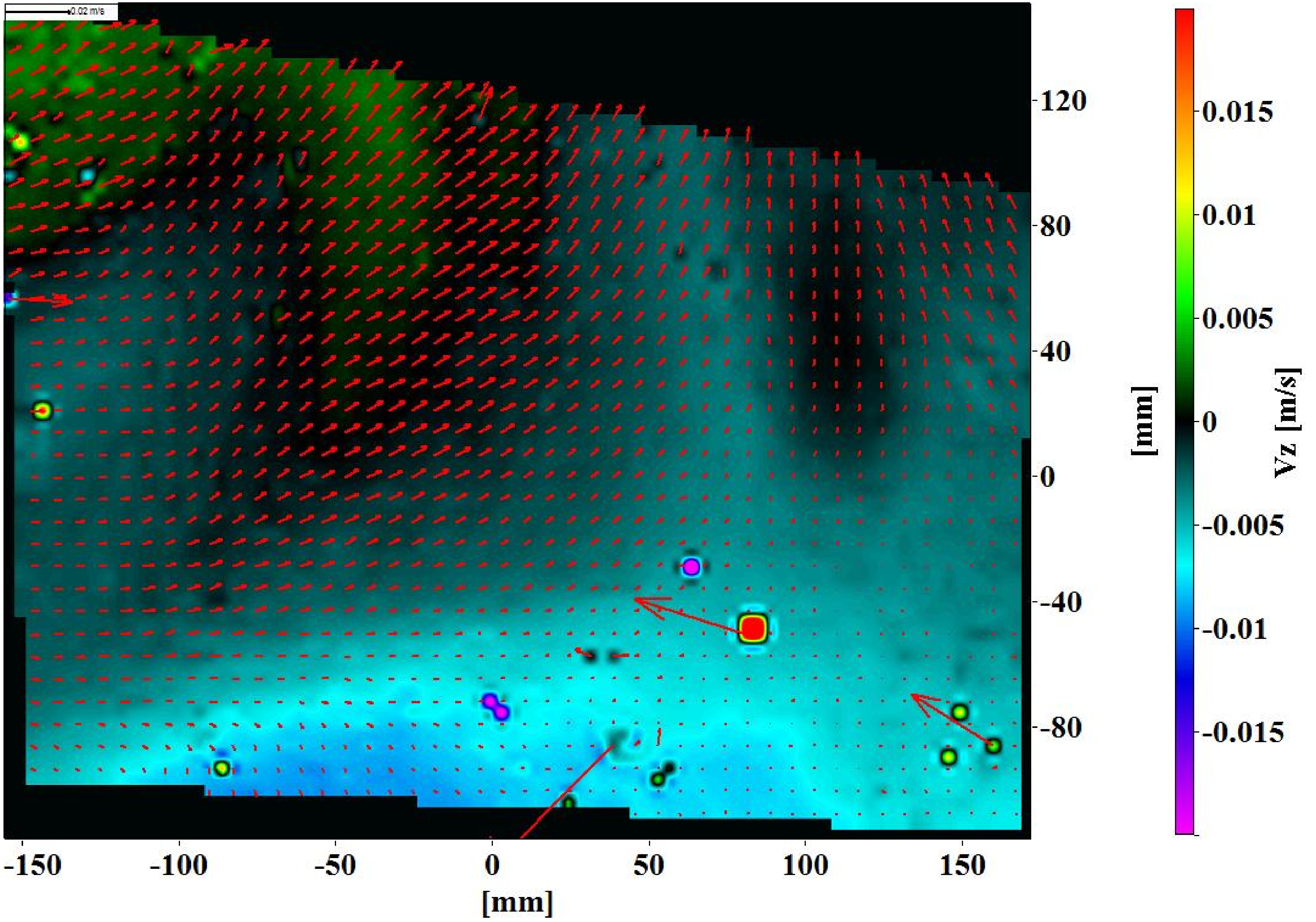
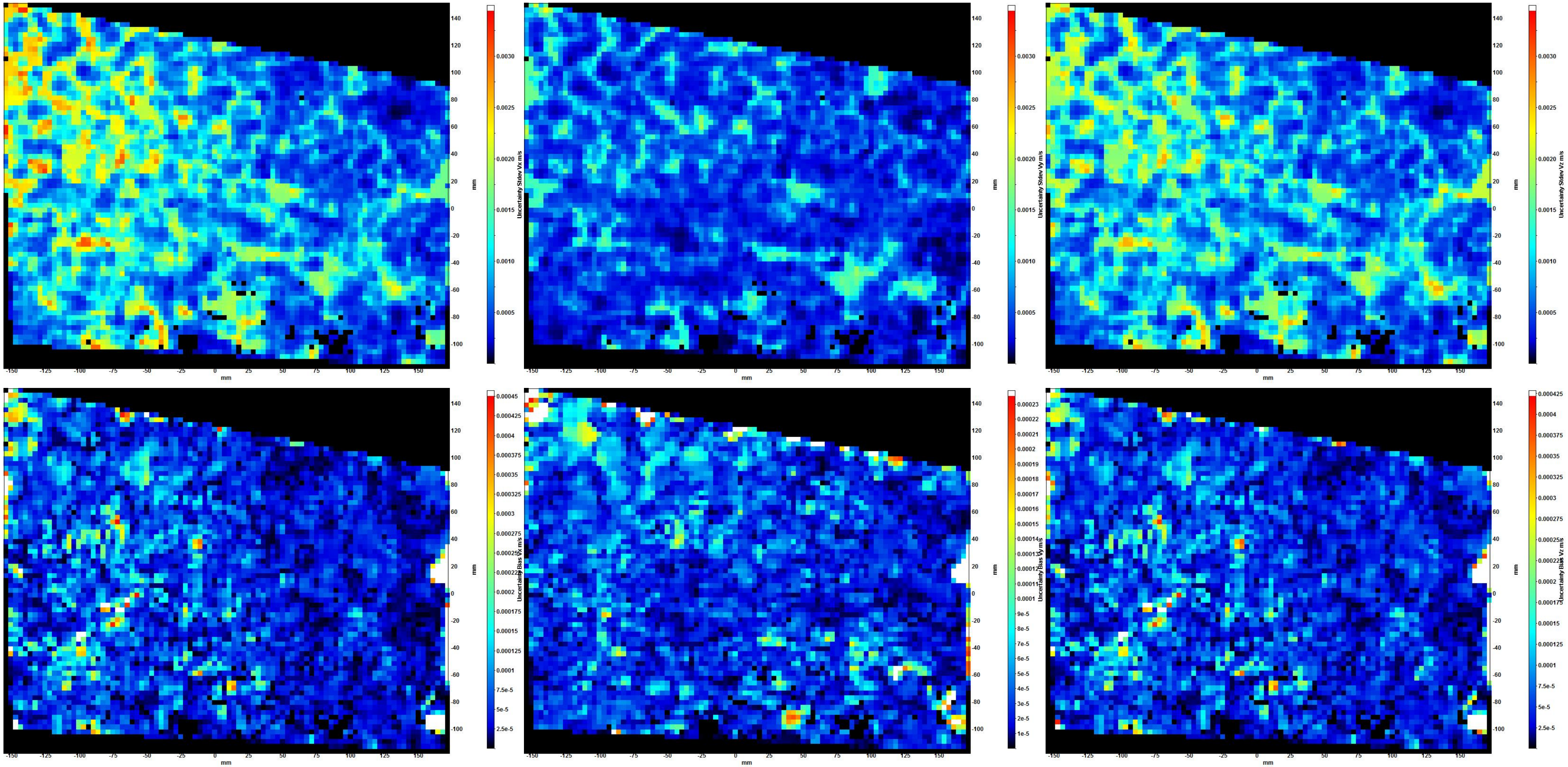
DCC06-3
t = 1405 s
T_{pool} = 23,603 °C
$P_{blowdown}$ = 2,8962 bar
P_{pool} = 2,8488 bar
$q_{m,steam}$ = 98 g/s




mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

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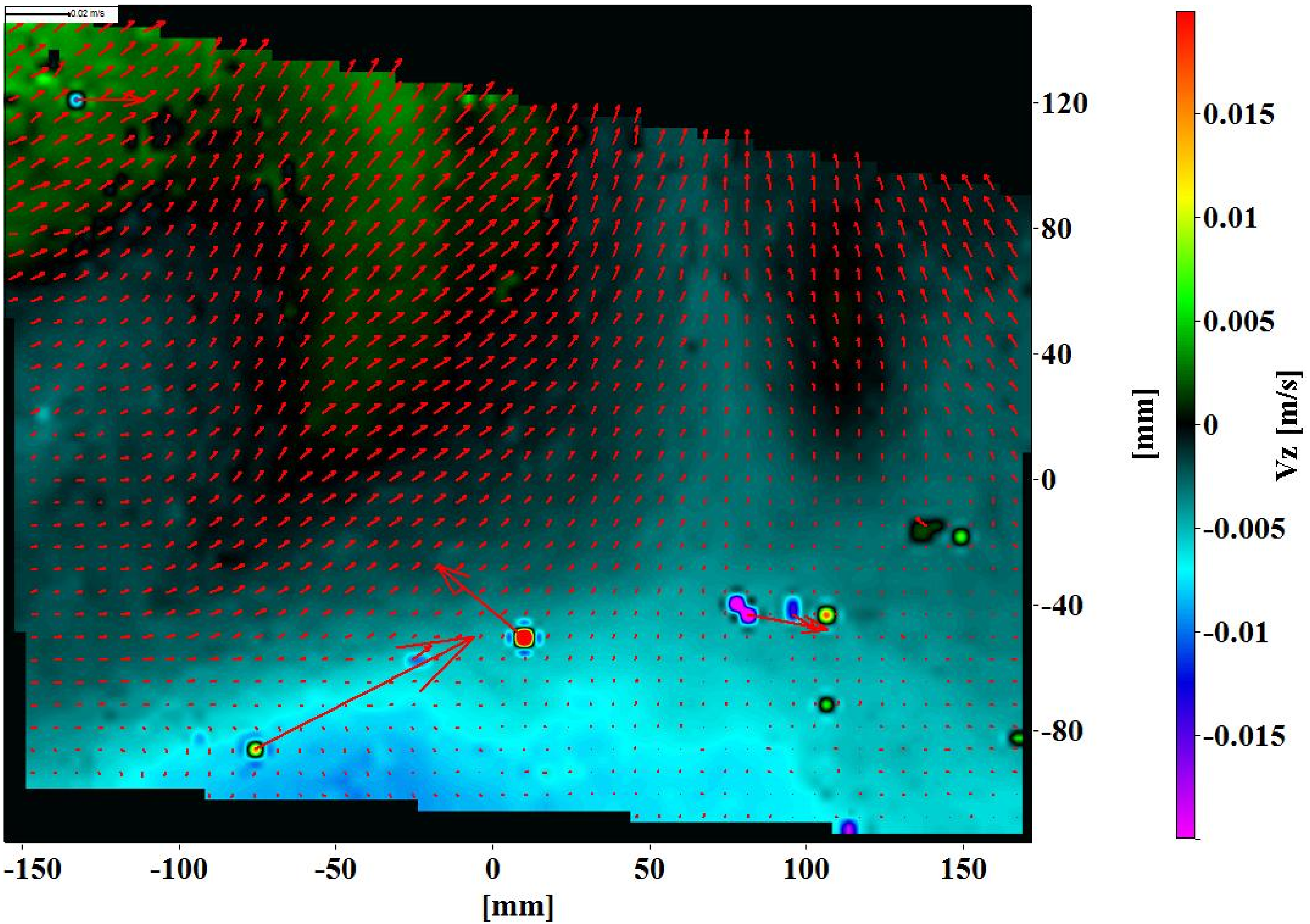
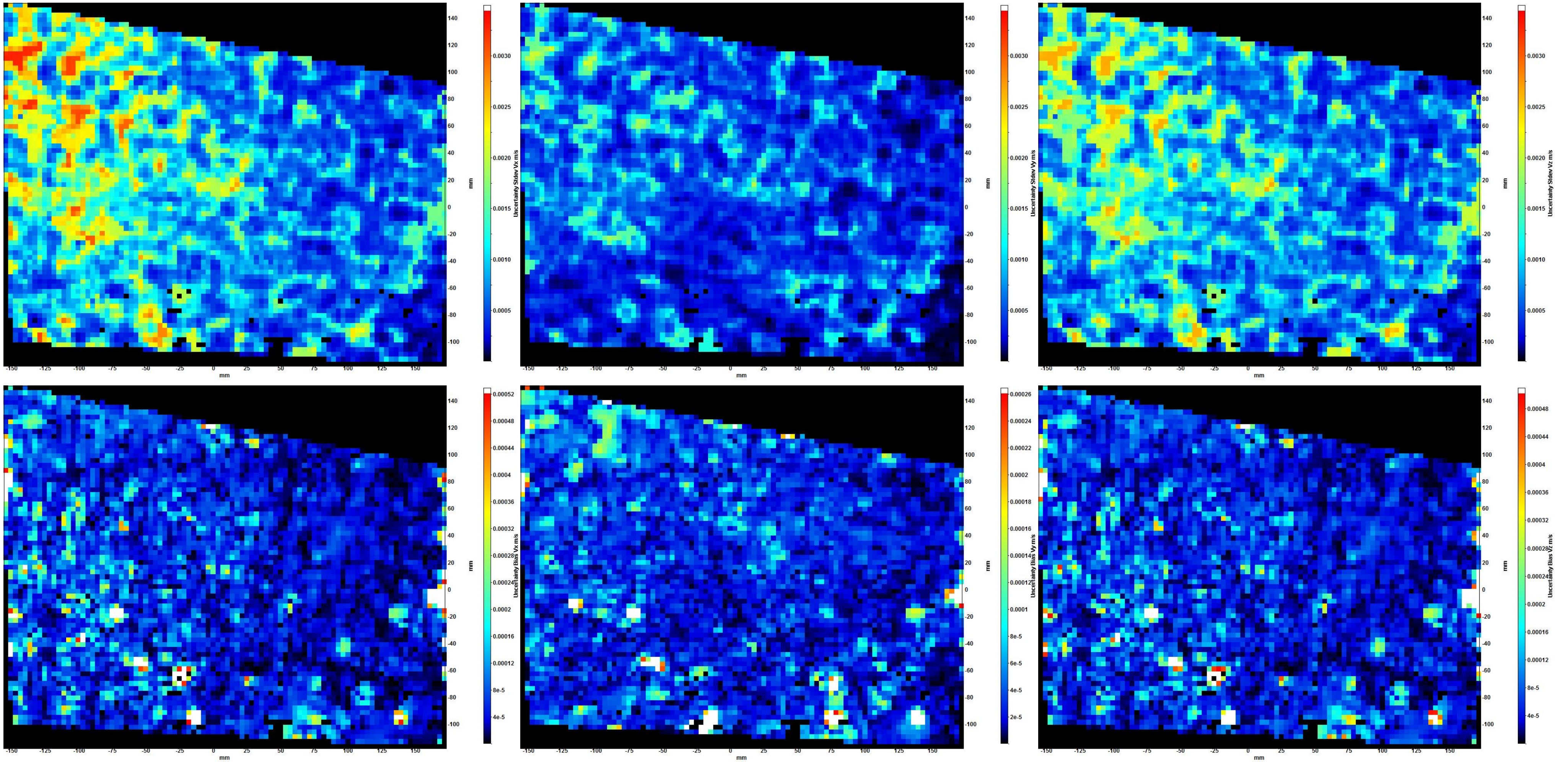
DCC06-3
t = 1406 s
T_{pool} = 23,603 °C
$P_{blowdown}$ = 2,8962 bar
P_{pool} = 2,8488 bar
$q_{m,steam}$ = 98 g/s





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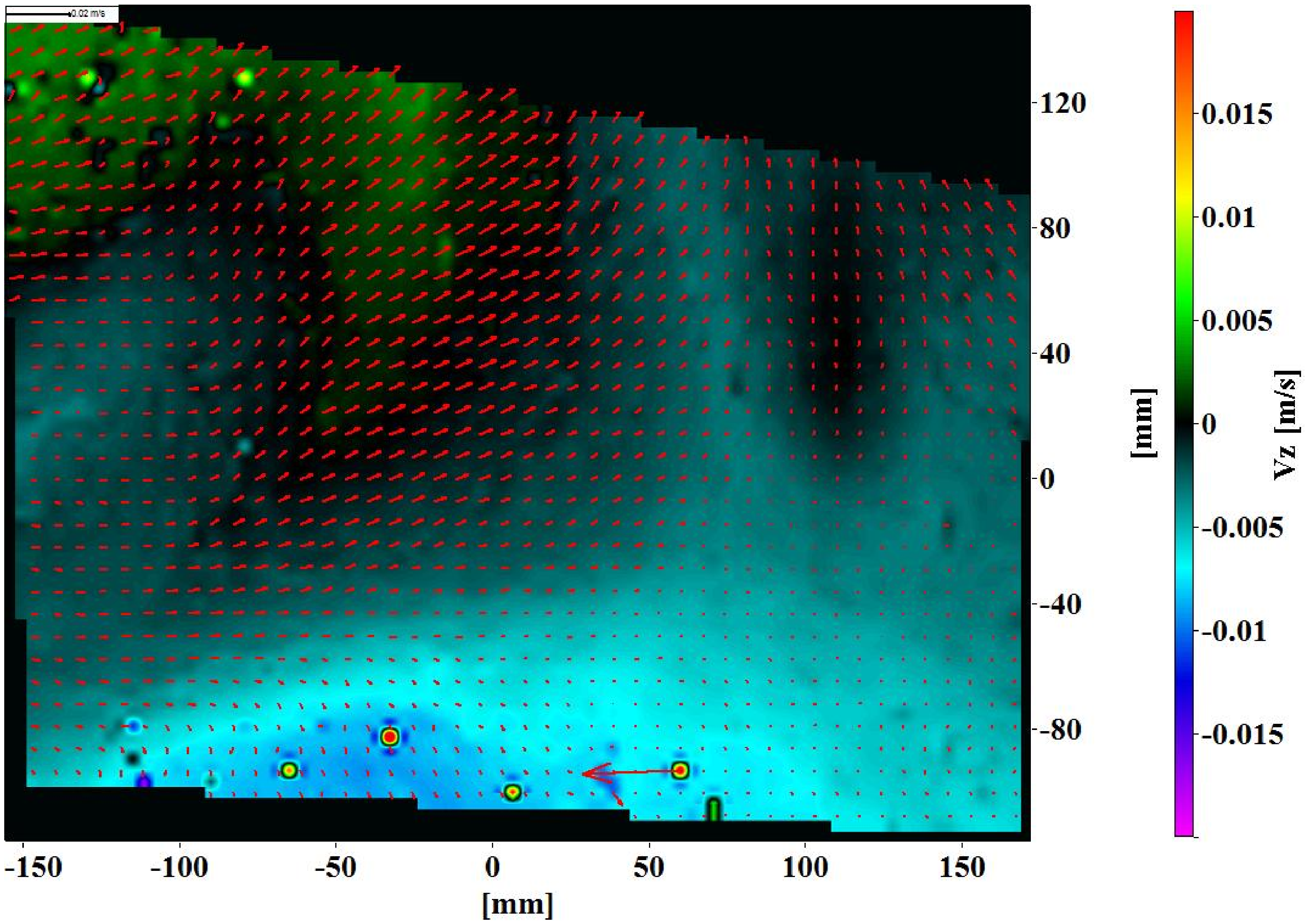
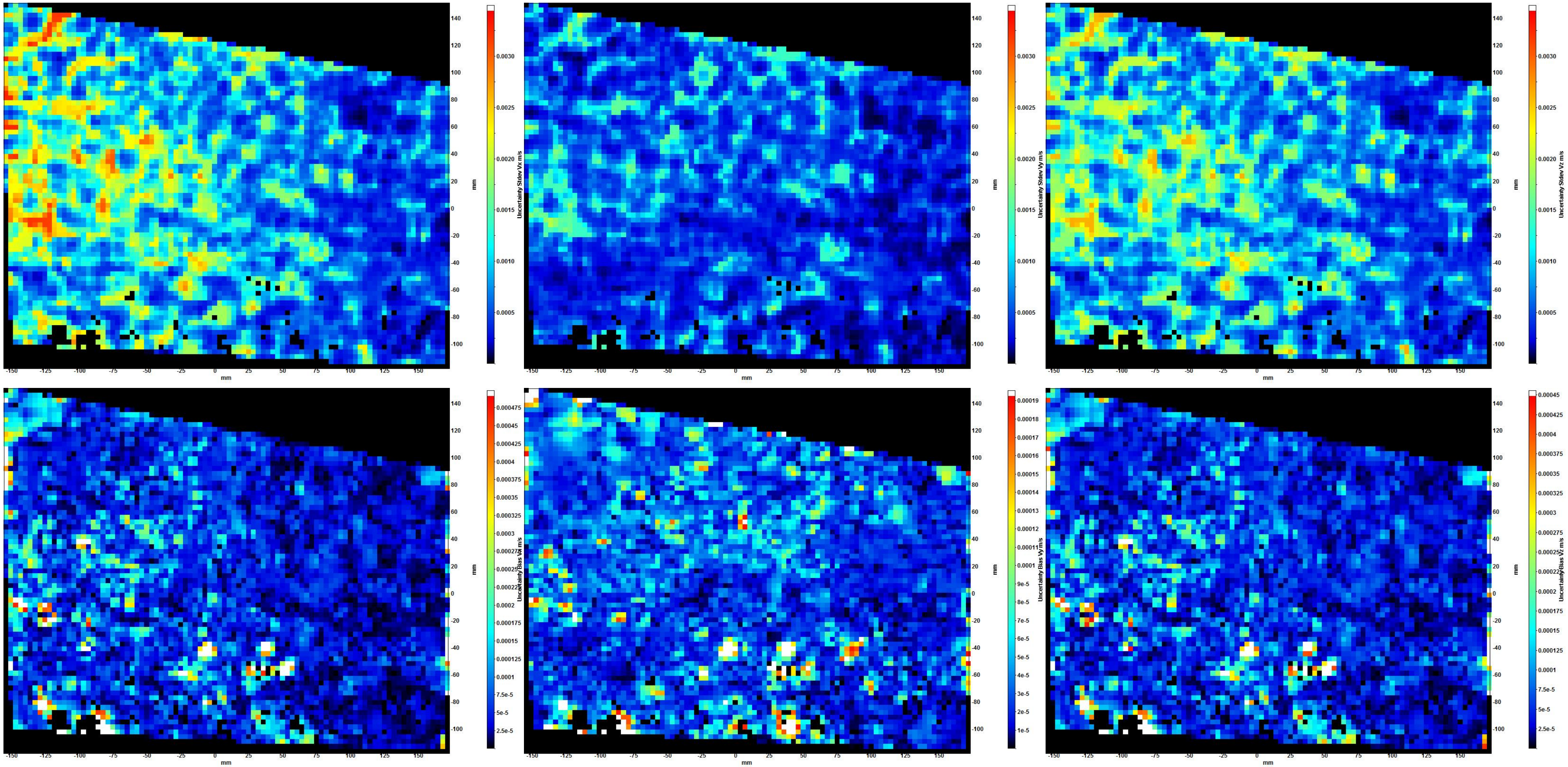
DCC06-3
t = 1407 s
T_{pool} = 23,603 °C
$P_{blowdown}$ = 2,8962 bar
P_{pool} = 2,8488 bar
$q_{m,steam}$ = 98 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
mm

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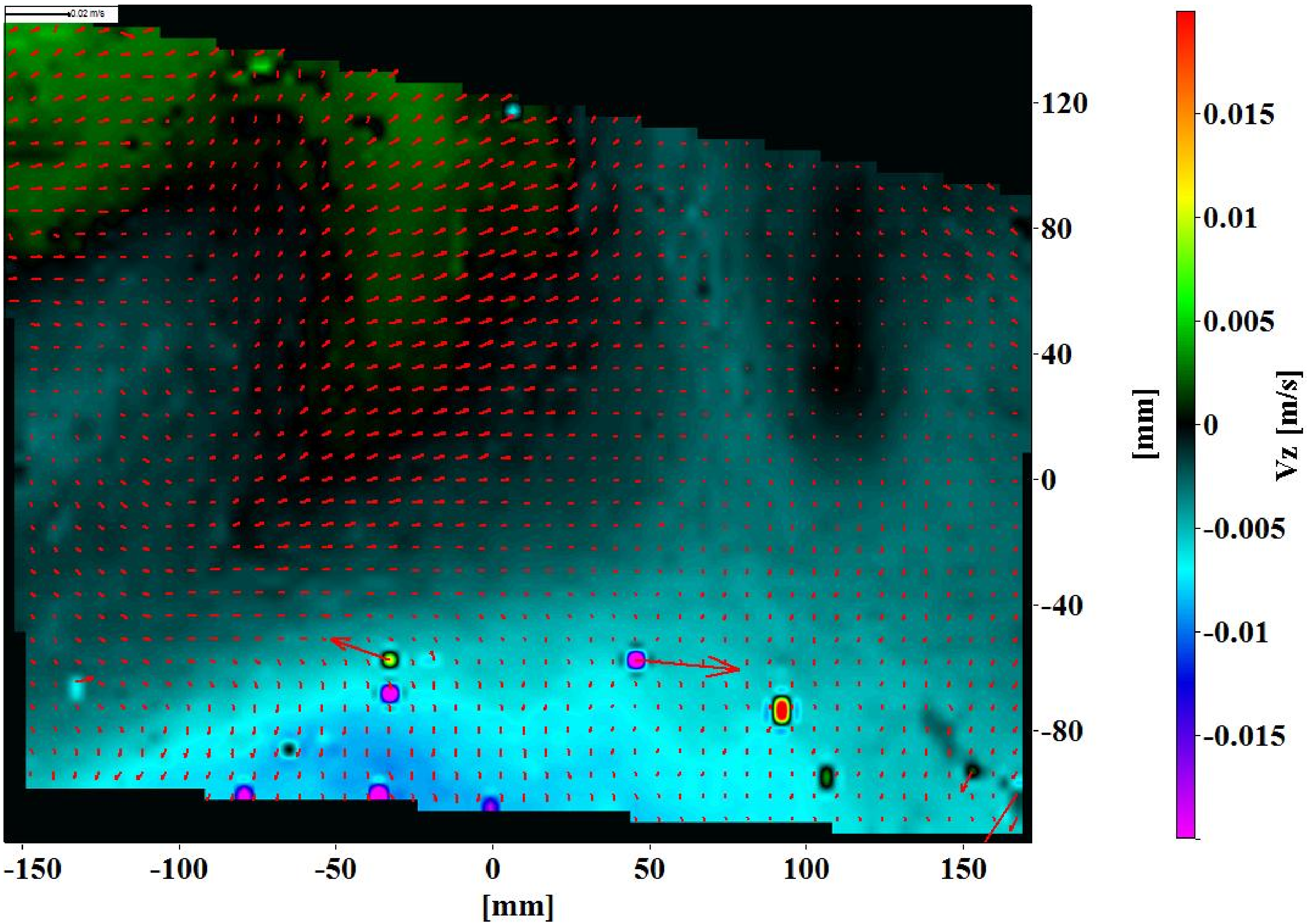
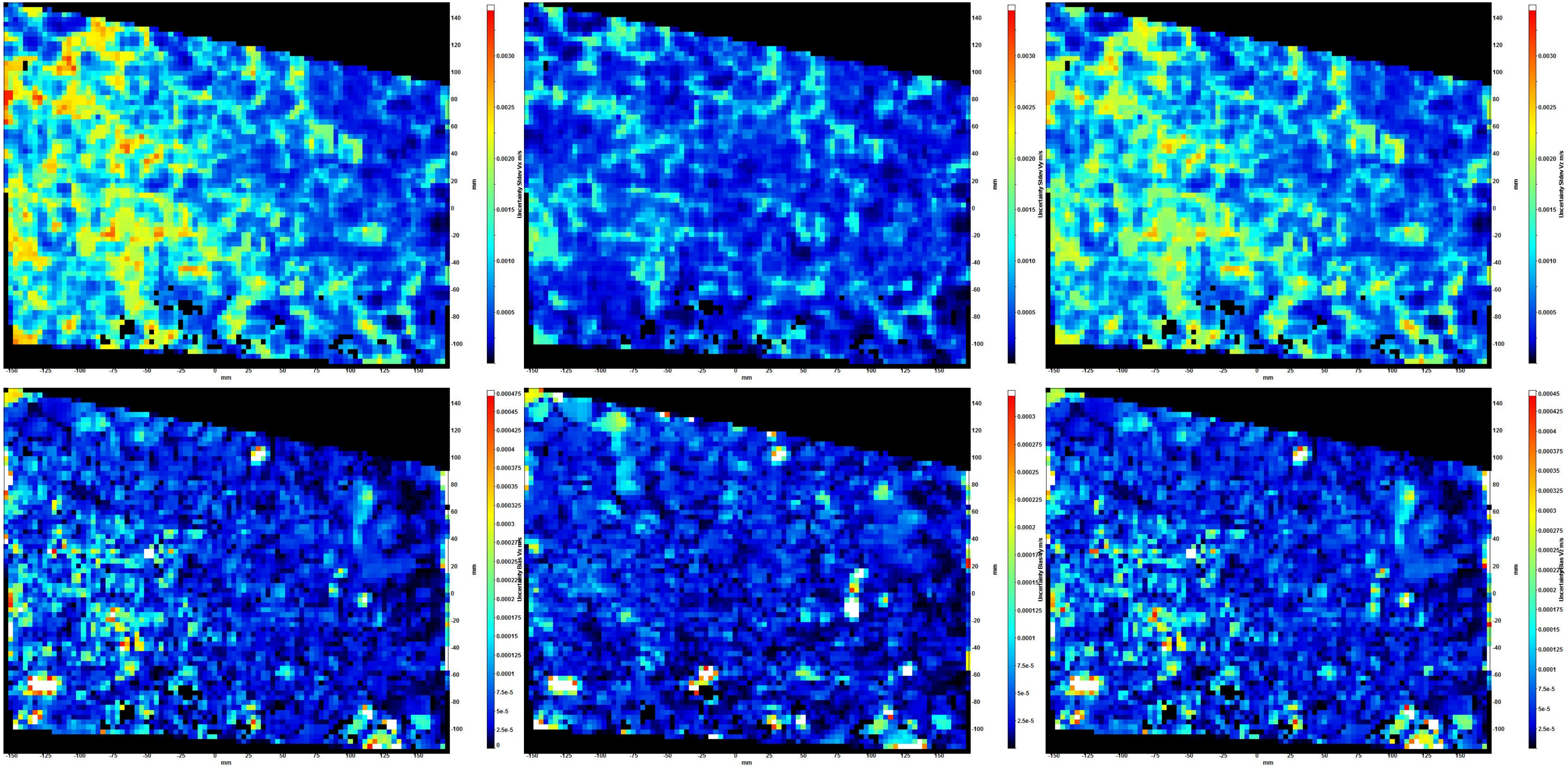
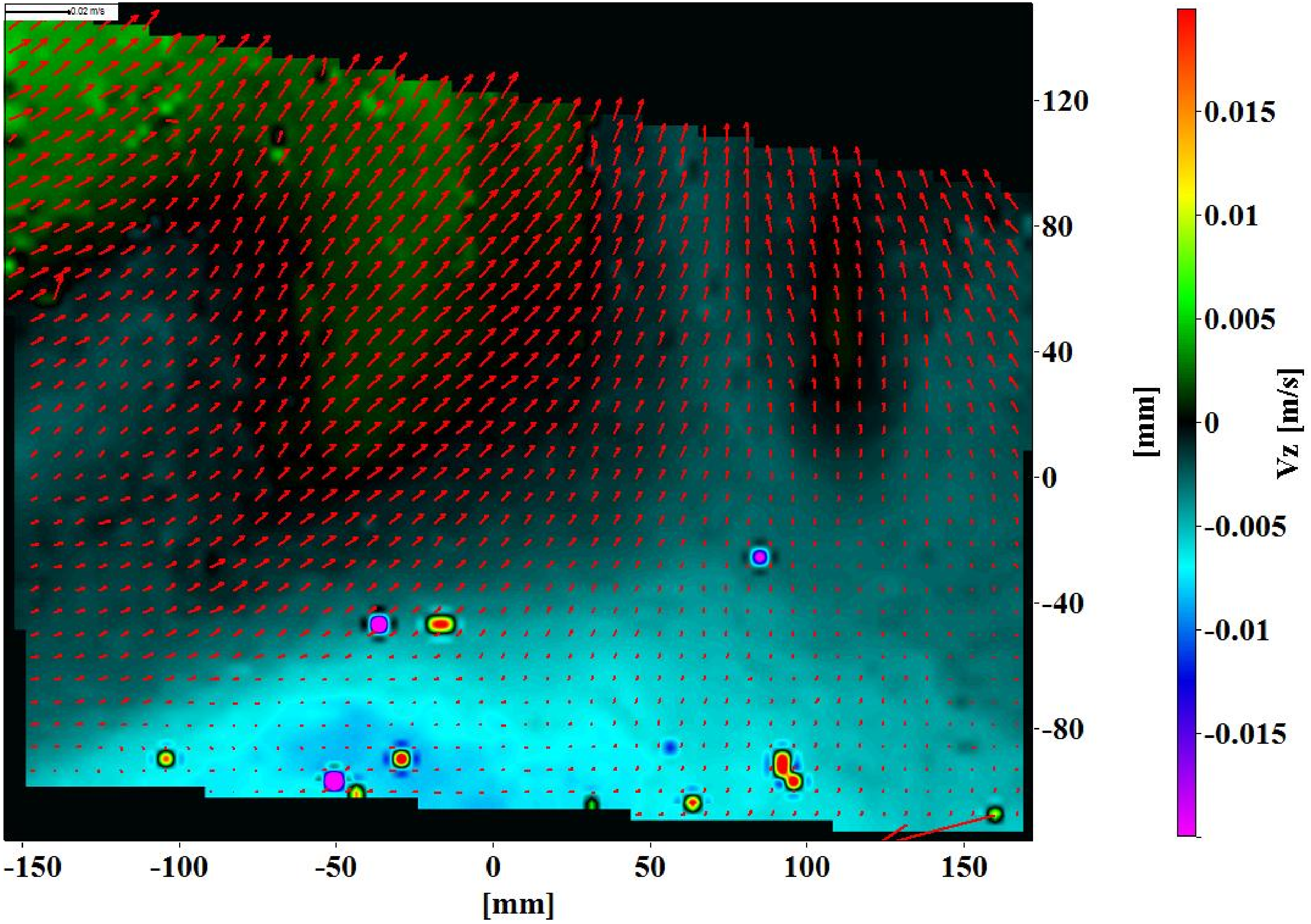
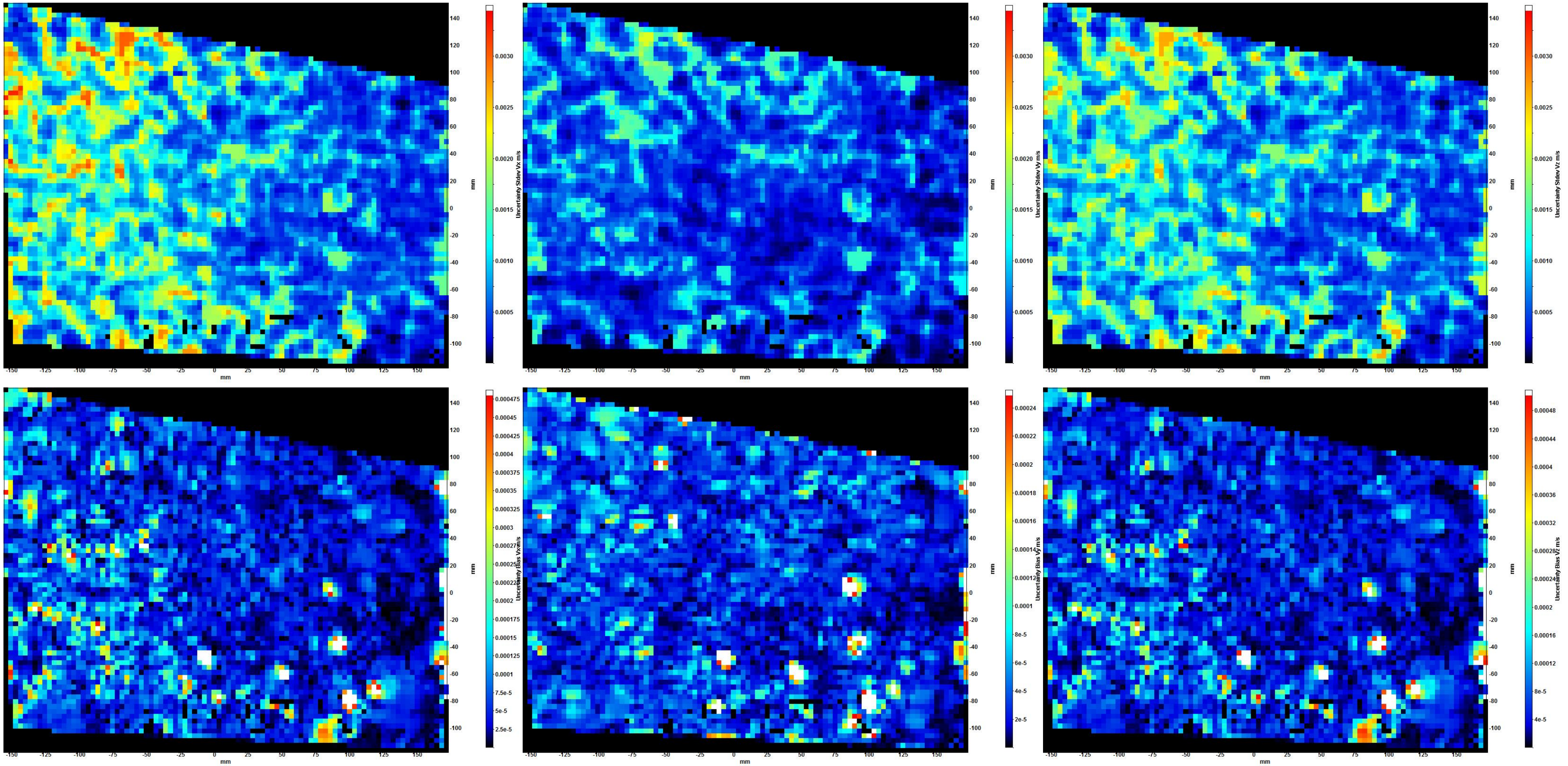
DCC06-3
t = 1408 s
T_{pool} = 23,603 °C
$P_{blowdown}$ = 2,8962 bar
P_{pool} = 2,8488 bar
$q_{m,steam}$ = 98 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC06-3
t = 1409 s
T_{pool} = 23,603 °C
$P_{blowdown}$ = 2,8962 bar
P_{pool} = 2,8488 bar
$q_{m,steam}$ = 98 g/s




mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

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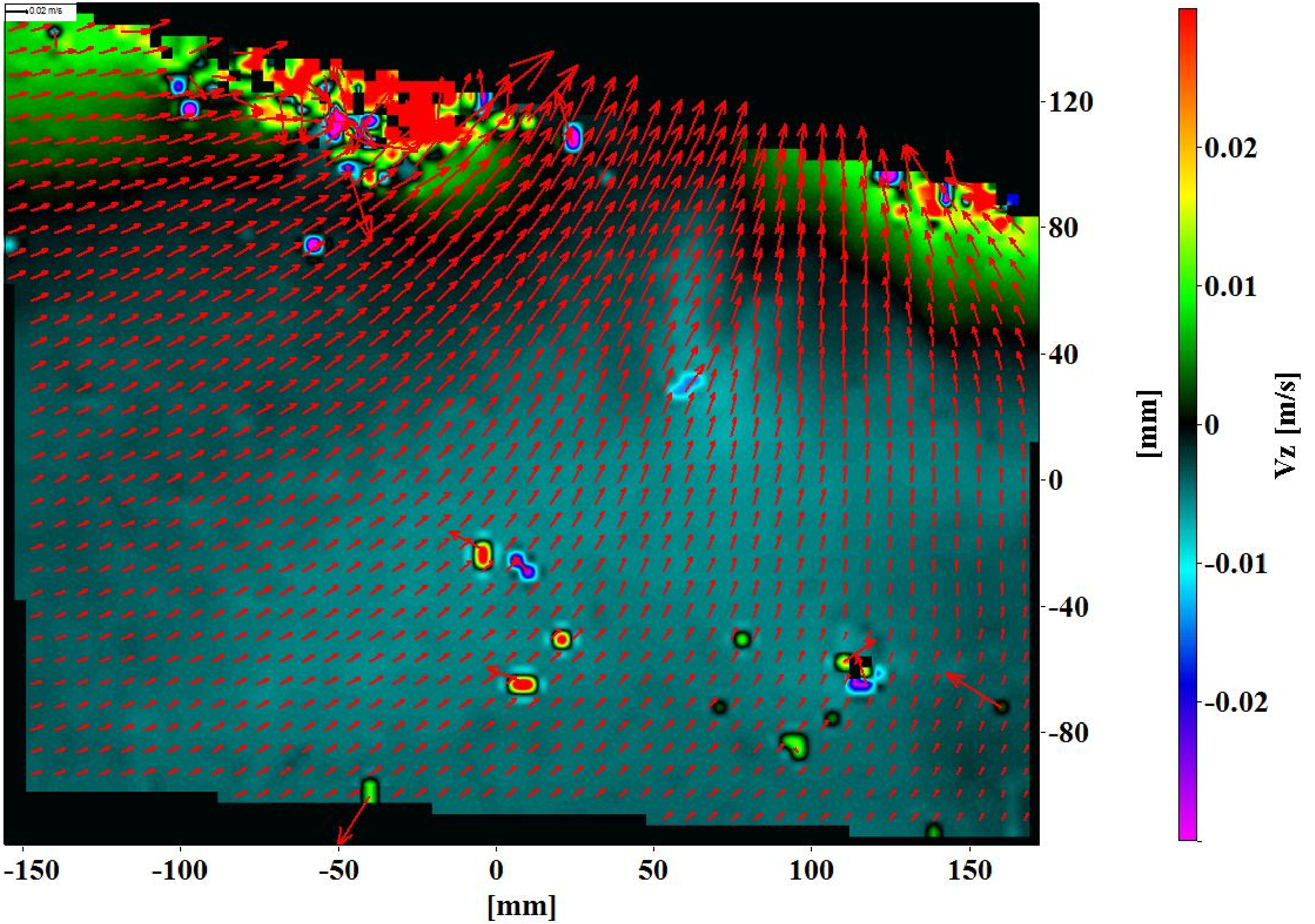
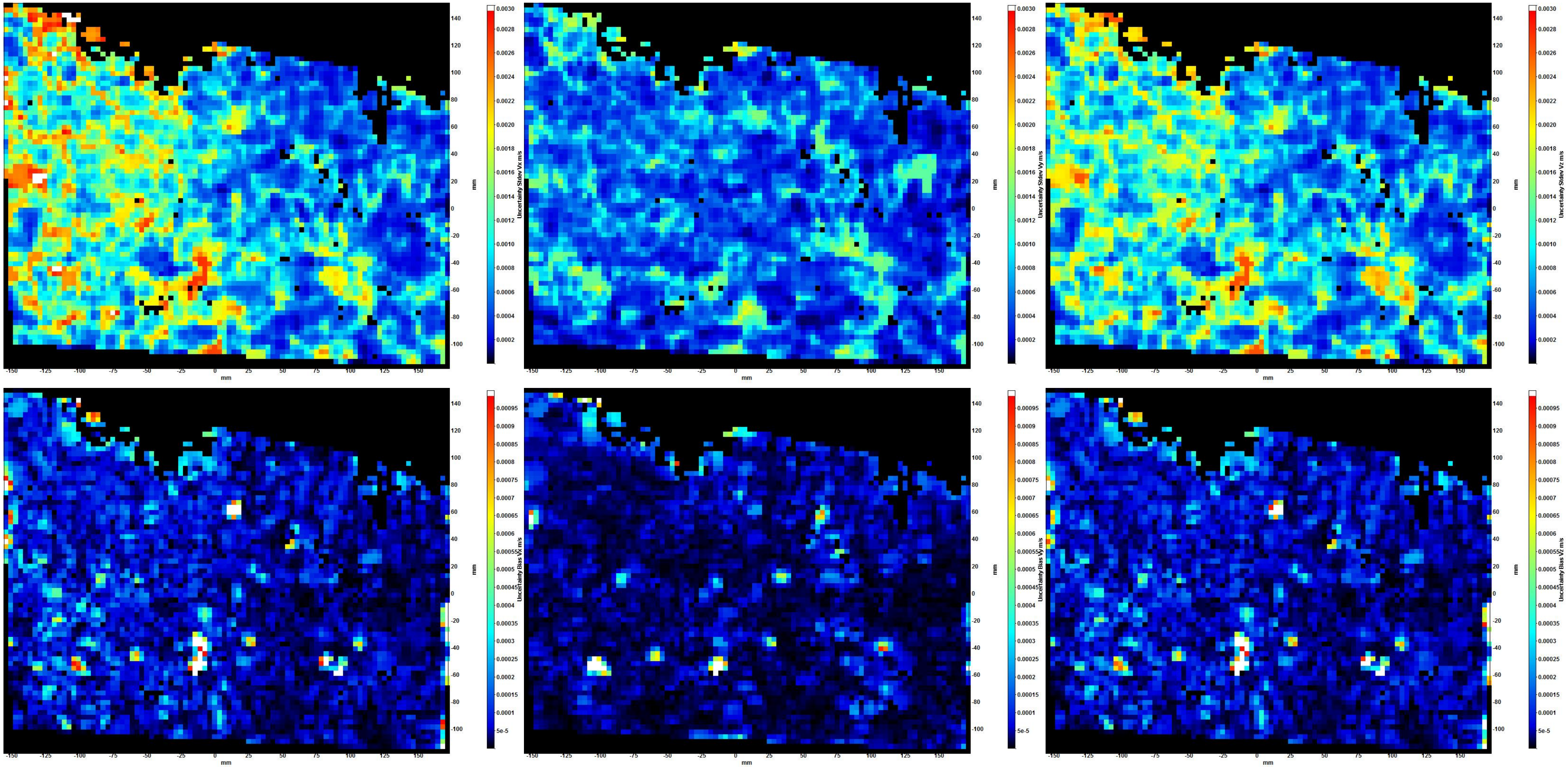
DCC06-4
t = 1745s
T_{pool} = 26,498 °C
$P_{blowdown}$ = 2,94 bar
P_{pool} = 2,8816 bar
$q_{m,steam}$ = 125 g/s





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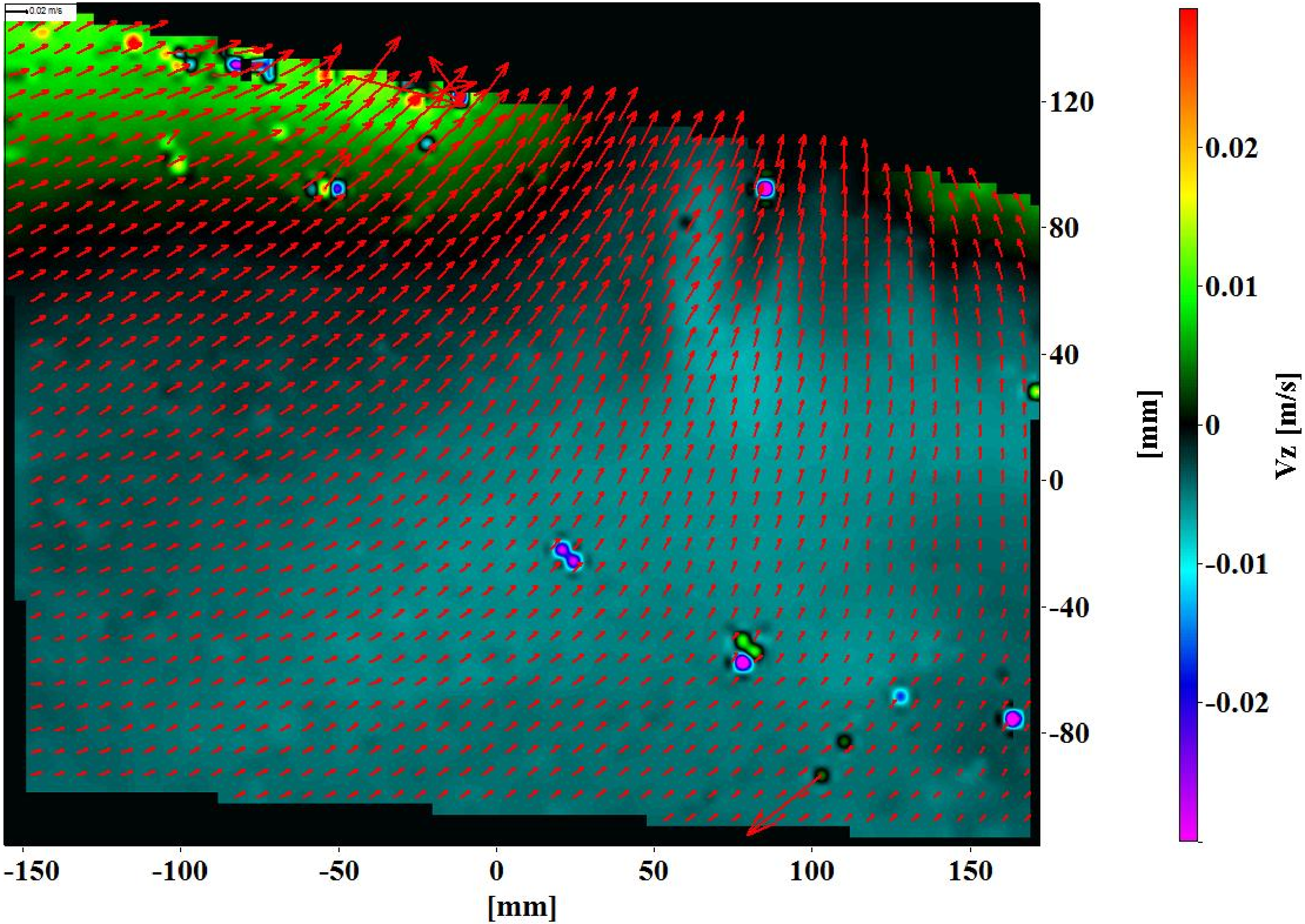
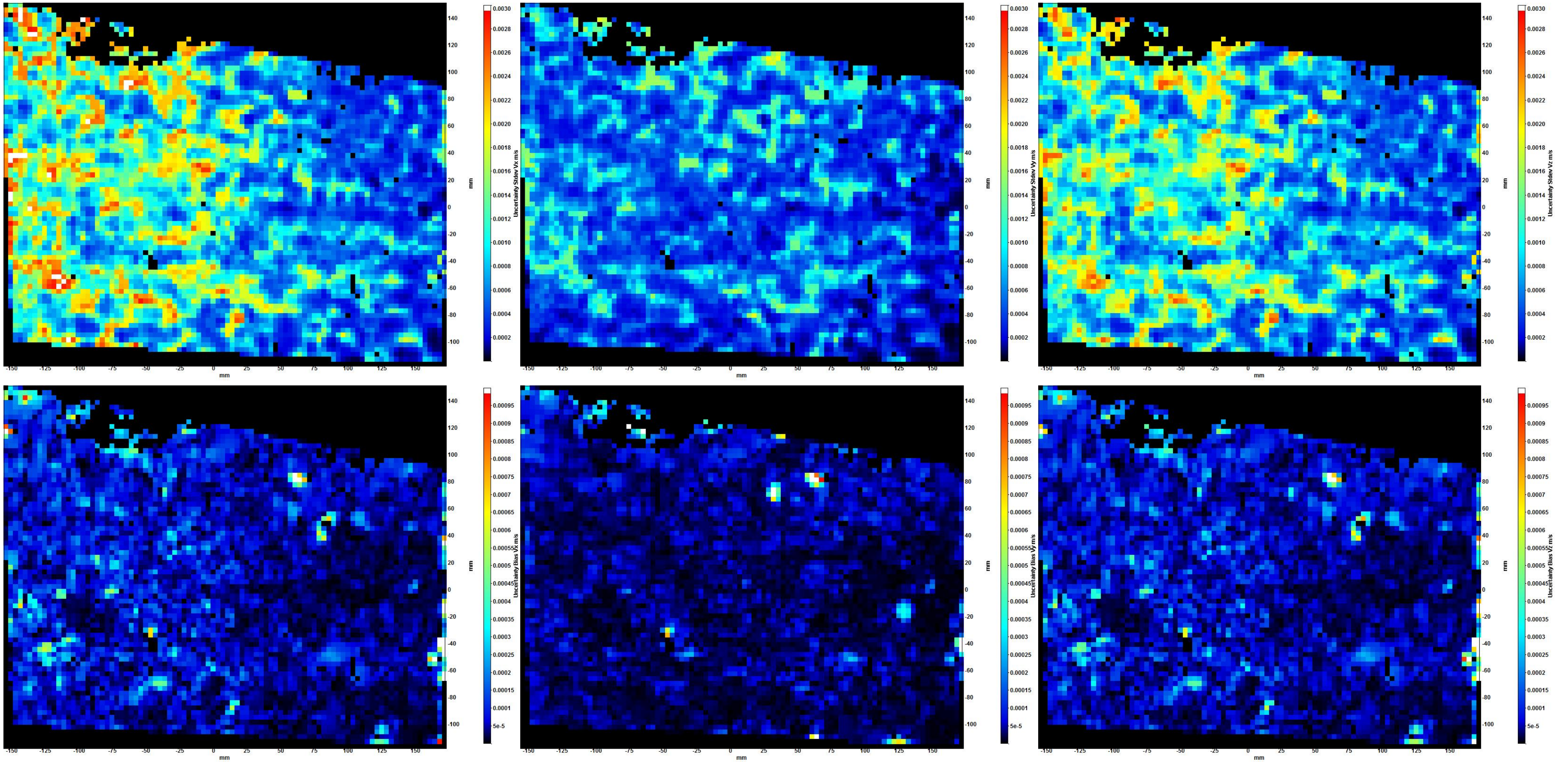
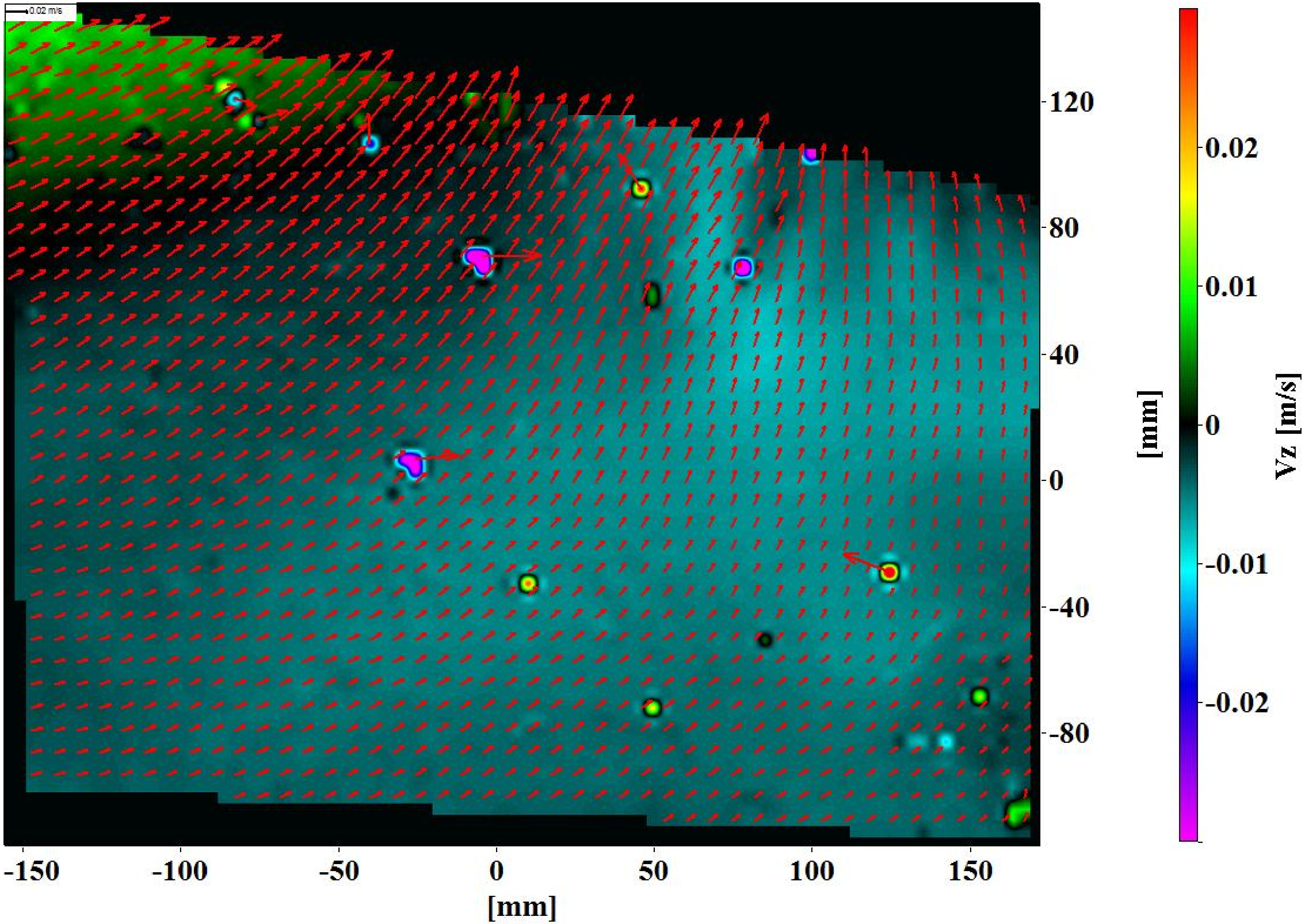
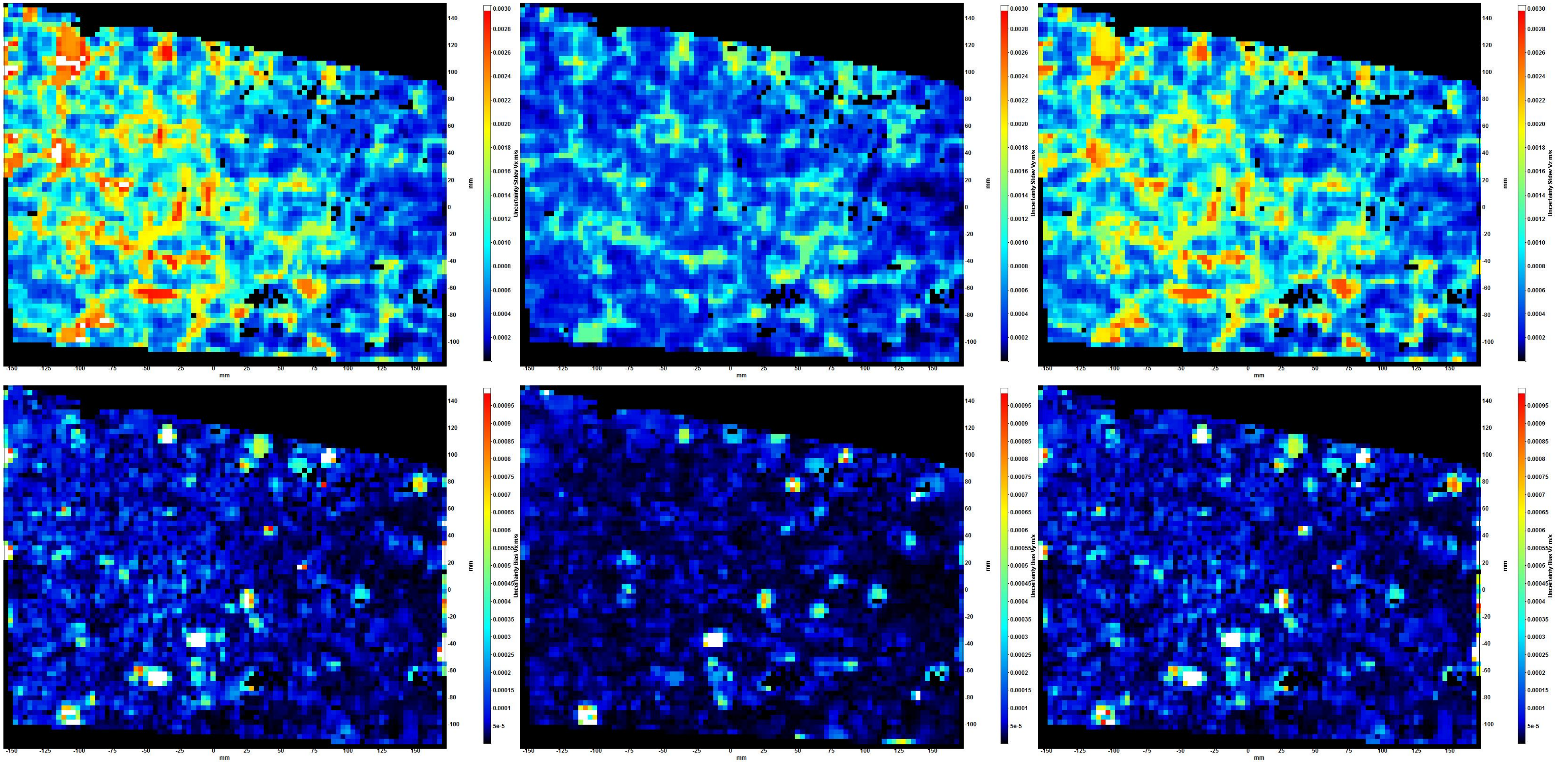
DCC06-4
t = 1746s
T_{pool} = 26,498 °C
$P_{blowdown}$ = 2,94 bar
P_{pool} = 2,8816 bar
$q_{m,steam}$ = 125 g/s



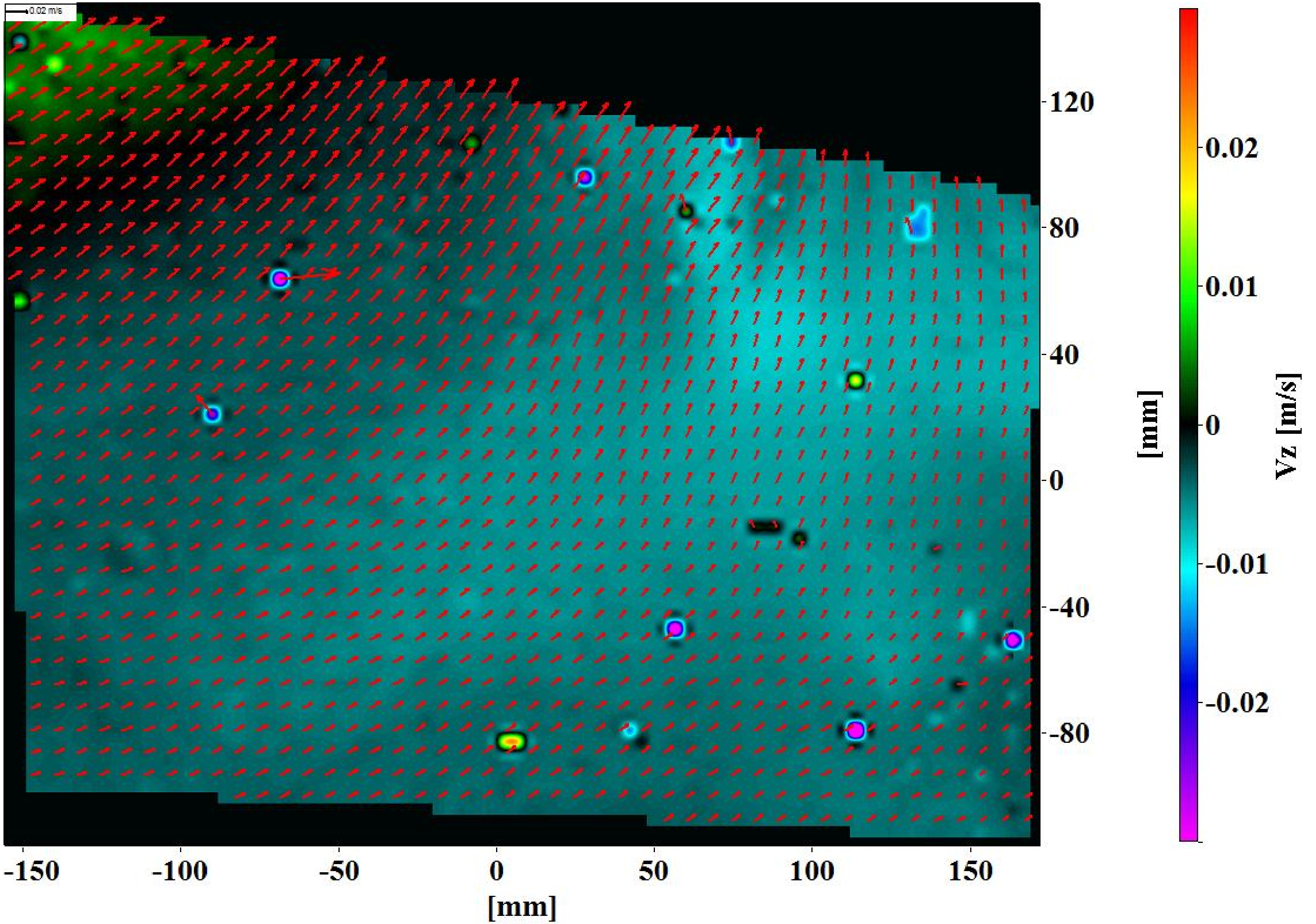

mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

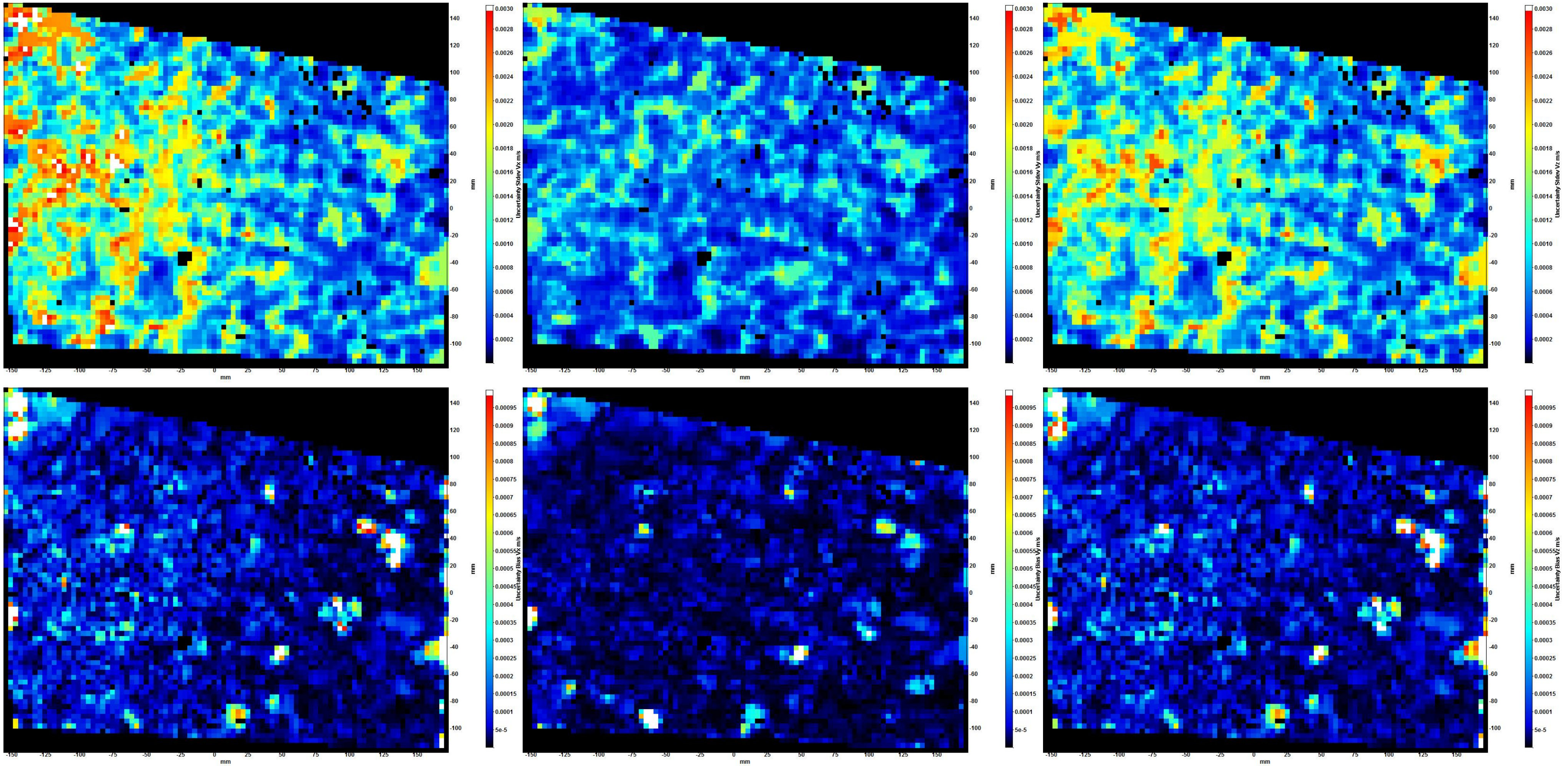
DCC06-4
t = 1747s
T_{pool} = 26,498 °C
$P_{blowdown}$ = 2,94 bar
P_{pool} = 2,8816 bar
$q_{m,steam}$ = 125 g/s





