RAPPORT

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Flow disturbance around various ADCPs and mounts, measured in a still lake

Kristoffer Florvaag-Dybvik

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Summary: This report explains a simple way to measure flow disturbance around various ADCPs and mounts, by comparing the measured water velocities in different depths as the ADCPs move through still water. If there are no differences, there is no flow disturbance. Any flow disturbance will cause gradients in the measured velocities.

Keywords: ADCP, flow disturbance, extrap, extrapolation, screening distance, discharge

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Forord

Denne rapporten beskriver en enkel metode man kan bruke for å måle strømningsforstyrrelser rundt forskjellige ADCP-er og innfestinger, ved å sammenligne de målte vannhastighetene i forskjellige dybder når ADCP-ene beveger seg gjennom stille vann. Hvis det ikke er forskjeller, er det ingen strømningsforstyrrelse. Enhver strømningsforstyrrelse vil forårsake gradienter i de målte hastighetene.

Rapporten konkluderer med hvilke ADCP-er og innfestinger som kan brukes uten forsiktighet, og som kun bør brukes hvis det ikke finnes noen alternativer.

Oslo, januar 2023

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Dokumentet sendes uten underskrift. Det er godkjent i henhold til interne rutiner.

Preface

This report explains a simple way to measure flow disturbance around various ADCPs and mounts, by comparing the measured water velocities in different depths as the ADCPs move through still water. If there are no differences, there is no flow disturbance. Any flow disturbance will cause gradients in the measured velocities.

The report concludes on which ADCPs and mounts that can be used without caution, and which should only be used if no options exist.

The report is aimed at experienced ADCP users who know the instruments, the way they work and the way they are used, and therefore it includes no ADCP basic descriptions.

For those who want to jump to the conclusions, please go to ch 8.2 (page 42).

In short:

Instrument/mount	Text
StreamPro in big and small trimaran	No caution
RiverPro in ARC-boat	We can use this setup to collect data. In postprocessing, if in doubt, choose power extrapolation at top and not constant or 3-point.
RiverRay in Trimaran	No caution as long as data is collected 25 cm from ADCP (default setup)
M9 in rQpod	We can use this setup to collect data. Based on these tests we can use data collected 25 cm or more from the ADCP. Based on USGS/Mueller there is flow disturbance down to 16 cm. When deciding top extrapolation, do not use data closer to the ADCP than 16 cm.
RiverPro in Trimaran	We can use this setup to collect data. In postprocessing, if in doubt, choose power extrapolation at top and not constant or 3-point.
RioGrande in Trimaran	We can use this setup to collect data. In postprocessing, data shall be very clear to choose constant or 3-point extrapolation at the top.
RioGrande Side mount or Front mount	Do not use this setup to collect data unless there is no other choice. In postprocessing, do not choose constant or 3-point extrapolation at the top.

Oslo, January 2023

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This document is sent without signature. The content is approved according to internal routines.

Contents

1 Introduction/background

ADCPs are widely used to measure discharge in rivers. They cannot measure all the way to the surface or to the bottom, so we need to extrapolate data to calculate discharge. In this text, the focus is on the top region. We need to use the measured data to extrapolate the top region, so it is very important that the uppermost part of the measured velocity profile show the true, un-biased velocities.

Investigations by USGS/Dave Mueller (Mueller 2015) showed that measured velocities close to some of the ADCPs we use are biased due to flow disturbance.

Internal discussions in NVE on the background of Mueller's investigations led us to investigate further how various instruments and instrument mounts affect the flow of water near the instruments.

2 Method

We discussed how to do this in a controlled way. The main problem is that we do not know for sure what the true, un-disturbed velocity profile in a river looks like. Theory tells us that under ideal circumstances, it shall be a logarithmic (or power law) shaped velocity profile in the central parts of a river where the ratio of width to depth is greater than 20. But wind and up- or downstream conditions can ruin this.

The only place (outside a laboratory) where we know the true velocity distribution is in still water. Velocity everywhere is zero. If we move an ADCP through still water, the entrapment of water by the ADCP should be equivalent to the way a still ADCP is disturbing the flow in running water. Since there is little or no turbulence in (so to say) still water, this will be a worst-case scenario.

We identified a lake an hour's drive from Oslo (Steinsfjorden, Buskerud) where there are no big rivers entering, so there is so to say no flow through the lake. We had to wait for long periods of no rain, snow melt or wind to make sure it was no circulation. Unfortunately, this does not happen often, and it is most common late in the autumn, just before the lake freezes over.

2.1 List of instruments and mounts

We tested mounts and instruments as listed below.

Instruments
- TRDI RioGrande (1200 kHz), StreamPro, RiverRay and RiverPro
- Sontek M9

Mounts
- NVE custom front- and side-mount for manned boat (Zodiac inflatable)
- Original and high-speed Ocen Science trimarans for StreamPro
- Original Ocean Science trimarans for RiverRay/RiverPro and RioGrande
- HR Wallingford ARC-boat (remote controlled boat)
- Sontek rQpod (remote controlled float)

Day 1 (2015.11.25)
- RioGrande in front mount and side mount
- RioGrande in trimaran in front of and beside manned boat

Day 2 (2015.11.26)
- StreamPro in big ("high speed") trimaran in front of manned boat
- StreamPro in big ("high speed") trimaran beside manned boat
- StreamPro in small ("original") trimaran in front of manned boat
- StreamPro in small ("original") trimaran beside manned boat

Day 3 (2017.11.13)
- RioGrande, rotated 45 deg in trimaran in front of manned boat
- RiverPro in trimaran in front of manned boat
- RiverRay in trimaran in front of manned boat
- StreamPro in big ("high speed") trimaran in front of manned boat StreamPro in small ("original") trimaran in front of manned boat

Day 4 (2019.08.27)
Data is not included in this report. Too much wind-driven circulation.
- RioPro in ARC, remote controlled boat
- StreamPro in ARC, remote controlled boat

Day 5 (2019.09.10)

- M9_rQpod-rc
- RiverPro in ARC, remote controlled boat
- RiverPro in trimaran in front of manned boat
- RiverRay in trimaran in front of manned boat
- StreamPro in small (“original”) trimaran in front of manned boat

Field crew four of five days: Frode Thorset Kvernhaugen and Kristoffer Florvaag-Dybvik
Field crew 2015.11.26: Frode Thorset Kvernhaugen.

2.2 Percent deviation and mean values

If there is no flow disturbance, and no velocities in the lake, all bins in an ADCP ensemble (“a vertical”) will show the same velocities: Zero if we look at velocities relative to the bottom, and the boat velocity if we look at velocities relative to the ADCP. If there is flow disturbance around the ADCP, it will show as larger velocities close to the ADCP if looking at velocities relative to the bed, and lower velocities close to the ADCP if looking at velocities relative to the ADCP.

For the measurements in this report, we look at the percent difference (P) between the individual bin velocities and a reference velocity (Vr). The reference velocity is the mean of the measured velocities between 1 and 2 meters below the ADCP. The water is this region is not, or very little, affected by the ADCP. If the water is still, the reference velocity will be the same as the boat velocity when we look at velocities relative to the ADCP. We use this mean value and not a single bin-value to smooth out noise. The percent difference (P) is

P=100*(V-Vr)/Vr.

V is the bin velocities. Vr is the reference velocity.

A more precise notation is $P_{i,j}=100*(V_{i,j}-Vr_j)/Vr_j$, where i is denoting bin number (~depth) and j is denoting ensemble number or equivalently, distance or time.

The velocities used to calculate percent difference in this report are velocities referenced to the ADCP. For the TRDI instruments, this is done by choosing “Ref. none” in the WinRiver software. For Sontek data, it is done by choosing Track Reference = System and Coordinate System = XYZ. Data in this report is XYZ, but ENU looks just the same.

In theory it shall not matter if we use velocities referenced to the ADCP or to the bed to calculate the percent difference, since velocities referenced to the bed is calculated by adding the same bed-velocity to the water velocities. But in practice the reference velocities (Vr) which we divide by, become very small numbers if we use velocities referenced to the bed. Rounding towards zero in data exported from the software creates more noisy data for percent difference.

If there is any flow disturbance, velocities measured in the bins close to the ADCP will be smaller than the reference velocity (boat velocity), since the ADCP pulls water along, and since we reference all velocities to the ADCP. This means that flow disturbance caused by entrapment by the ADCP will show as negative values for percent difference (P) and a plot where the top part is bent to the left. This is equivalent to an ADCP slowing down the water when flowing water is passing a (so to say) stationary ADCP.

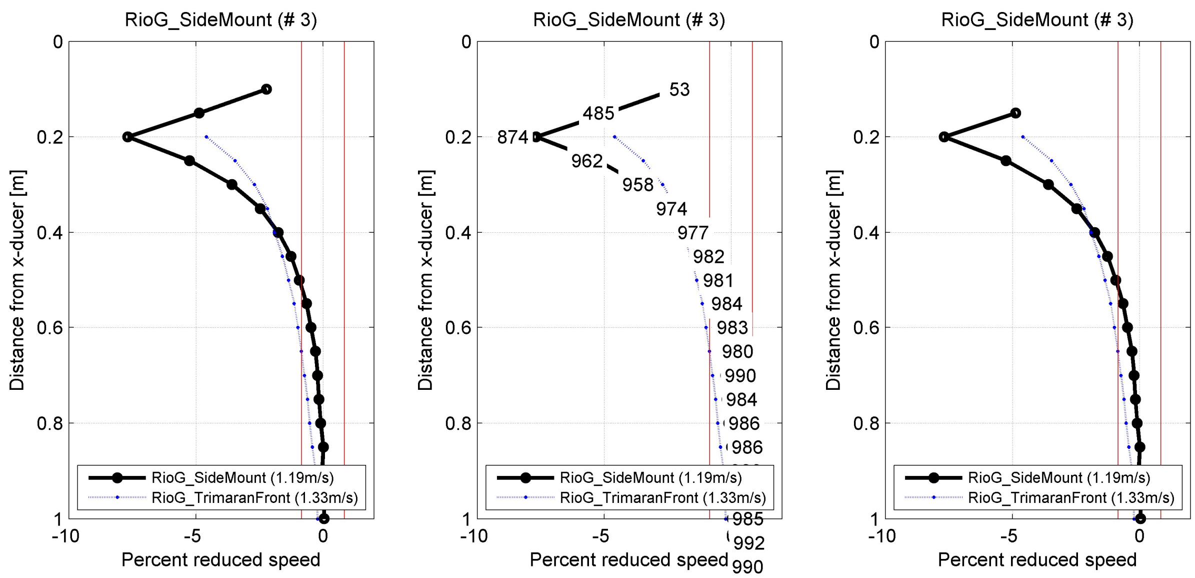
The percent difference is first calculated for all bins.

To calculate *mean* percent difference for a measurement for ADCPs with fixed bin size, we simply calculate the mean for bin 1,2,…n for all ensembles.

For ADCPs with varying bin size we first group the ensembles with equal bin depths. Then we calculate the mean value for each group like if it was an ADCP with fixed bin size. In this way, all bin-depths in the measurement have a mean value for percent difference (P).

These mean values are the values presented in this report.

In some cases, there is significant loss of data for bins at some depth(s). If the number of valid bins at a certain depth is less than 20% of the maximum number of valid bins for all depths, then data from this depth is filtered out (discarded). Typically, there is a lot of lost data in the top 1-3 bins for RioGrande data when using Water Mode 11 and pushing the blanking to measure close to the ADCP. The plots below show an example of original data, number of valid data for each depth and result after discarding as described.



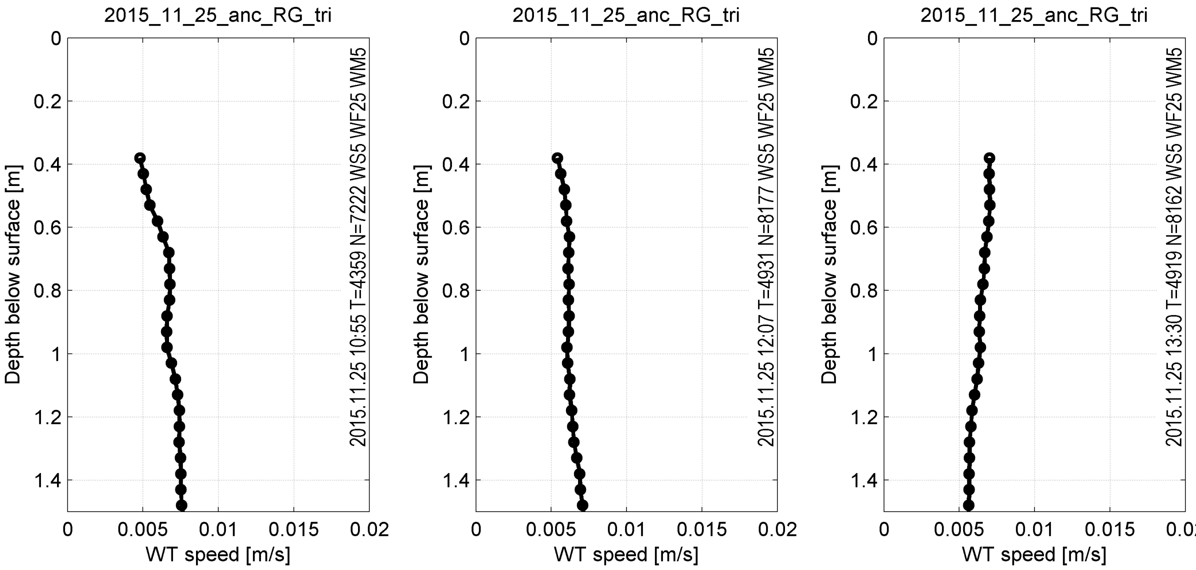
Y values in this report are usually distance from ADCP and not depth below surface.

Ideally there should be no velocities in the lake, and in particular no velocity gradients. Unfortunately, there are. Gradients are at the order of 1 cm/s on all days except one when they were greater. Data from this day in not included in this report.
The plots in ch. 4 have red lines that shows how many percent a 1 cm/s gradient would cause.
The red lines = +/-100*dV/Vr, where dV is the gradient and it is set to 0,01 m/s and Vr is the reference velocity.
Any flow disturbance within the bounds of the red lines might be caused by the velocity gradients in the lake.

3 Still water?

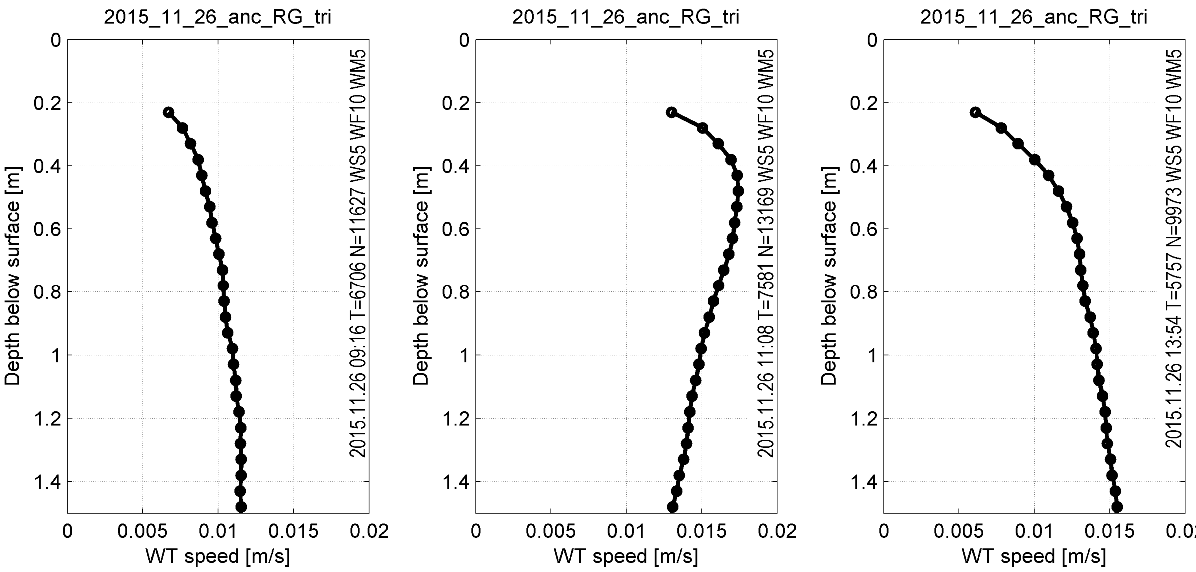
On all days we anchored an ADCP to measure if there was movement in the water, or at least no velocity gradients. We measured this by anchoring an ADCP and measuring velocities for a long time, one or more times during the day.
Mean velocities from the anchored ADCPs are calculated as the square root of the sum of the squared mean east and north velocities:
V = sqrt(mean(Ve)^2 + mean(Vn)^2)

Day 1 (2015.11.25)



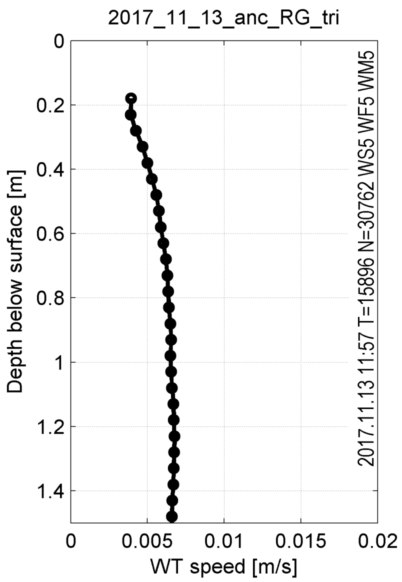
Very little motion in the water column this day. Mean velocities less than 1 cm/s and gradients almost zero.
Measuring flow disturbance this day was ok.

