2 Campaign log

2.1 Team

The campaign took place between April 1 and 2, 2025 with the following people:

- Jean-Charles Sausserau (iTECH-Drone, UAV pilot)
- Mahé Liard (iTECH-Drone, UAV pilot)

2.2 Super-sites

The campaign covered 5 super-sites over the Po and the Tiber rivers:

- Po River
  - Casale Monferrato/Pontestura super-site
  - Isola-Pescaroli super-site
- Tiber River
  - Pierantonio / Umbertide super-site
  - Deruta super-site
  - Santa-Lucia super-site

Figure 1 and Figure 2 show the flight plan over the Po River and the Tiber River, respectively.

Isola-Pescaroli super site

Pontestura super site

Figure 1: Flight plan of the campaign on Po River.

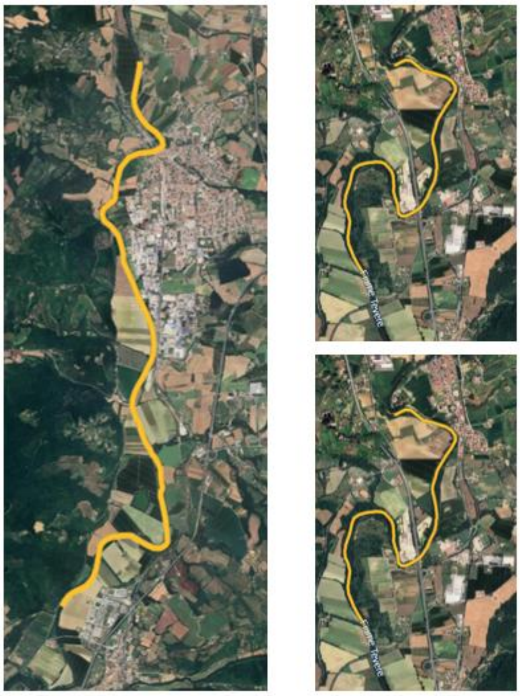

Figure 2: Flight plan of the campaign on Tiber River.

2.3 Instruments

Below is the list of drones and equipment used during the campaign:

- 2 DJI M350 (No. 564 & No. 795).
- 2 DJI BS60/65 battery charging stations
- 4 LiPO 8000 mAh batteries (Tatou) for long-term power supply to the Septentrio head
- GNSS antenna mount (on the M350)
- Screws required for the antenna.
- Ecoflow charging station

Regarding GNSS stations and accessories, we used:

- 1 Septentrio Galileo GNSS station.
- 2 Sensors "VTX-2".
- GNSS antenna

The Matrice 350 RTK boasts a robust design, powerful propulsion, good protection rating, and excellent flight performance in harsh environments. The aircraft and remote controller feature a four-antenna transceiver system that intelligently selects the two optimal antennas for signal transmission, with all four antennas receiving signals simultaneously. This significantly improves anti-interference capabilities and optimizes transmission stability. The drone and its radio have an IP54 protection rating. The operating temperature range allows for flight in extremely hot or cold environments.

It is equipped with the VTX-2 sensor from vorteX-io. This lidar sensor was designed on a DJI gimbal that allows SDK connection with the drone, allowing full control of the sensor through the drone's control interface.

3 Sensor performance analysis

3.1 Base positioning

To obtain high-quality positioning for drone flights, GNSS base station measurements are needed to perform PPK (Post-Processing Kinematic). The better the quality of the base station positioning, the more accurate the altimeter positioning will be.

3.1.1 Po River campaign

During this day, we used two base measurements as a reference. One for each super-site because of the distance between the two sites (145 km). The two base positions are very good with an STD around 1 mm and more than 15 satellites tracked (Figure 3).