DCC06-4
t = 1748s
T_{pool} = 26,498 °C
$P_{blowdown}$ = 2,94 bar
P_{pool} = 2,8816 bar
$q_{m,steam}$ = 125 g/s





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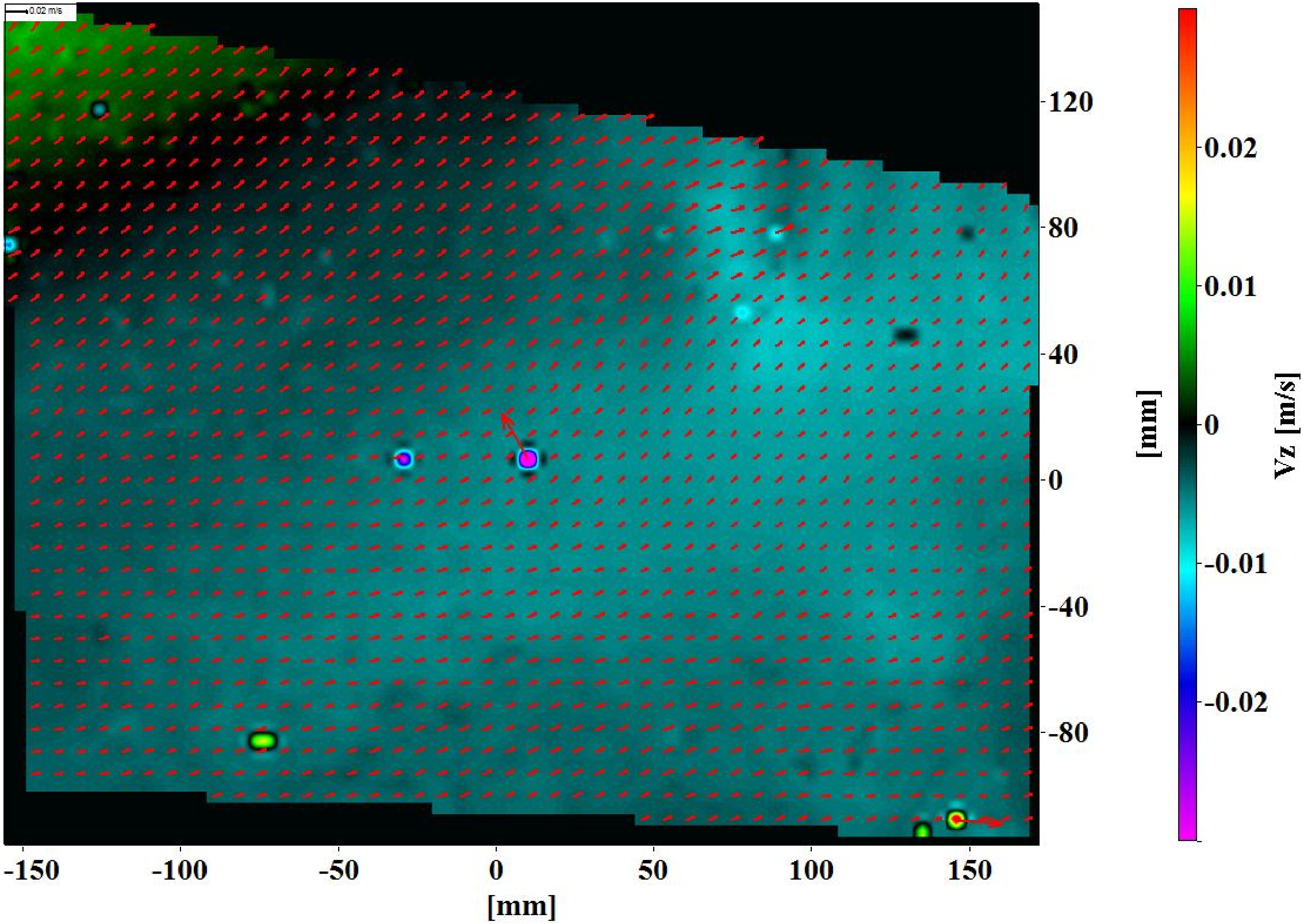
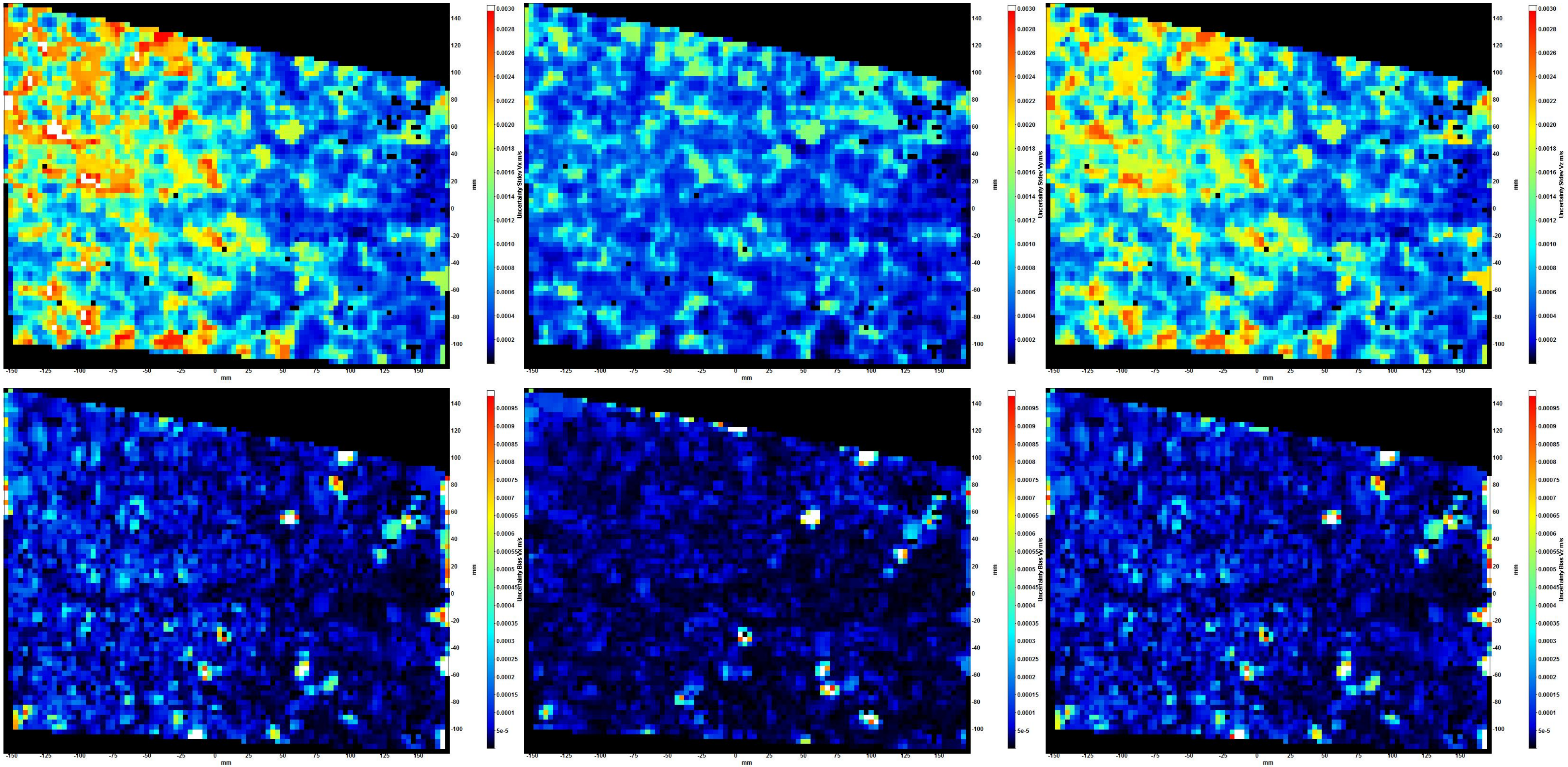
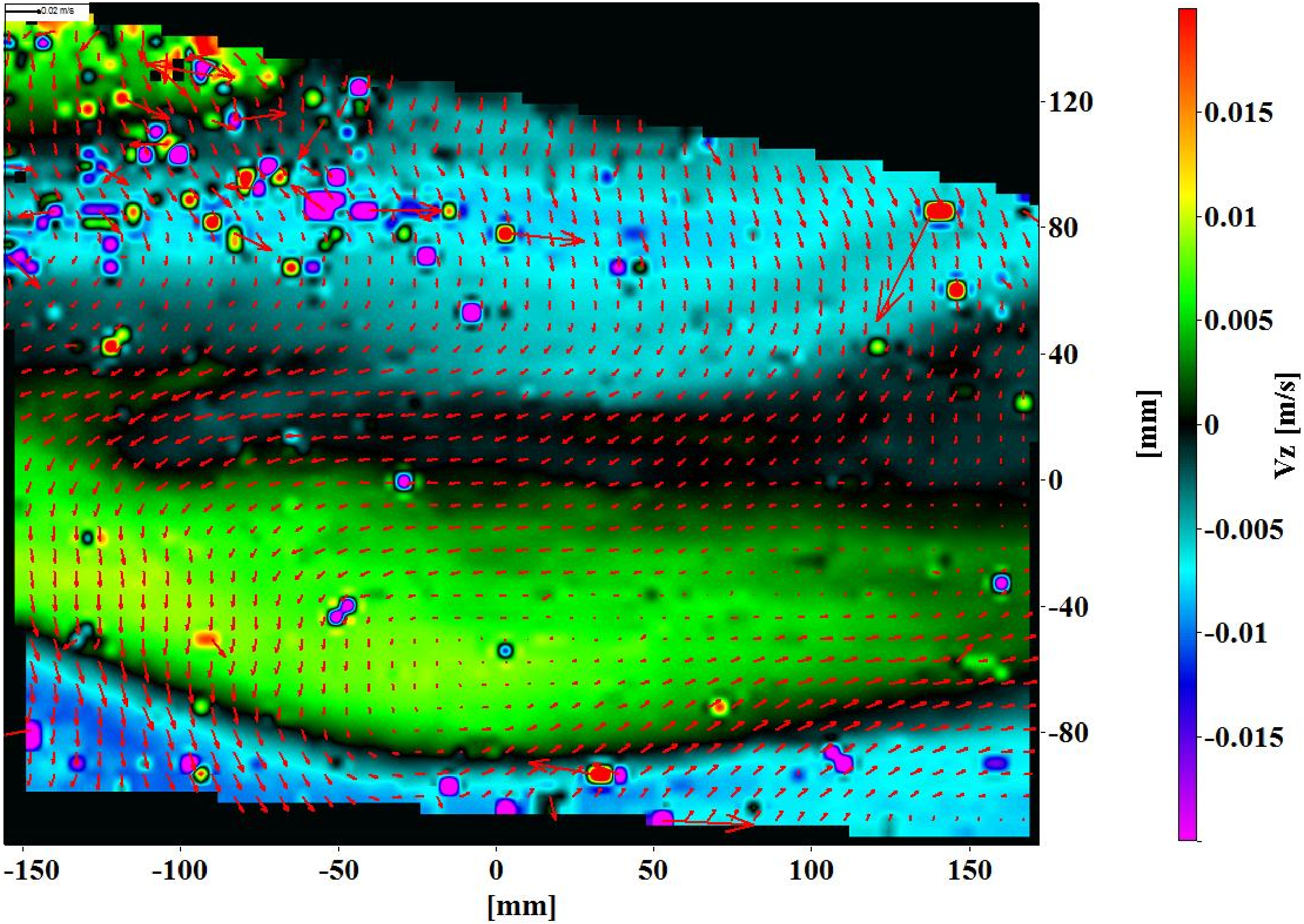
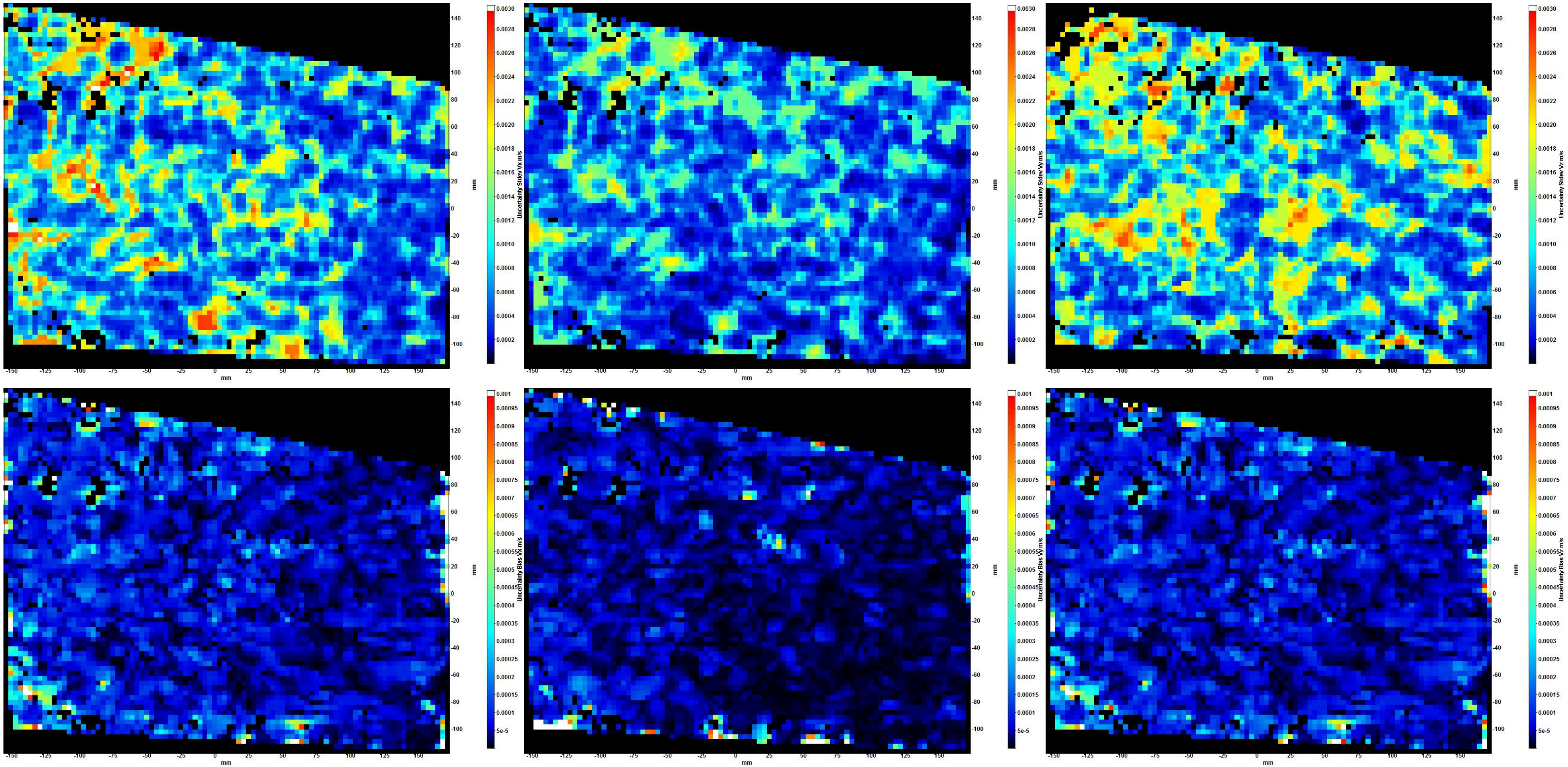
DCC06-4
t = 1749s
T_{pool} = 26,498 °C
$P_{blowdown}$ = 2,94 bar
P_{pool} = 2,8816 bar
$q_{m,steam}$ = 125 g/s




mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

DCC06-9
t = 3942 s
T_{pool} = 49,222 °C
$P_{blowdown}$ = 3,2636 bar
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 83 g/s