Day 2 (2015.11.26)



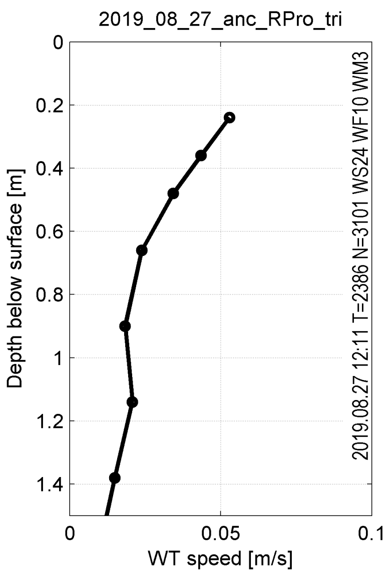
Velocity in the range 0-2 cm/s and velocity gradients is in the range 1 cm/s.
Measuring flow disturbance this day this day was ok.

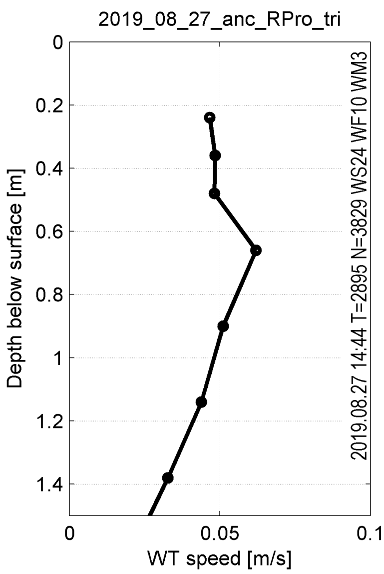
Day 3 (2017.11.13)

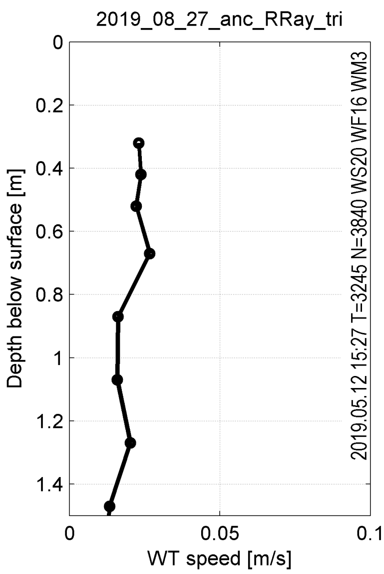


Velocity in the range 0-0.5 cm/s and velocity gradients is in the range 0.5 cm/s.
Measuring flow disturbance this day was ok.

Day 4 (2019.08.27)

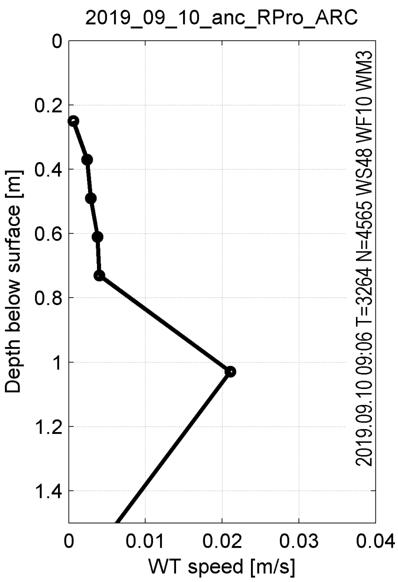


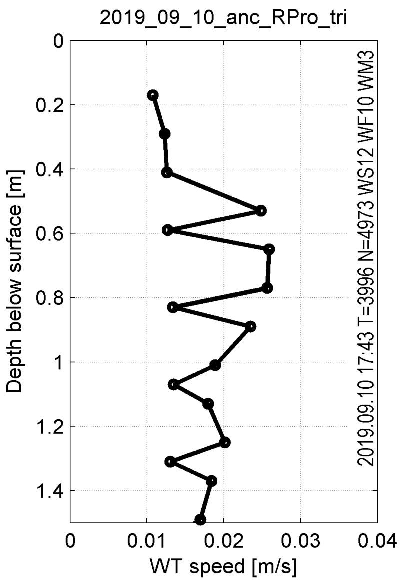




Velocity in the range 0-6 cm/s and velocity gradients up to 5 cm/s.
Measuring flow disturbance this day was not ok, and data from 2019.08.27 is not included in this report.

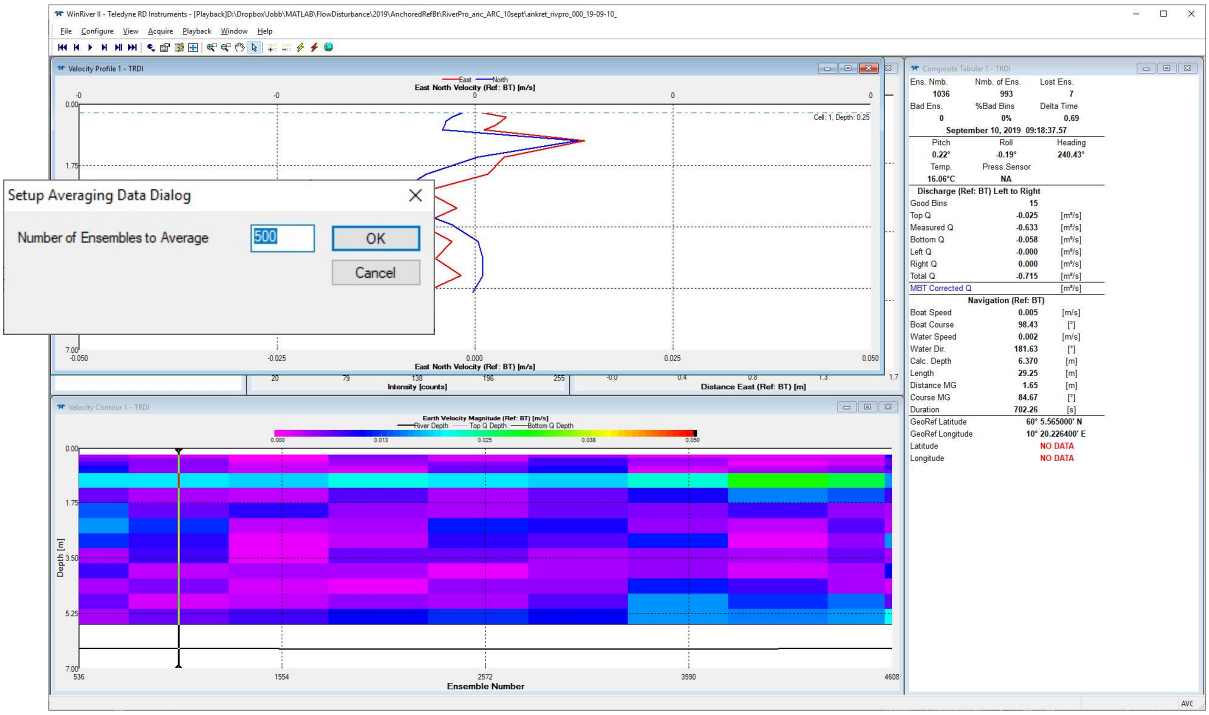
Day 5 (2019.09.10)





Velocity in the range 0-2 cm/s and velocity gradients is in the range 1 cm/s.
Measuring flow disturbance this day was ok.

There is a strange feature in the first plot (RiverPro), which will not be investigated in this report.
It is visible in WinRiverII as well:



4 Measurements

For many years, the preferred solution for medium to deep rivers was to use the RioGrande ADCP mounted in a custom-made front- or side-rig (-mount). Gradually we shifted to use the RioGrande mounted in the trimaran, either in front of the manned boat, or by rope and pulley. The latter one, RioGrande in trimaran in front of the manned boat, will be used as a reference instrument/mount throughout this report. This is to ease visualizing how well an instrument/mount performs. The plots in the following chapters will display data for the different instruments/mounts and data for RioGrande mounted in the trimaran, in front of the manned boat. In addition, there will be tables for selected values. The values in these tables might be interpolated, but not extrapolated.

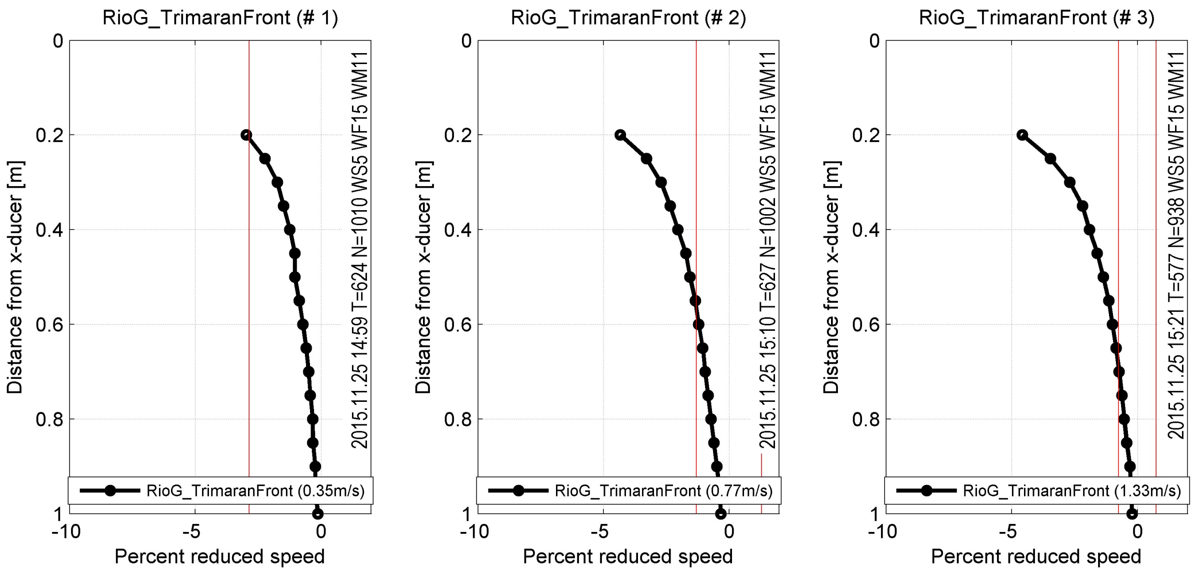
The tests with a trimaran in front of the manned boat was performed using a two meters pole, like we do on regular measurements. We believe that the flow the ADCP measures is not affected by the manned boat, but we have no data to prove it. If data collected using this setup (with the ADCP on a two-meters pole) is in fact unaffected by flow disturbance from the manned boat, the results will be valid for ADCP in trimaran by rope and pulley as well.

Each field-day, we tested the different instruments/mounts on different speeds. Unfortunately, on some days we tested at slow, medium and fast speeds, and on other days we tested at medium and fast only. In addition, the meaning of slow, medium and fast varies between the days. The actual speeds are listed in or below the plots.
Some additional metadata is displayed along the right-hand side y axis of the plots. These metadata are date and time, duration of measurement, maximum number of ensembles being averaged, bin-size, blanking and water mode. Meta data is intended for the “advanced reader”, meaning those who know what bin-size, blanking and water mode means.

4.1 RioGrande (trimaran, front)

Picture 1 RioGrande, trimaran in front of the manned boat

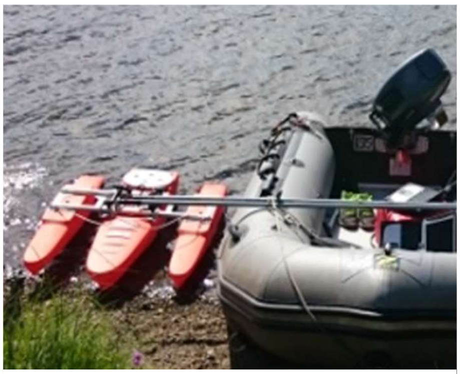
Rio Grande in trimaran attached to a 2 meters rod, in front of the manned boat.
This setup produces a clear flow disturbance with a reduction in flow speed at 3-5% 20 cm from the ADCP.
We can keep using this setup, but if post processing indicates a non-standard velocity profile, the indication shall be clear to choose constant or 3-point extrapolation at the top.
This setup has been used quite a lot by NVE. It will serve as a benchmark for the other setups in this report. All other setups will be compared to this one.



InstrAndMount	RefVel	Dist=0,1m	Dist=0,2m	Dist=0,3m	Dist=0,5m
RioG_TrimaranFront	0,35 m/s	NaN%	-3,0 %	-1,7 %	-1,0 %
RioG_TrimaranFront	0,77 m/s	NaN%	-4,3 %	-2,7 %	-1,6 %
RioG_TrimaranFront	1,33 m/s	NaN%	-4,6 %	-2,7 %	-1,4 %

Table for selected values

4.2 RioGrande (trimaran, side)



Picture 2 RioGrande in trimaran, beside manned boat

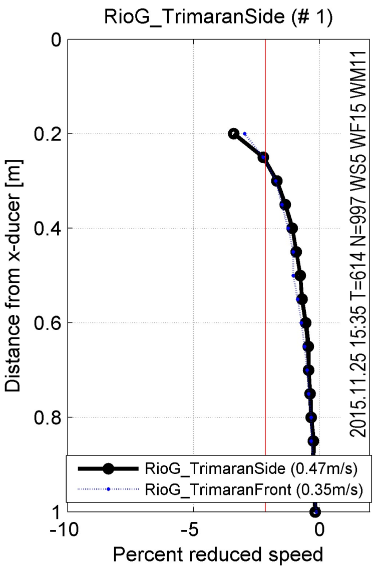
Rio Grande in trimaran beside the manned boat, tested at slow, medium and fast speed. See plot legends

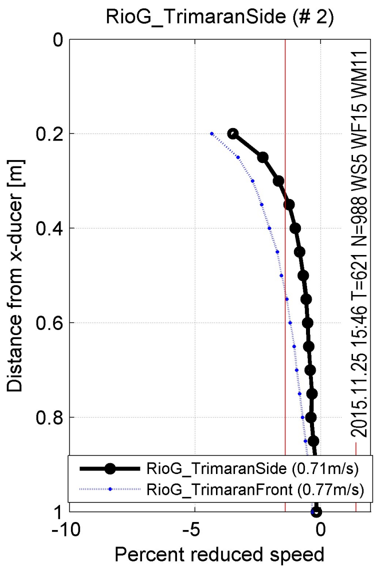
This setup produces a clear flow disturbance with a reduction in flow speed at around 3-4% 20 cm from the ADCP.

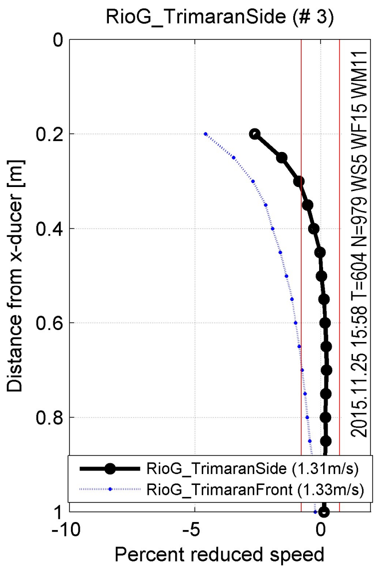
We can still use this setup, but if post processing indicates a non-standard velocity profile, the signal shall be very clear to choose constant or 3-point extrapolation at the top.

When comparing trimaran beside the manned boat and trimaran in front there is no big difference. There is *less* flow disturbance when towing the Trimaran next to the manned boat. We do not believe that this result will be the same for all sorts of boats, and this result probably cannot be generalized.

We can use this setup, but if post processing indicates a non-standard velocity profile, the signal shall be clear to choose constant or 3-point extrapolation at the top.