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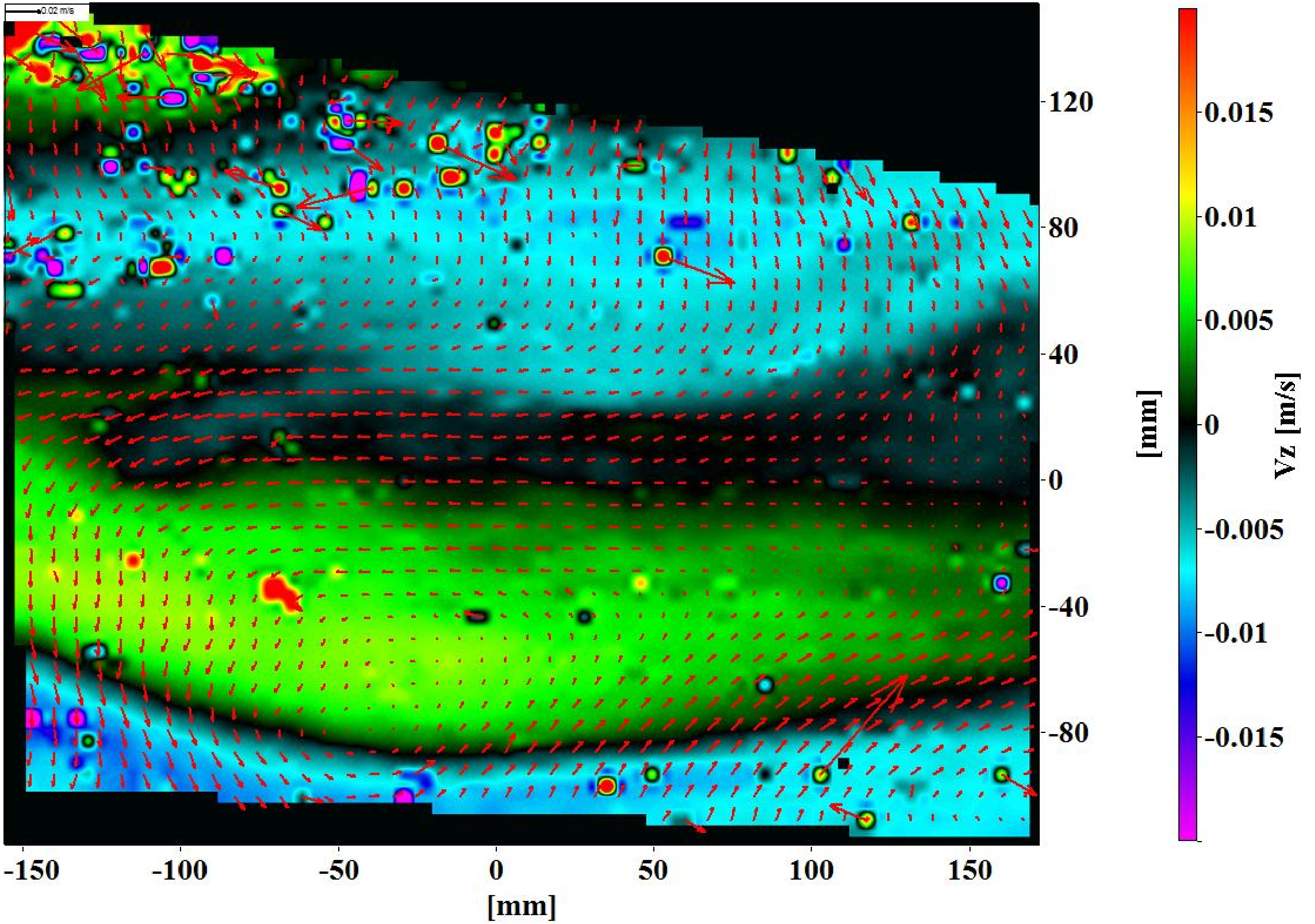
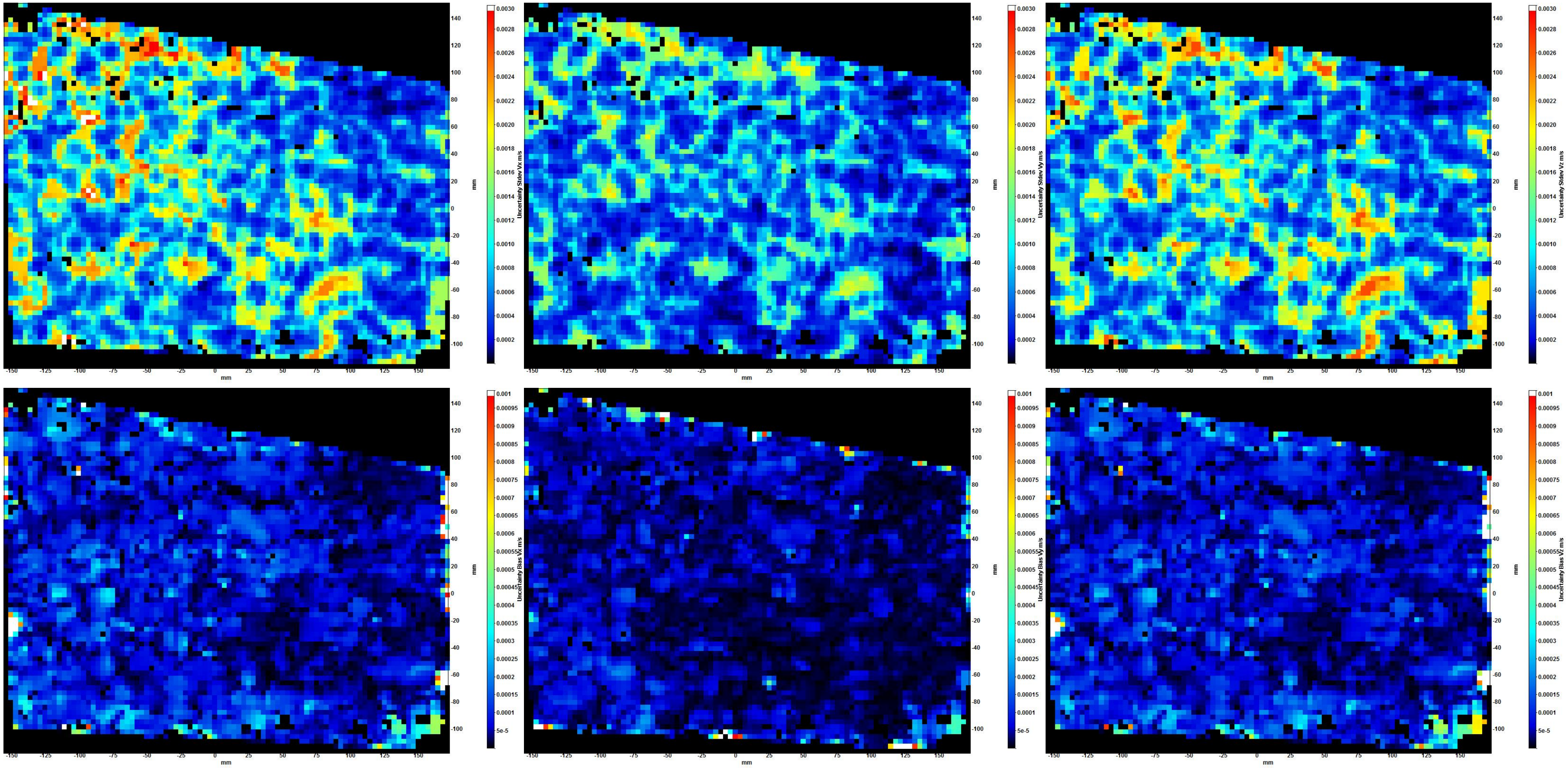
DCC06-9
t = 3943 s
T_{pool} = 49,222 °C
$P_{blowdown}$ = 3,2636 bar
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 83 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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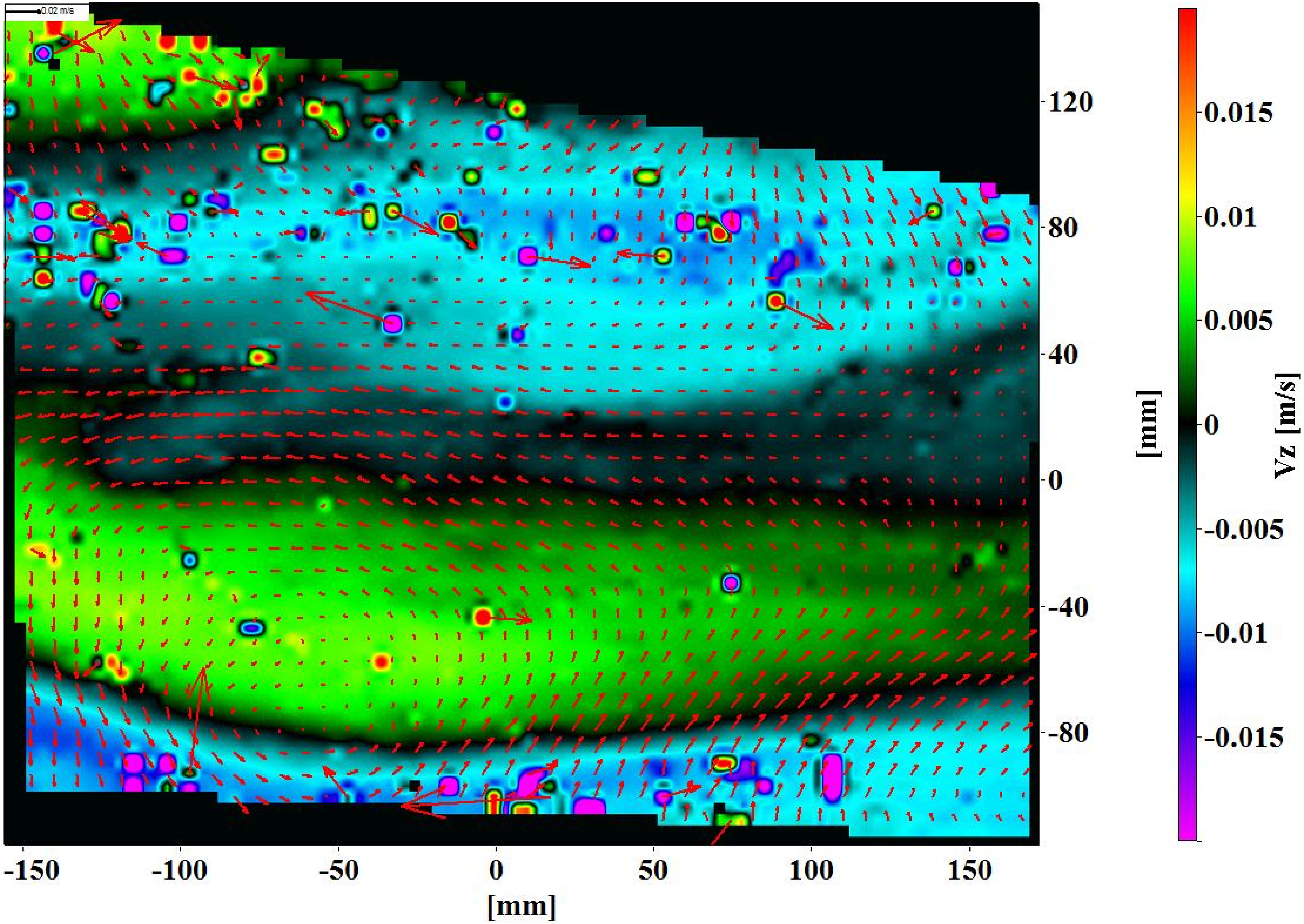
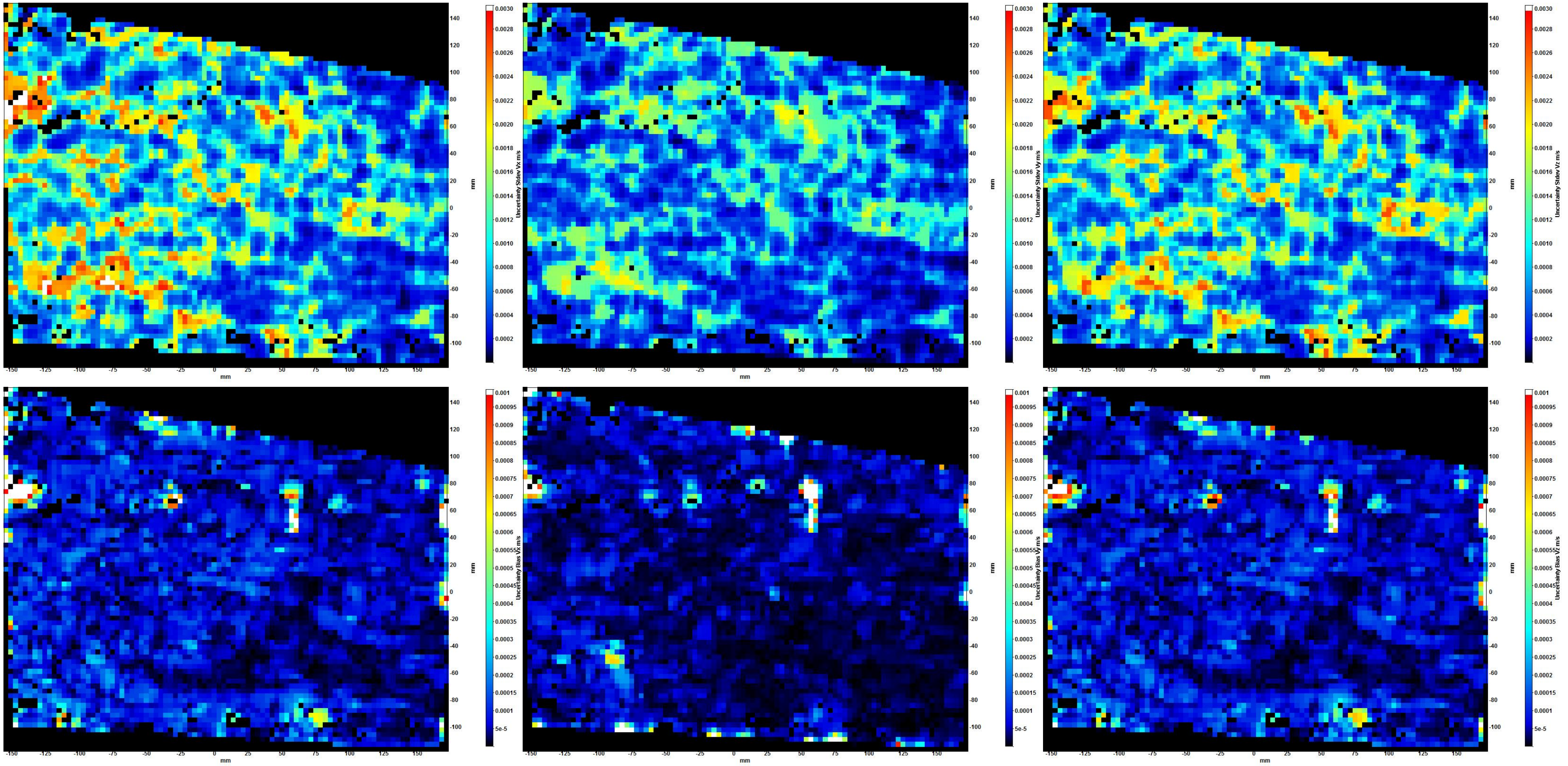
DCC06-9
t = 3944 s
T_{pool} = 49,222 °C
$P_{blowdown}$ = 3,2636 bar
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 83 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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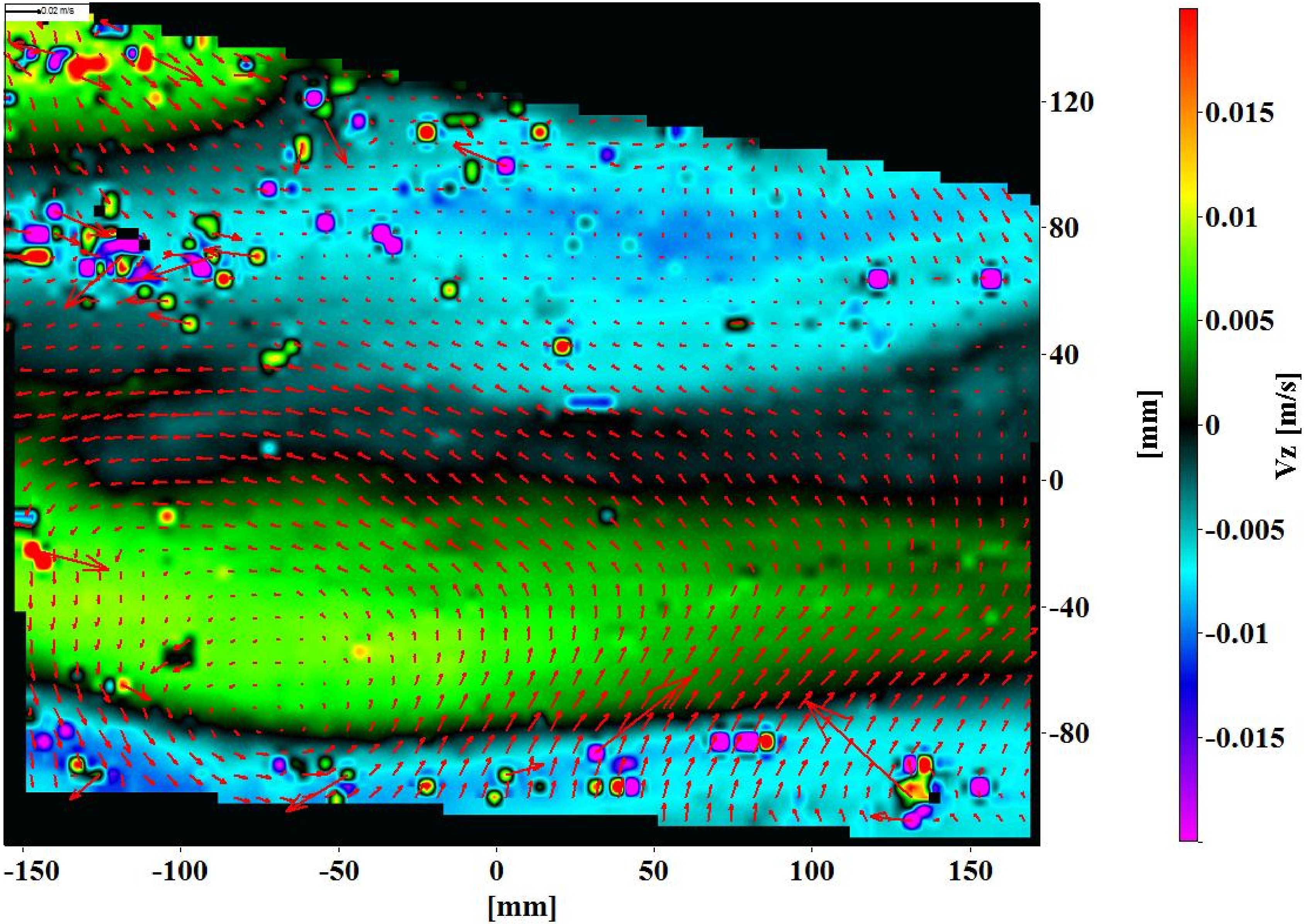
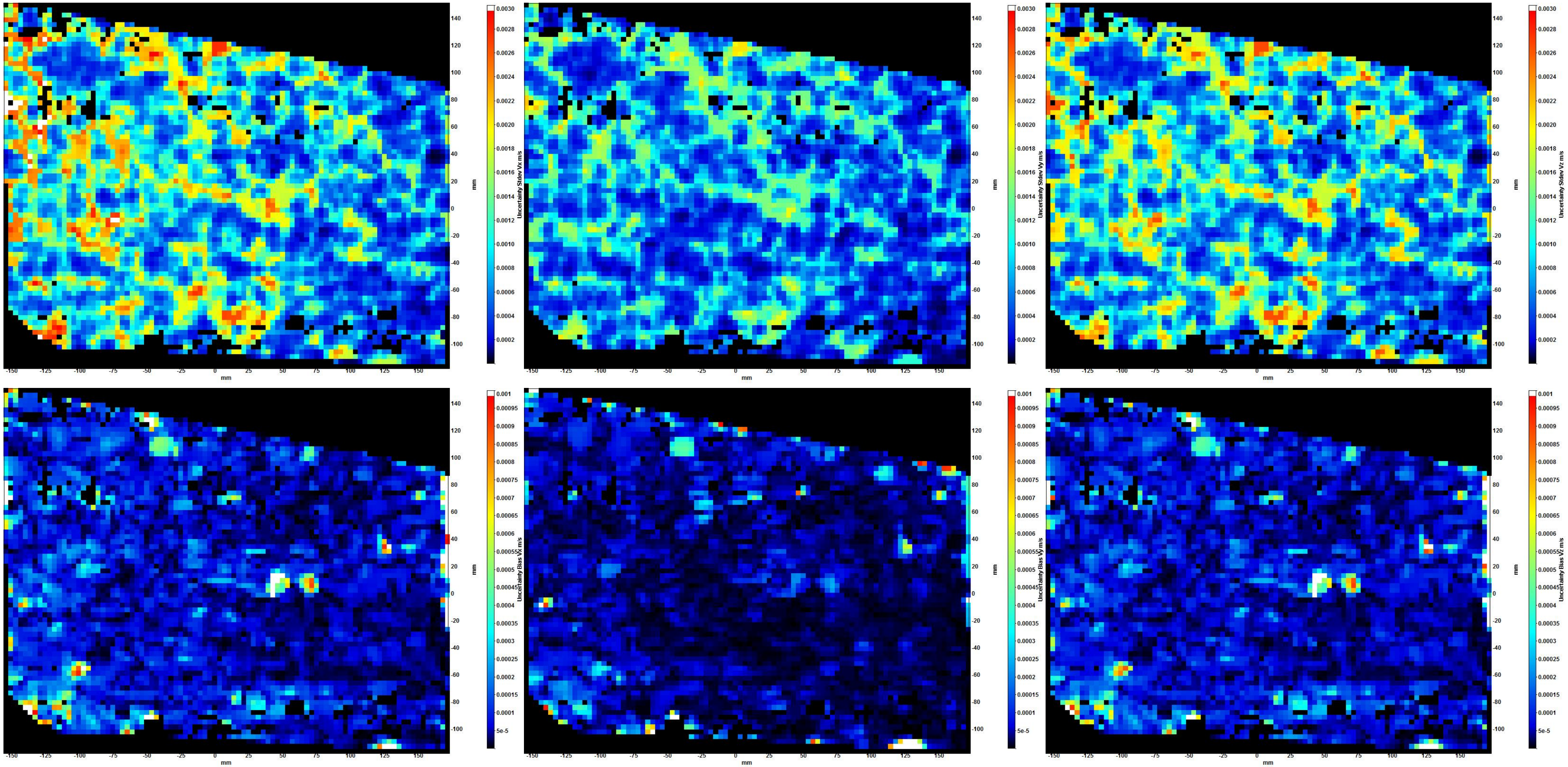
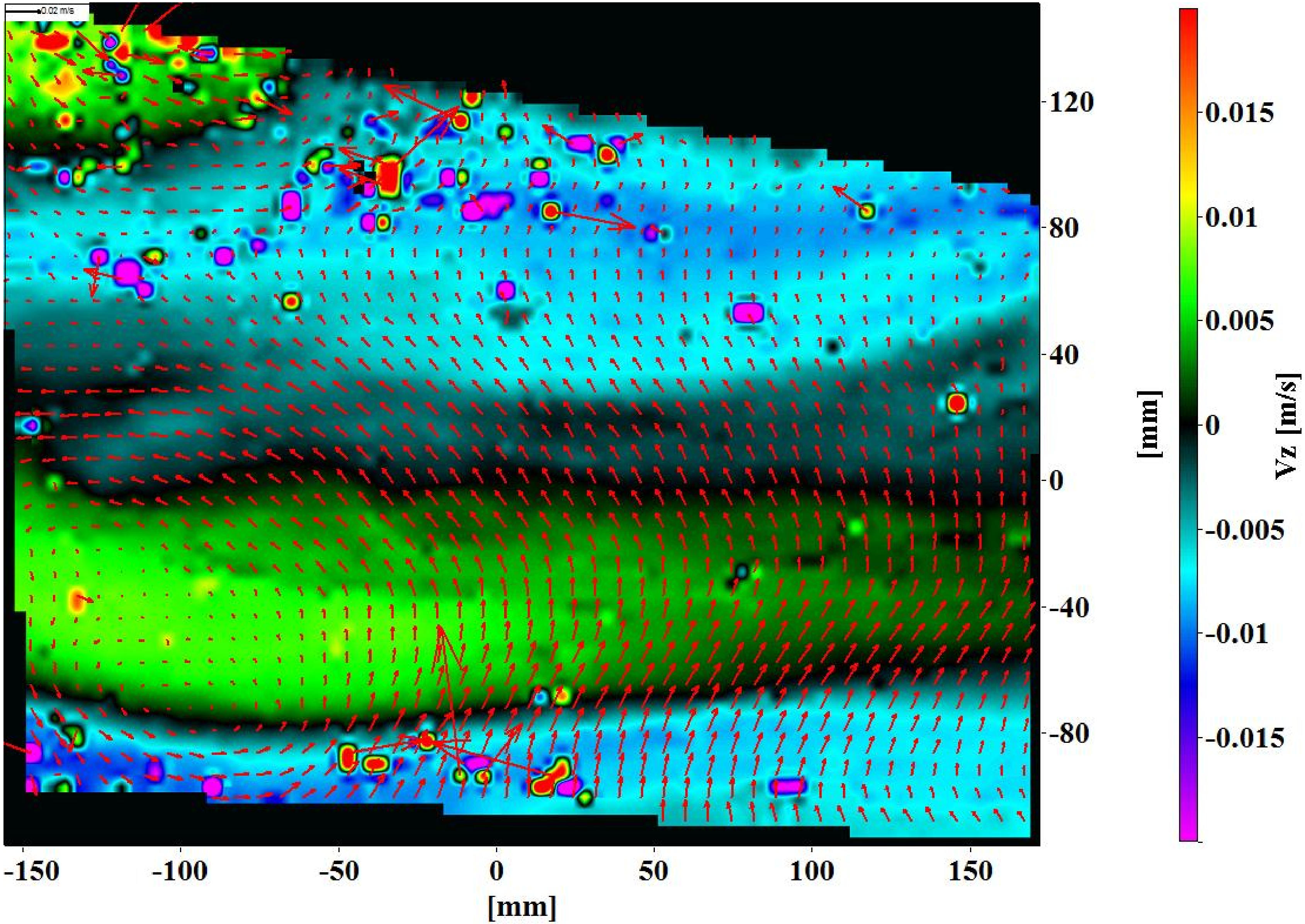
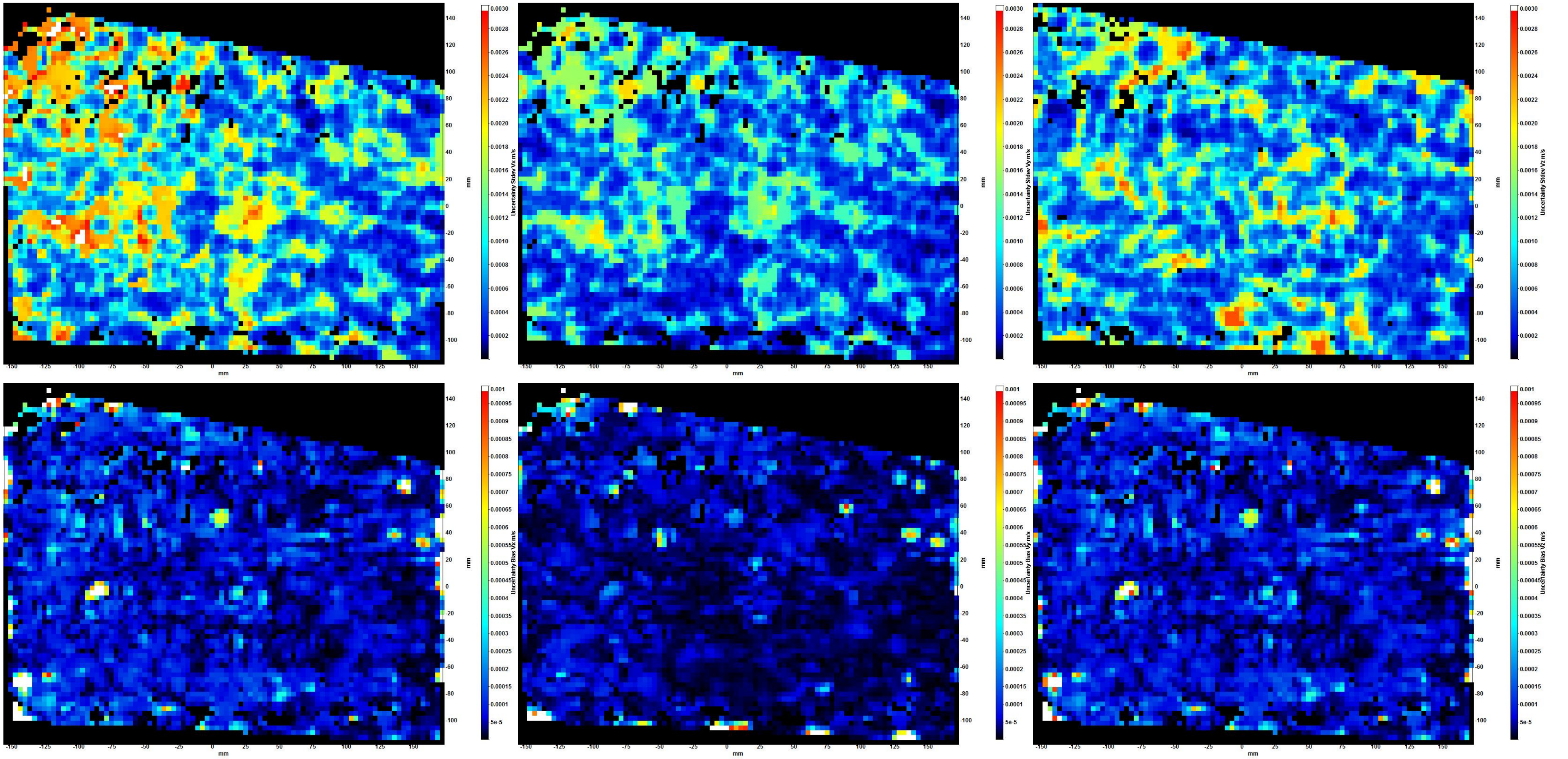
DCC06-9
t = 3945 s
T_{pool} = 49,222 °C
$P_{blowdown}$ = 3,2636 bar
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 83 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC06-9
t = 3946 s
T_{pool} = 49,222 °C
$P_{blowdown}$ = 3,2636 bar
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 83 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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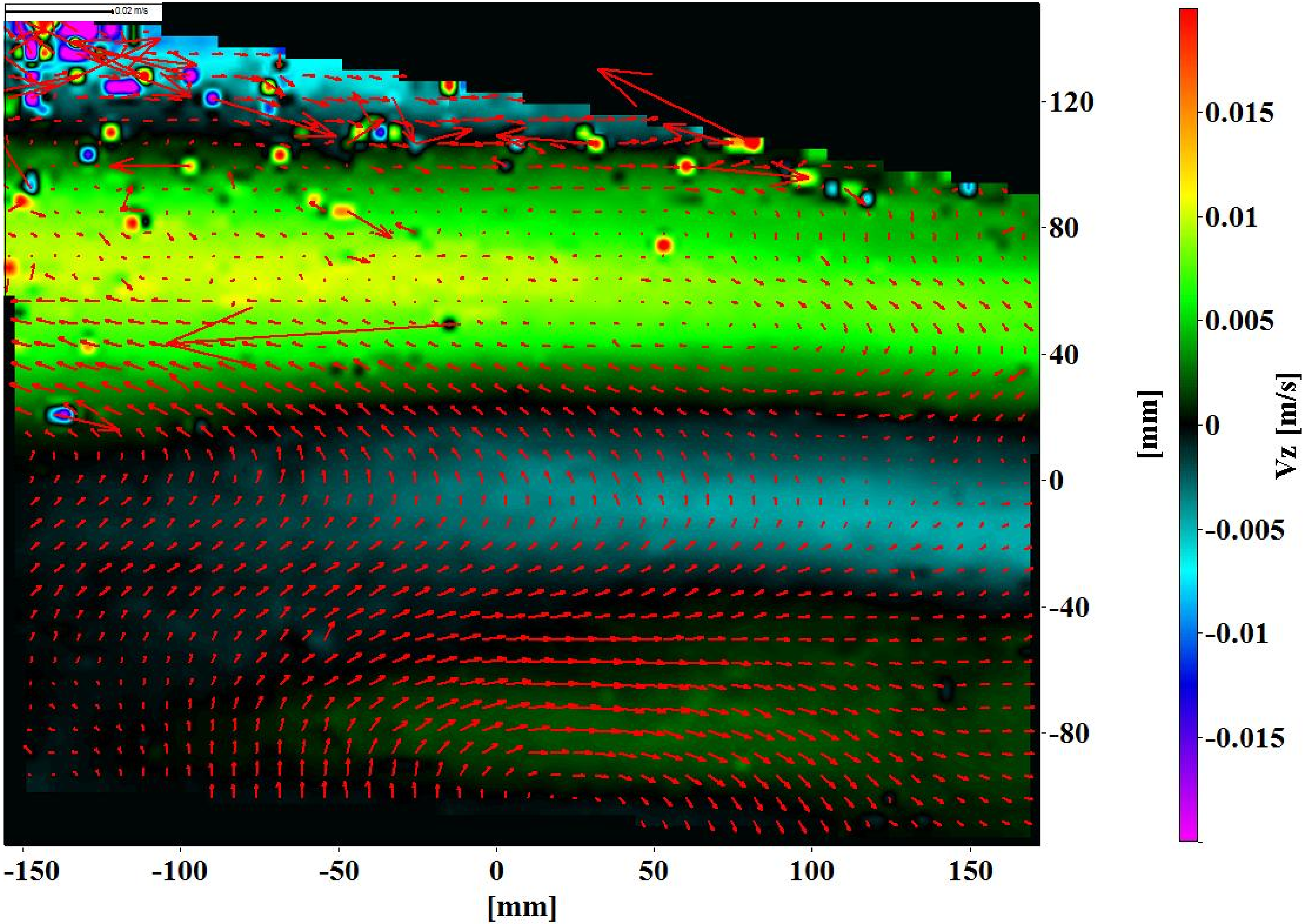
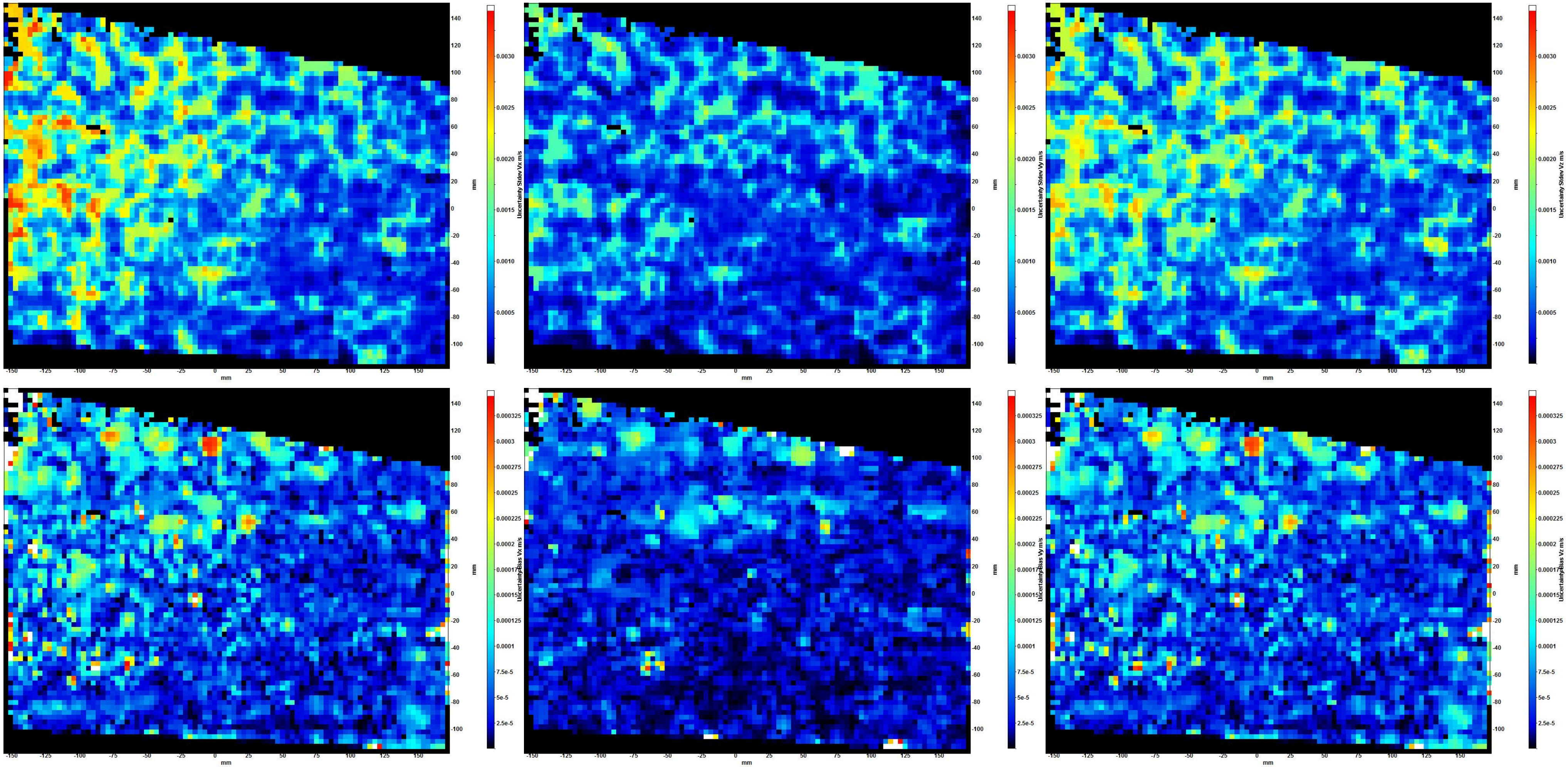
DCC06-10
T_{pool} = 52,957 °C
T_{bottom} = 21,829 °C
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 0 g/s





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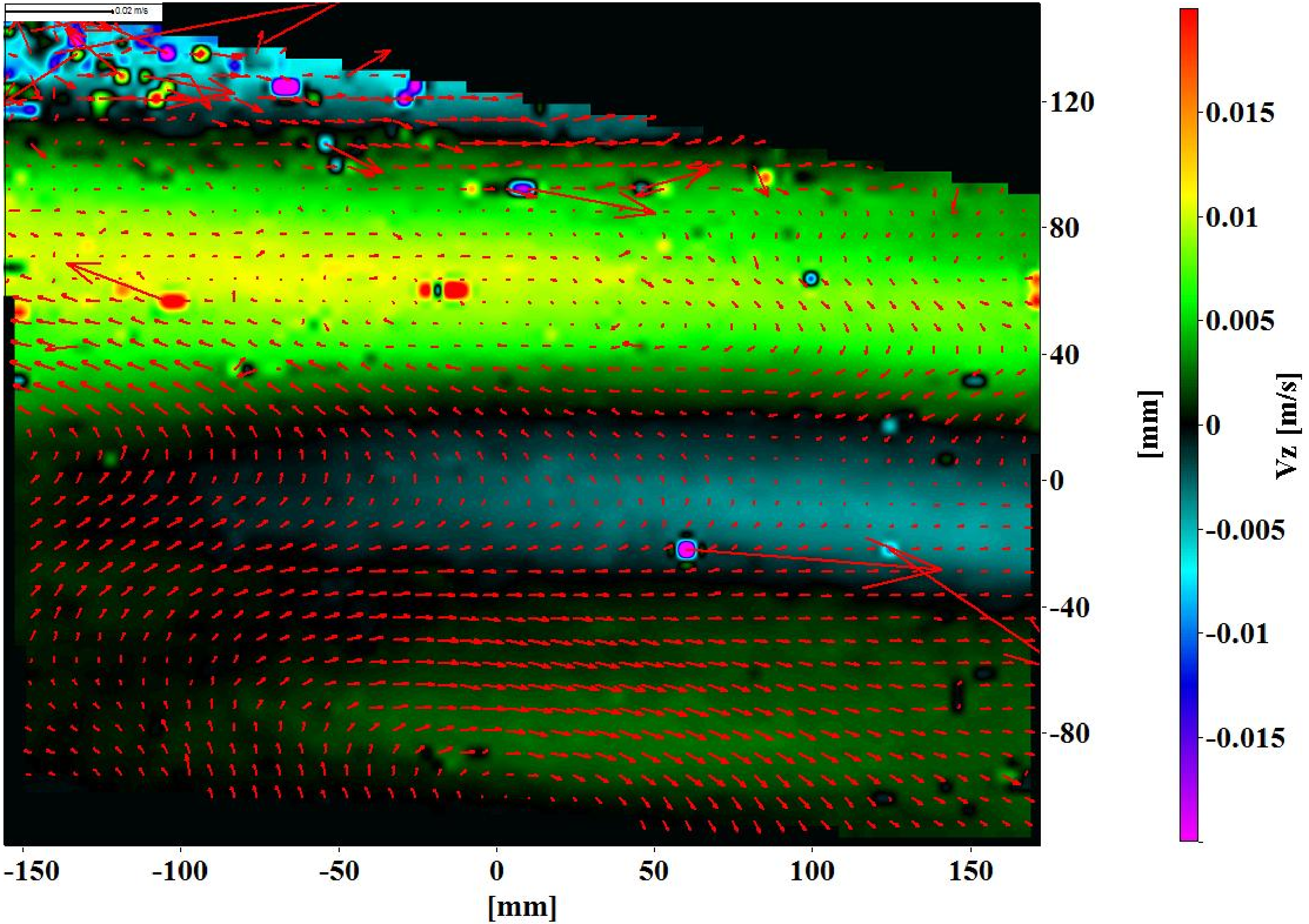
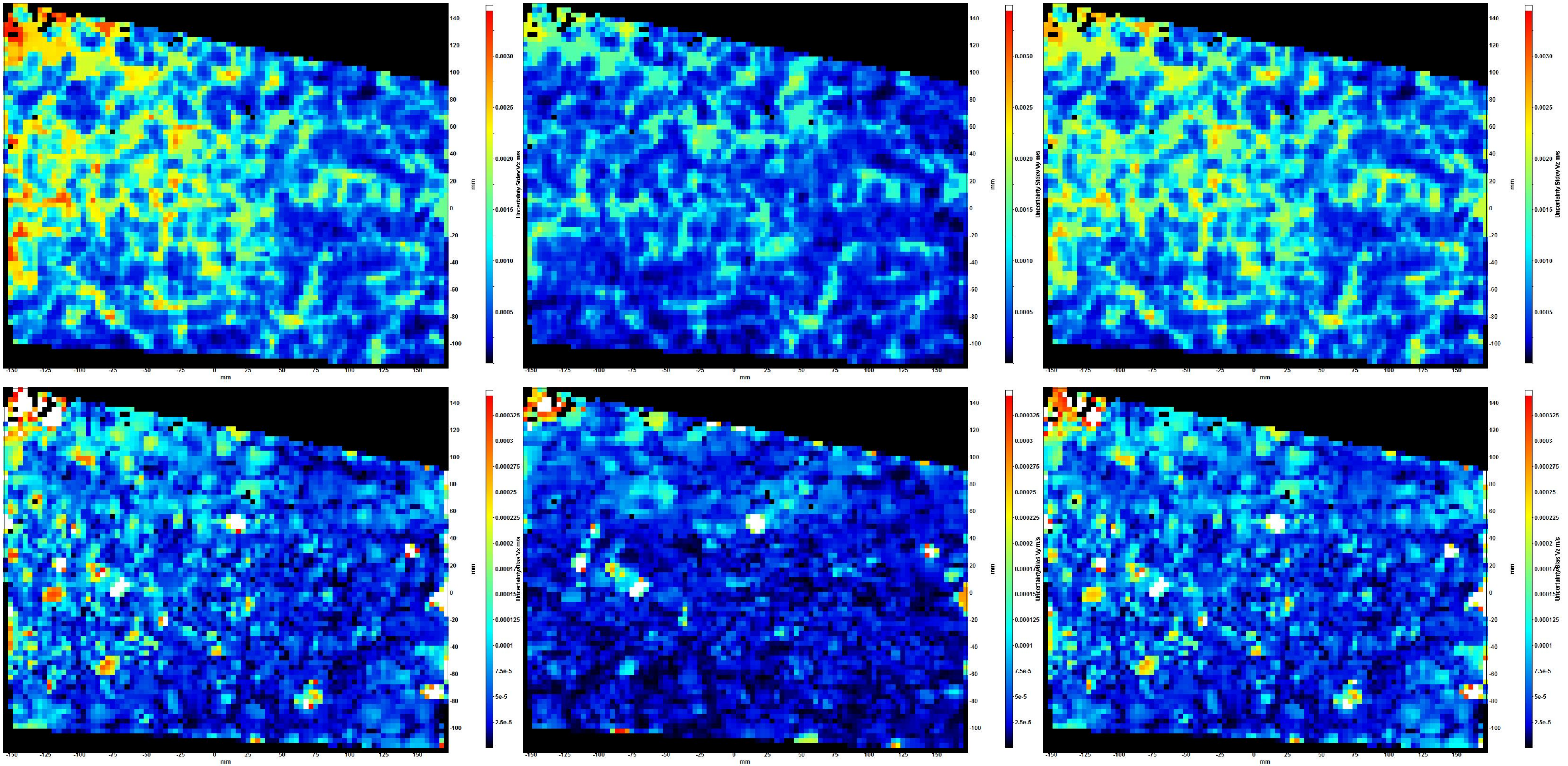
DCC06-10
T_{pool} = 52,957 °C
T_{bottom} = 21,829 °C
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 0 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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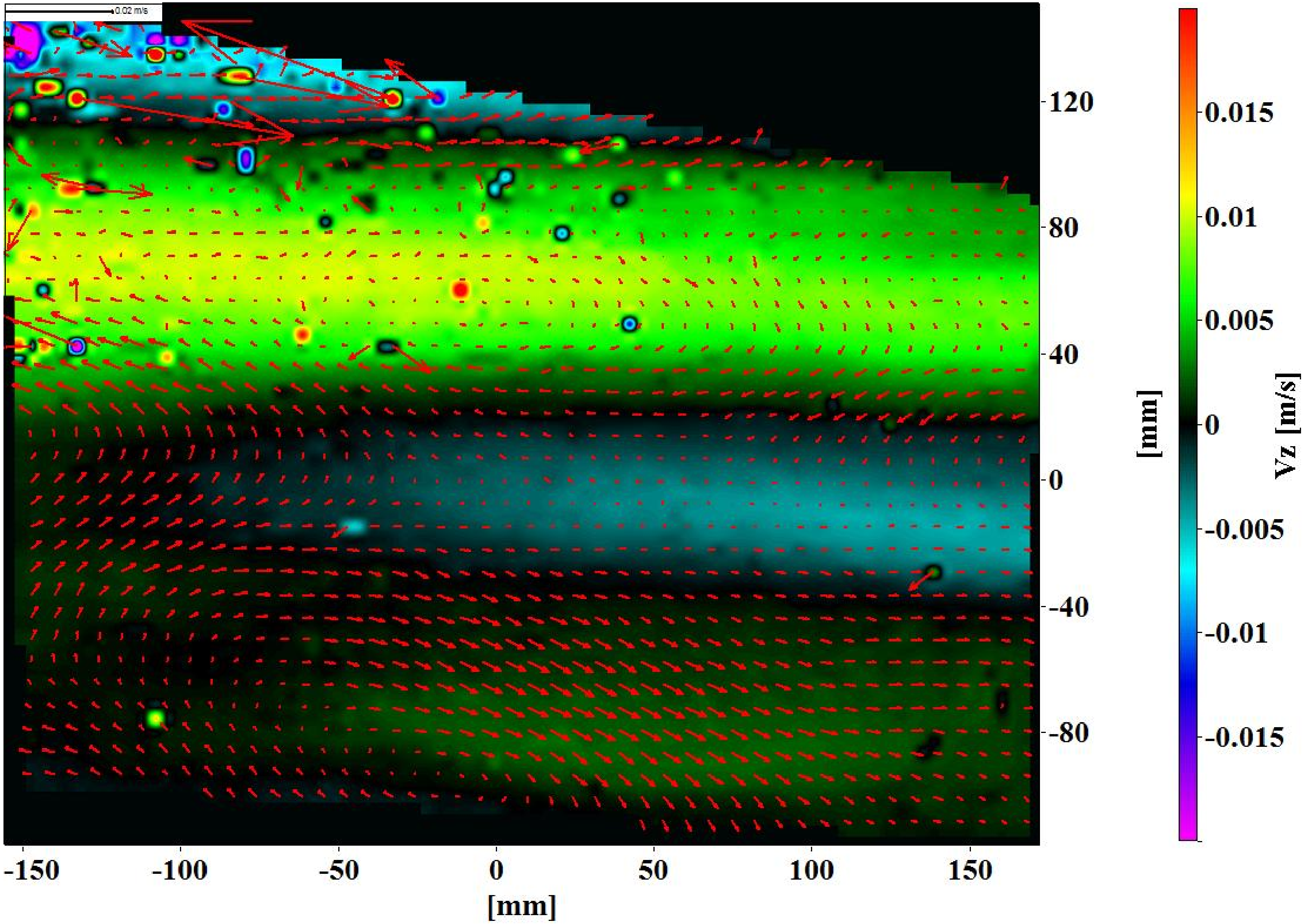
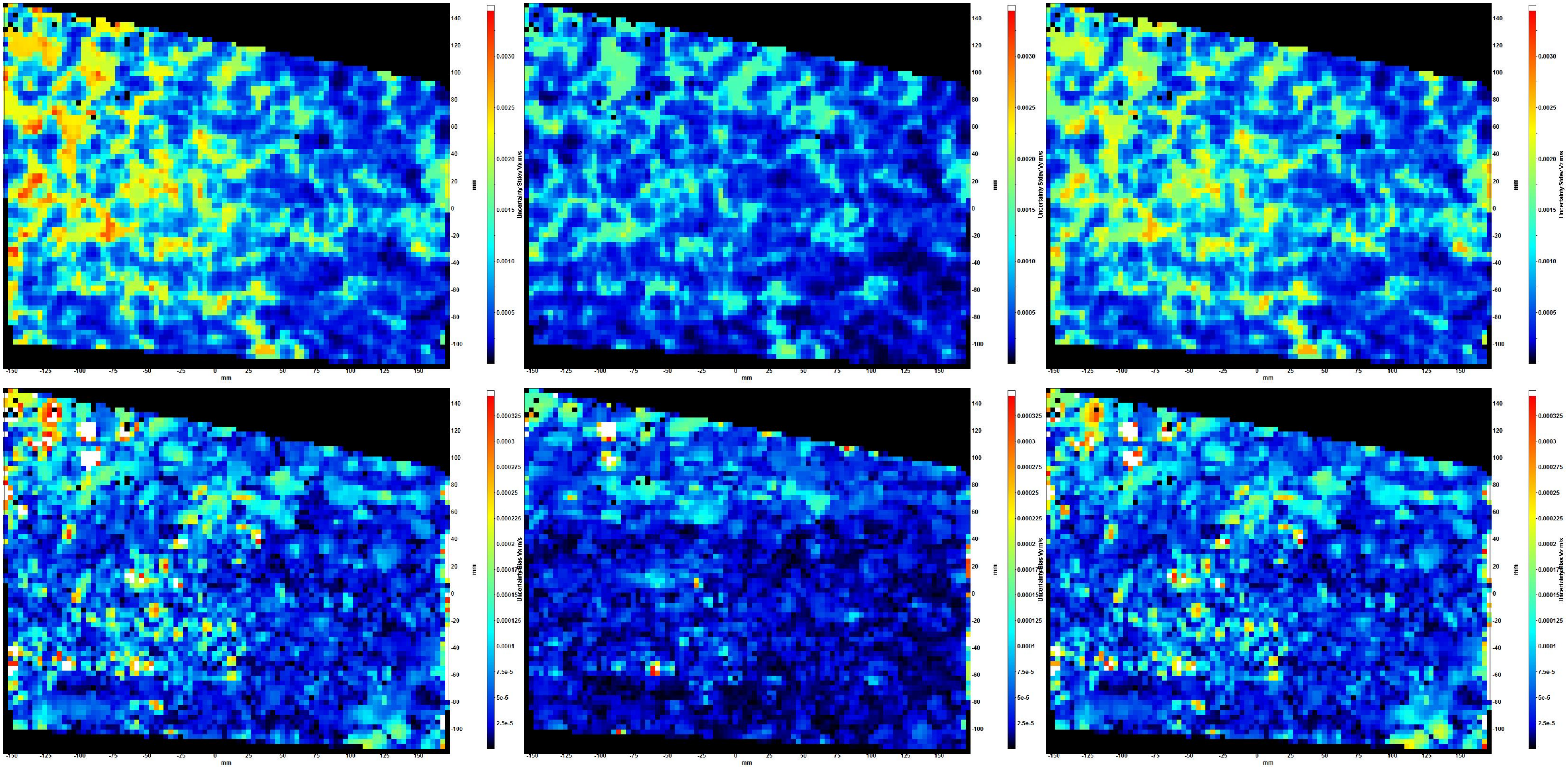
DCC06-10
T_{pool} = 52,957 °C
T_{bottom} = 21,829 °C
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 0 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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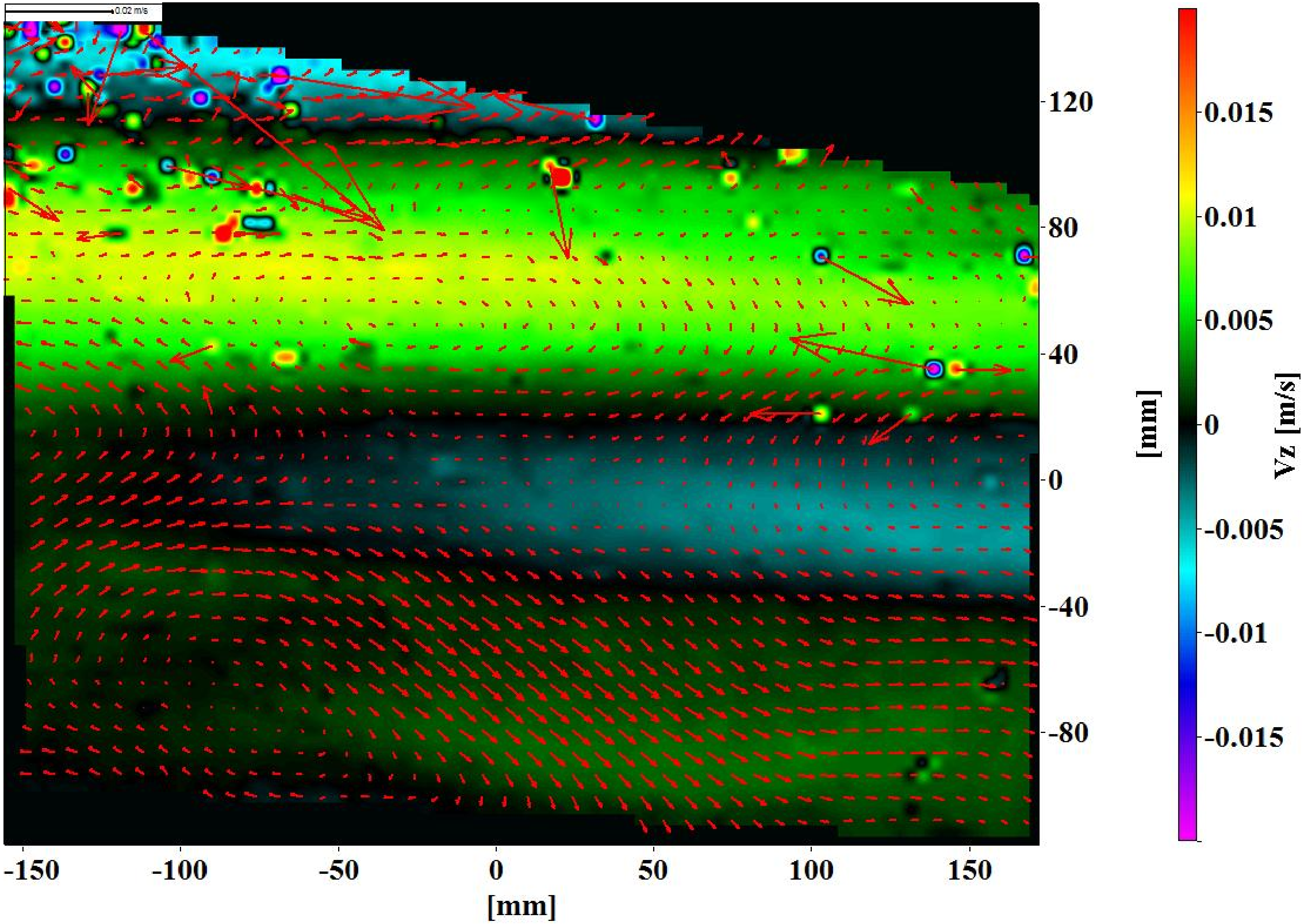
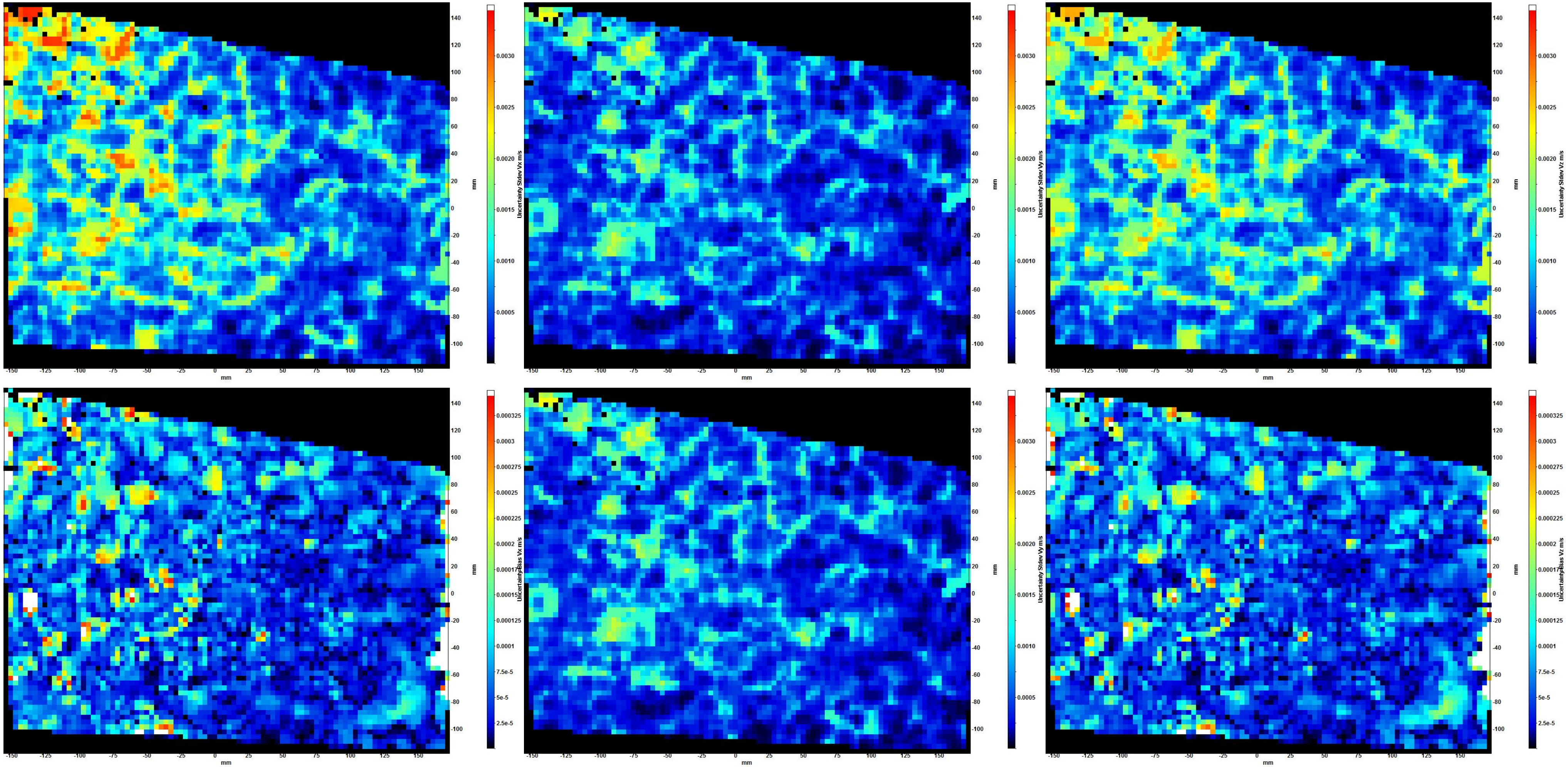
DCC06-10
T_{pool} = 52,957 °C
T_{bottom} = 21,829 °C
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 0 g/s