InstrAndMount	**mRefVel**	**D=0,1**	**D=0,2**	**D=0,3**	**D=0,5**
RioG_TrimaranSide	0,47m/s	NaN%	-3,4 %	-1,7 %	-0,8 %
RioG_TrimaranSide	0,71m/s	NaN%	-3,5 %	-1,7 %	-0,7 %
RioG_TrimaranSide	1,31m/s	NaN%	-2,6 %	-0,9 %	0,0 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

4.3 RioGrande (side-mount)

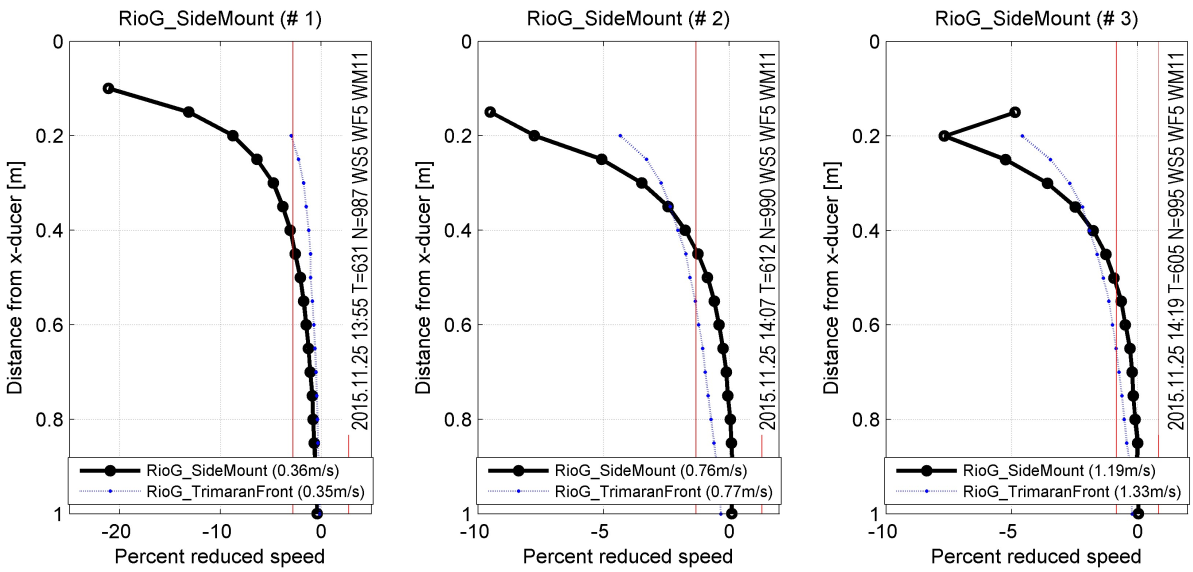
Picture 3 RioGrande, fixed mount at the side (side mount)

The RioGrande was mounted on the NVE custom "side-mount". This setup produced a severe flow disturbance, reaching 50-70 cm from the ADCP, and a reduction in speed up to 20% at the first bin, 10 cm from the transducer. We used water mode 11 and pushed the blanking distance to get data close to the ADCP. The top bins show a strange behavior. Data is very noisy, and a lot of ensembles lose data for the top bins. This might be due to ringing or to water shooting under the ADCP.

After this test we decided to not use this setup for routine discharge measurements anymore.

When comparing RioGrande in side-mount and trimaran in front it is quite clear that the side mount setup creates more flow disturbance, in particular for the bins closest to the ADCP.

For the deeper bins, the picture is not that clear. Remember that there is a natural gradient in the lake, as indicated by the red vertical lines.



NB! Please note the x-scale at plot (#1)

InstrAndMount	mRefVel	D=0,1	D=0,2	D=0,3	D=0,5
RioG_SideMount	0,36 m/s	-21,0 %	-8,7 %	-4,8 %	-2,1 %
RioG_SideMount	0,76 m/s	NaN%	-7,7 %	-3,5 %	-0,9 %
RioG_SideMount	1,19 m/s	NaN%	-7,6 %	-3,6 %	-0,9 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

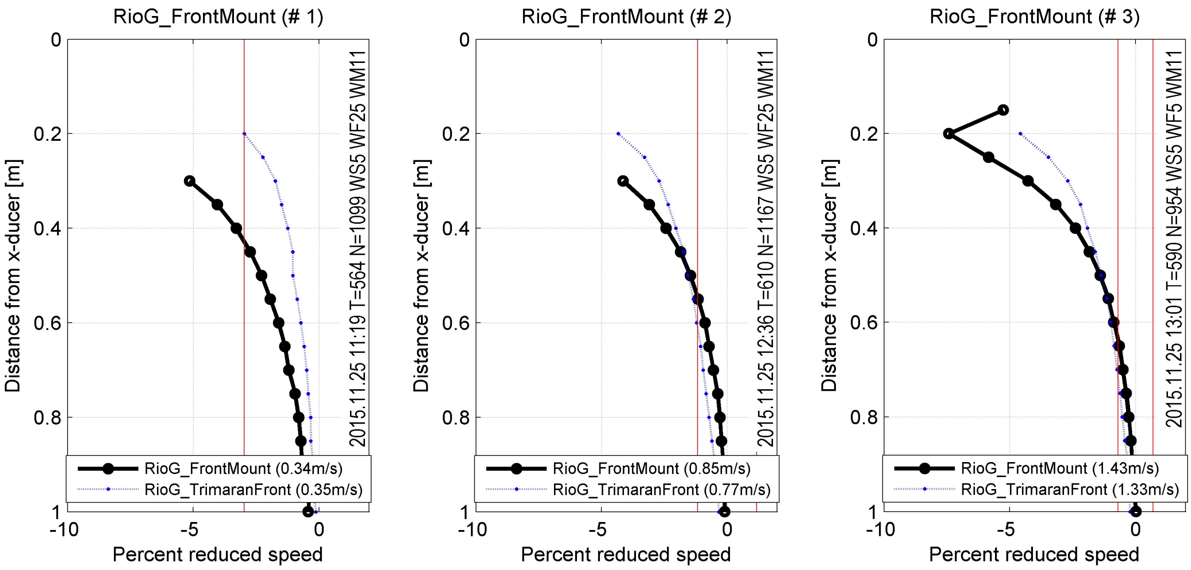
4.4 RioGrande (front-mount)

Picture 4 RioGrande, fixed mount at bow (front mount)

The RioGrande mounted on the NVE custom front-mount, tested at slow, medium and fast speed. See plot legends! This setup produced a severe flow disturbance, reaching 60-80 cm from the ADCP. On plot #3 below (fast speed), we pushed the blanking distance to get data closer to the ADCP. The top bins show a strange behavior and are very noisy. This might be due to ringing or to water shooting under the ADCP. Still, we should have pushed the blanking on the other two as well to get data closer to the ADCP.

When comparing RioGrande in front mount to Rio Grande in trimaran in front of the manned boat, we see that the front mount generates way more flow disturbance. This is particularly clear on plots #1 and #3 below, that is on the tests for slow and high speed. For some reason it there less difference for medium speed.

After this test we decided to not use this setup for routine discharge measurements anymore. This mount must be avoided unless there is no other option. If postprocessing data collected using this setup, do not choose constant or no-slip at the top unless data is really, unless there is no doubt at all.

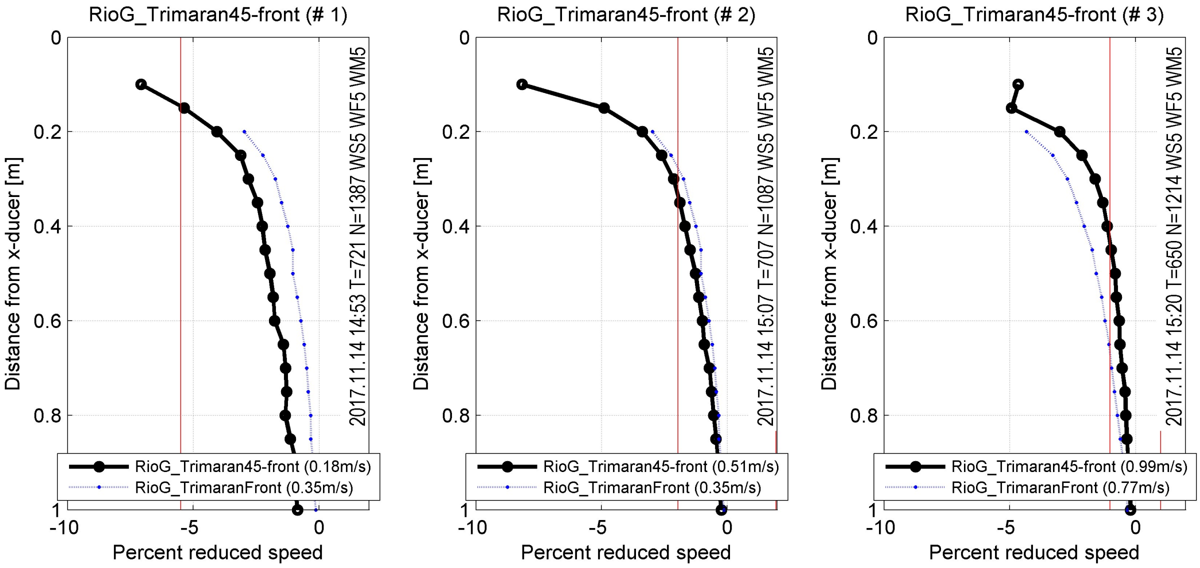


InstrAndMount	mRefVel	D=0,1	D=0,2	D=0,3	D=0,5
RioG_FrontMount	0,34m/s	NaN%	NaN%	-5,1 %	-2,3 %
RioG_FrontMount	0,85m/s	NaN%	NaN%	-4,1 %	-1,5 %
RioG_FrontMount	1,43m/s	NaN%	-7,4 %	-4,3 %	-1,4 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

4.5 RioGrande (trimaran, front) rotated 45 degrees

There was some talking and discussions about rotating the ADCPs 45 degrees to reduce the impact of flow disturbance, since all beams will be further to the side of the float. We tried this, but the only way we manage to attach the RioGrande to the trimaran in an improvised way caused it to sit a little deeper in the moon pool. The plots below show data from the normal setup (blue, thin line) and the 45 degrees rotation (black). The results are very similar. Remember that the red lines indicate the magnitude of the velocity gradient in the lake! The similarity might be the combined result of a deeper mount which increases drag, and a rotated ADCP which possibly measure less disturbed water. This test is inconclusive.



InstrAndMount	mRefVel	D=0,1	D=0,2	D=0,3	D=0,5
RioG_Trimaran45-front	0,18m/s	-7,0 %	-4,0 %	-2,8 %	-1,9 %
RioG_Trimaran45-front	0,51m/s	-8,1 %	-3,4 %	-2,1 %	-1,2 %
RioG_Trimaran45-front	0,99m/s	-4,7 %	-3,0 %	-1,6 %	-0,8 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

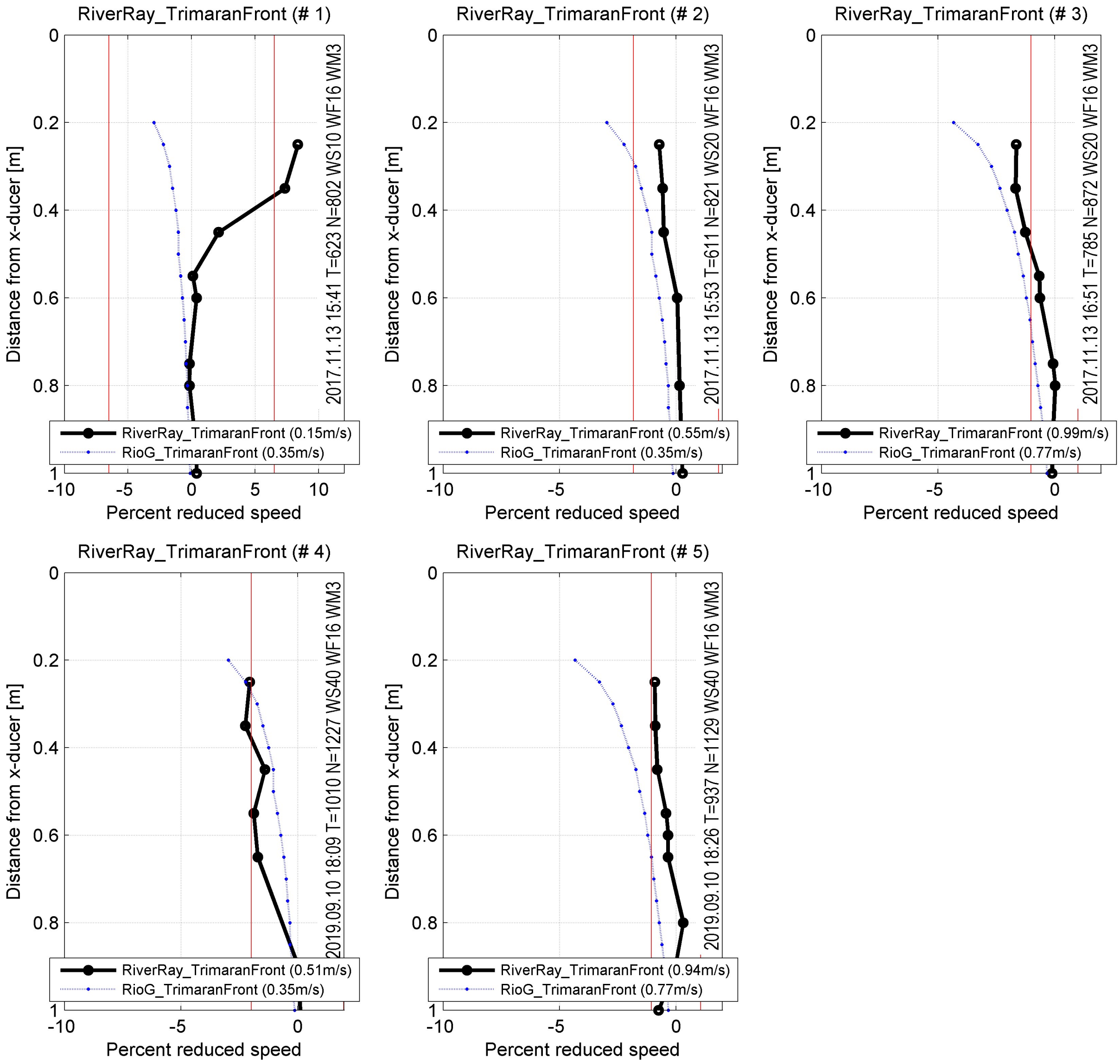
Table for selected values

4.6 RiverRay (trimaran, front)

Picture 5 RiverRay/RiverPro in trimaran

The RiverRay was mounted in the original trimaran which was attached to a two-meter pole in front of the manned boat. We measured on two different days due to strange data in plot (#1). It seems like water is accelerated under the ADCP, but this might be due to the velocity gradients in the lake itself. The red lines indicate the natural velocity gradient in the lake.

The general picture is that the RiverRay in the original trimaran, mounted in front of the manned boat, creates very little flow disturbance, and we can trust data even from bins close to the ADCP. We also see clearly that the RiverRay creates less flow disturbance than the RioGrande in trimaran.



Note different scaling on x-axis on plot (#1)

InstrAndMount	**mRefVel**	**D=0,1**	**D=0,2**	**D=0,3**	**D=0,5**
RiverRay_TrimaranFront	0,15m/s	NaN%	NaN%	7,8 %	1,1 %
RiverRay_TrimaranFront	0,99m/s	NaN%	NaN%	-1,6 %	-0,9 %
RiverRay_TrimaranFront	0,55m/s	NaN%	NaN%	-0,6 %	-0,3 %
RiverRay_TrimaranFront	0,51m/s	NaN%	NaN%	-2,2 %	-1,6 %
RiverRay_TrimaranFront	0,94m/s	NaN%	NaN%	-0,9 %	-0,6 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

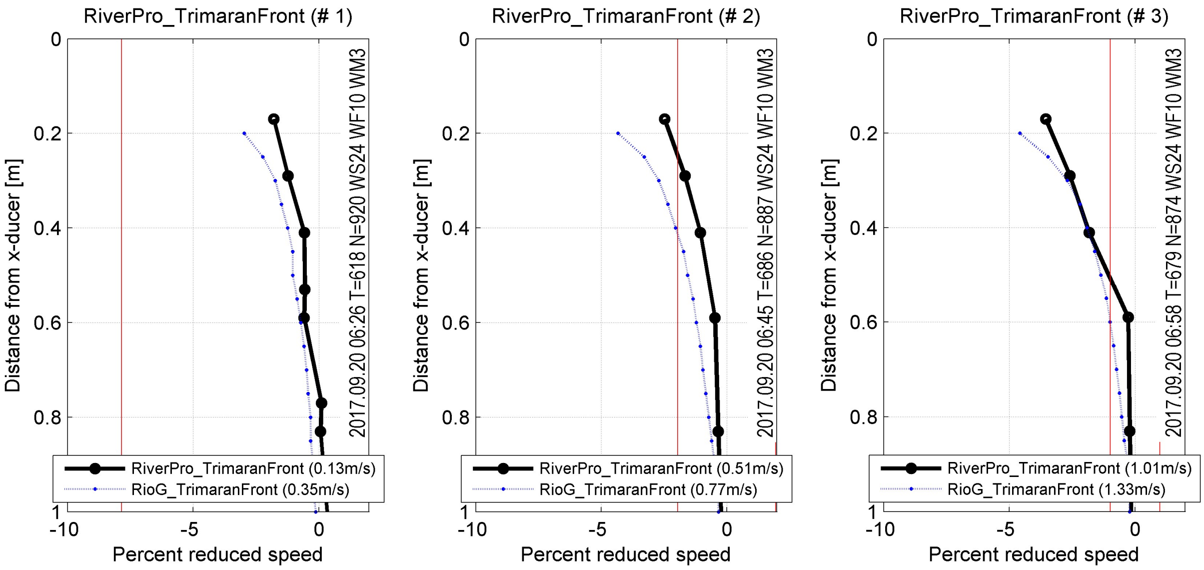
4.7 RiverPro (trimaran, front)

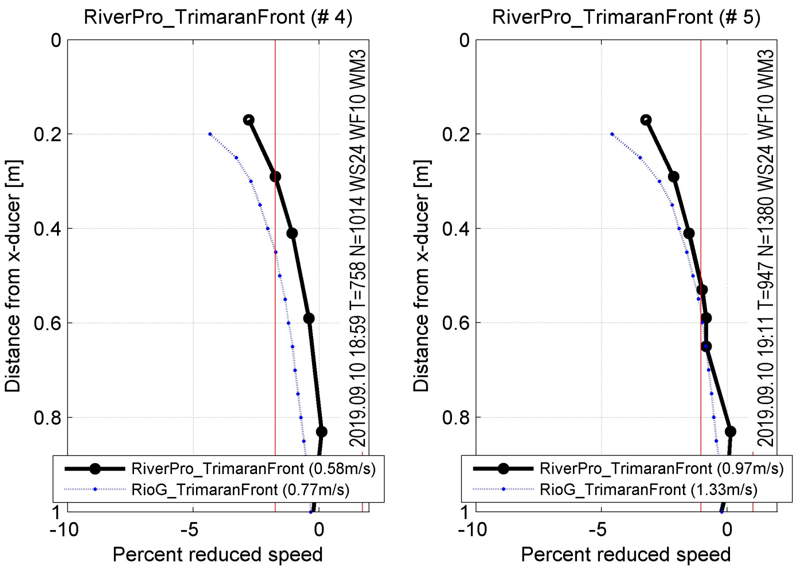
Picture 6 RiverRay/RiverPro in trimaran

The RiverPro was mounted in original trimaran from a two-meter pole in front of the manned boat. We measured on two different days due to what we thought was noisy data on the first day. The noise was caused by very few measurements in a few bins and has been filtered out in the plots below.

This setup creates some flow disturbance, up to around 3% 20 cm from the ADCP. (The red lines indicate the natural velocity gradient in the lake.). This is less than the RioGrande in trimaran, but it cannot be completely neglected.

If extrapolation software indicates a constant velocity profile at the top instead of the regular power/power, and if it is very unclear if the top-extrapolation is constant or power, the user must be aware that data is impacted by flow disturbance. In all other cases, choosing constant should be unproblematic.



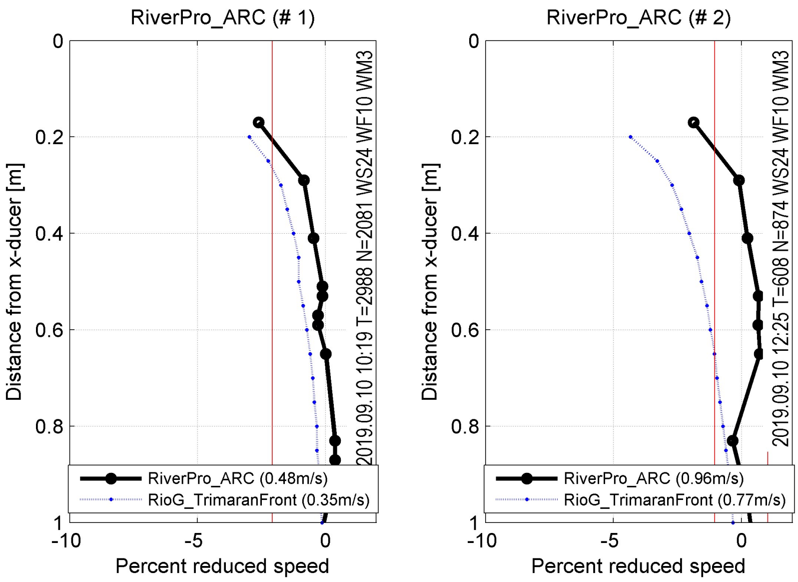


InstrAndMount	**mRefVel**	**D=0,1**	**D=0,2**	**D=0,3**	**D=0,5**
RiverPro_TrimaranFront	0,13m/s	NaN%	-1,6 %	-1,2 %	-0,6 %
RiverPro_TrimaranFront	0,51m/s	NaN%	-2,3 %	-1,6 %	-0,8 %
RiverPro_TrimaranFront	1,01m/s	NaN%	-3,3 %	-2,5 %	-1,0 %
RiverPro_TrimaranFront	0,58m/s	NaN%	-2,5 %	-1,7 %	-0,7 %
RiverPro_TrimaranFront	0,97m/s	NaN%	-2,9 %	-2,1 %	-1,1 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

4.8 RiverPro (ARC boat)

The RiverPro was mounted in an ARC boat, a remote-controlled boat manufactured by HR Wallingford.
This setup shows little disturbance with a reduction in flow speed at around 2-3% 20 cm from the ADCP.
We can use this setup, but if post processing only weakly indicates a non-standard velocity profile, be careful if considering a constant or 3-points extrapolation at the top.
The RiverPro in the ARC boat creates notably less flow disturbance than the RioGrande in trimaran.



InstrAndMount	mRefVel	D=0,1	D=0,2	D=0,3	D=0,5
RiverPro_ARC	0,48m/s	NaN%	-2,1 %	-0,8 %	-0,1 %
RiverPro_ARC	0,96m/s	NaN%	-1,4 %	-0,1 %	0,6 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

4.9 M9 (rQpod)

The M9 was mounted in an rQpod. The Sontek rQpod system is a Torrent Board with motors, batteries and radio, so it becomes a remote-controlled boat.

Data from this test was initially very strange, showing that water accelerated past the boat. These data included a large number of samples that were affected by beam separation, that is, air bubbles on one transducer. Beam separation can bias data and is filtered out in the data presented below.

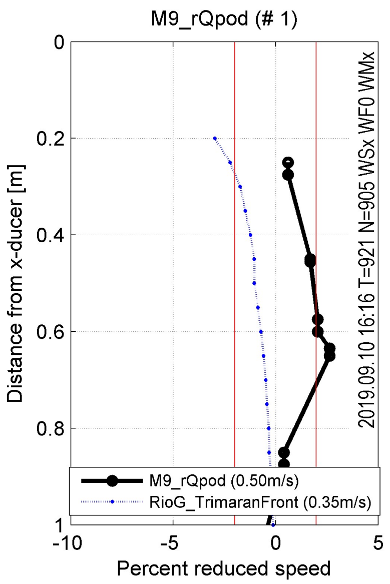
Unfortunately, this leaves the fast run useless, since all ensembles with data close to the M9 had beam separation. For the medium fast run (0,5 m/s) we see that data is not biased outside the band (red lines) representing the velocity gradients in the lake this day.

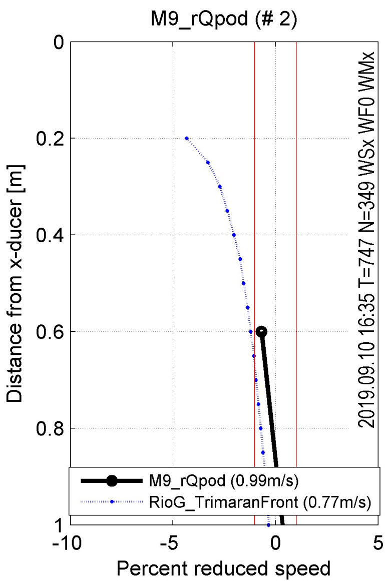
This means that, based on these tests, we can safely use data 25 cm from the M9 when extrapolating to the surface.

However, based on numerical modelling and field tests by USGS/Mueller 2015 [i], the M9 do have flow disturbance reaching down to around 16 cm from the ADCP. The data presented below neither confirms nor contradicts this, since we did not collect good data this close to the ADCP.

Unpublished works show that for RioGrande and StreamPro, the numerical simulations in Mueller 2015 gives equal or less flow disturbances than our measurements. The modelling tool does not give *worse* results than the field measurements. For this reason, we shall not measure closer to the M9 than 16 cm if it can be avoided. If we still need to do so, make sure that the extrapolation does not use data closer to the M9 than 16 cm. In particular if data indicates a constant or no-slip extrapolation at the top.

Usually, on a deep river only the ensembles close to the bank will contain bins close to the ADCP, since it shifts to larger bins further from the M9 the deeper it gets. On rivers where the M9 uses small bins (3 MHz/SmartPulse) on the major parts of the river, we must screen the top 16 cm or use another instrument.



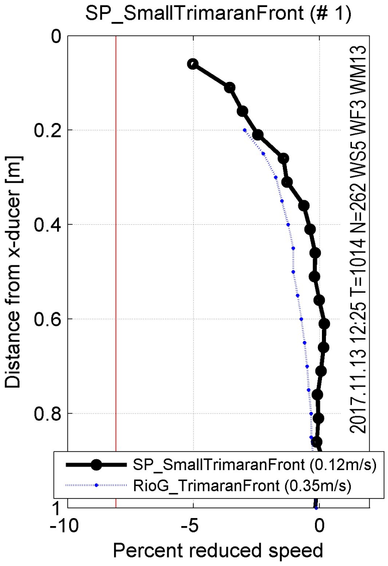


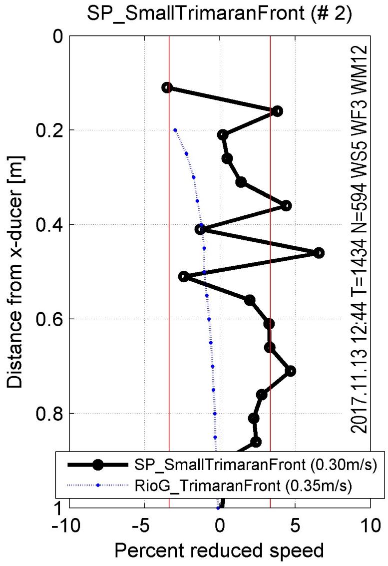
InstrAndMount	**mRefVel**	**D=0,1**	**D=0,2**	**D=0,3**	**D=0,5**
M9_rQpod	0,50m/s	NaN%	NaN%	0,80 %	1,80 %
M9_rQpod	0,99m/s	NaN%	NaN%	NaN%	NaN%
RiverPro_TrimaranFront	*0,51m/s*	*NaN%*	*-2,3 %*	*-1,6 %*	*-0,8 %*
RiverPro_TrimaranFront	*0,97m/s*	*NaN%*	*-2,9 %*	*-2,1 %*	*-1,1 %*

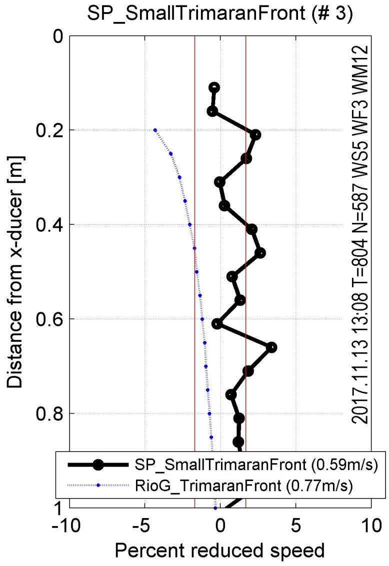
Table for selected values

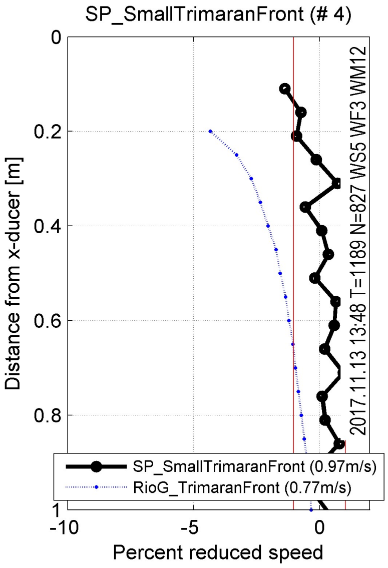
4.10 StreamPro (small trimaran, front)

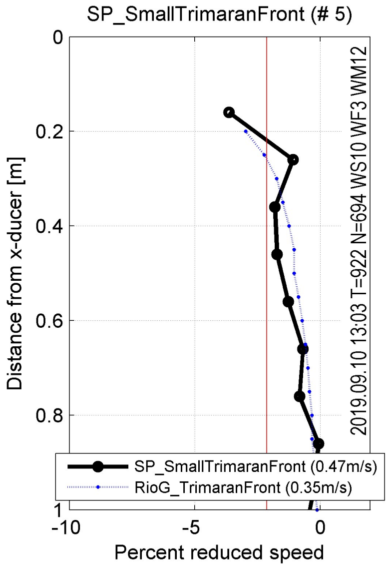
StreamPro in small (original) raft attached to a 2 meters rod, in front of the manned boat. We measured on several days. The general picture is that there is no or very little flow disturbance.
Data on plot (#1) was collected using water mode 13 and there is little noise. The rest of the data was collected using water mode 12 and small bins. Data is very noisy, even if we measured for more than 10 minutes.
The gradient on plot (# 1) with Reference velocity 0.12 m/s shows a trend, but this gradient is less than the measured velocity gradient in the lake. This means that the bend in the curve either shows flow disturbance or a gradient in the lake, and thus it is inconclusive.
The data in plot (#2) with Reference velocity 0,30 m/s shows noise and bias reaching 90 cm from the transducer. Looking at the plot for mean velocity (#2b) it seems like the upper layer, above 90 cm, moves relative to the lower layer. Visually it looks neither like a natural gradient in the lake nor flow disturbance, so data is inconclusive.
Plot (#3), velocity=0.77 m/s, shows no flow disturbance, but data is noisy, so it is no solid proof to rule out flow disturbance.
Plots (#4) is relatively un-noisy, since the velocity is higher (0.97 m/s). There might be a slight bend close to the top, but velocities from this run seem to be un-affected by flow disturbance, or very little affected.
We used larger bins on data collected 10 sept 2019, plot (#5) and (#6). There is less noise but start of data is further from the ADCP. Plot (#5), 0.47 m/s, shows a quite clear bias in the top bin, and it is larger than what we might expect from the gradients in the lake (indicated by the red lines). Plot (#6), 0.93 m/s, is not noisy and it shows very little flow disturbance.
Based on these test results it is not straight forward to determine if the StreamPro in the small trimaran generates flow disturbance or not. Plots (#2) and (#3), that is, small bins and relatively low velocities are too noisy to draw conclusions, and the bias in plot (#1) might be gradients in the lake. This means that we need to look closely at plots (#4, 5 and 6) to conclude. Two of these, (#4 and #6) at 0.97 m/s and 0.93 m/s, shows very little flow disturbance, while (#5) at 0.47 m/s shows flow disturbance with the same magnitude as RioGrande in trimaran.
This means that we cannot rule out flow disturbance from the StreamPro in the small trimaran, but yet, we do not lay any restrictions in the choice of extrapolation using this setup. This conclusion is founded both on these tests and on the tests and simulations by USGS/Mueller.