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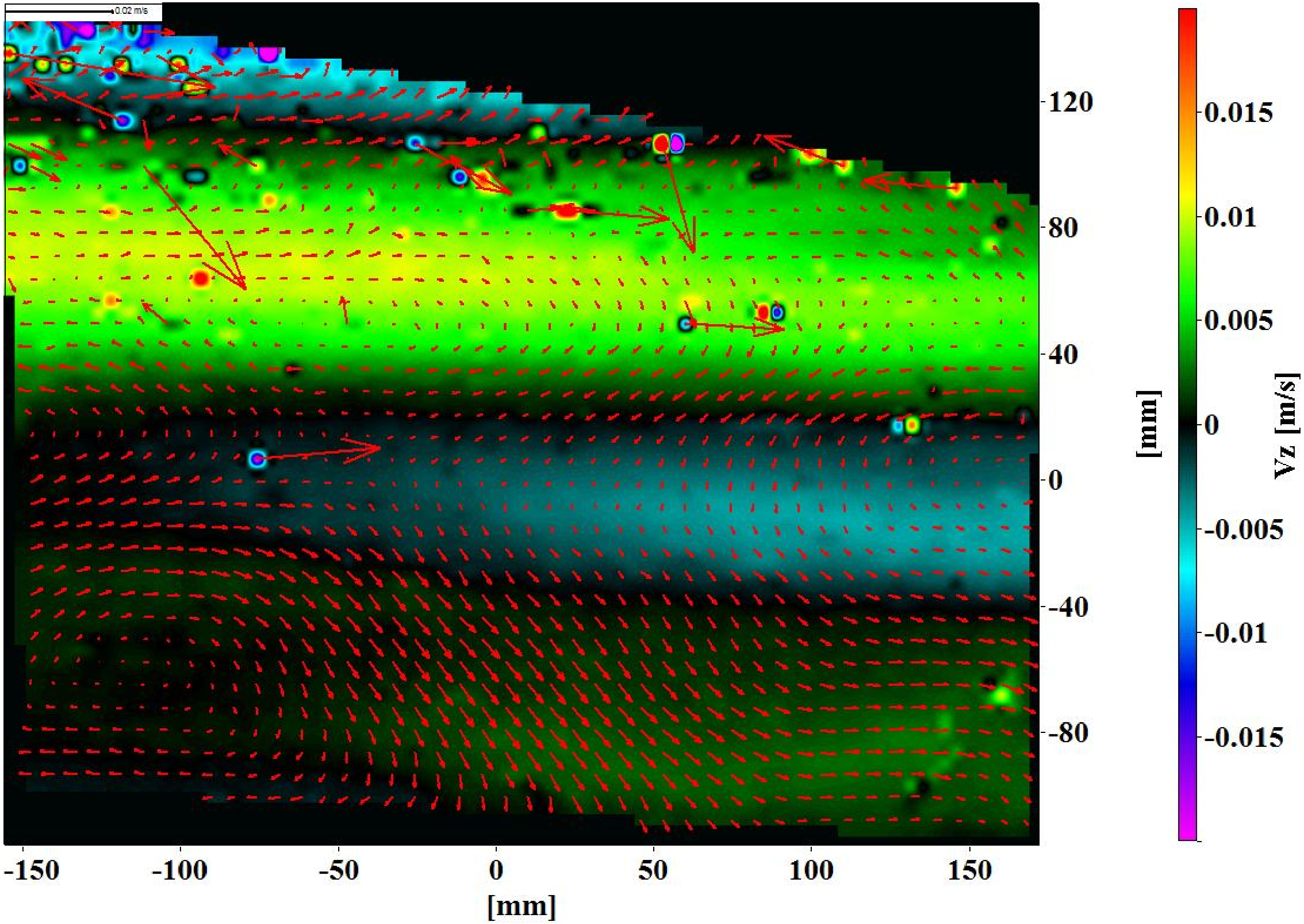
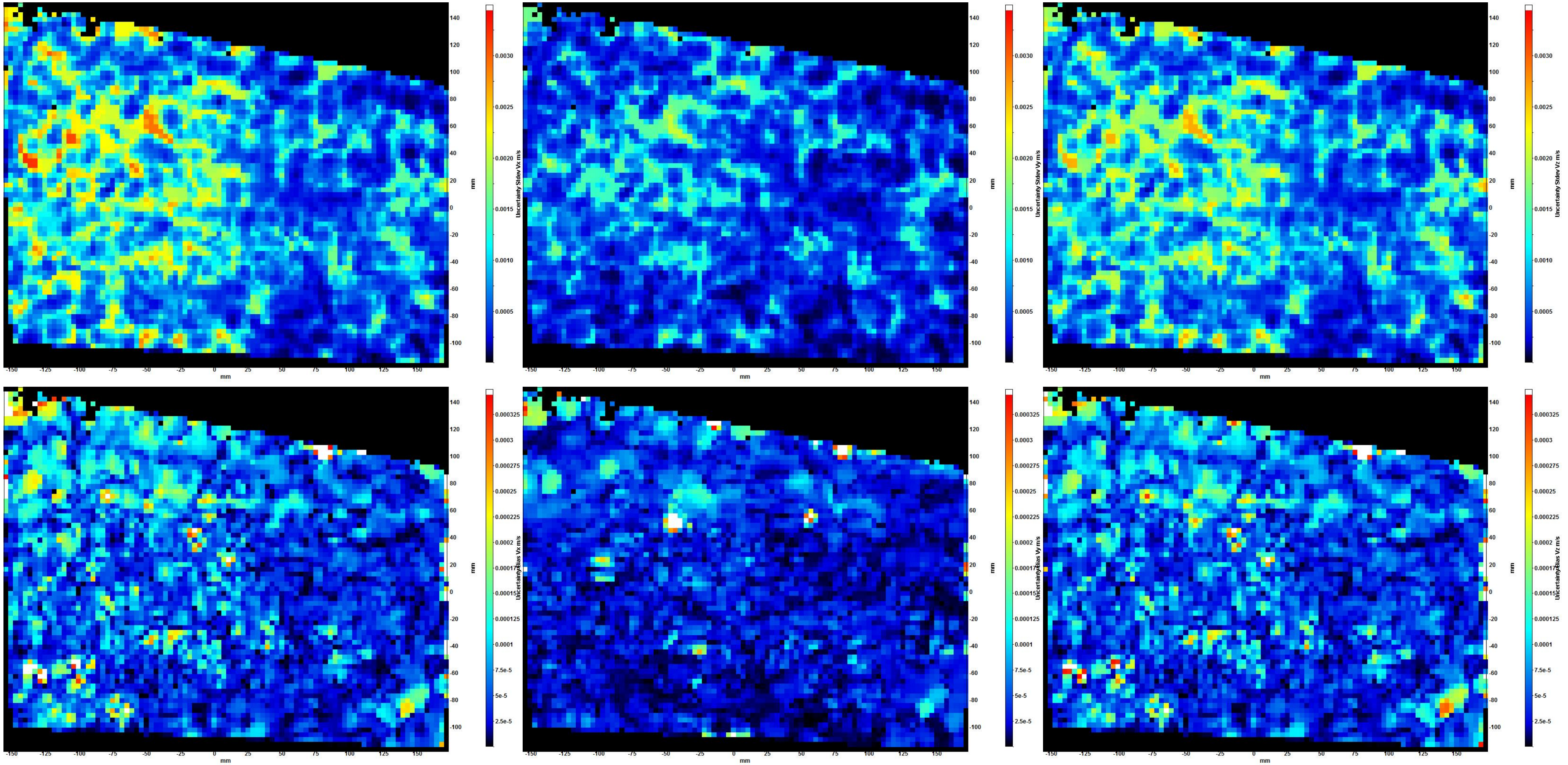
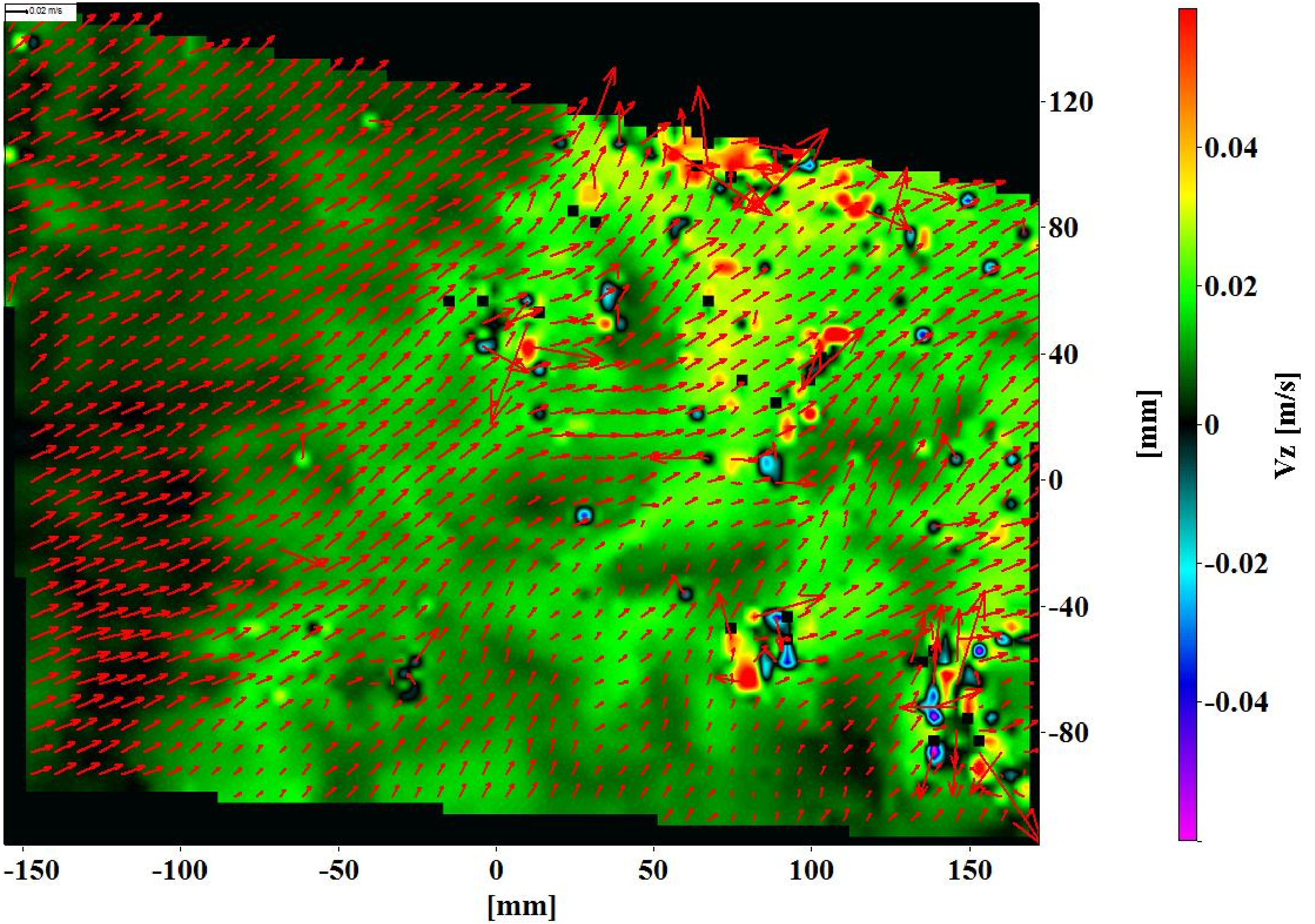
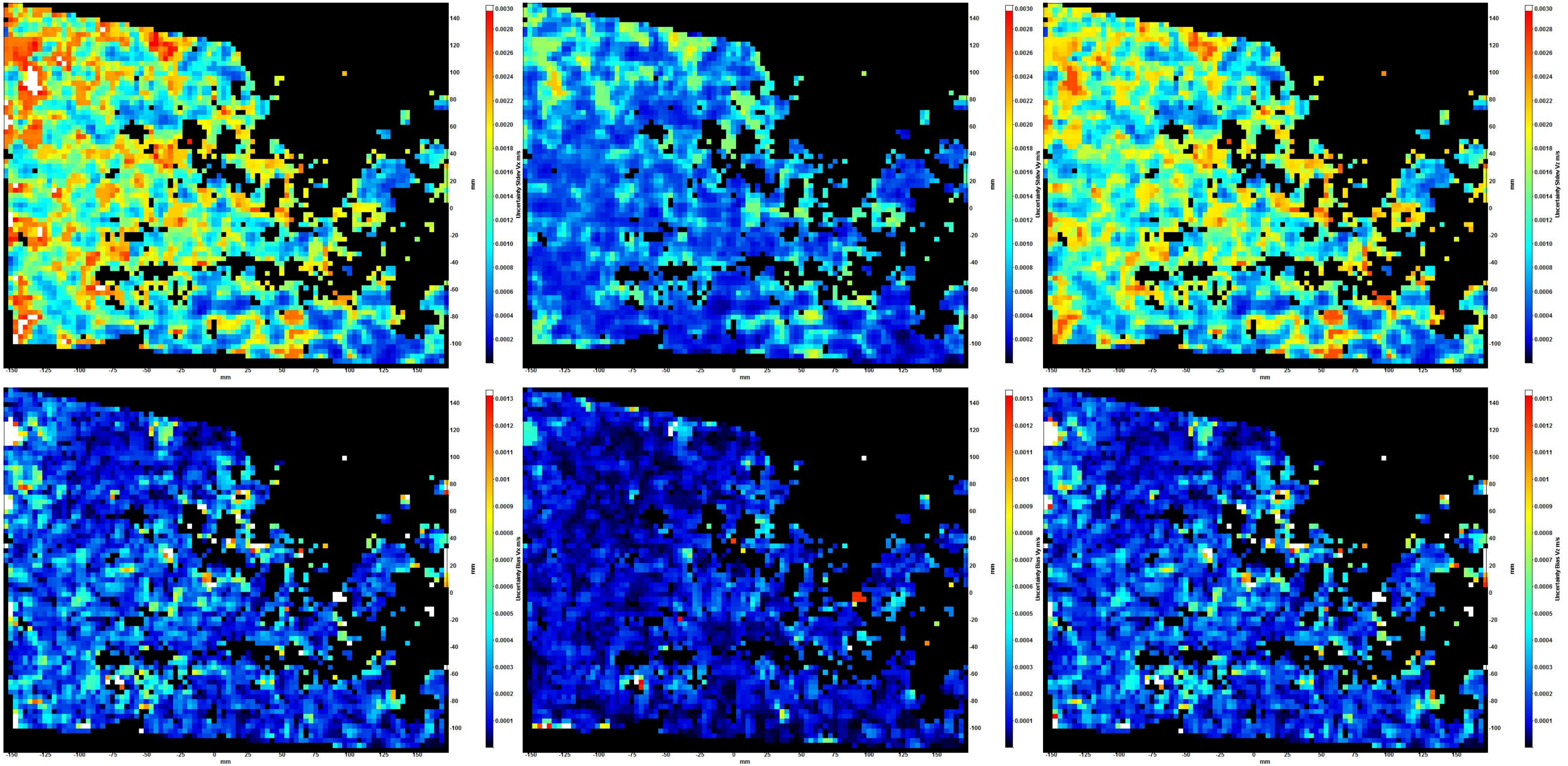
DCC06-10
T_{pool} = 52,957 °C
T_{bottom} = 21,829 °C
P_{pool} = 3,2118 bar
$q_{m,steam}$ = 0 g/s





DCC07-1
t = 562 s
T_{pool} = 23.447 °C
$P_{blowdown}$ = 2.8390 bar
P_{pool} = 2.7786 bar
$q_{m,steam}$ = 91 g/s




mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

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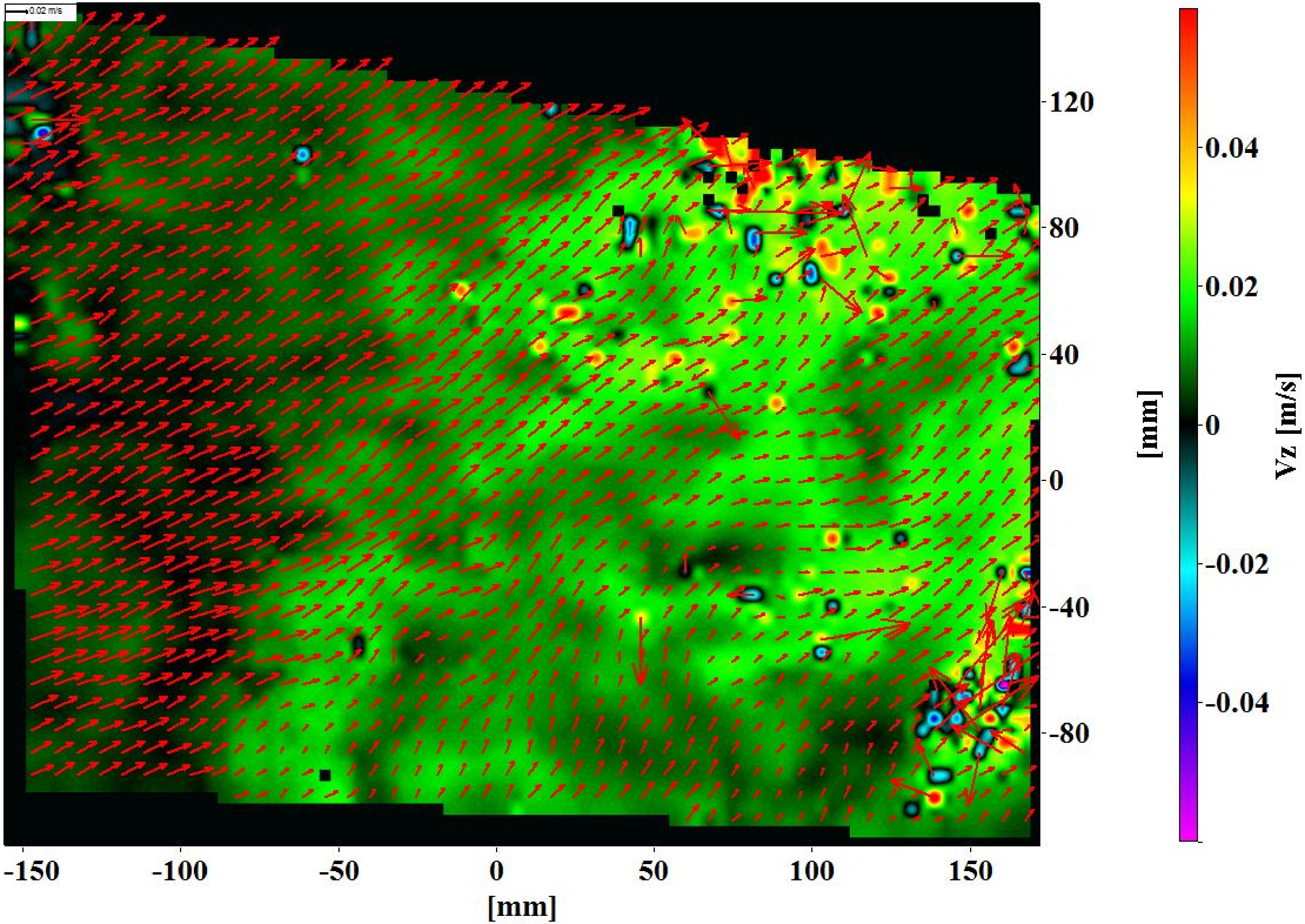
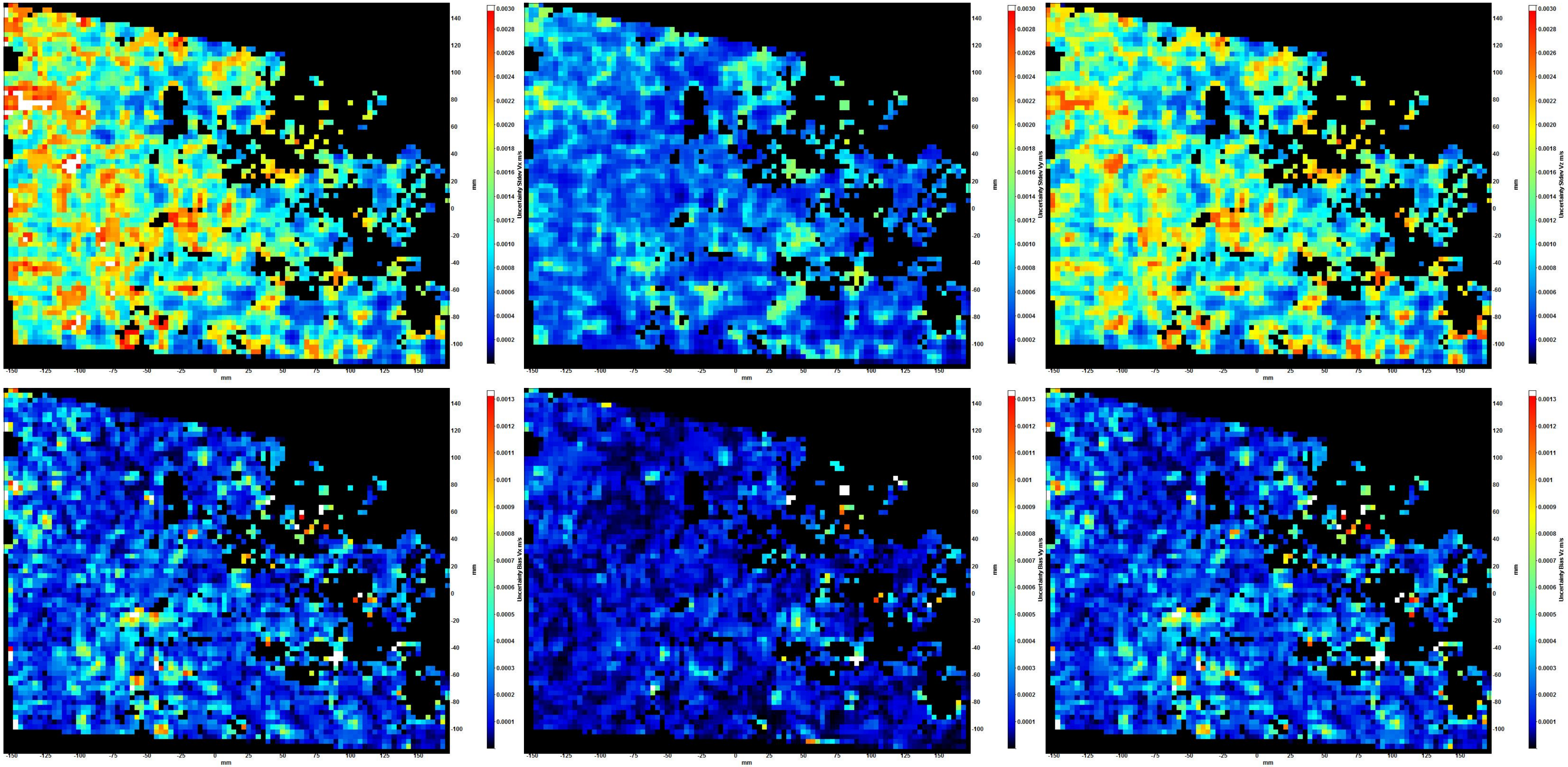
DCC07-1
t = 563 s
T_{pool} = 23.479 °C
$P_{blowdown}$ = 2.8393 bar
P_{pool} = 2.7789 bar
$q_{m,steam}$ = 91 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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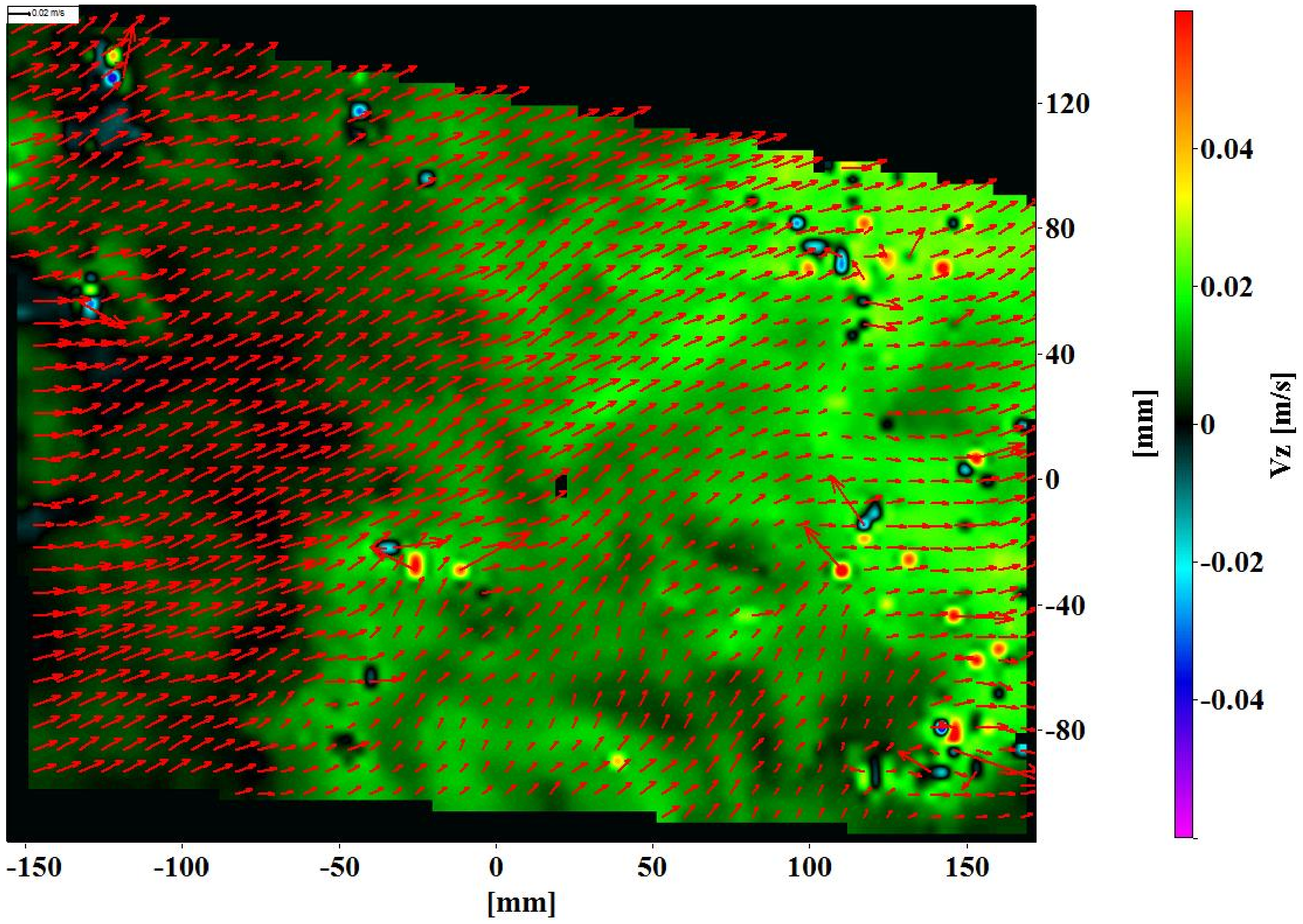
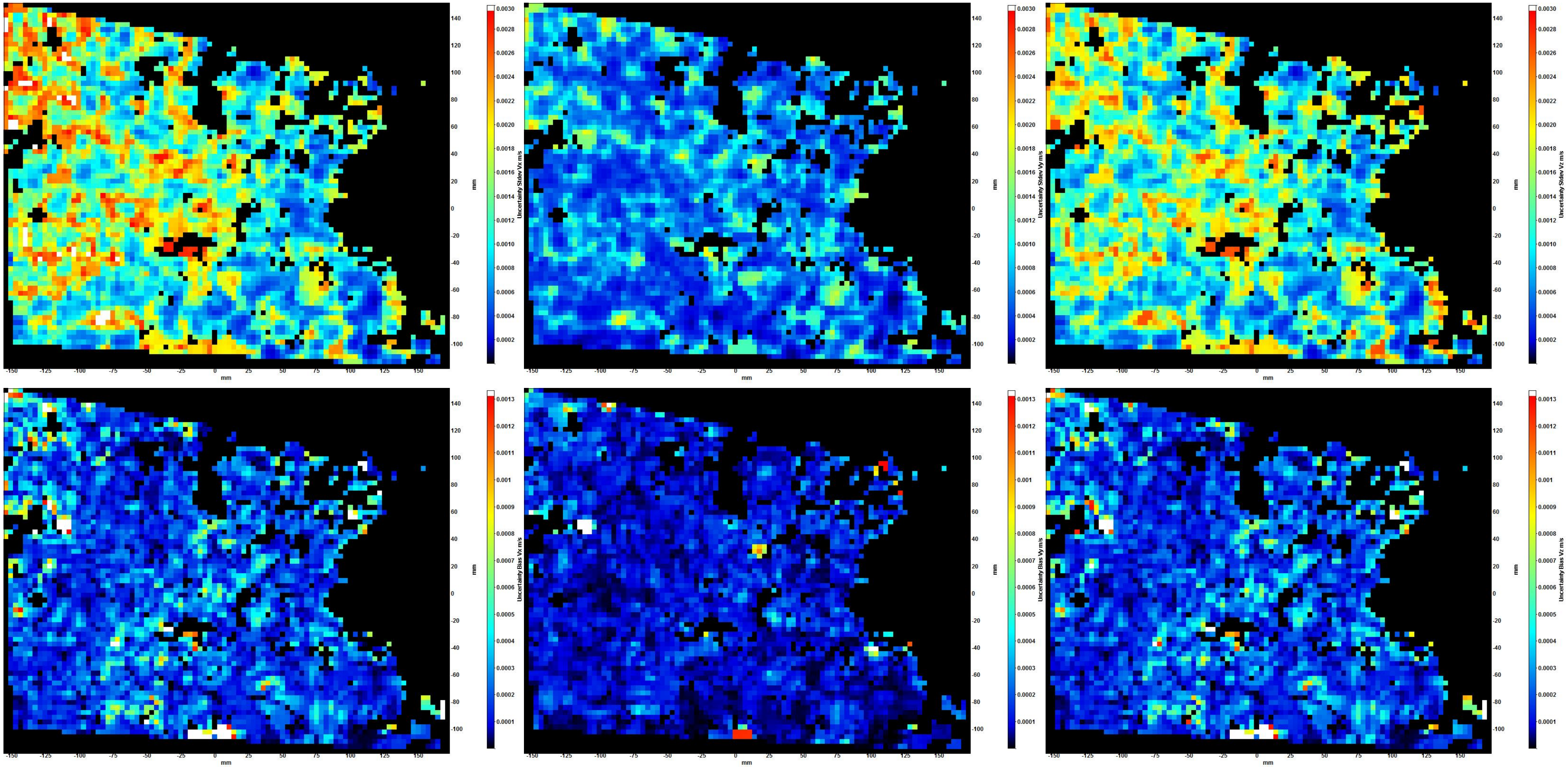
DCC07-1
t = 564 s
T_{pool} = 23.479 °C
$P_{blowdown}$ = 2.8393 bar
P_{pool} = 2.7789 bar
$q_{m,steam}$ = 91 g/s