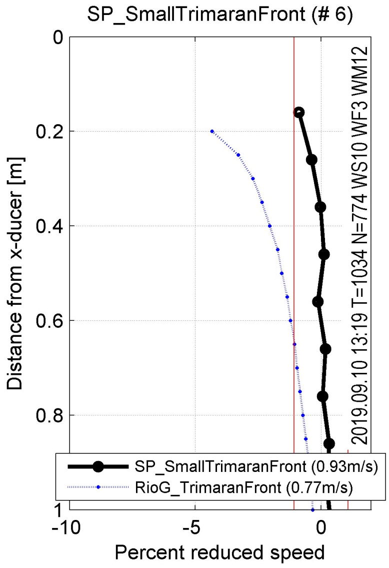

SP_SmallTrimaranFront (# 1)
Distance from x-ducer [m]
Percent reduced speed
SP_SmallTrimaranFront (0.12m/s)
RioG_TrimaranFront (0.35m/s)
2017.11.13 12:25 T=1014 N=262 WS5 WF3 WM13

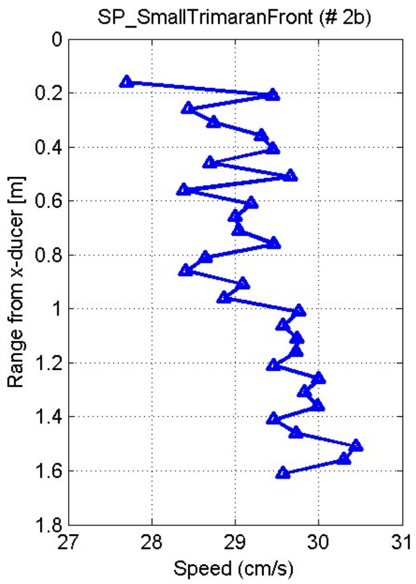

SP_SmallTrimaranFront (# 2)
Distance from x-ducer [m]
Percent reduced speed
SP_SmallTrimaranFront (0.30m/s)
RioG_TrimaranFront (0.35m/s)
2017.11.13 12:44 T=1434 N=594 WS5 WF3 WM12


SP_SmallTrimaranFront (# 3)
Distance from x-ducer [m]
Percent reduced speed
SP_SmallTrimaranFront (0.59m/s)
RioG_TrimaranFront (0.77m/s)
2017.11.13 13:08 T=804 N=587 WS5 WF3 WM12


SP_SmallTrimaranFront (# 4)
Distance from x-ducer [m]
Percent reduced speed
SP_SmallTrimaranFront (0.97m/s)
RioG_TrimaranFront (0.77m/s)
2017.11.13 13:48 T=1189 N=827 WS5 WF3 WM12


SP_SmallTrimaranFront (# 5)
Distance from x-ducer [m]
Percent reduced speed
SP_SmallTrimaranFront (0.47m/s)
RioG_TrimaranFront (0.35m/s)
2019.09.10 13:03 T=922 N=694 WS10 WF3 WM12


SP_SmallTrimaranFront (# 6)
Distance from x-ducer [m]
Percent reduced speed
SP_SmallTrimaranFront (0.93m/s)
RioG_TrimaranFront (0.77m/s)
2019.09.10 13:19 T=1034 N=774 WS10 WF3 WM12

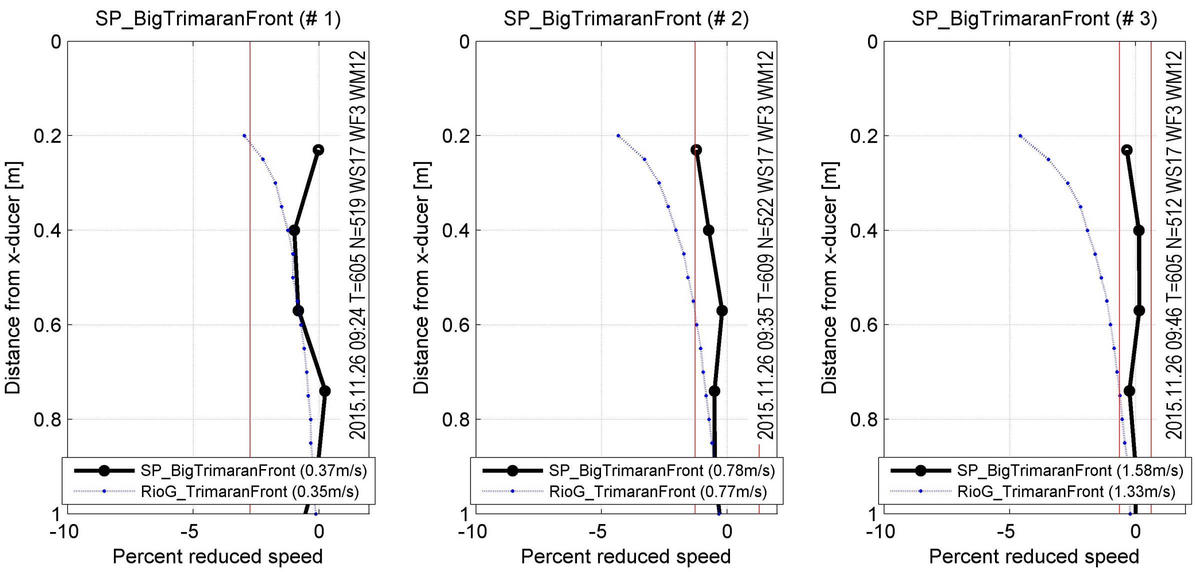

SP_SmallTrimaranFront (# 2b)
Range from x-ducer [m]
Speed (cm/s)

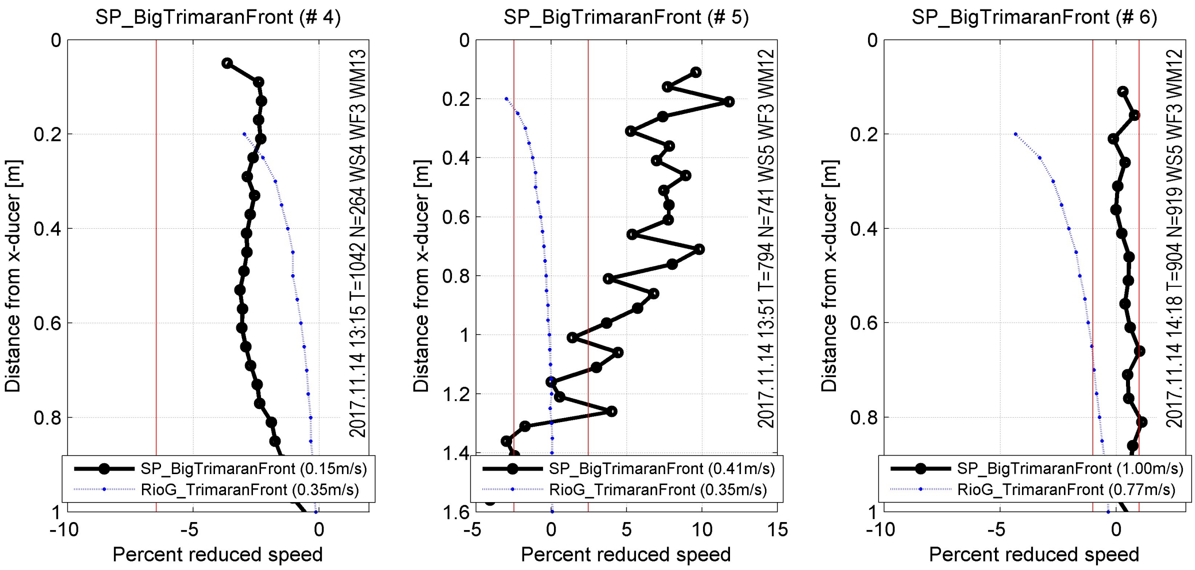
InstrAndMount	mRefVel	D=0,1	D=0,2	D=0,3	D=0,5
SP_SmallTrimaranFront	0,13m/s	-3,4 %	-2,3 %	-1,4 %	-0,3 %
SP_SmallTrimaranFront (*)	0,30m/s	NaN%	2,2 %	3,9 %	0,2 %
SP_SmallTrimaranFront (*)	0,59m/s	NaN%	1,9 %	0,3 %	1,2 %
SP_SmallTrimaranFront	0,97m/s	NaN%	-0,9 %	0,6 %	-0,1 %
SP_SmallTrimaranFront	0,47m/s	NaN%	-2,6 %	-1,4 %	-1,5 %
SP_SmallTrimaranFront	0,93m/s	NaN%	-0,7 %	-0,2 %	0,0 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values. (*) Disregard these

4.11 StreamPro (big trimaran, front)

The StreamPro in the big ("high speed") trimaran, attached to a 2 meters rod, in front of the manned boat.
We measured on several different days, but unfortunately, on some runs we used quite big bin sizes. This means that we did not measure close to the ADCP, even if data is way less noisy. Generally, there is little or no flow disturbance.
The gradient on plot (#4) with Reference velocity 0,15 m/s shows a trend, but this gradient is less than the measured velocity gradient in the lake. This means that the bend in the curve either shows flow disturbance or a gradient in the lake, and thus it is inconclusive.
Plot (#5), reference velocity 0,41 m/s, is strange. There must have been a velocity gradient in the lake at this reach at this time that we did not measure with the stationary ADCP or on the two other two runs.
The last plot, (#6), reference velocity 1 m/s, shows no flow disturbance.
The remaining plots (#1-3) with data from 26. Nov 2015 is less noisy due to larger bins. There might be a small sign of flow disturbance in (#2) but generally these plots don't indicate any problems.





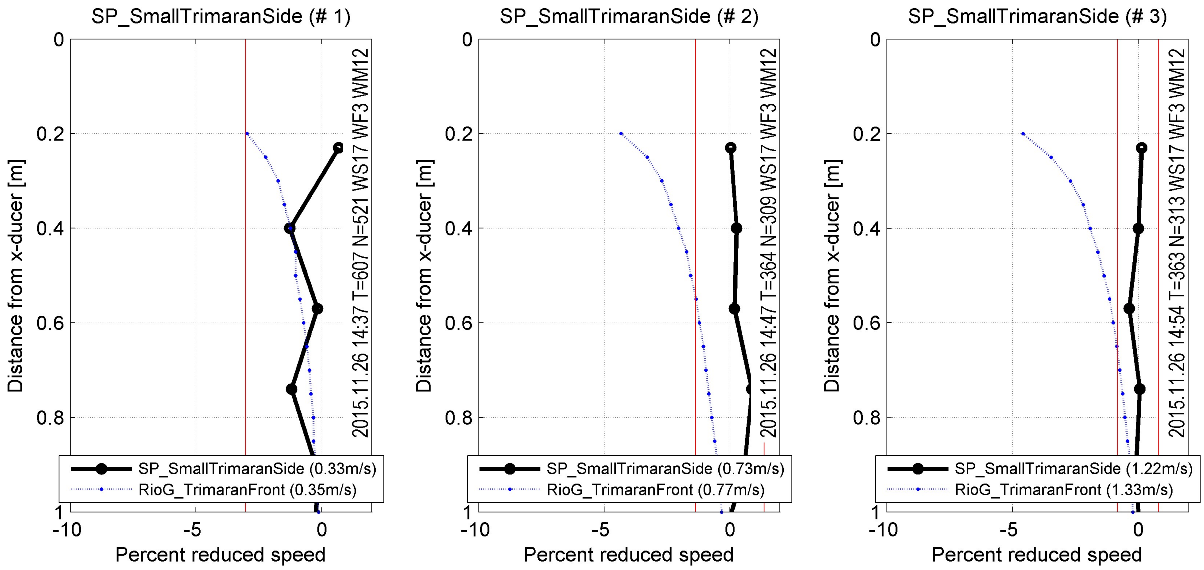
InstrAndMount	**mRefVel**	**D=0,1**	**D=0,2**	**D=0,3**	**D=0,5**
SP_BigTrimaranFront	0,15m/s	-1,8 %	-1,9 %	-2,3 %	-2,4 %
SP_BigTrimaranFront (*)	0,41m/s	NaN%	11,1 %	5,6 %	7,7 %
SP_BigTrimaranFront	1,00m/s	NaN%	0,0 %	0,1 %	0,5 %
SP_BigTrimaranFront	0,37m/s	NaN%	NaN%	-0,4 %	-0,9 %
SP_BigTrimaranFront	0,78m/s	NaN%	NaN%	-1,0 %	-0,4 %
SP_BigTrimaranFront	1,58m/s	NaN%	NaN%	-0,1 %	0,1 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

(*) Disregard this one

4.12 StreamPro (small trimaran, side)

The StreamPro mounted in the small, original trimaran, attached to the side of the manned boat. This is not a setup we use a lot. Unfortunately, we used quite big bin sizes. This means that we did not measure close to the ADCP, even if data is less noisy this way. There is no flow disturbance.

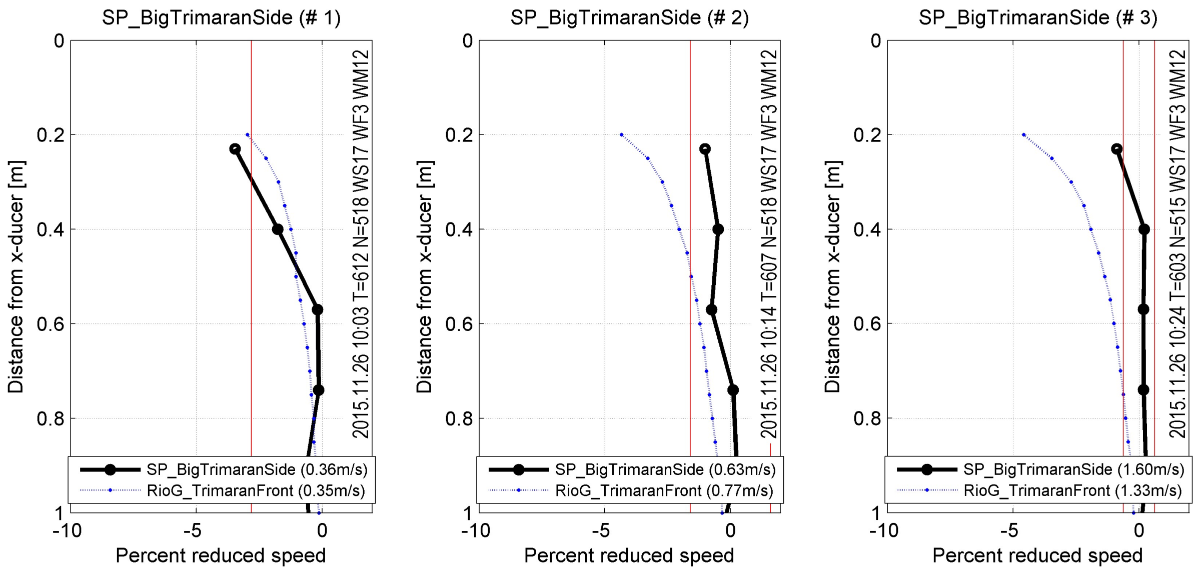


InstrAndMount	mRefVel	D=0,1	D=0,2	D=0,3	D=0,5
SP_SmallTrimaranSide	0,33m/s	NaN%	NaN%	-0,1 %	-0,6 %
SP_SmallTrimaranSide	0,73m/s	NaN%	NaN%	0,1 %	0,2 %
SP_SmallTrimaranSide	1,22m/s	NaN%	NaN%	0,1 %	-0,2 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

4.13 StreamPro (big trimaran, side)

The StreamPro mounted in the big (“high speed”) trimaran, attached to the side of the manned boat. This is not a setup we use a lot. Unfortunately, we used quite big bin sizes. This means that we did not measure close to the ADCP, even if data is less noisy this way. There is a little flow disturbance on low and high speed, but both are barely outside the bands indicating the velocity gradient in the lake.



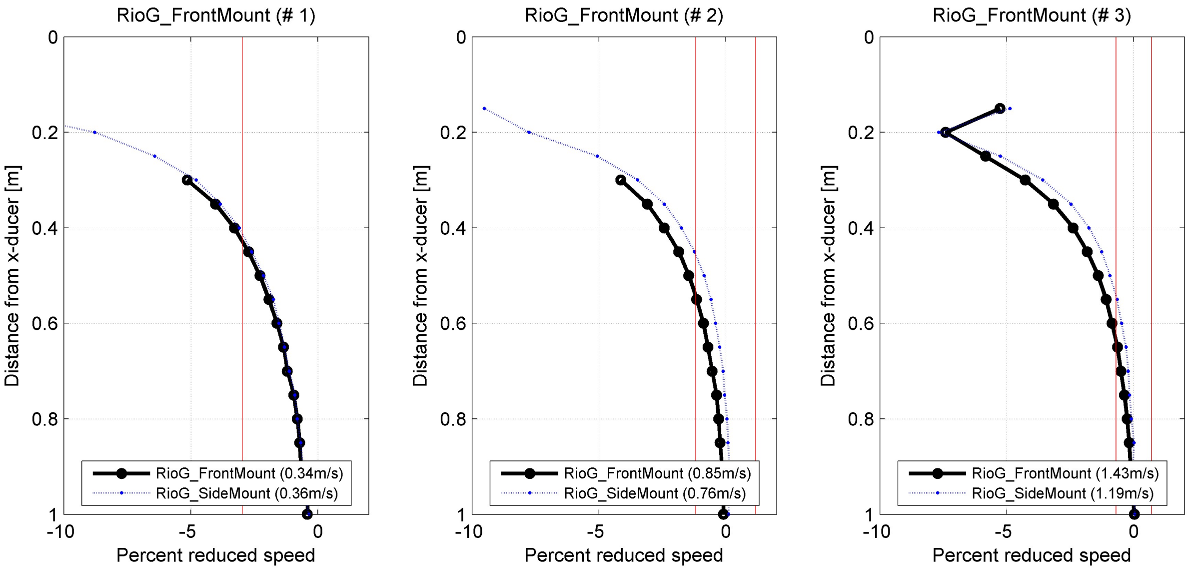
InstrAndMount	mRefVel	D=0,1	D=0,2	D=0,3	D=0,5
SP_BigTrimaranSide	0,36m/s	NaN%	NaN%	-2,8 %	-0,8 %
SP_BigTrimaranSide	0,63m/s	NaN%	NaN%	-0,8 %	-0,7 %
SP_BigTrimaranSide	1,60m/s	NaN%	NaN%	-0,4 %	0,2 %
RioG_TrimaranFront	*0,35 m/s*	*NaN%*	*-3,0 %*	*-1,7 %*	*-1,0 %*
RioG_TrimaranFront	*0,77 m/s*	*NaN%*	*-4,3 %*	*-2,7 %*	*-1,6 %*
RioG_TrimaranFront	*1,33 m/s*	*NaN%*	*-4,6 %*	*-2,7 %*	*-1,4 %*

Table for selected values

5 Additional comparsions

5.1 RioGrande: Side mount vs. front mount

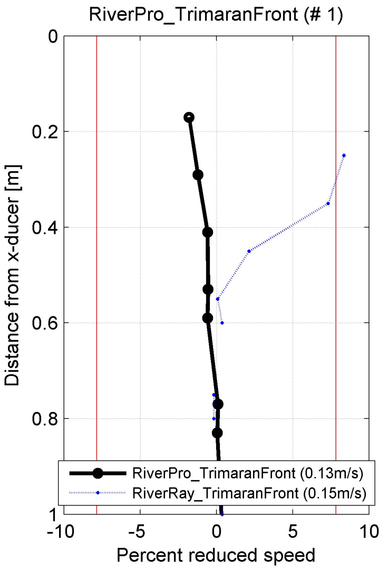
The plot below shows Rio Grande in the front mount (black) and the side mount (blue). For some reason which might be just by chance, there is slightly less flow disturbance when using side-mount than side-mount, but the general picture is that they are equally bad. This means that when using inflatable boats like NVE’s it probably does not matter if we use the front mount or the side mount.
These mounts must be avoided unless there is no other option.

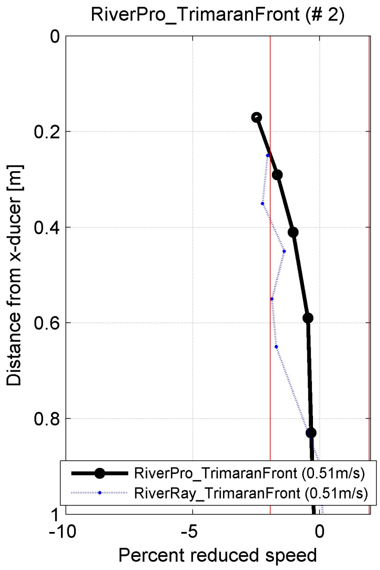


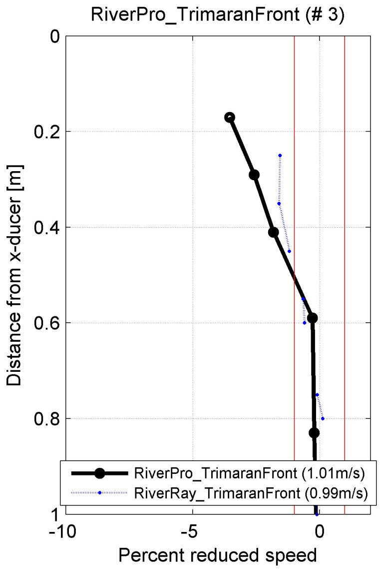
5.2 Trimaran, front: RiverPro vs RiverRay

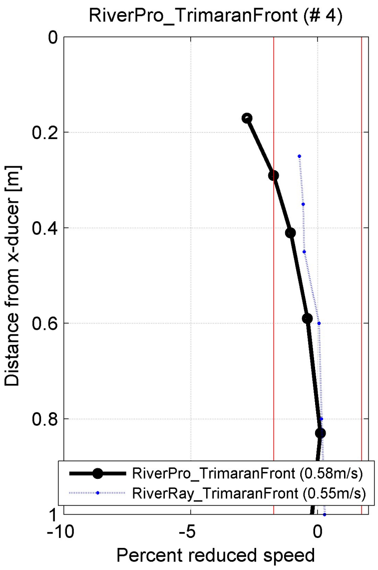
The plots below show RiverPro in trimaran versus RiverRay in identical trimarans. The instruments' housing has the same diameter, but the RiverRay has a flat transducer face and a phased array transducer, while the RiverPro has a 20 degrees convex transducer face with four piston transducers and one vertical transducer. This means that the only difference between them is the shape of the transducer face.

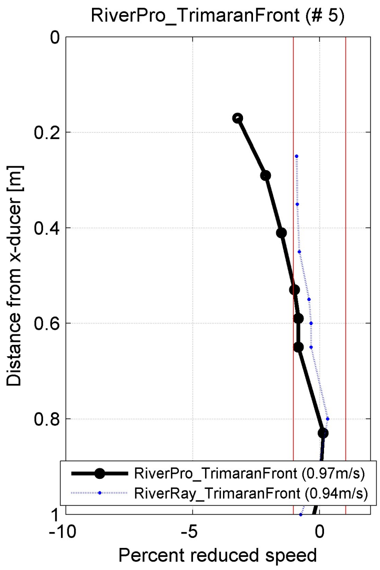
These measurements show that the RiverRay creates less flow disturbance than the RiverPro, and that the shape of the transducer face matters.





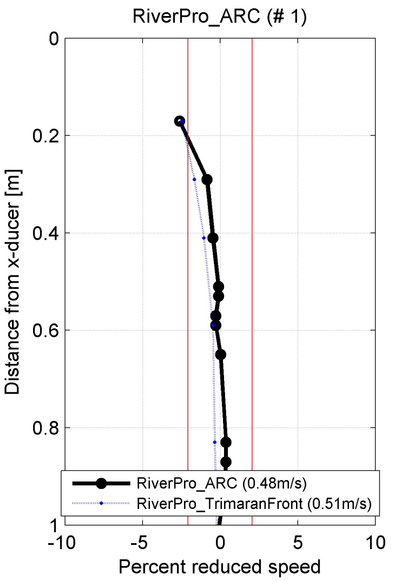


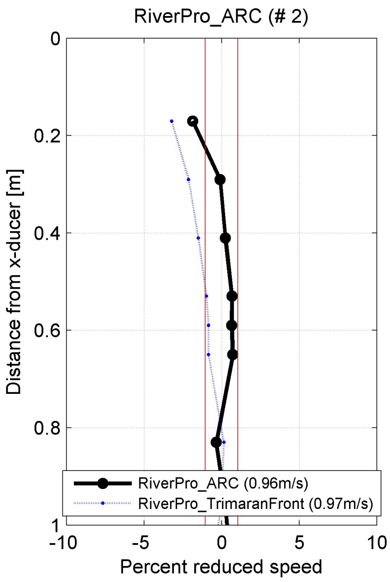




5.3 RiverPro: ARC boat vs trimaran

We use the RiverPro both in the original trimaran and in the ARC-boat, so we want to know how they compare. This comparison also shows the impact of two different vessels with the same instrument mounted in them. At medium speed, around 0.5 m/s, the two compare well, and there are very small differences. At higher speed (around 1 m/s) these tests indicate that the ARC boat generates slightly less flow disturbance than the original trimaran. This is a surprise since the hull of the ARC-boat is wider and sits deeper in the water than the trimaran.
In any case there is no very big differences between them. Neither create a big disturbance and both can be used if one take just a *little* care if the extrapolation software only vaguely shows constant or 3-point at the top.



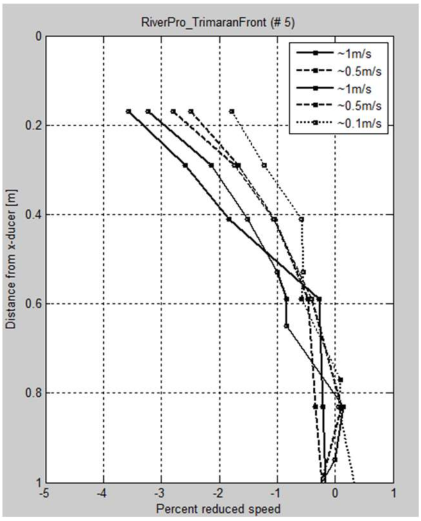


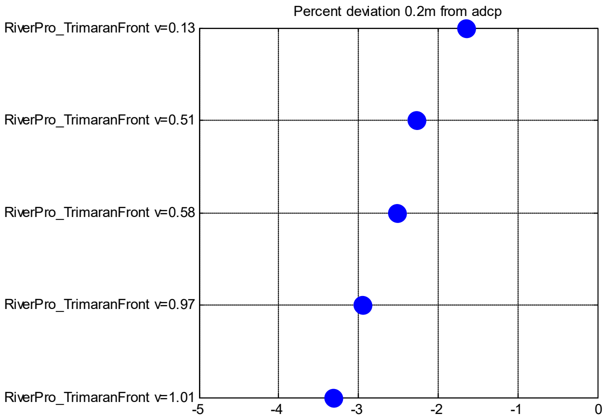
InstrAndMount	**mRefVel**	**D=0,1**	**D=0,2**	**D=0,3**	**D=0,5**
RiverPro_ARC	0,48m/s	NaN%	-2,1 %	-0,8 %	-0,1 %
RiverPro_ARC	0,96m/s	NaN%	-1,4 %	-0,1 %	0,6 %
RiverPro_TrimaranFront	*0,51m/s*	*NaN%*	*-2,3 %*	*-1,6 %*	*-0,8 %*
RiverPro_TrimaranFront	*0,97m/s*	*NaN%*	*-2,9 %*	*-2,1 %*	*-1,1 %*

Table for selected values

5.4 RiverPro (trimaran, front) vs speed

An interesting feature of this setup is that the flow disturbance worsens with speed.
This is not the case for the other instrument/mount combinations, and we have no explanation for this.
Data is consistent, even if it is collected over two different days.



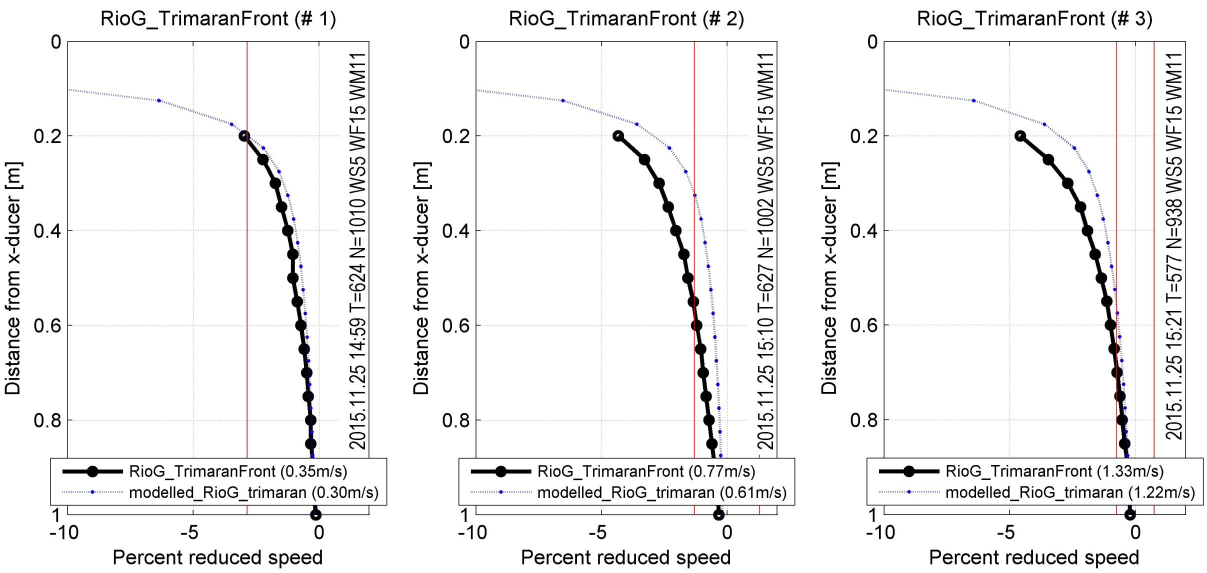


6 Modelled data

Mueller (2015) showed that velocities close to various ADCPs are biased, mainly through numerical modelling but also through field tests. Muller have shared data, and the following chapters show our data compared to his modelled data.

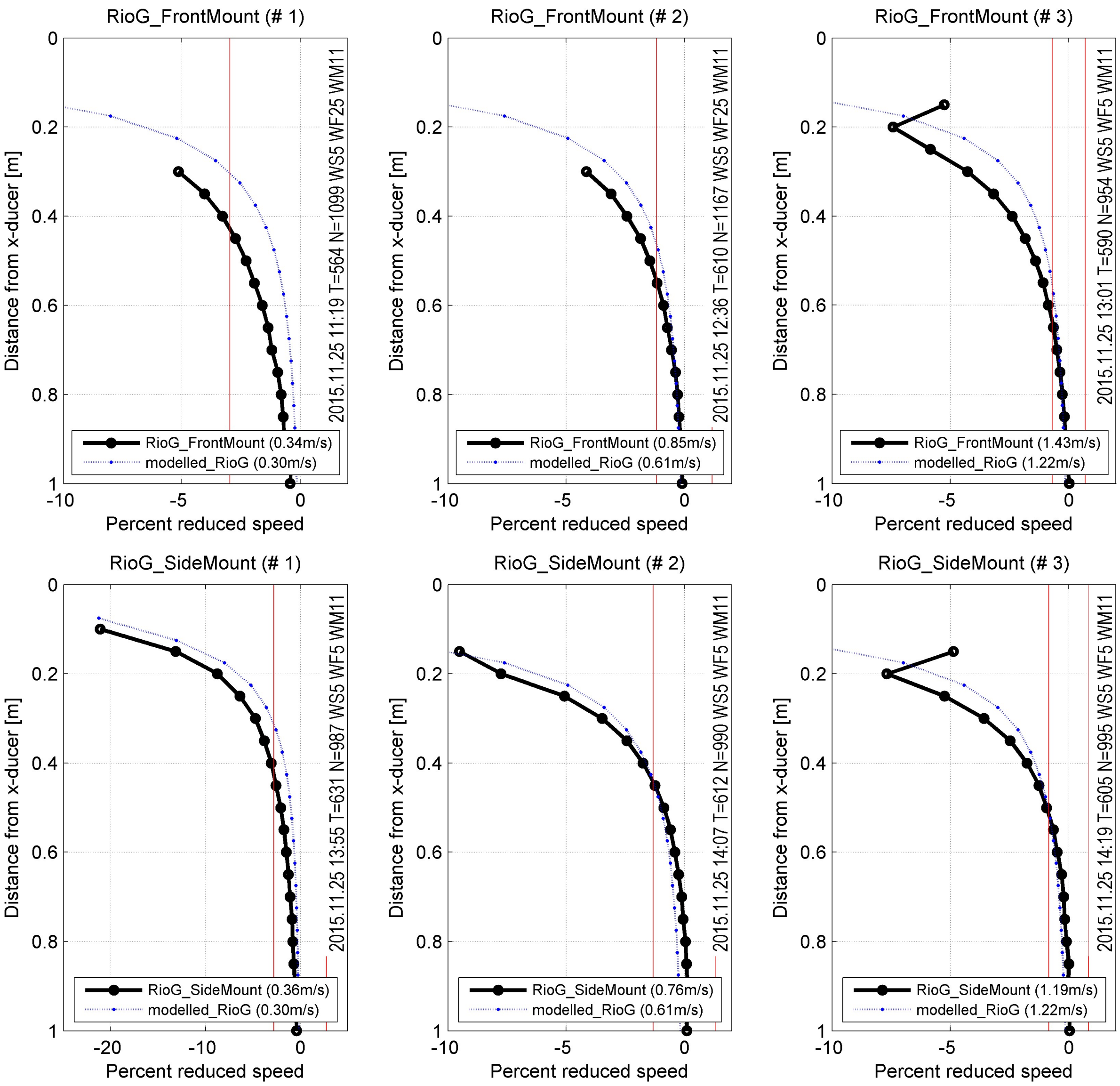
6.1 RioGrande (trimaran, front) measured vs modelled data

The modelled data show less or equal flow disturbance for the range of depths where we have measured data.



6.2 RioGrande (side- and front-mount), measured vs modelled data

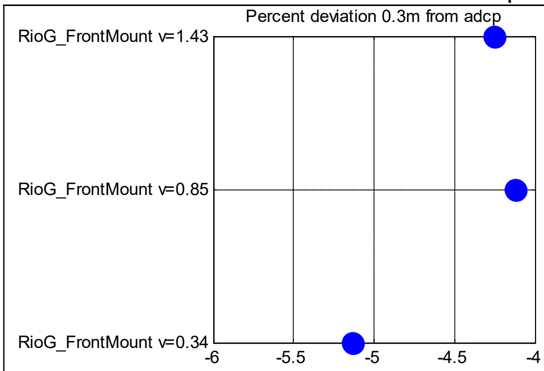
Mueller (2015) modelled flow disturbance for the RioGrande ADCP by itself. Our front- or side-mounts are not quite the same as a RioGrande by itself, see pictures in ch. 5.1. The ADCP is mounted in a clamp, and this clamp will probably affect the flow. In addition, the flow might be affected by the manned boat. Still, the setup is quite similar, so it is interesting to compare modelled and measured data. The modelled data show similar or less flow disturbance than the measured data.
Note that RioGrande in side-mount resembles modelled data more than RioGrande in front-mount. Front-mount and side-mount are compared in ch 5.1.