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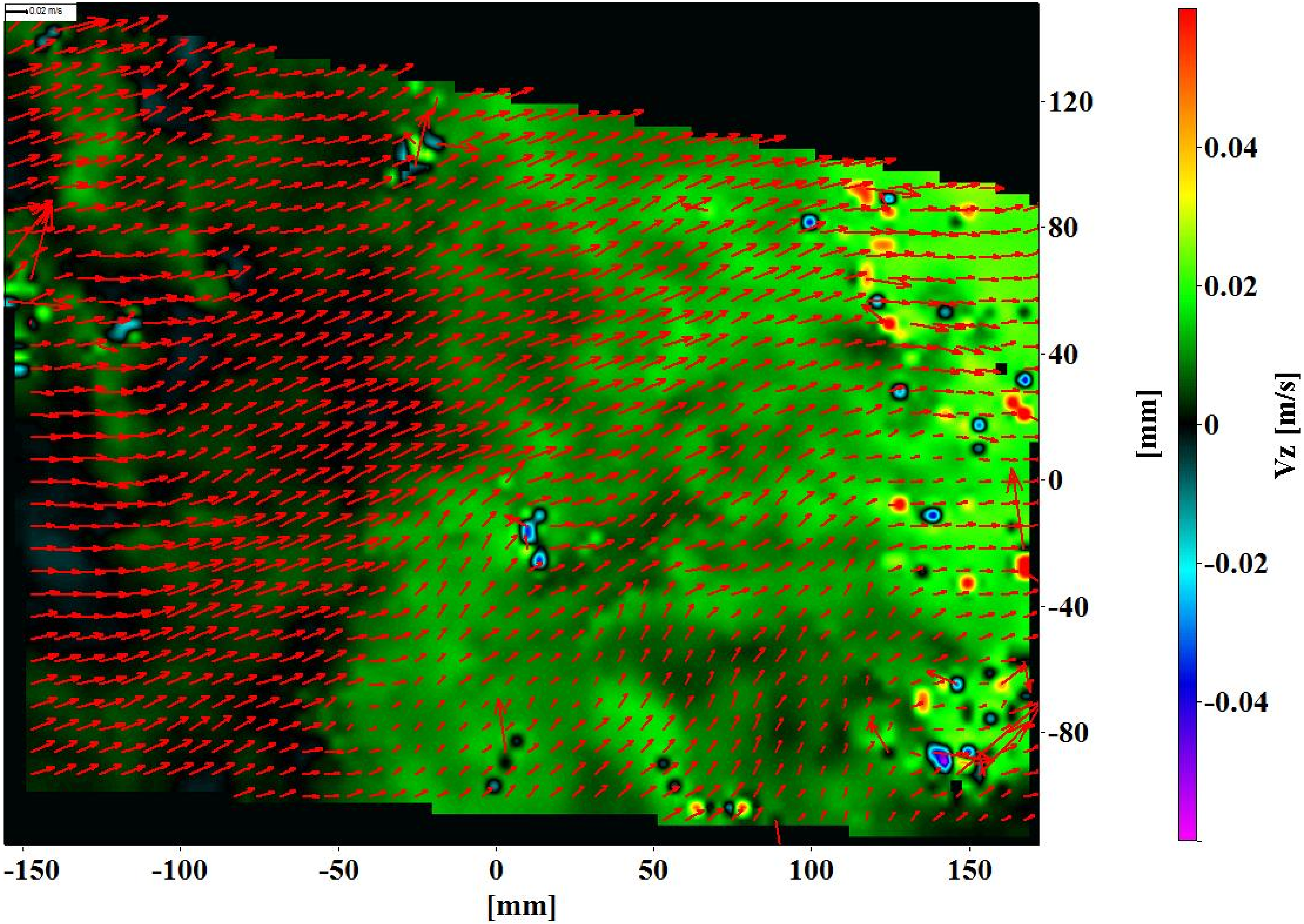
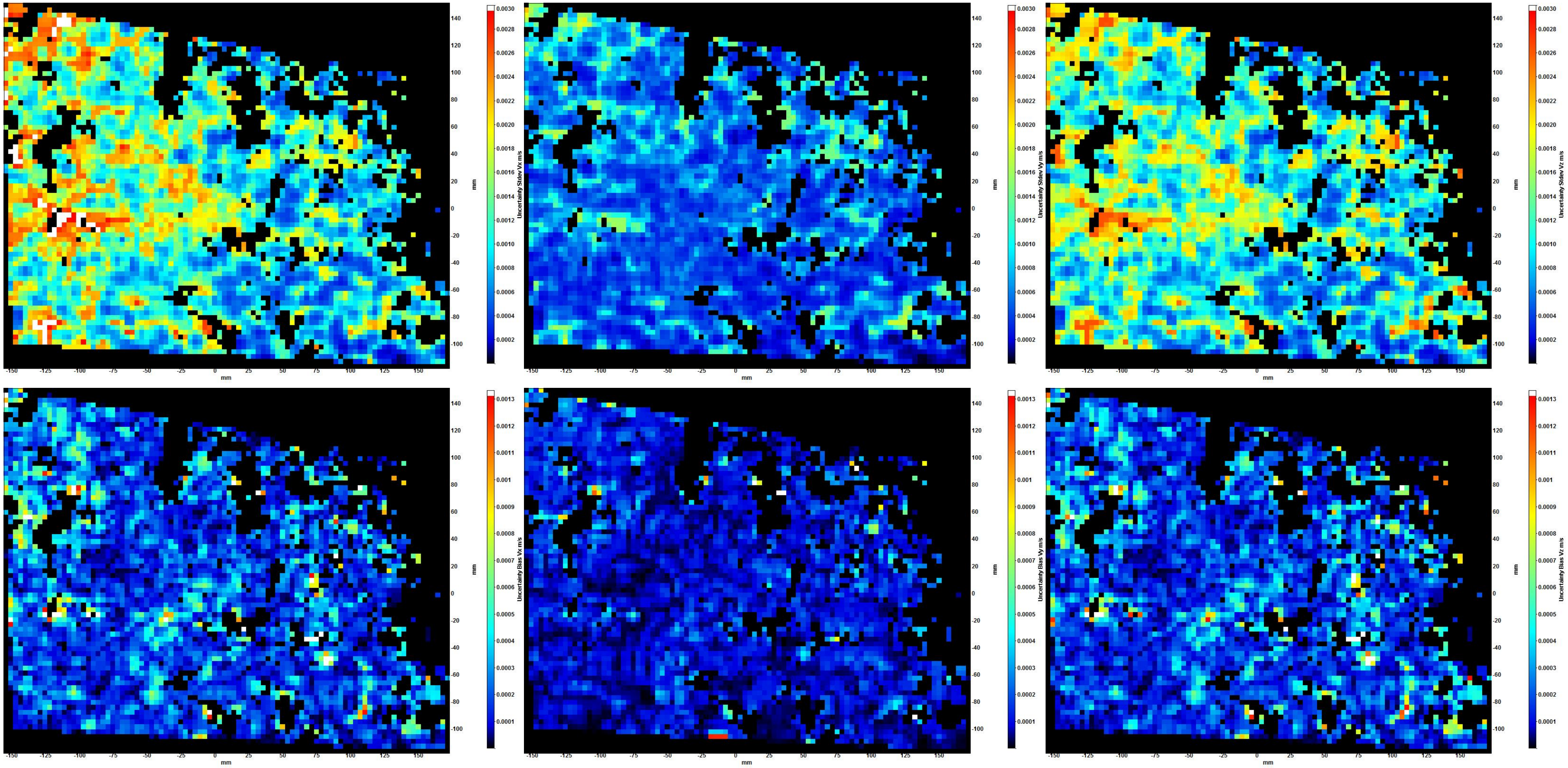
DCC07-1
t = 565 s
T_{pool} = 23.479 °C
$P_{blowdown}$ = 2.8396 bar
P_{pool} = 2.7789 bar
$q_{m,steam}$ = 91 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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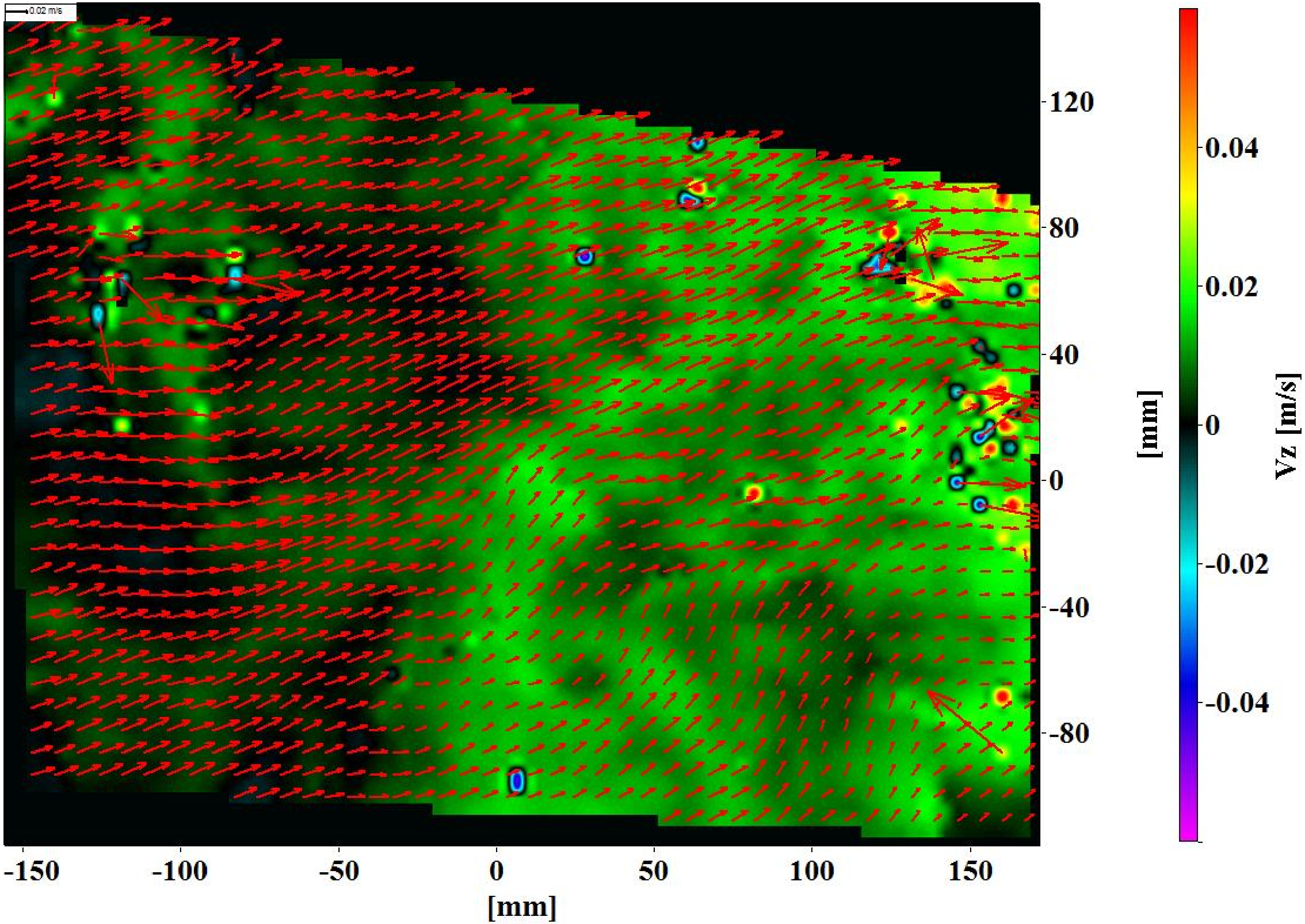
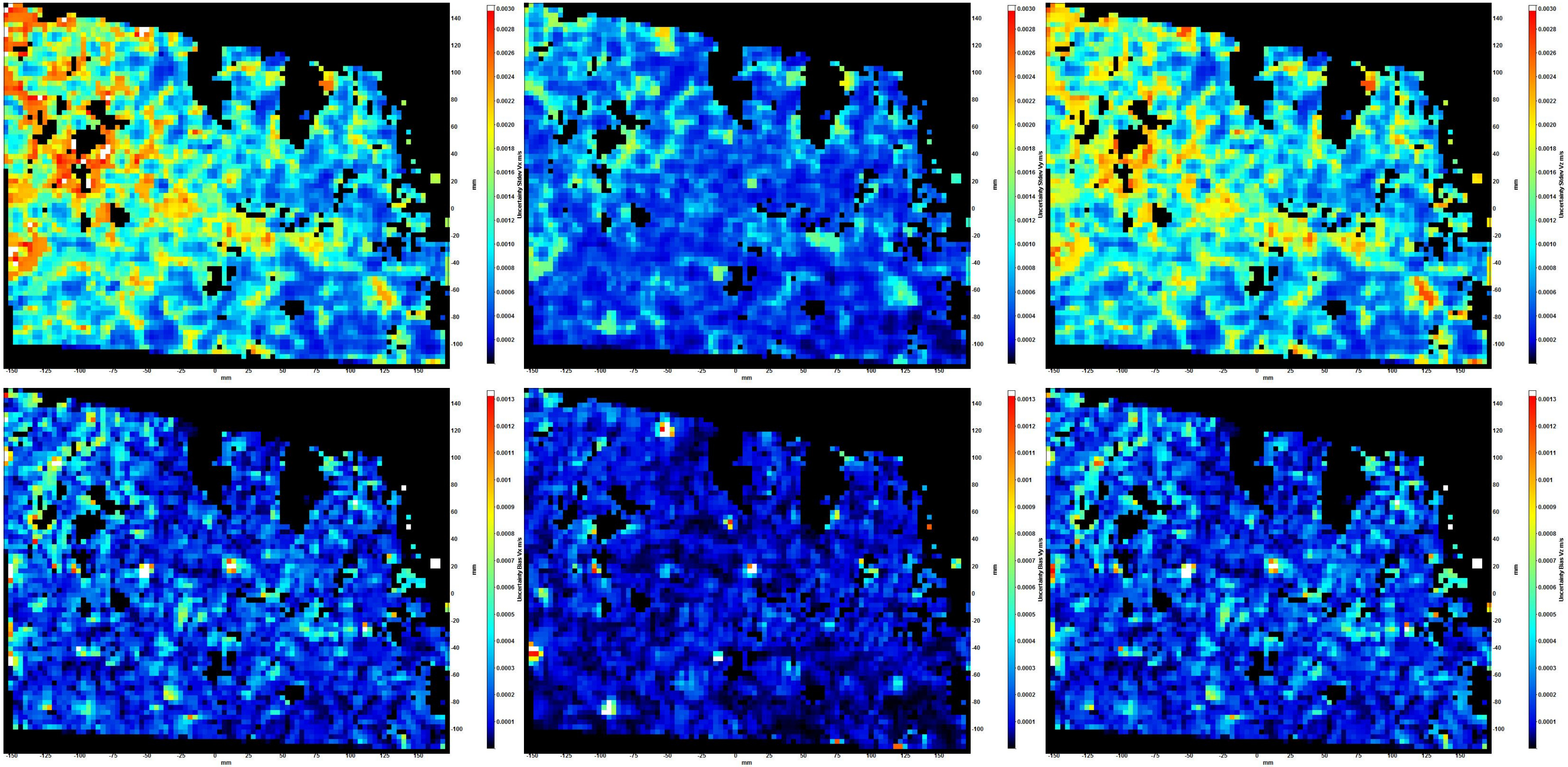
DCC07-1
t = 566 s
T_{pool} = 23.510 °C
$P_{blowdown}$ = 2.8391 bar
P_{pool} = 2.7786 bar
$q_{m,steam}$ = 91 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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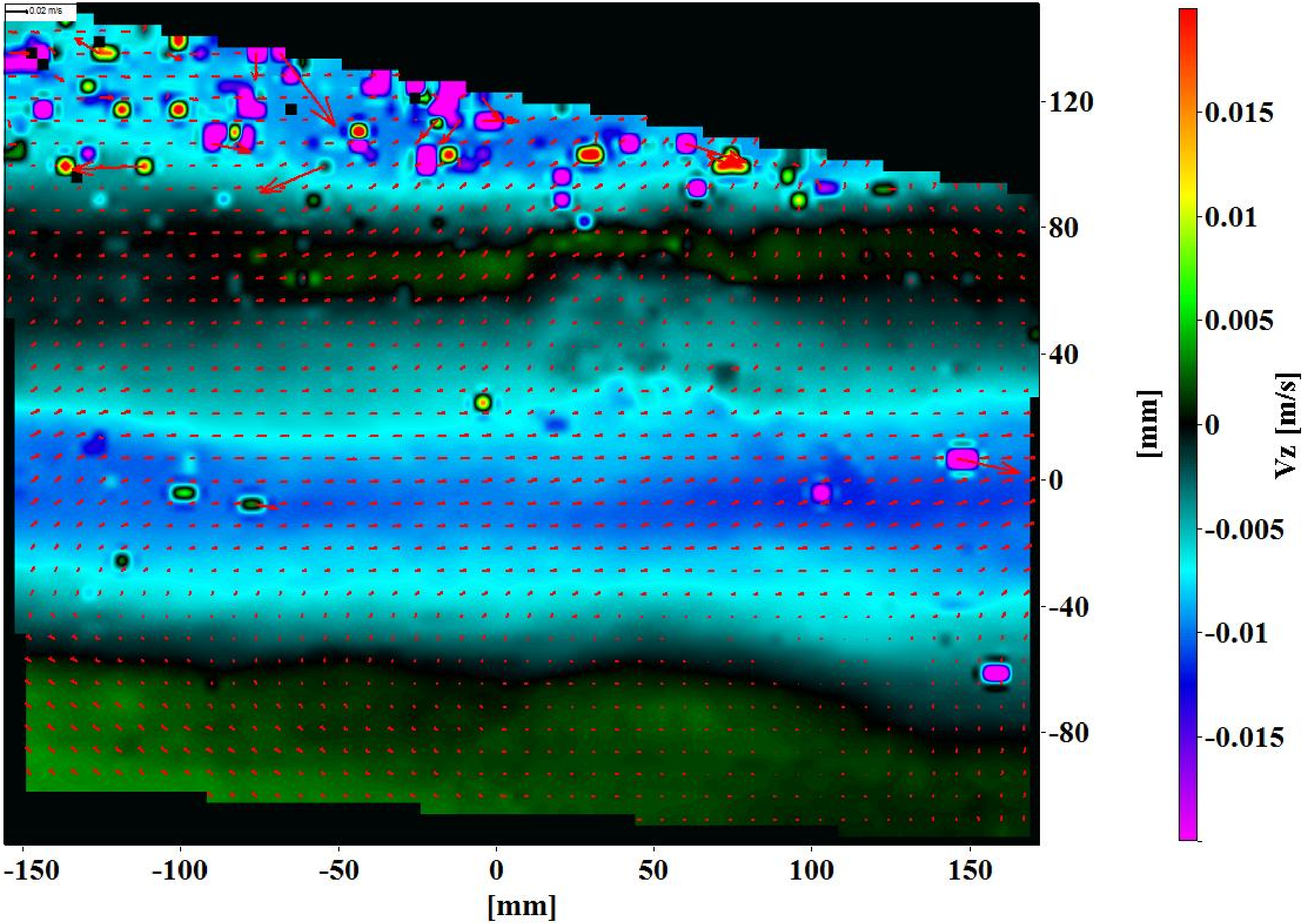
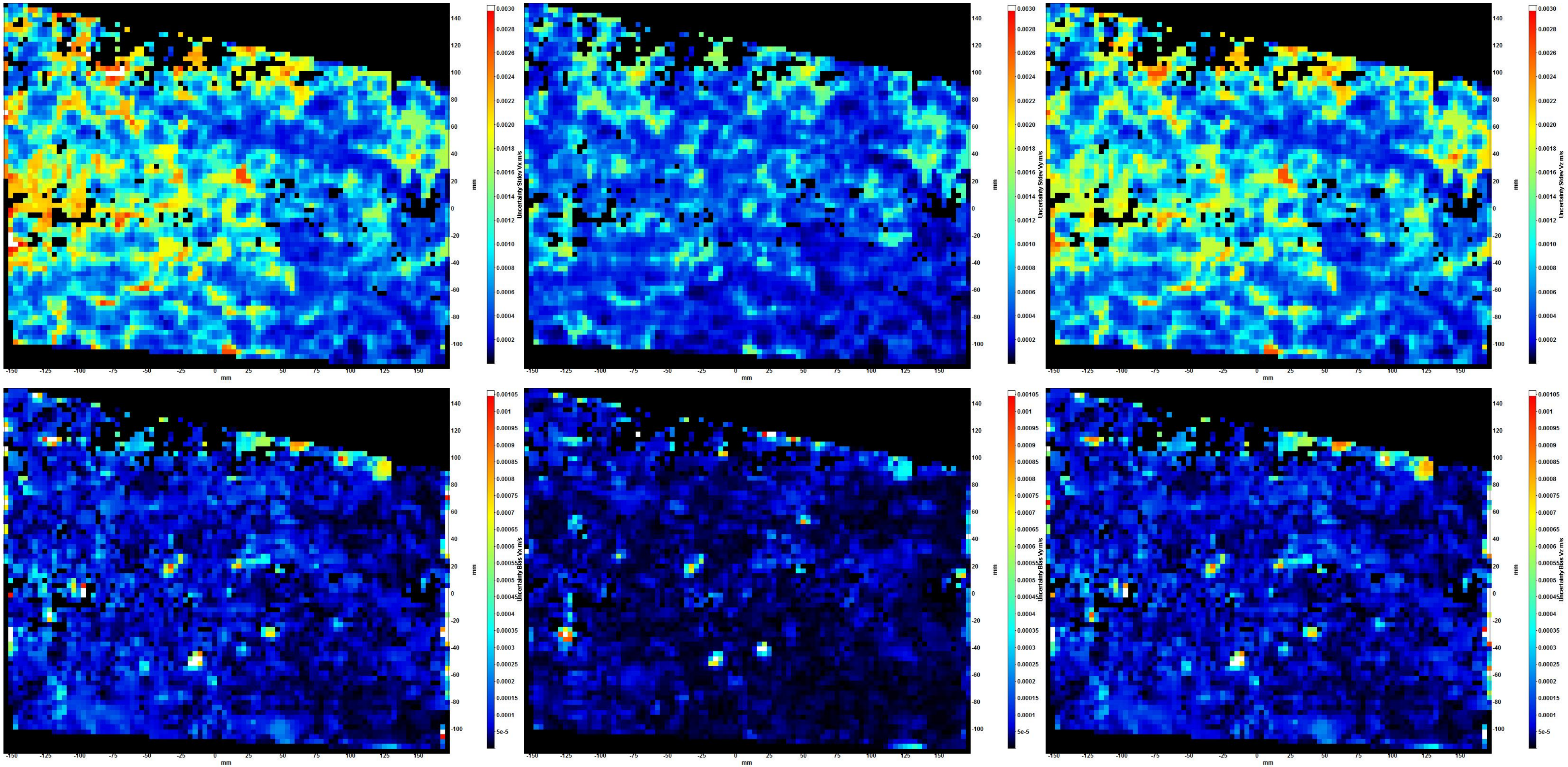
DCC07-3
t = 3767 s
T_{pool} = 50.156 °C
$P_{blowdown}$ = 3.2924 bar
P_{pool} = 3.2415 bar
$q_{m,steam}$ = 34 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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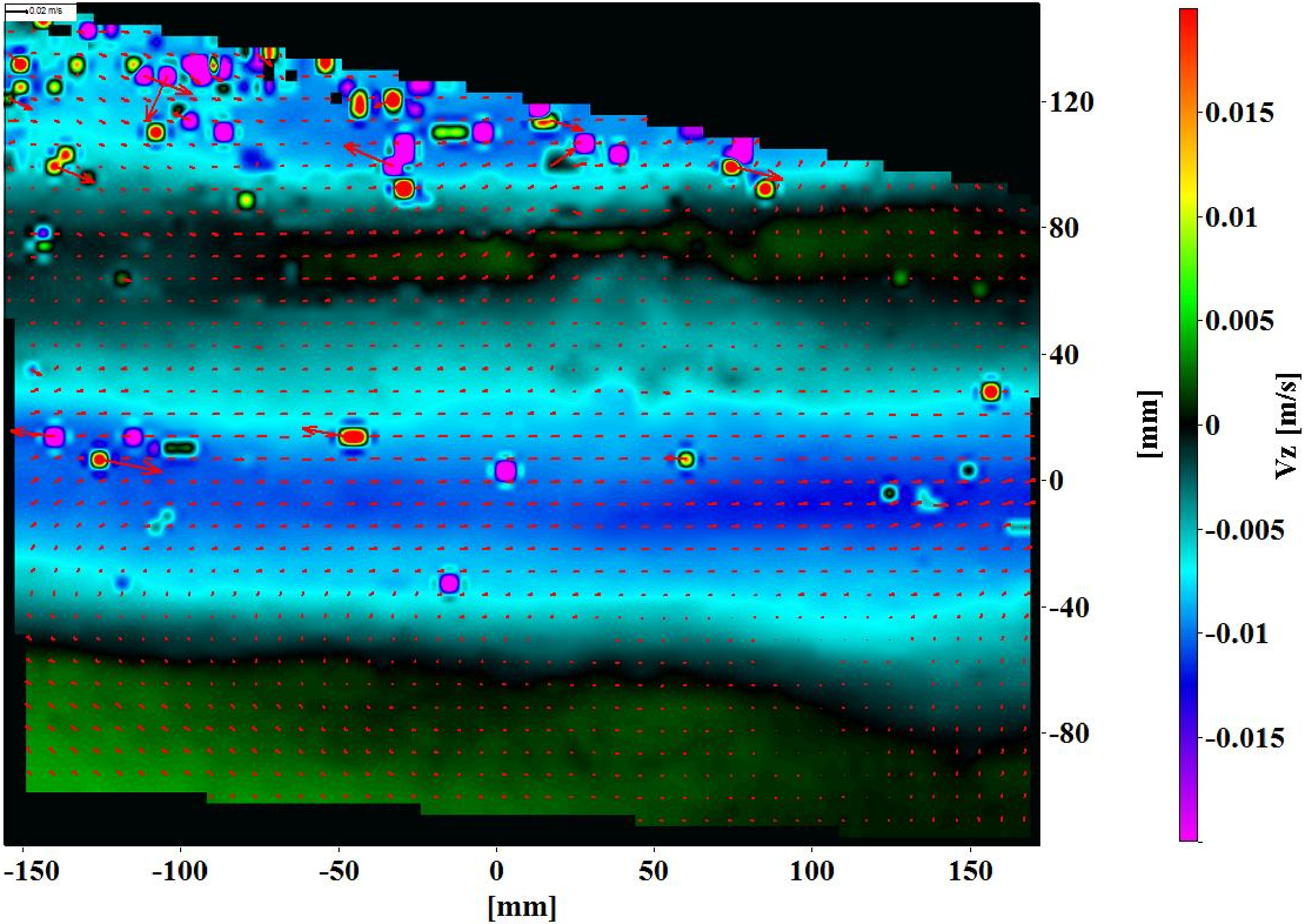
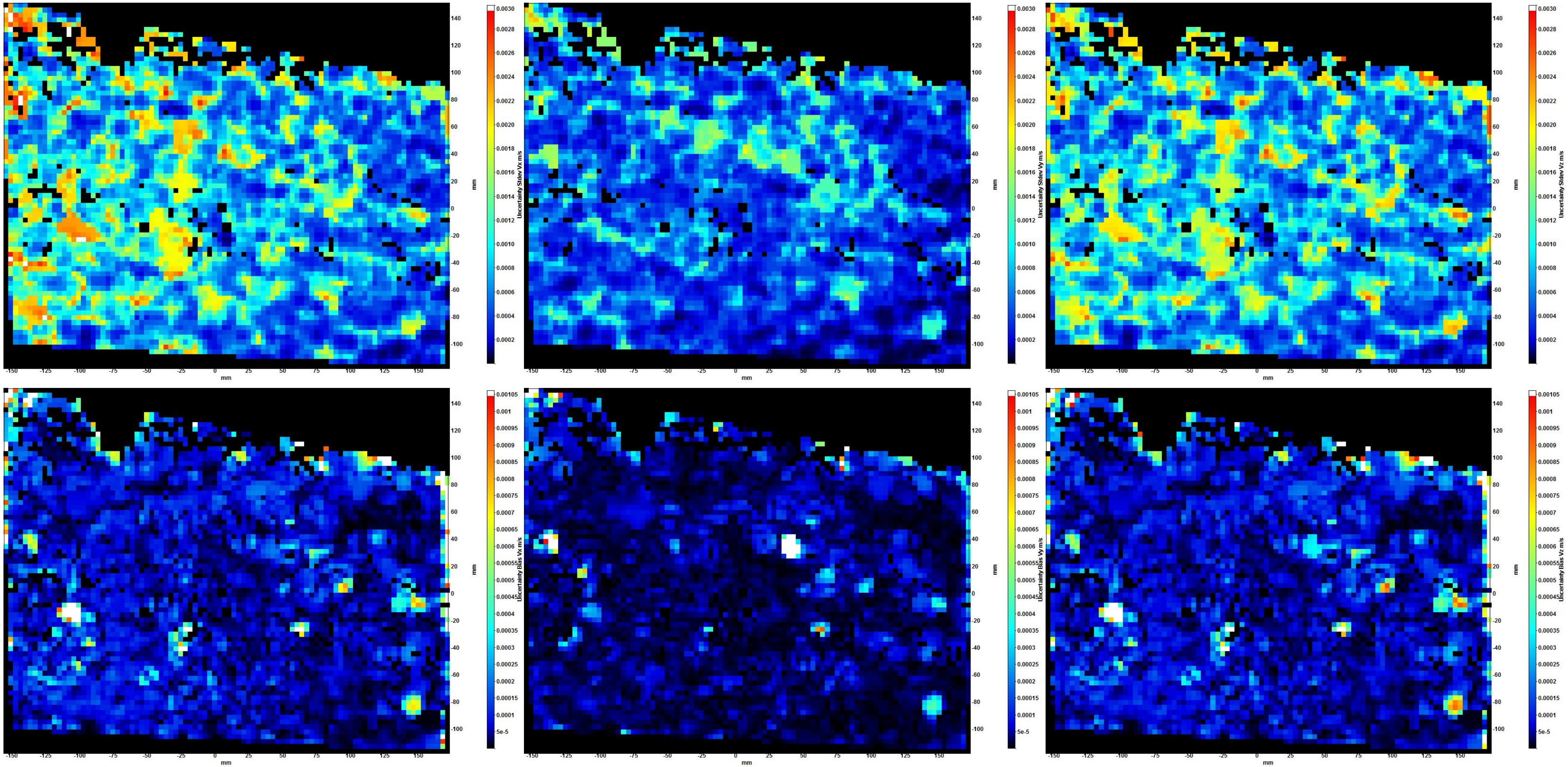
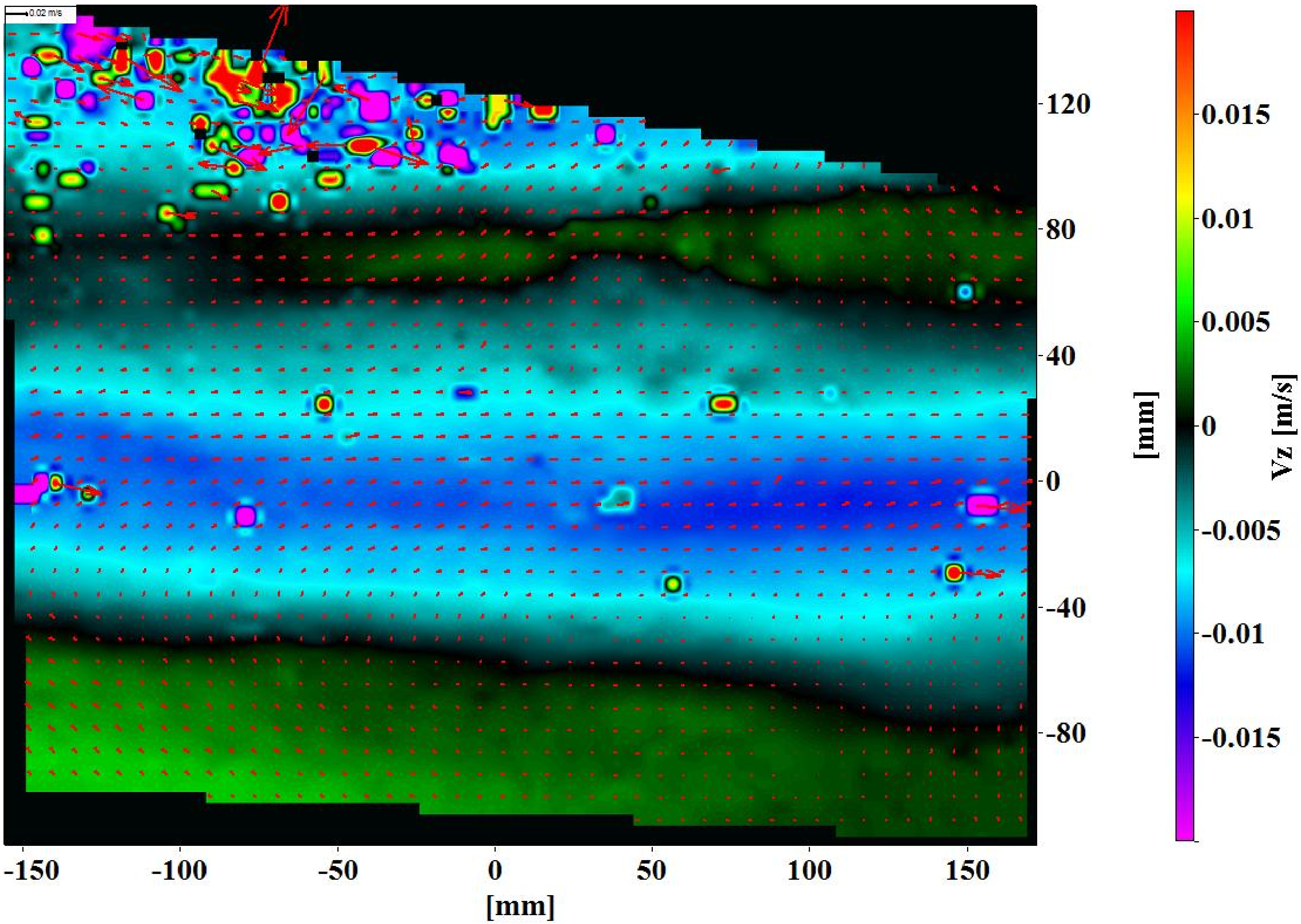
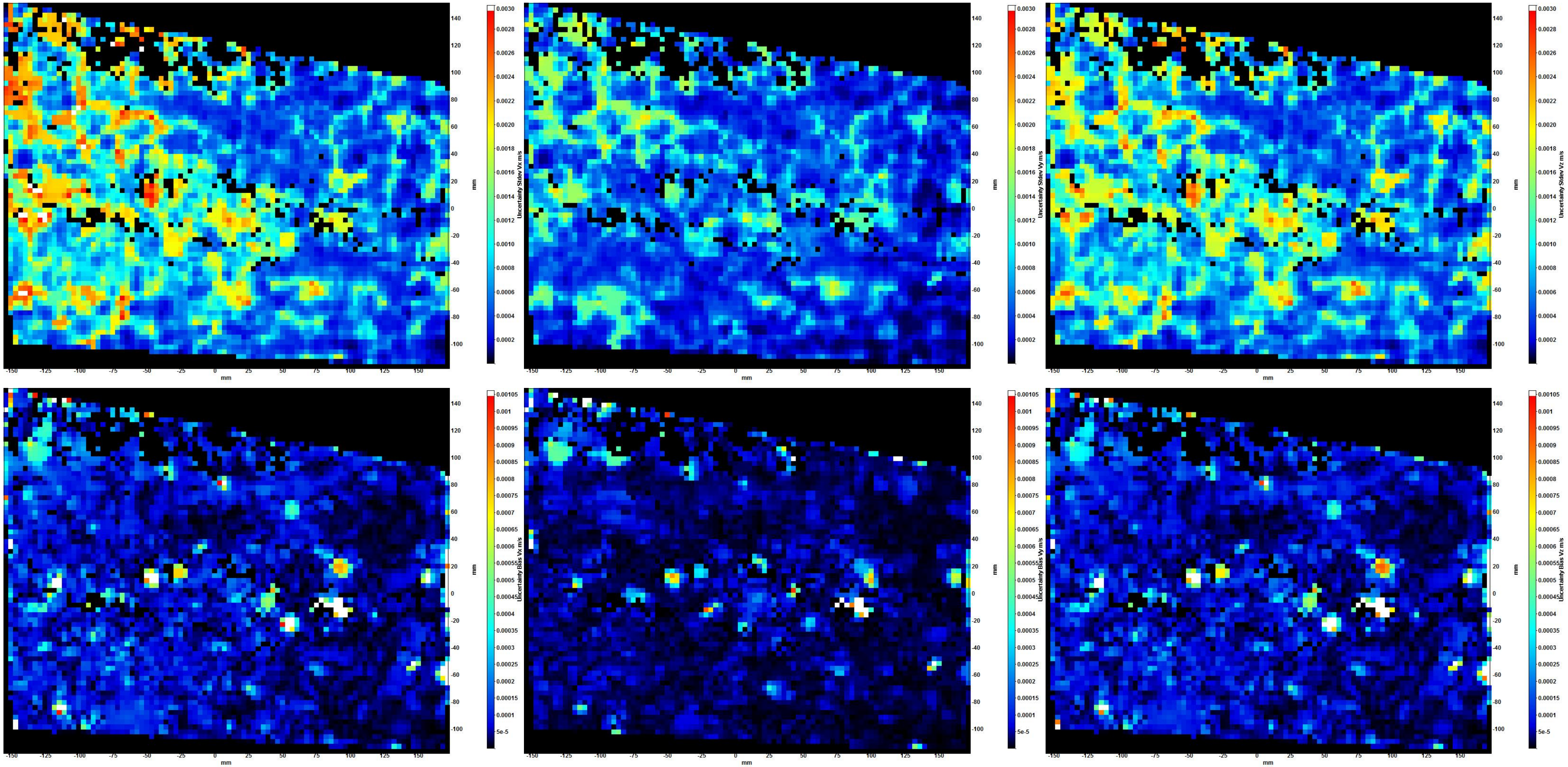
DCC07-3
t = 3768 s
T_{pool} = 50.125 °C
$P_{blowdown}$ = 3.2915 bar
P_{pool} = 3.2412 bar
$q_{m,steam}$ = 34 g/s