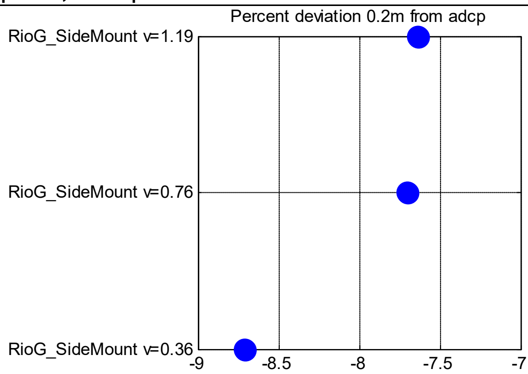
7 A matter of speed?

The plots below show mean flow disturbance versus speed for 20 or 30 cm distances from the ADCP, 20 cm if there is data, 30 cm if not. The plots are ordered (sorted) by reference speed (boat speed), with speed as marked along the y-axis. Data in the plots below are interpolated linearly to 10 cm increments.

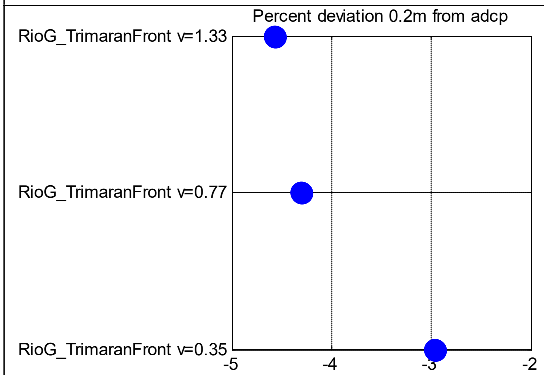
We see that flow disturbance does not depend on speed, except for RiverPro in trimaran.



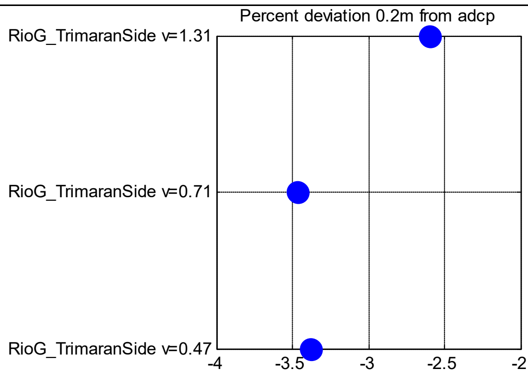
RioGrande, front mount.
Flow disturbance not depending on speed



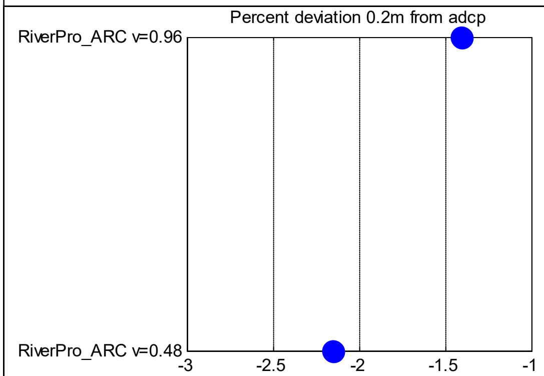
RioGrande, side mount
Flow disturbance not depending on speed



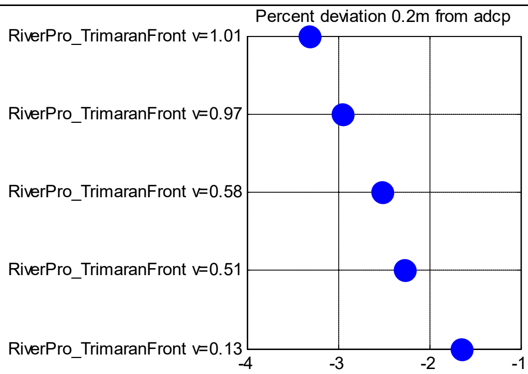
RioGrande, trimaran, front
Flow disturbance not depending on speed



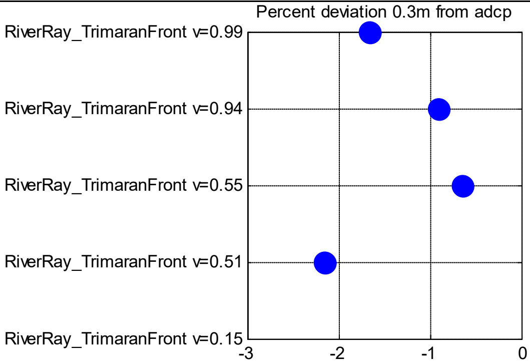
RioGrande, trimaran, side
Flow disturbance not depending on speed



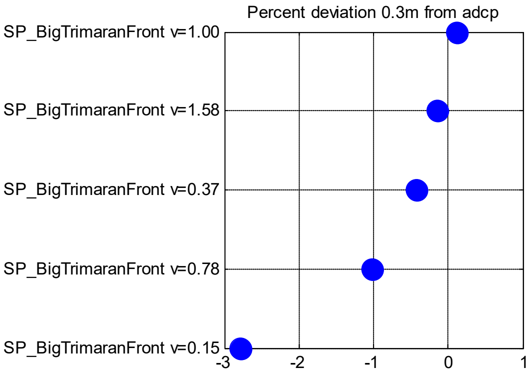
RiverPro, ARC boat
Flow disturbance decreasing with speed (not clear)



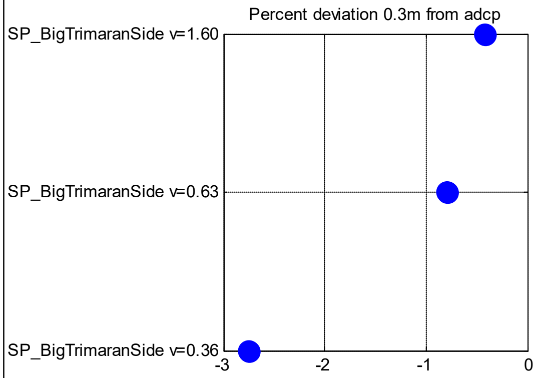
RiverPro, trimaran, front
Flow disturbance increasing with speed



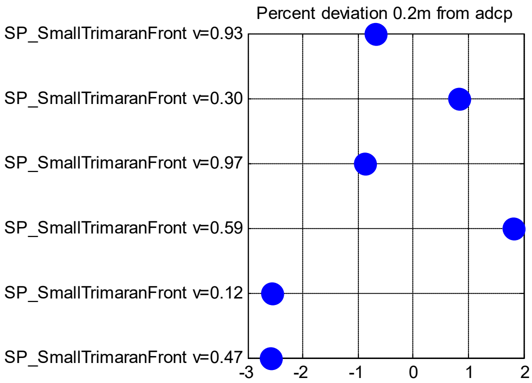
RiverRay, trimaran, front
Flow disturbance not depending on speed



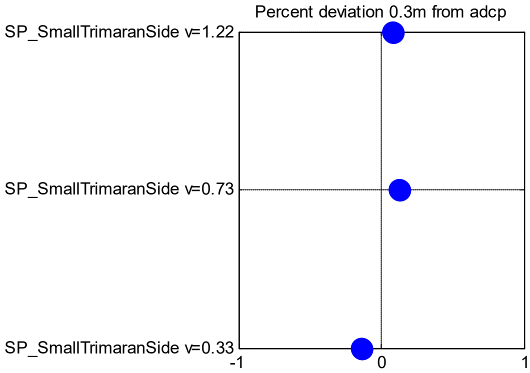
StreamPro, big trimaran, front
Flow disturbance not depending on speed



StreamPro, big trimaran, side
Flow disturbance not depending on speed



StreamPro, small trimaran, front
Flow disturbance not depending on speed

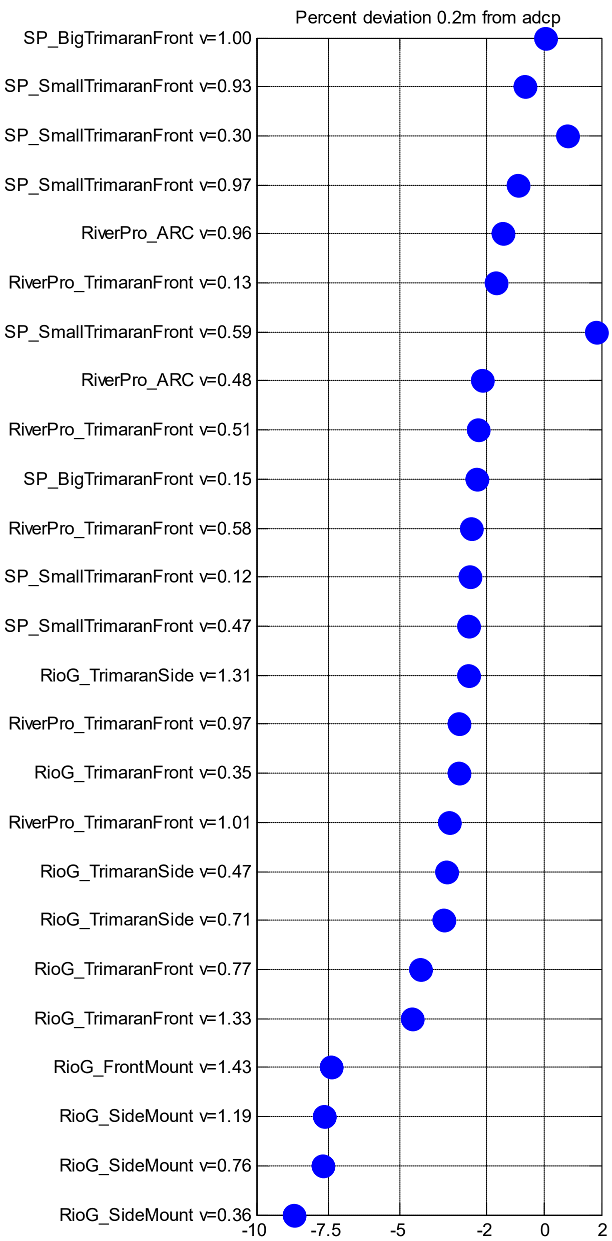


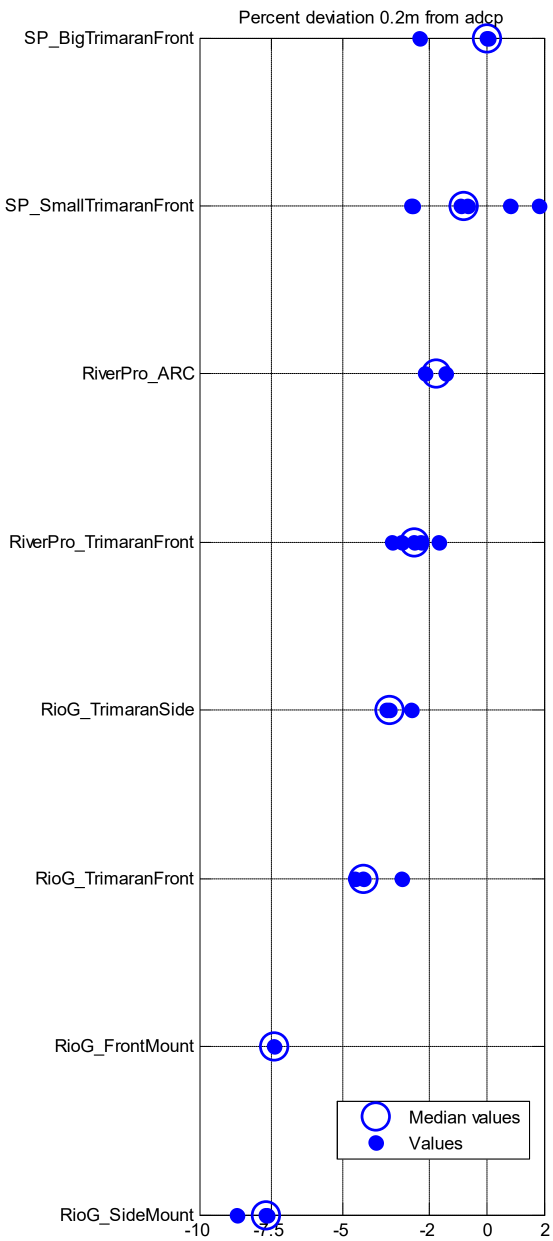
StreamPro, small trimaran, side
Flow disturbance not depending on speed

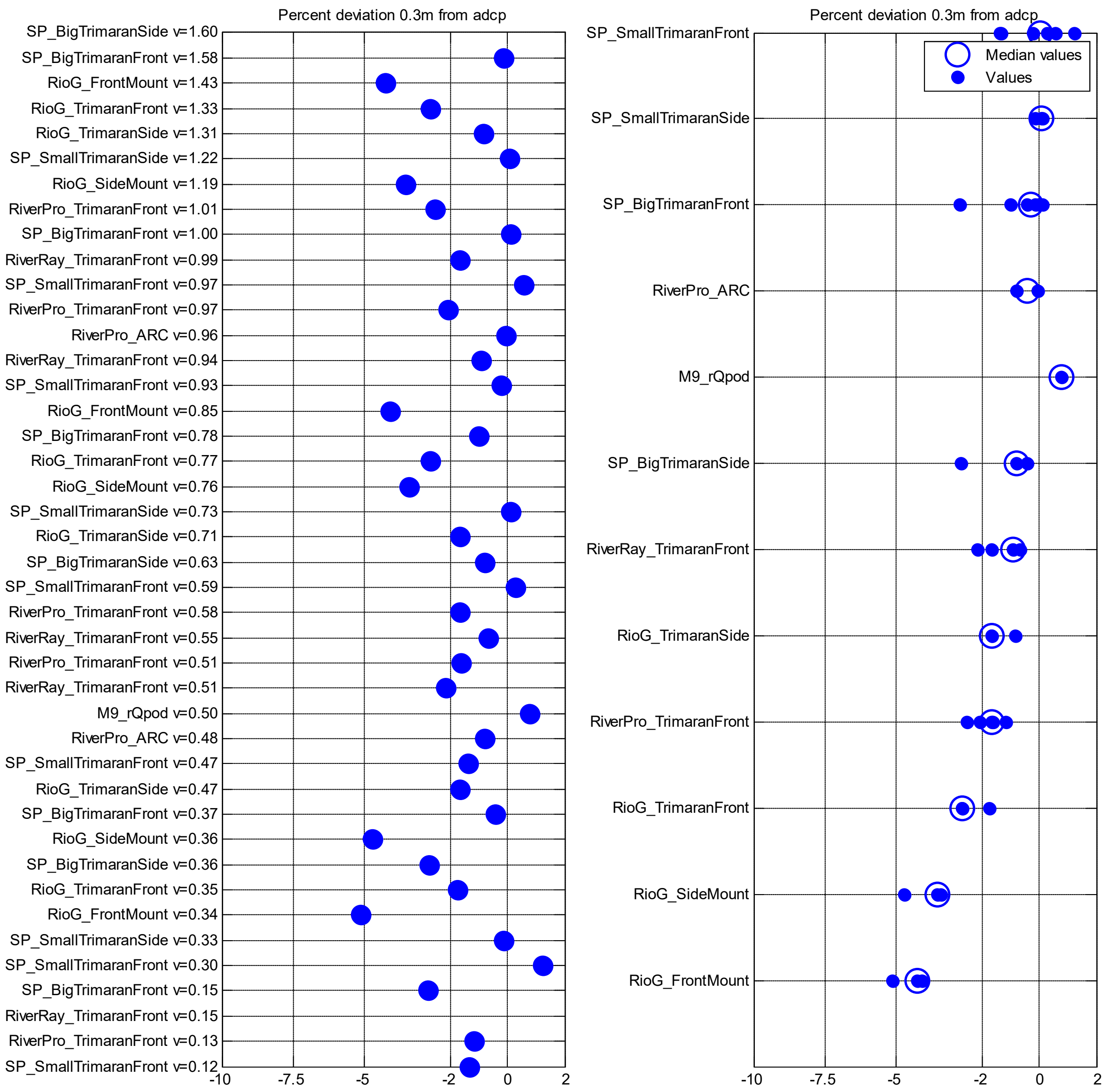
8 Summary

8.1 Summary, plots

The first two pairs of plots below show mean flow disturbance for the different instruments, like the data presented in the previous chapters, but interpolated to 20 and 30 cm distances from the ADCPs. The left-hand side plots show the individual instrument & velocity combinations. The right-hand side plots show median of these mean values for each instrument (circles) and also the same values as in the left-hand side plot (small dots).
They are ordered by the mean values' median distance from zero for each instrument.
The first pair of plots show values 20 cm from the ADCP, the second show the values 30 cm from the ADCP.
We observe that using this rating, StreamPro in small or large trimaran, and RiverPro in ARC boat, occupy the top-three rating both 20 and 30 cm from the ADCP.



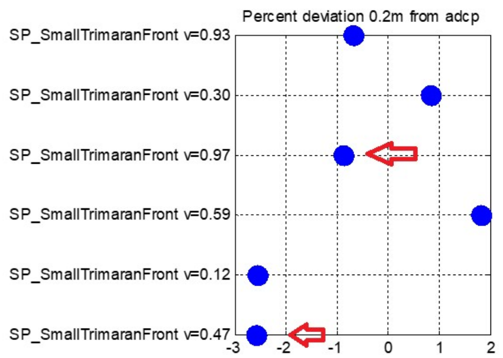


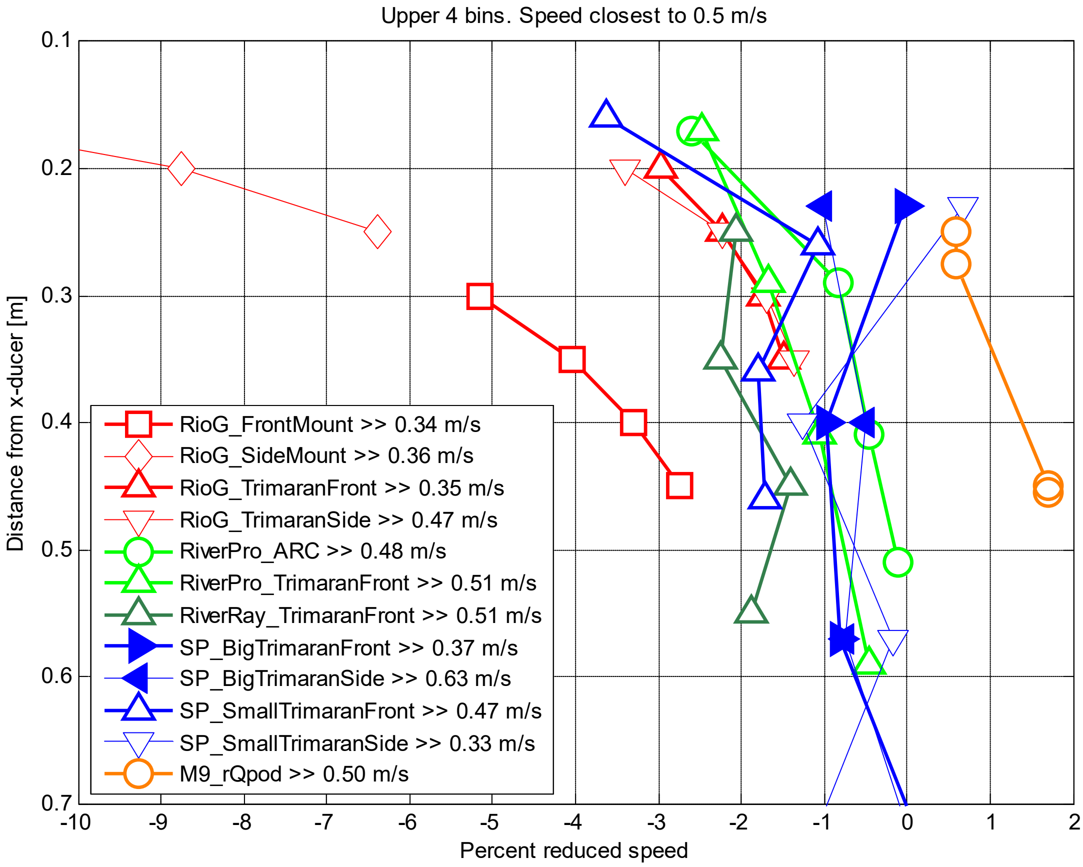

Percent deviation 0.3m from adcp
SP_BigTrimaranSide v=1.60
SP_BigTrimaranFront v=1.58
RioG_FrontMount v=1.43
RioG_TrimaranFront v=1.33
RioG_TrimaranSide v=1.31
SP_SmallTrimaranSide v=1.22
RioG_SideMount v=1.19
RiverPro_TrimaranFront v=1.01
SP_BigTrimaranFront v=1.00
RiverRay_TrimaranFront v=0.99
SP_SmallTrimaranFront v=0.97
RiverPro_TrimaranFront v=0.97
RiverPro_ARC v=0.96
RiverRay_TrimaranFront v=0.94
SP_SmallTrimaranFront v=0.93
RioG_FrontMount v=0.85
SP_BigTrimaranFront v=0.78
RioG_TrimaranFront v=0.77
RioG_SideMount v=0.76
SP_SmallTrimaranSide v=0.73
RioG_TrimaranSide v=0.71
SP_BigTrimaranSide v=0.63
SP_SmallTrimaranFront v=0.59
RiverPro_TrimaranFront v=0.58
RiverRay_TrimaranFront v=0.55
RiverPro_TrimaranFront v=0.51
RiverRay_TrimaranFront v=0.51
M9_rQpod v=0.50
RiverPro_ARC v=0.48
SP_SmallTrimaranFront v=0.47
RioG_TrimaranSide v=0.47
SP_BigTrimaranFront v=0.37
RioG_SideMount v=0.36
SP_BigTrimaranSide v=0.36
RioG_TrimaranFront v=0.35
RioG_FrontMount v=0.34
SP_SmallTrimaranSide v=0.33
SP_SmallTrimaranFront v=0.30
SP_BigTrimaranFront v=0.15
RiverRay_TrimaranFront v=0.15
RiverPro_TrimaranFront v=0.13
SP_SmallTrimaranFront v=0.12
-10
-7.5
-5
-2
0
2
Percent deviation 0.3m from adcp
Median values
Values
SP_SmallTrimaranFront
SP_SmallTrimaranSide
SP_BigTrimaranFront
RiverPro_ARC
M9_rQpod
SP_BigTrimaranSide
RiverRay_TrimaranFront
RioG_TrimaranSide
RiverPro_TrimaranFront
RioG_TrimaranFront
RioG_SideMount
RioG_FrontMount
-10
-7.5
-5
-2
0
2

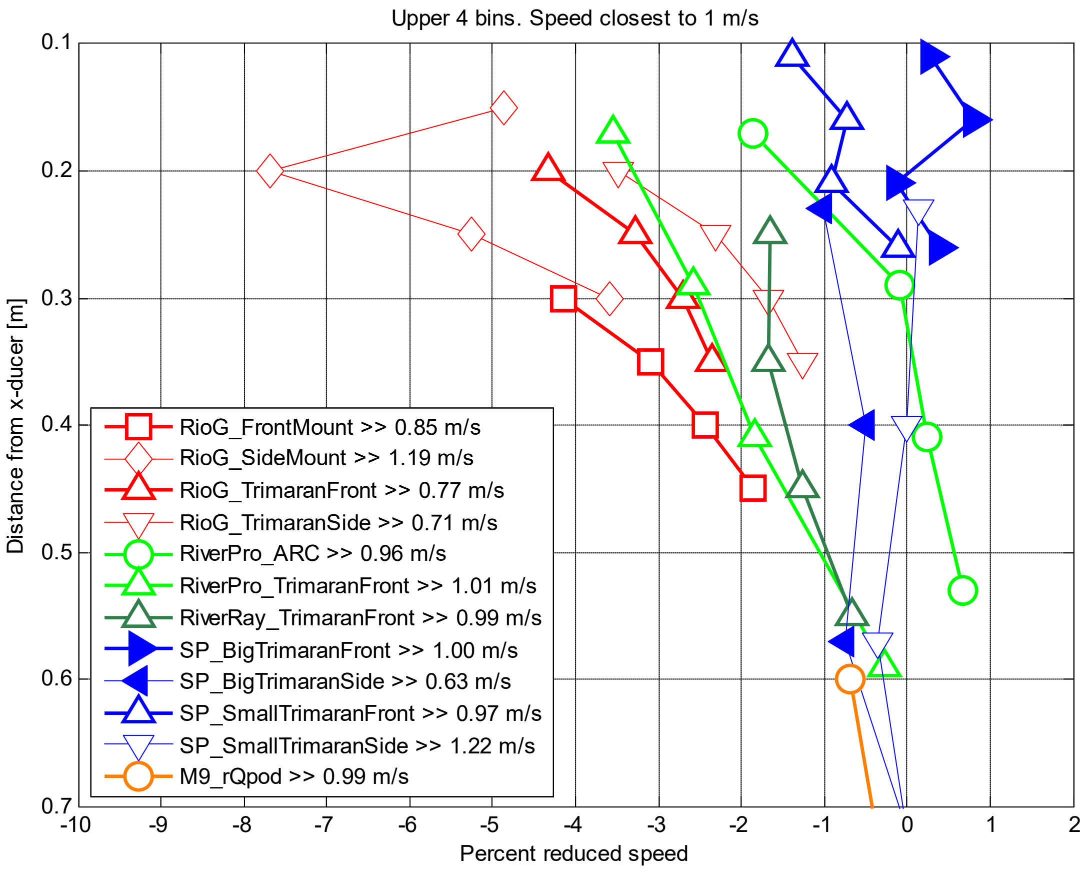
The following two plots show the actual values for the top 4 bins for all instruments. The first of these plots shows values for the runs closest to 0.5 m/s and the second of them shows the values for the runs closest to 1 m/s.
There are a lot of colors and markers on these plots, but there is a system to the chaos:

- Triangles = Trimaran. (SP big trimaran is filled, SP small trimaran is open)
- Circles = Remote controlled boats.
- Squares = Fixed mounts
- Thin line = Beside manned boat.
- Thick line = Not beside manned boat (Remote controlled or in front of manned boat)
- Colors = Different instruments

These plots show that there is not a lot of difference between tests at ~0,5 m/s and tests at ~1,0 m/s. The exceptions are RiverPro in trimaran which display way more flow disturbance at the higher speed, and StreamPro, small trimaran, front that seems to have more flow disturbance at low speeds.
For the StreamPro, this seems to be a random variation. Below is a copy of the plot in ch 0, where the data points from the plots below are highlighted.




Upper 4 bins. Speed closest to 0.5 m/s
Distance from x-ducer [m]
Percent reduced speed
RioG_FrontMount >> 0.34 m/s
RioG_SideMount >> 0.36 m/s
RioG_TrimaranFront >> 0.35 m/s
RioG_TrimaranSide >> 0.47 m/s
RiverPro_ARC >> 0.48 m/s
RiverPro_TrimaranFront >> 0.51 m/s
RiverRay_TrimaranFront >> 0.51 m/s
SP_BigTrimaranFront >> 0.37 m/s
SP_BigTrimaranSide >> 0.63 m/s
SP_SmallTrimaranFront >> 0.47 m/s
SP_SmallTrimaranSide >> 0.33 m/s
M9_rQpod >> 0.50 m/s


Upper 4 bins. Speed closest to 1 m/s
Distance from x-ducer [m]
Percent reduced speed
RioG_FrontMount >> 0.85 m/s
RioG_SideMount >> 1.19 m/s
RioG_TrimaranFront >> 0.77 m/s
RioG_TrimaranSide >> 0.71 m/s
RiverPro_ARC >> 0.96 m/s
RiverPro_TrimaranFront >> 1.01 m/s
RiverRay_TrimaranFront >> 0.99 m/s
SP_BigTrimaranFront >> 1.00 m/s
SP_BigTrimaranSide >> 0.63 m/s
SP_SmallTrimaranFront >> 0.97 m/s
SP_SmallTrimaranSide >> 1.22 m/s
M9_rQpod >> 0.99 m/s

8.2 Summary, table

The table below summarizes these measurements by showing the median flow disturbance in percent 20 and 30 cm from the ADCP. If the instrument did not collect data at distances 20 or 30 cm, data is interpolated linearly.
The color coding indicates the level of potential impact on flow around the ADCP, and also, the level of problems one will run into while choosing the correct top extrapolation in post processing

- 0-1 % is green, meaning no problem
- 1-2 % is yellow, meaning possibly a problem.
- 2-5 % is orange, meaning be careful.
- 5 % and more is red, meaning avoid use.

The text in the last column summarizes the recommendations.

Instrument/mount	Flow disturbance at 20 cm	Flow disturbance at 30 cm	Text
SP_SmallTrimaranFront	-0,77	0,02	No caution
SP_SmallTrimaranSide		0,08	No caution
SP_BigTrimaranFront	0,00	-0,28	No caution
SP_BigTrimaranSide		-0,79	No caution
RiverPro_ARC	-1,78	-0,43	We can use this setup to collect data. In postprocessing, if in doubt, choose power extrapolation at top and not constant or 3-point.
RiverRay_TrimaranFront		-0,90	No caution as long as data is collected 25 cm from ADCP (default setup)
M9_rQpod		1,04	We can use this setup to collect data. Based on these tests we can use data collected 25 cm or more from the ADCP. Based on USGS/Mueller there is flow disturbance down to 16 cm. When deciding top extrapolation, do not use data closer to the ADCP than 16 cm.
RiverPro_TrimaranFront	-2,52	-1,68	We can use this setup to collect data. In postprocessing, if in doubt, choose power extrapolation at top and not constant or 3-point.
RioG_TrimaranSide	-3,38	-1,67	We can use this setup to collect data. In postprocessing, data shall be very clear to choose constant or 3-point extrapolation at the top.
RioG_TrimaranFront	-4,31	-2,69	We can use this setup to collect data. In postprocessing, data shall be very clear to choose constant or 3-point extrapolation at the top.
RioG_SideMount	-7,70	-3,56	Do not use this setup to collect data unless there is no other choice. In postprocessing, do not choose constant or 3-point extrapolation at the top.
RioG_FrontMount	-7,39	-4,25	Do not use this setup to collect data unless there is no other choice. In postprocessing, do not choose constant or 3-point extrapolation at the top.

9 Improvements for future continued testing

- Measure as close to the ADCP as possible. Use fixed WT mode/bin size if possible. If not, pay close attention to data while measuring for ADCPs that change bin size etc. depending on depth and speed.
- If possible, review data using the Matlab scripts on site, to find out if data is too noisy.
- For M9: Pay close attention to beam separation. This partially ruined the measurements so far.
- Abort measurements if vegetation is present. In Steinsfjorden where we measured there are areas with Elodea canadensis (American waterweed, “vasspest” in Norwegian). This is a freshwater grass that can be several meters long. It is possible to collect data in areas with waterweed, but data gets very noisy.
- Take notes or use GPS track to document the approximate locations. Don’t rely on memory.

10 Observations and discussion

A question raised in the start of this report was if data collected with an ADCP in a trimaran attached to a two-meters pole in front of the manned boat is affected by flow disturbance from the manned boat. There is one indication that it might be so: The RioGrande in trimaran display less flow disturbance beside the manned boat than in front. We need further testing if we want to answer this issue.

There are two observations that is worth to highlight.
The first is that the flow disturbance (in percent) is not affected by speed.
The second is that it seems like the ARC boat generates less flow disturbance than the RiverRay/RiverPro trimaran. The ARC boat is bigger than the trimaran, but the bigger monohull seems to disturb flow less than the 3 smaller hulls of the trimaran.

The testing of instruments on a calm lake has worked quite well but there are some pitfalls and problems.
First of all, since this is nature, it is not very often we can expect the lake to be completely calm. We need a long period of no or little wind, and no runoff into the lake. Unfortunately, for the lake in question, these periods often occur late in the autumn, and a couple of times the lake froze before we could do testing.
Also, the lake needs to be rather big, since the instruments needs long runs to average out noise. In particular the StreamPro. We drive in (somewhat) straight lines to avoid measuring in our own wake, and a 600 second's average at 1 m/s need 600 meters of lake.
It is important to measure if the water is still, and not to rely on surface appearance. We anchor one ADCP to measure this for a long time, and on some days, several times during the test day. We had to discard an entire day's work after looking at data from the anchored ADCP, since there were too high velocity gradients in the lake.
When testing instruments, it is important to measure as close to the ADCP as possible. Even if this means noisy data. Noise can be overcome by longer averaging. And it is an advantage to lock the instrument setup or to pay closer attention than we did on some tests to see if bin size or water mode changes due to varying depth in the lake. This, and problems with beam separation (air bubbles on the transducer face) partially ruined our M9 test. Also, whenever it is possible to fix the bin size and you want small bins, do so.
We will probably keep testing instruments like this, since it is a low-cost test compared to laboratories, and since it mainly gives results we trust in.

11 Conclusion

Based on observations and visual, subjective inspection, all instruments/mounts are approved and can be used operationally by NVE, except RioGrande ADCP in side-mount or front-mount. The StreamPro in trimaran is the instrument/mount that creates less flow disturbance.
RioGrande ADCP in side-mount or front-mount can still be used if no other options are available, but it is strongly recommended to only use pwr/pwr extrapolation in post processing.
See details in table in ch 8.2 (Summary, table).
The M9 needs to be tested once more. Until then, the advice for NVE is to follow the USGS recommendation to not use data closer to the transducer than 16 cm. If forced to use data closer than 16 cm, the main rule shall be to use pwr/pwr extrapolation.

12 References

David S. Mueller (2015) *Velocity bias induced by flow patterns around ADCPs and associated deployment platforms*, DOI 10.1109/CWTM.2015.7098103 (https://pubs.er.usgs.gov/publication/70155866)

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