mm
Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s

DCC07-3
t = 3769 s
T_{pool} = 50.125 °C
$P_{blowdown}$ = 3.2915 bar
P_{pool} = 3.2412 bar
$q_{m,steam}$ = 34 g/s

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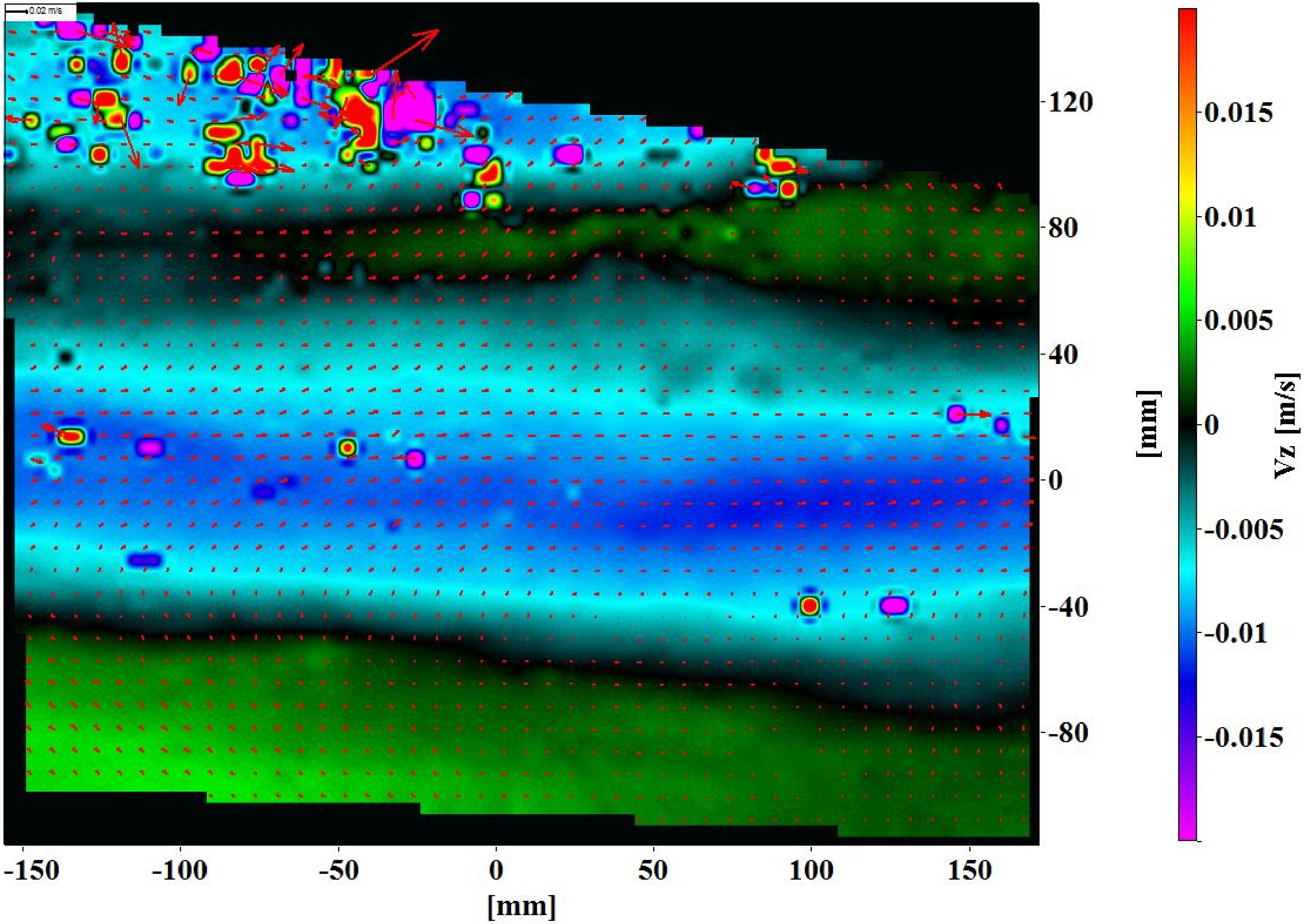
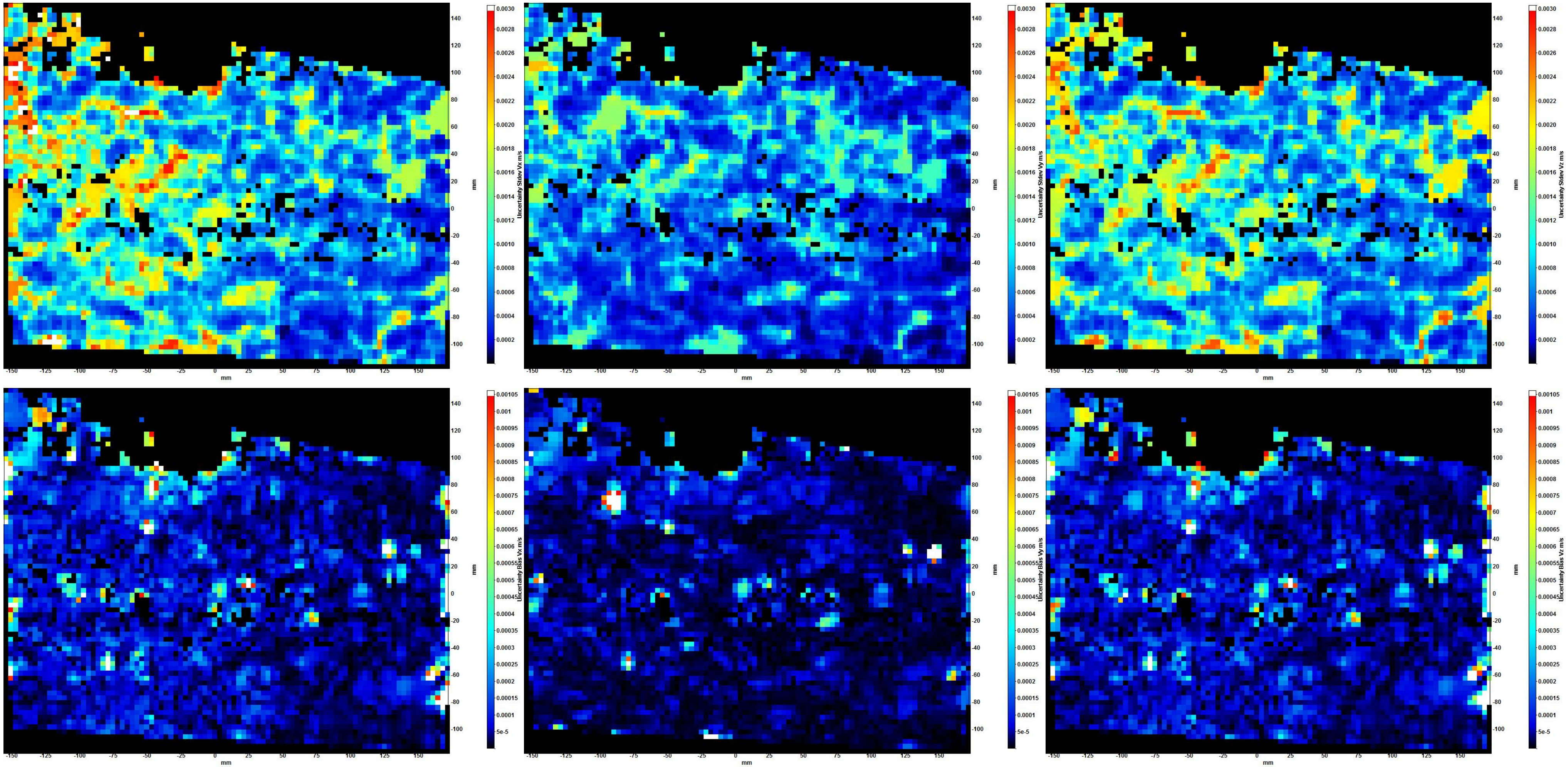
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC07-3
t = 3770 s
T_{pool} = 50.125 °C
$P_{blowdown}$ = 3.2930 bar
P_{pool} = 3.2418 bar
$q_{m,steam}$ = 34 g/s

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Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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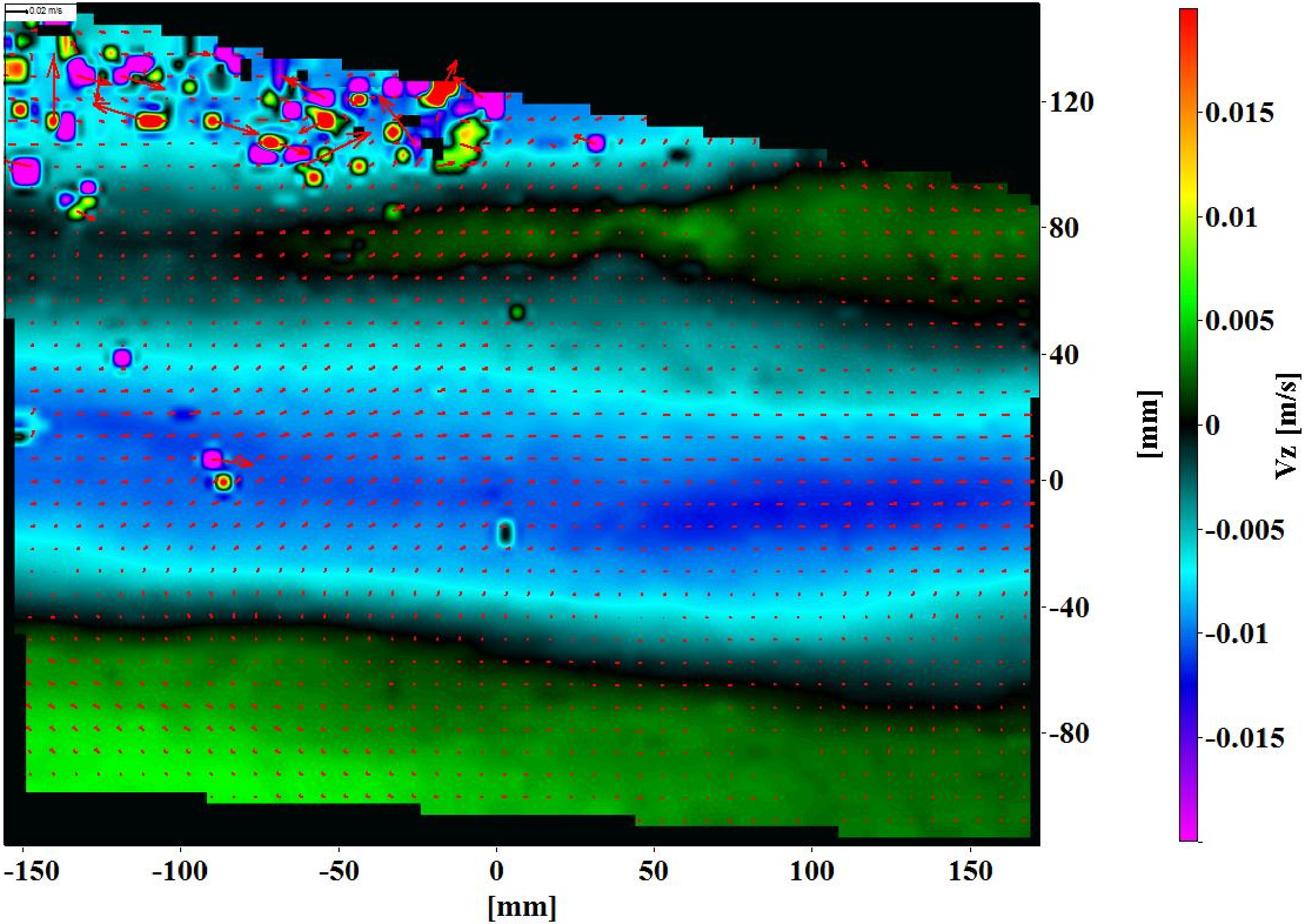
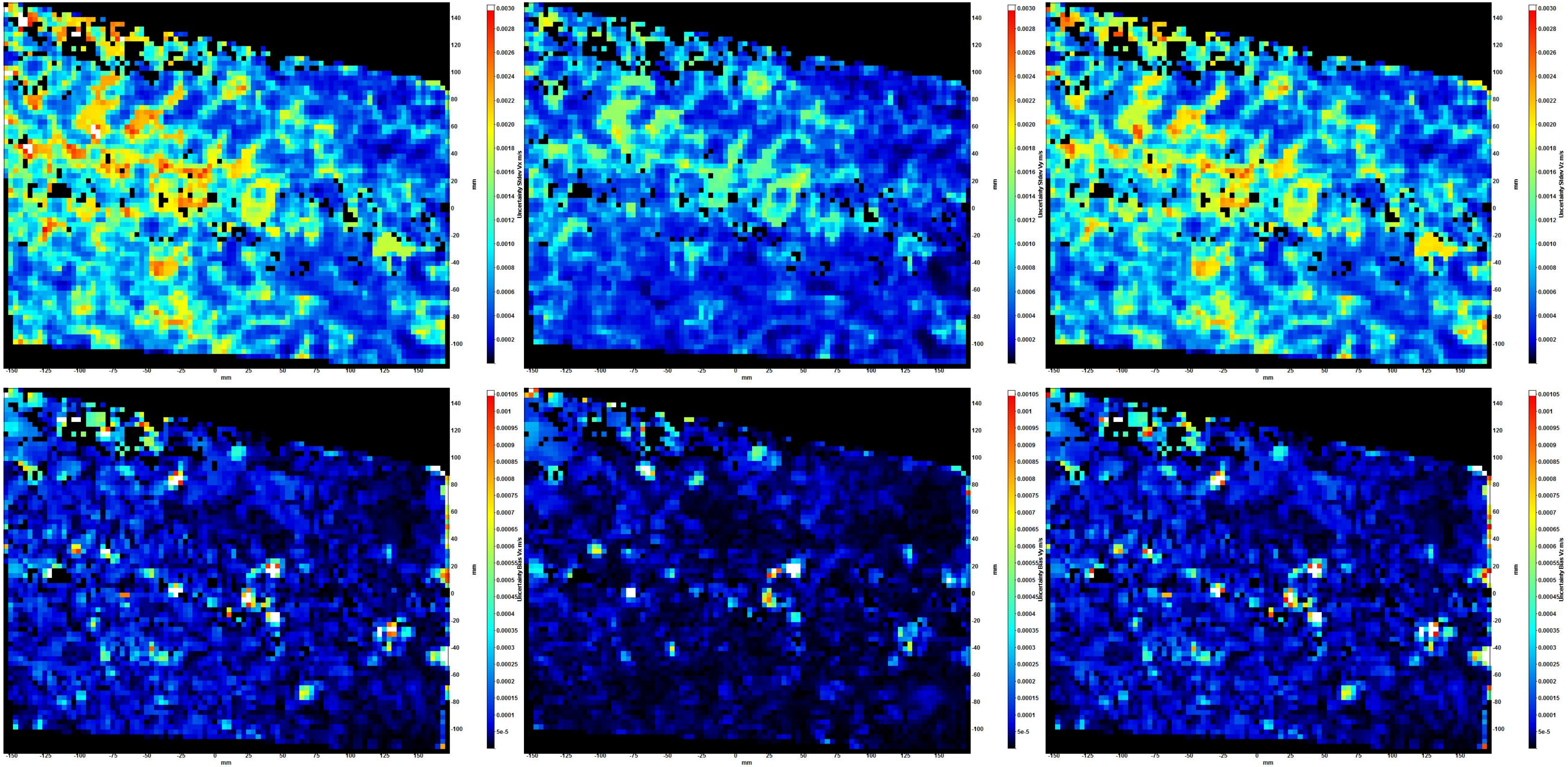
DCC07-3
t = 3771 s
T_{pool} = 50.093 °C
$P_{blowdown}$ = 3.2930 bar
P_{pool} = 3.2418 bar
$q_{m,steam}$ = 34 g/s

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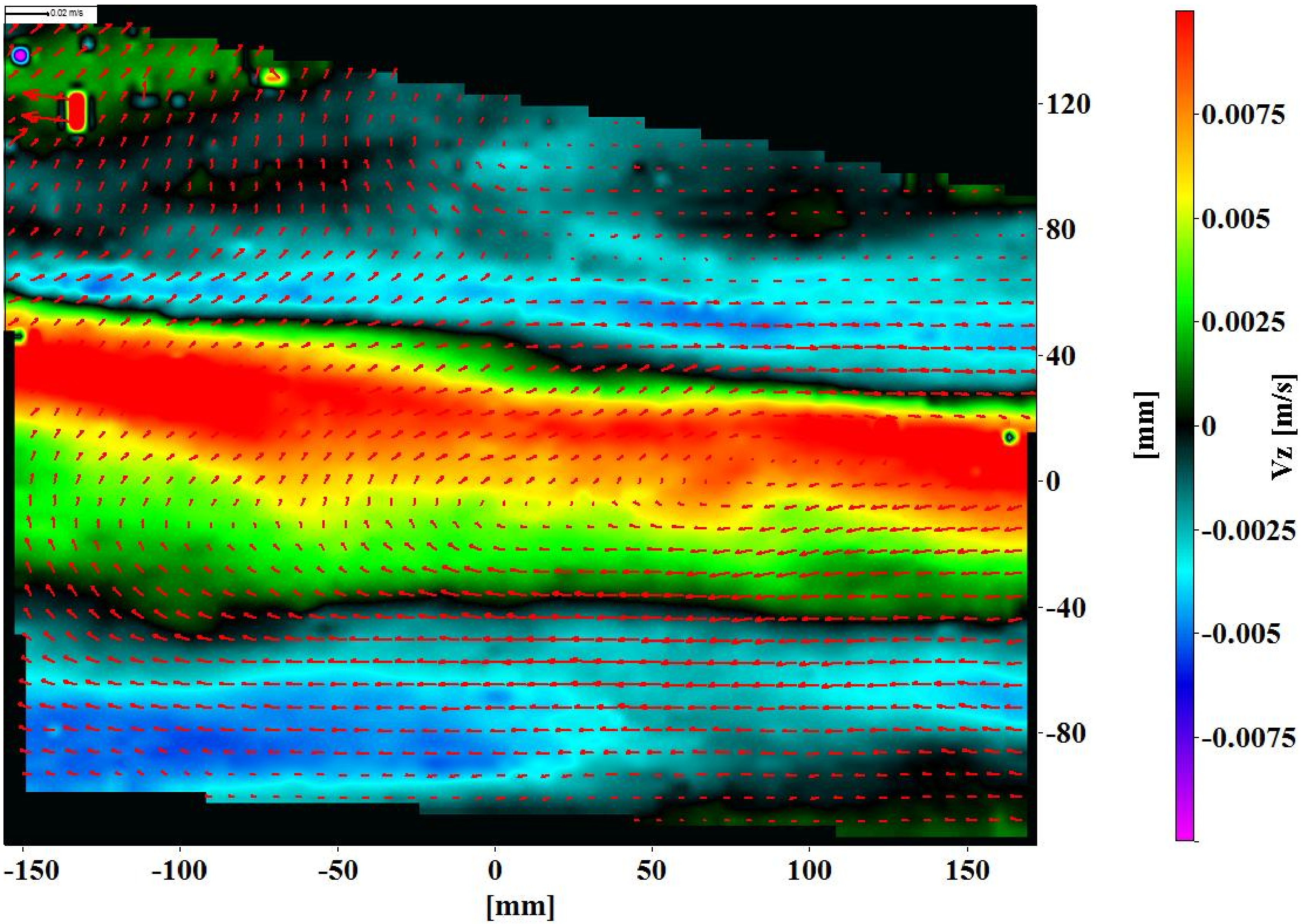
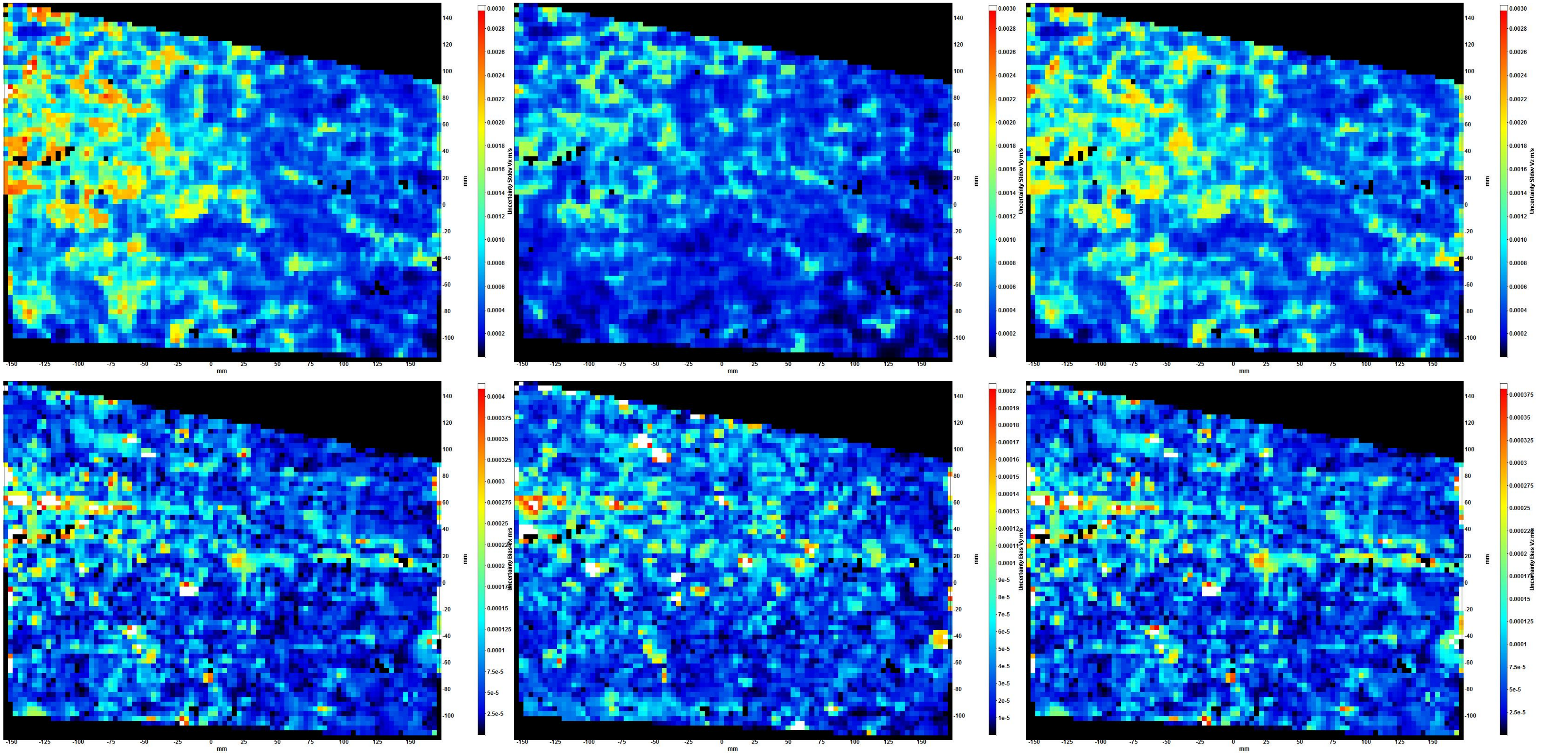
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC07-4
T_{pool} = 50.156 °C
T_{bottom} = 25.751 °C
P_{pool} = 3.2415 bar
$q_{m,steam}$ = 0 g/s

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Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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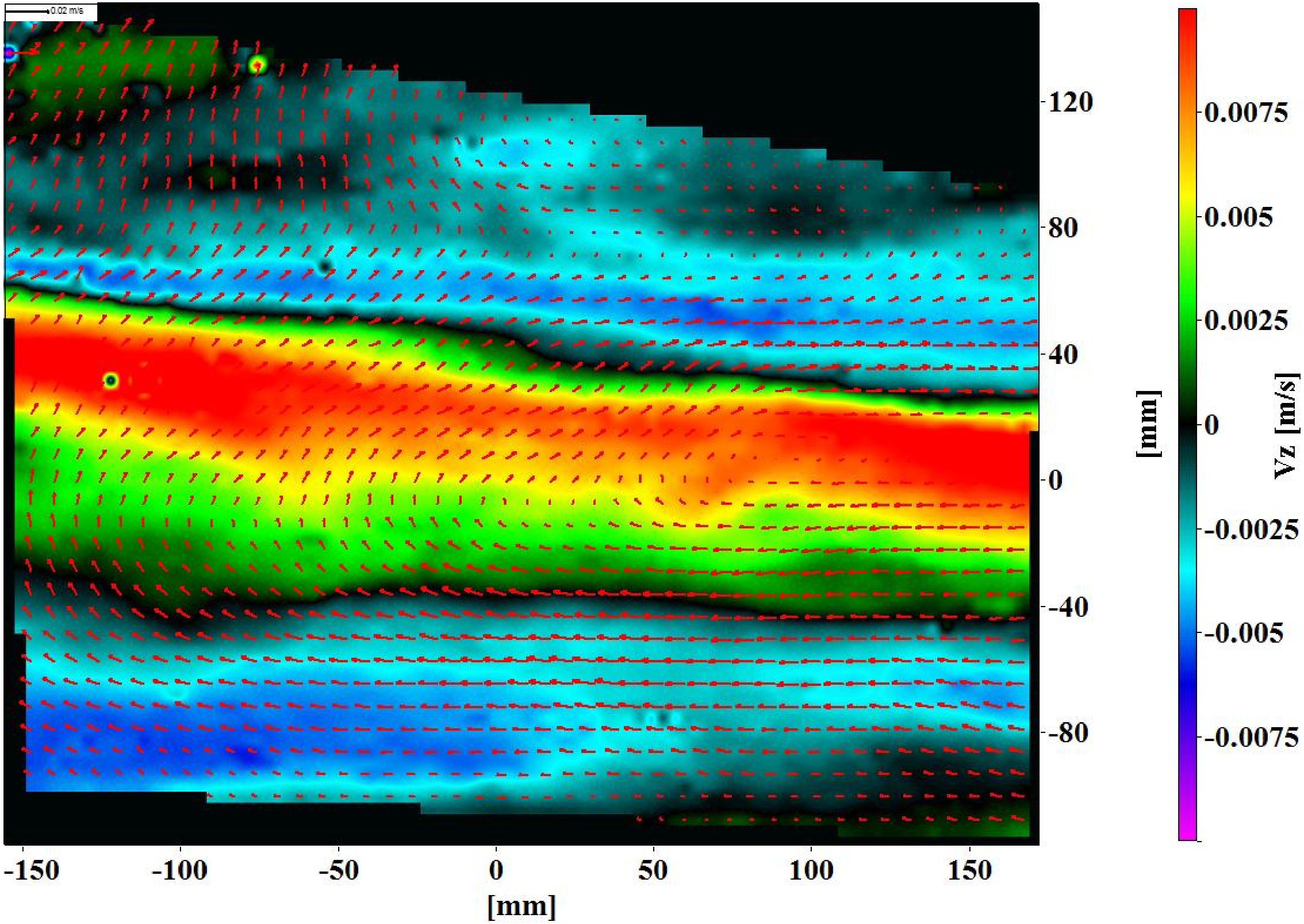
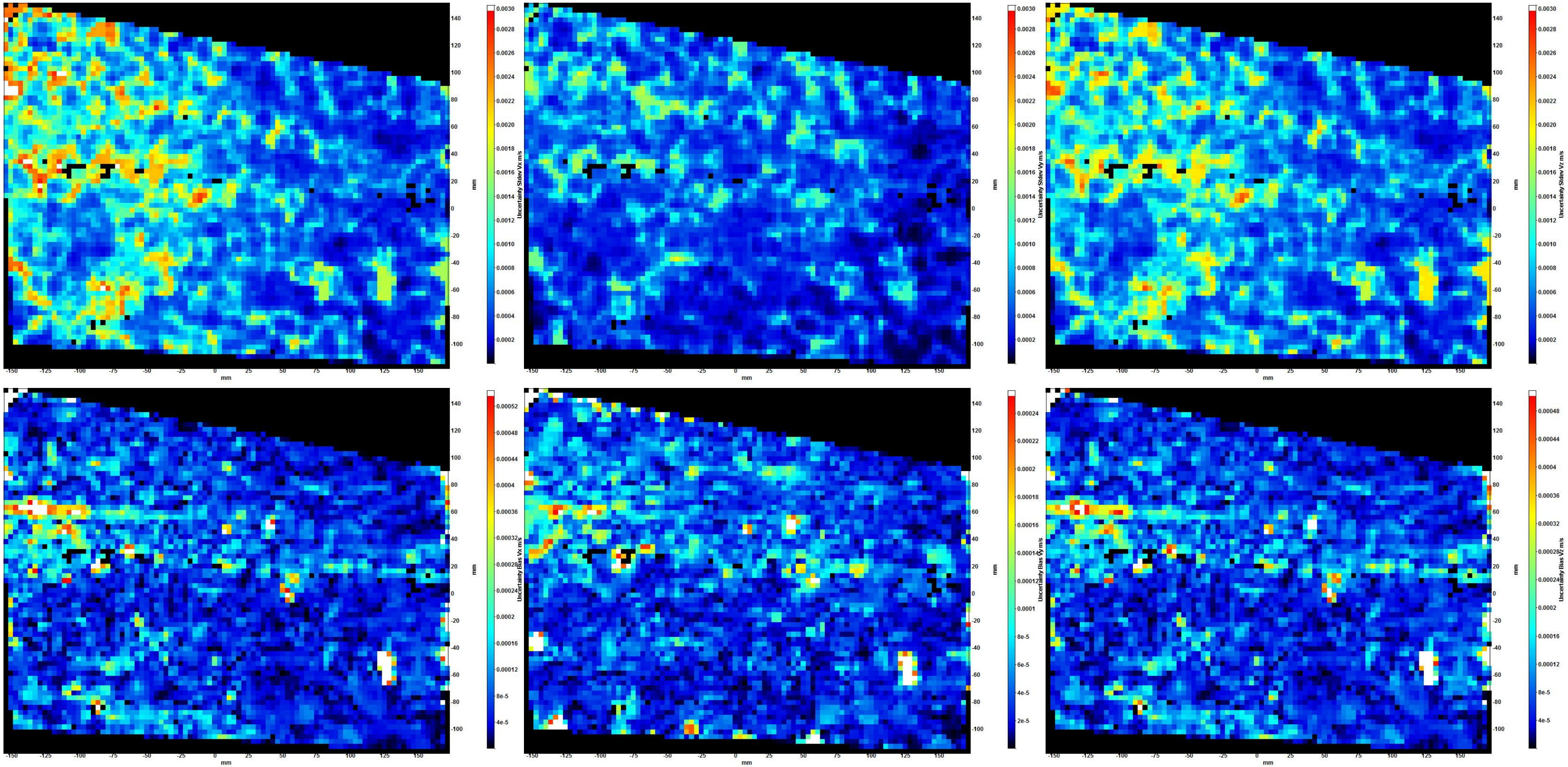
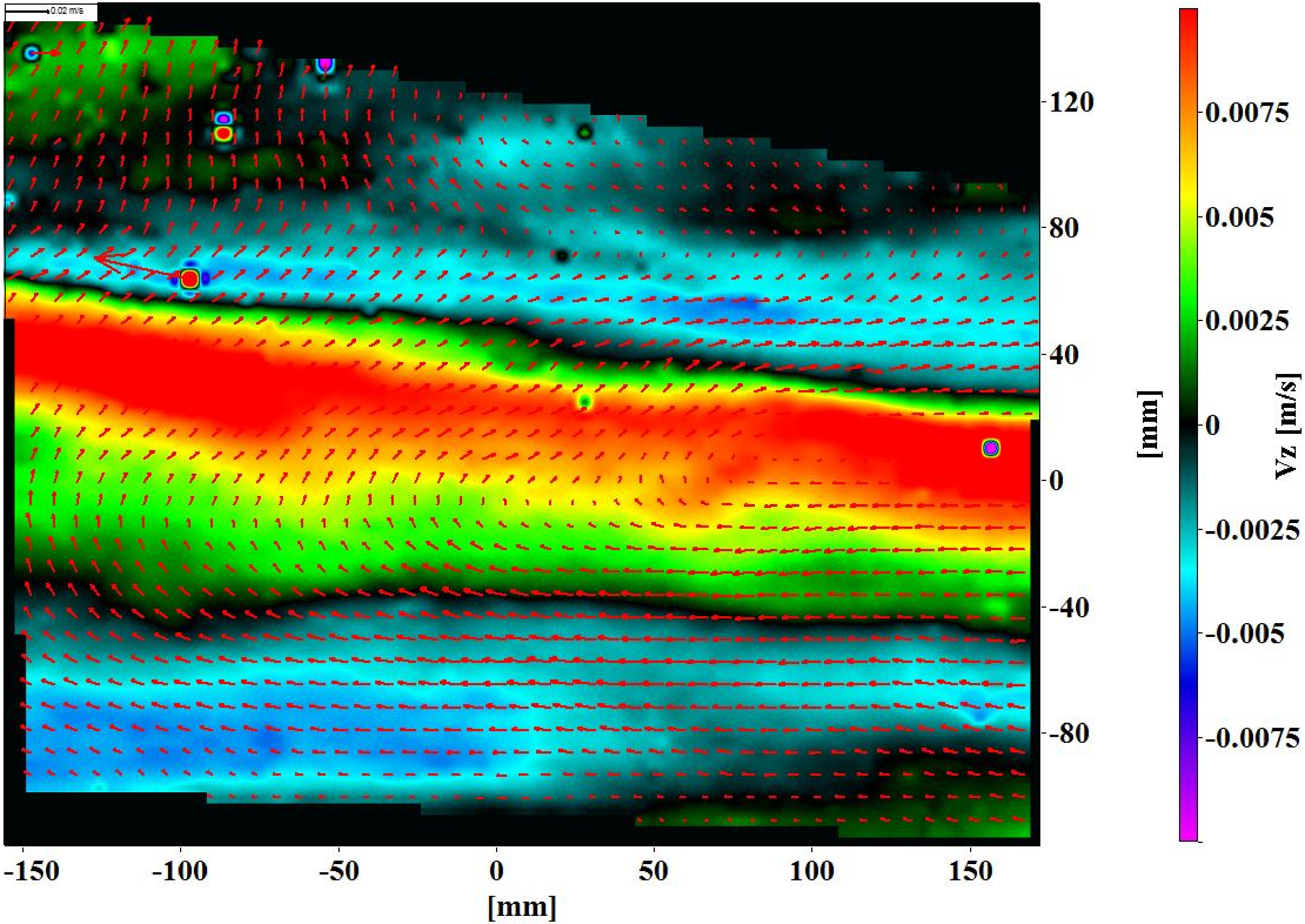
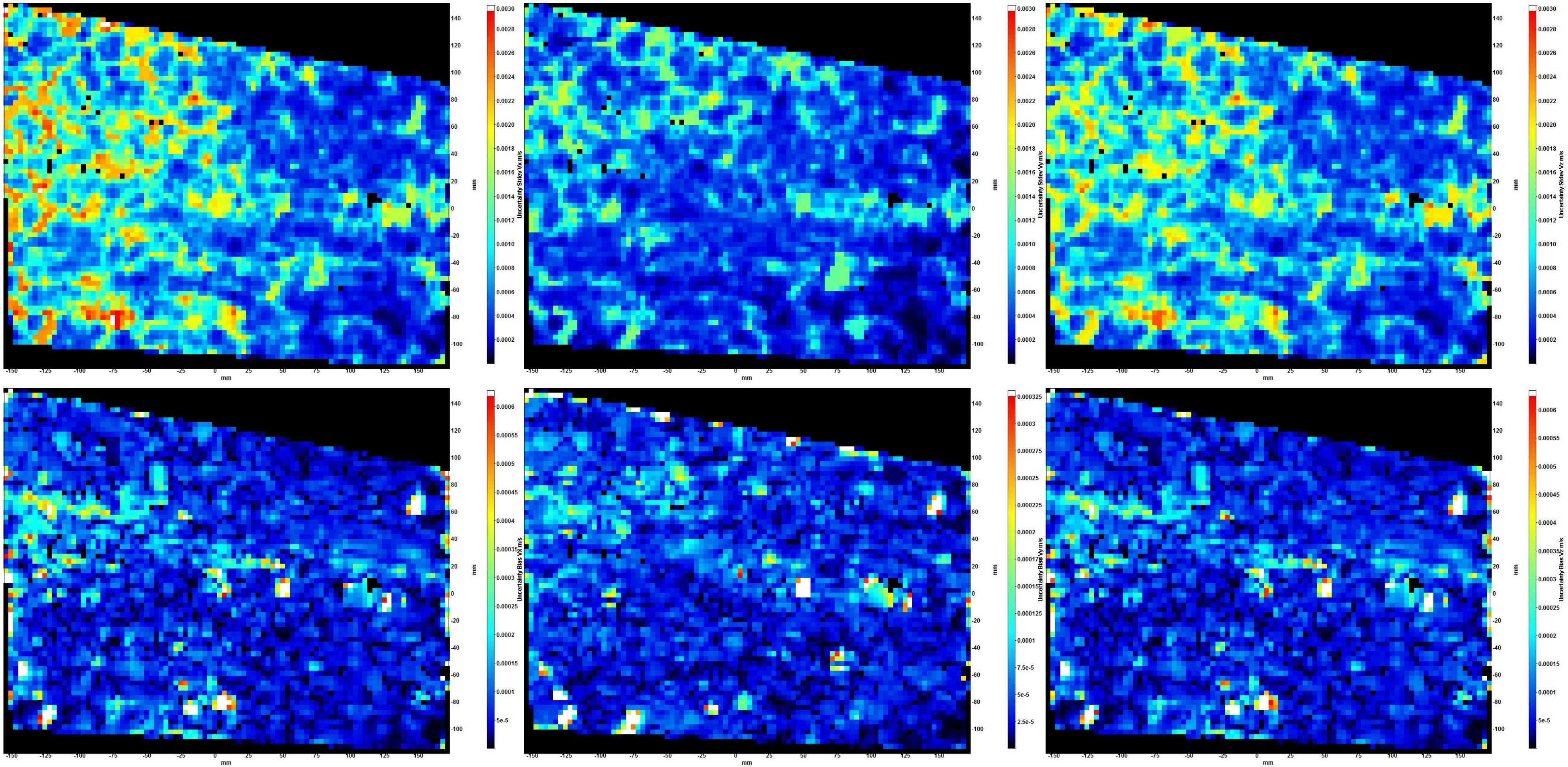
DCC07-4
T_{pool} = 50.156 °C
T_{bottom} = 25.751 °C
P_{pool} = 3.2415 bar
$q_{m,steam}$ = 0 g/s




Uncertainty Stdev Vx m/s
Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

DCC07-4
T_{pool} = 50.156 °C
T_{bottom} = 25.751 °C
P_{pool} = 3.2415 bar
$q_{m,steam}$ = 0 g/s

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Uncertainty Stdev Vy m/s
Uncertainty Stdev Vz m/s
Uncertainty Bias Vx m/s
Uncertainty Bias Vy m/s
Uncertainty Bias Vz m/s
mm

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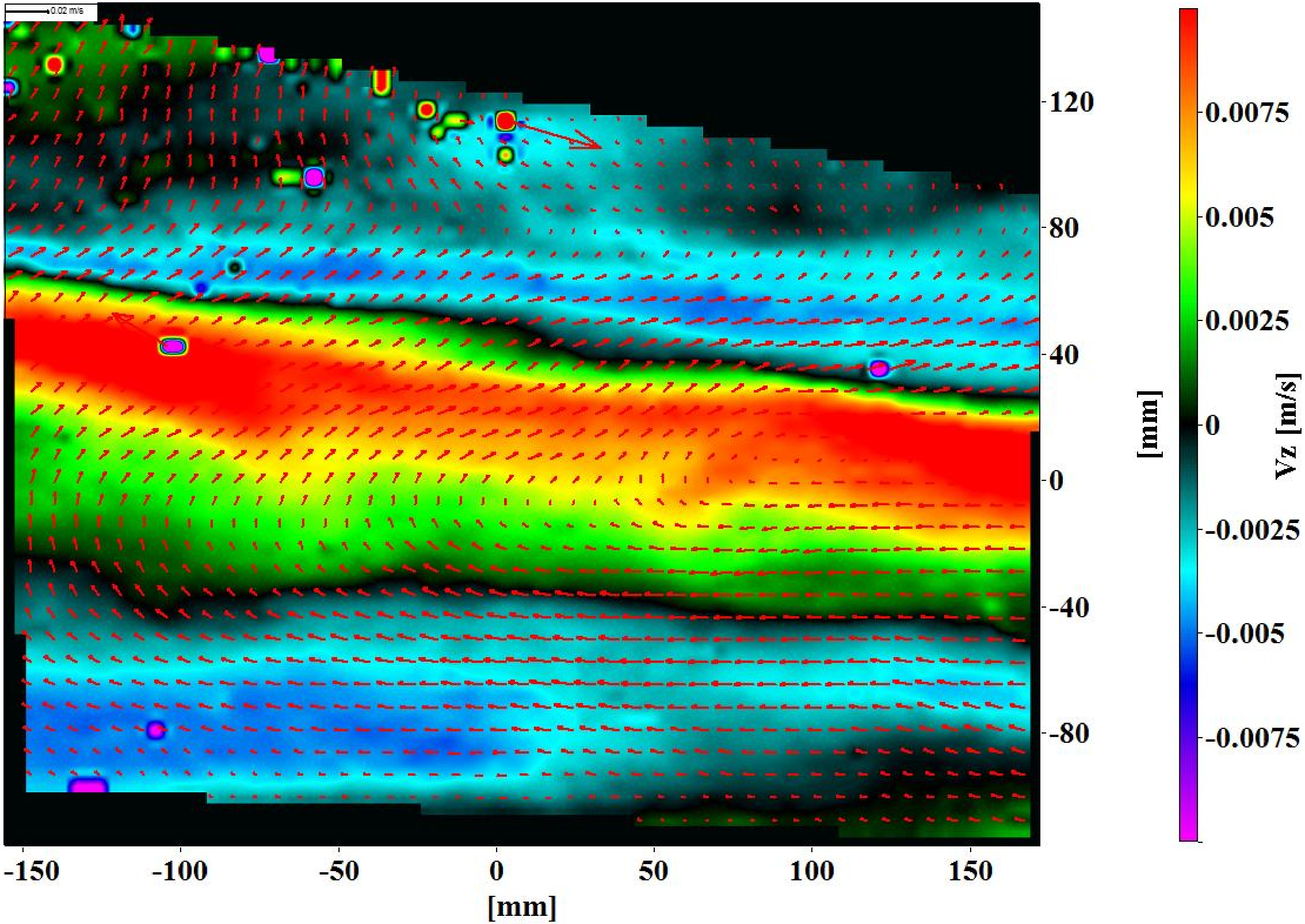
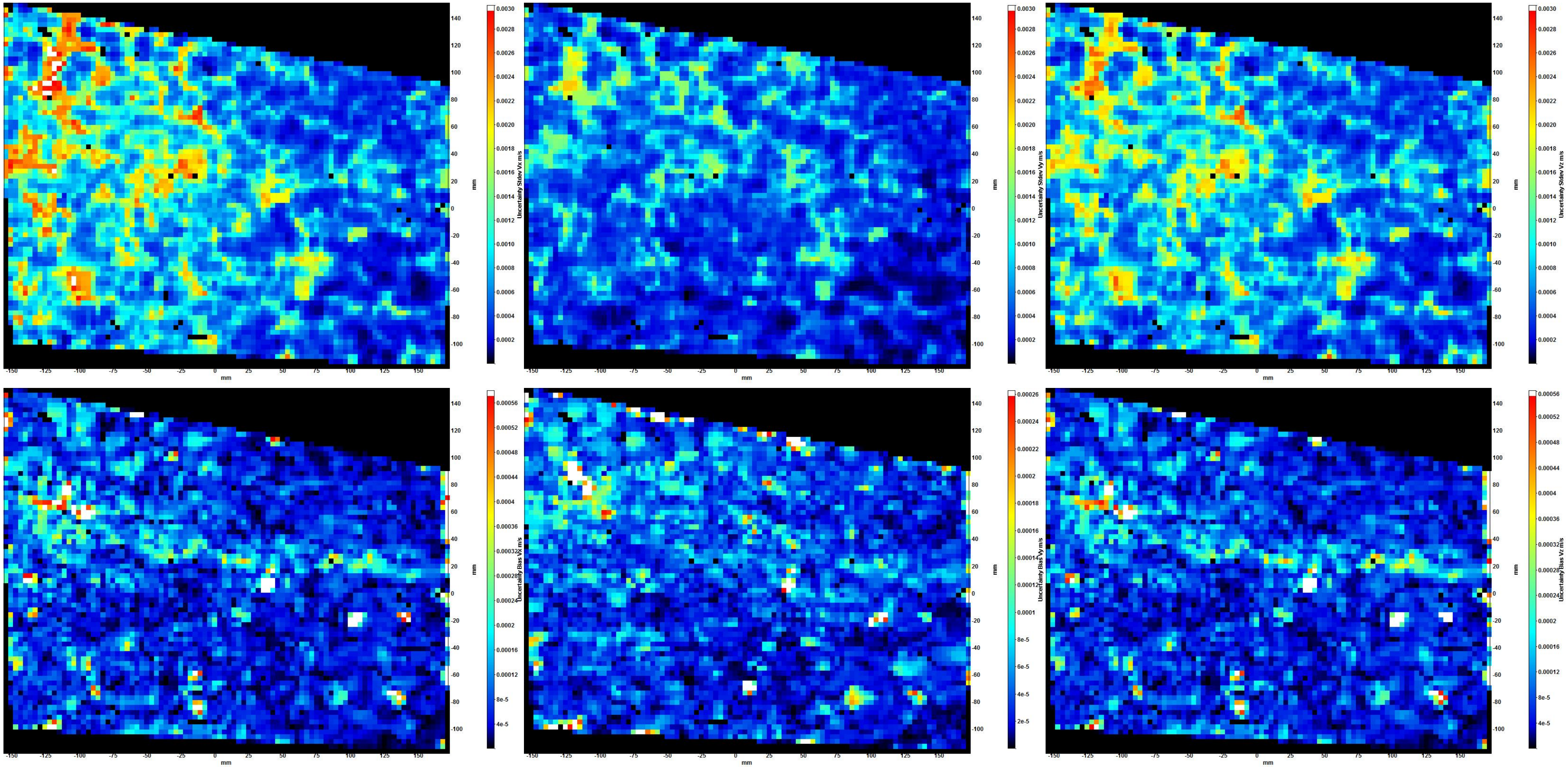
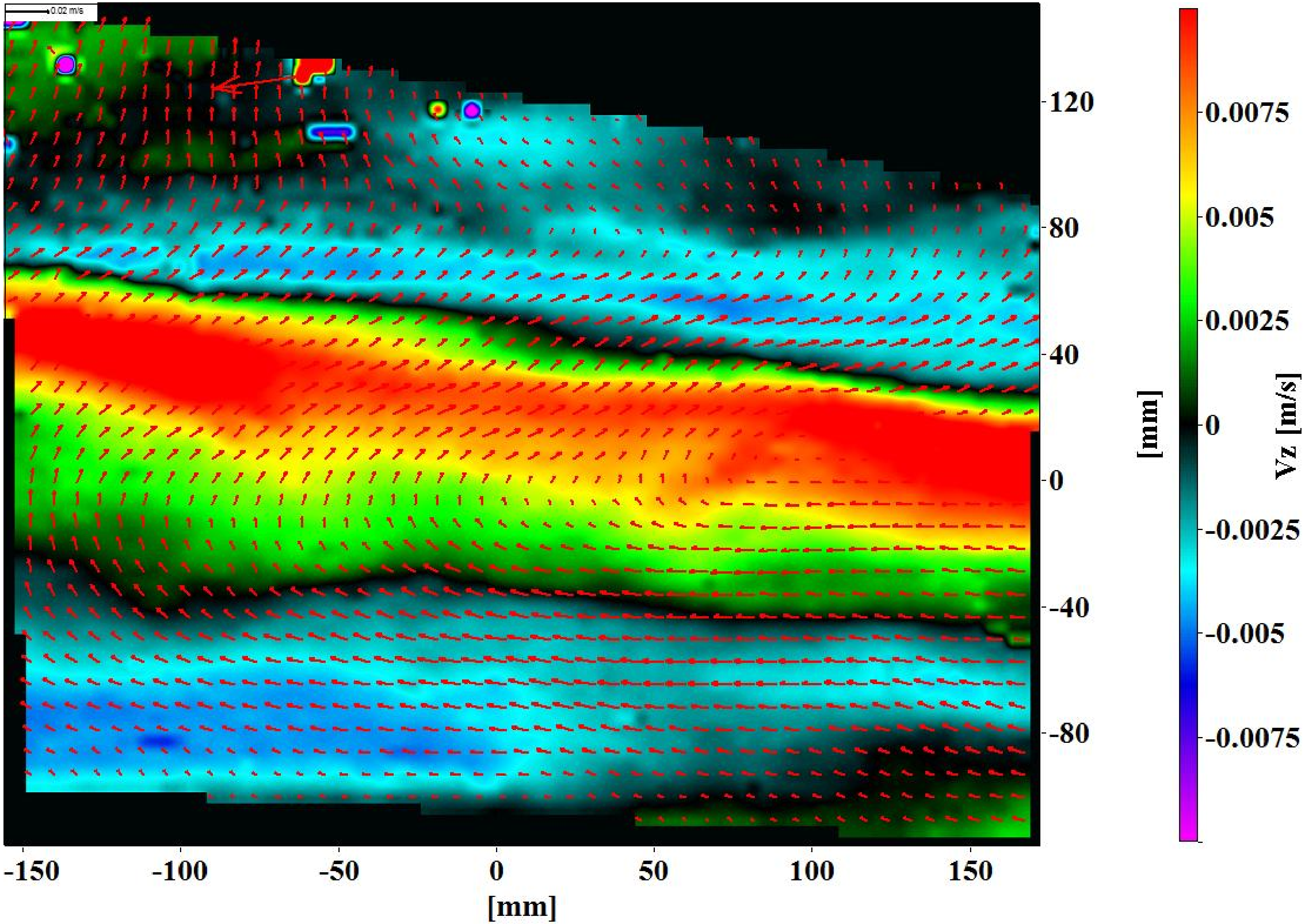
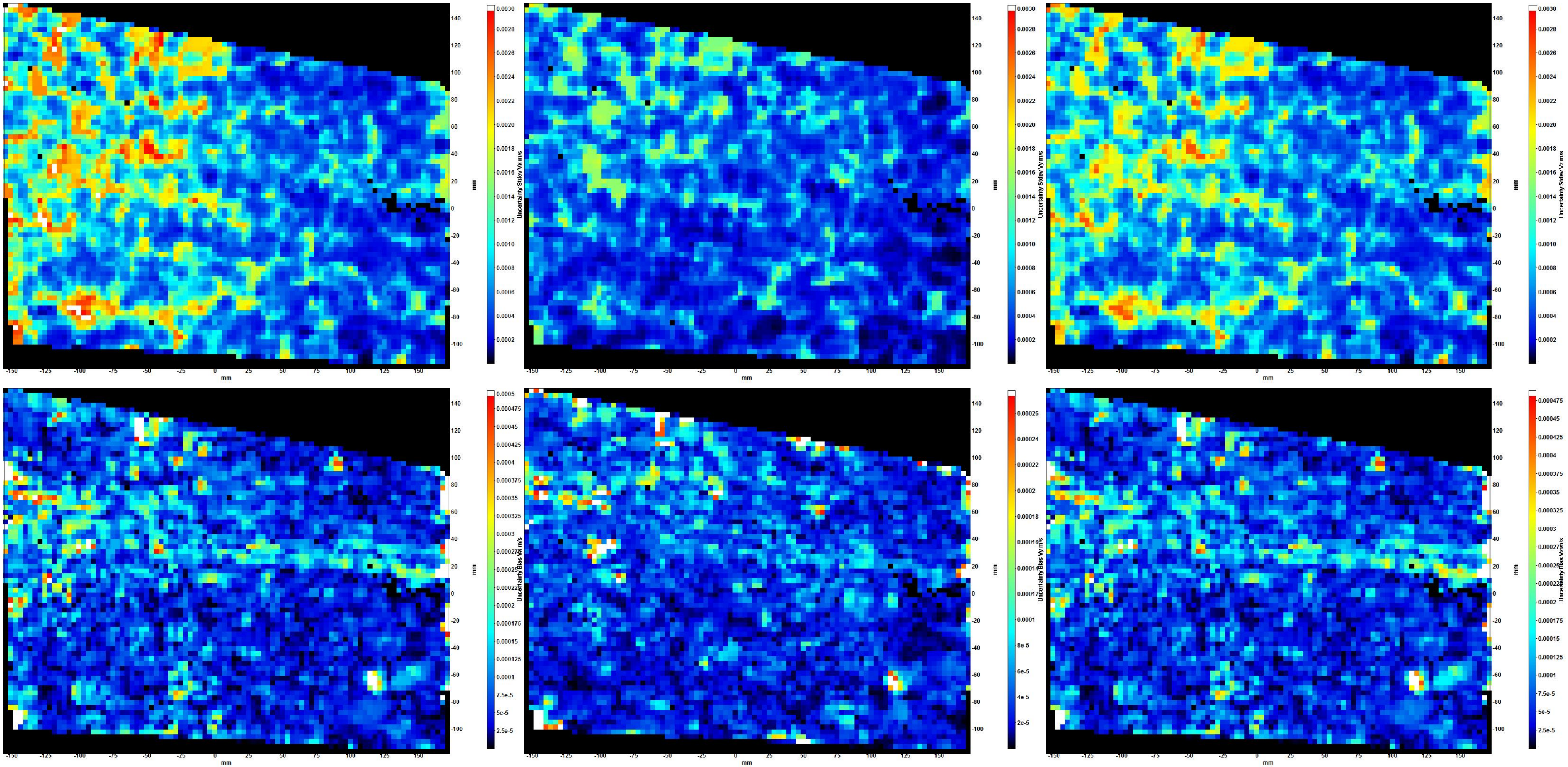
DCC07-4
T_{pool} = 50.156 °C
T_{bottom} = 25.751 °C
P_{pool} = 3.2415 bar
$q_{m,steam}$ = 0 g/s





DCC07-4
T_{pool} = 50.156 °C
T_{bottom} = 25.751 °C
P_{pool} = 3.2415 bar
$q_{m,steam}$ = 0 g/s





Bibliographic Data Sheet **NKS-333**

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Author(s)	Lauri Pyy, Joonas Telkkä
Affiliation(s)	Lappeenranta University of Technology, Nuclear Safety Research Unit, Finland
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Abstract
max. 2000 characters

This report summarizes the results of the DCC-06 and DCC-07 steam discharge experiments carried out with the scaled down PPOOLEX test facility designed and constructed at Lappeenranta University of Technology. Steam was blown through the vertical DN100 blowdown pipe to the condensation pool filled with sub-cooled water.

The main objective of the experiments was to use the PIV measurement system in different direct contact condensation situations in order to obtain velocity field data to be used in verification of CFD simulation results.

Both experiments consisted of several PIV measurement sequences, where different steam flow rates and pool water temperatures were used. Most of the time the steam/water interface moved up and down along the blowdown pipe as a result of rapid condensation taking place either inside the pipe or at the pipe outlet. There was only a short period of time in DCC-06, when the steam/water interface was quite calm at the blowdown pipe outlet.

Steam release into the pool water created major optical problems for the PIV measurements. The problems couldn’t be avoided even with the new red band pass filters. Time-averaging of the PIV images did not work due to the fluctuating behaviour of the water phase. Therefore, the PIV results from the DCC-06 and DCC-07 experiments can be presented only as individual vector images from those measurement sequences where optically intact raw images are available. It is possible to measure the velocity field of the water phase, but only from areas where condensing does not occur.

The main finding from the DCC-06 and DCC-07 experiments is that PIV cannot be applied successfully for velocity measurements near the blowdown pipe outlet with the current PPOOLEX measuring set-up. The character of the flow in most steam discharge experiments is fluctuating and chaotic. These fluctuations make the time-averaging of PIV images impossible because there is no constant flow direction to be found. In addition, when there are optical distortions present, the PIV vector result is corrupted. At the moment there is not a way to get around these optical distortions even though the new filters succeeded well by cutting the reflections from the actual steam bubbles.

Key words condensation pool, steam blowdown, PIV measurements

Available on request from the NKS Secretariat, P.O.Box 49, DK-4000 Roskilde, Denmark.
Phone (+45) 4677 4041, e-mail: nks@nks.org, www.nks.org