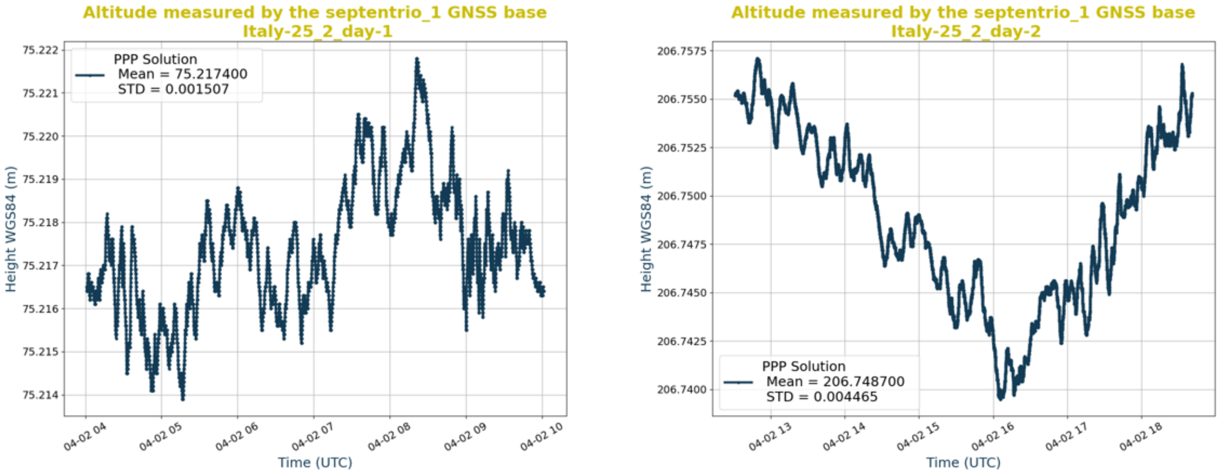

Figure 3: Altitude measured by the GNSS base during the 2 days of Po campaign.

3.1.2 Tiber River campaign

We obtained an excellent position for this base for the deployment day, with a standard deviation under a millimeter, with a mean of 18 satellites observed (Figure 4 and Figure 5).

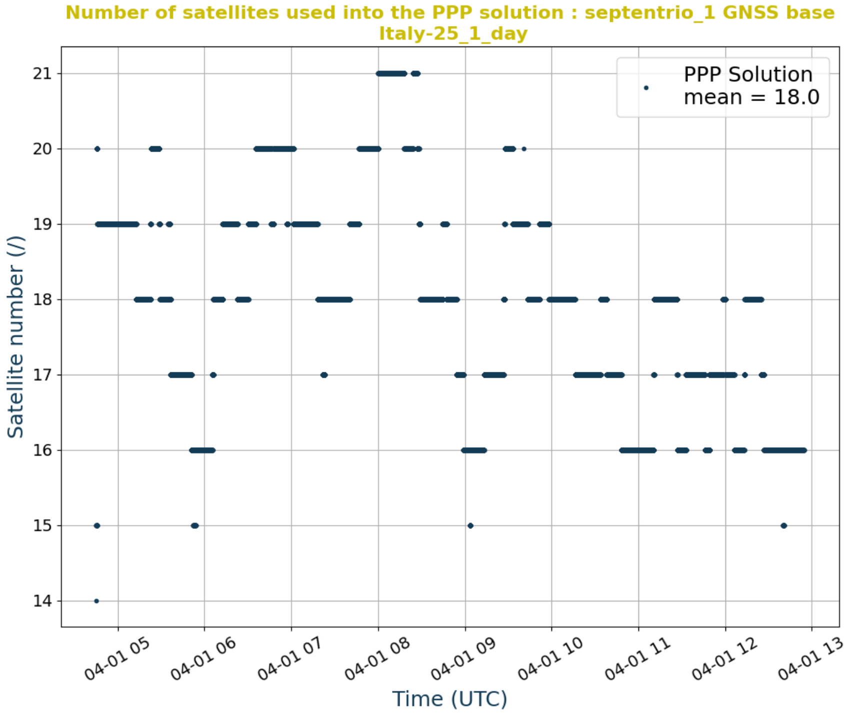

Figure 4: Number of satellites used in PPP solution on Tiber campaign.

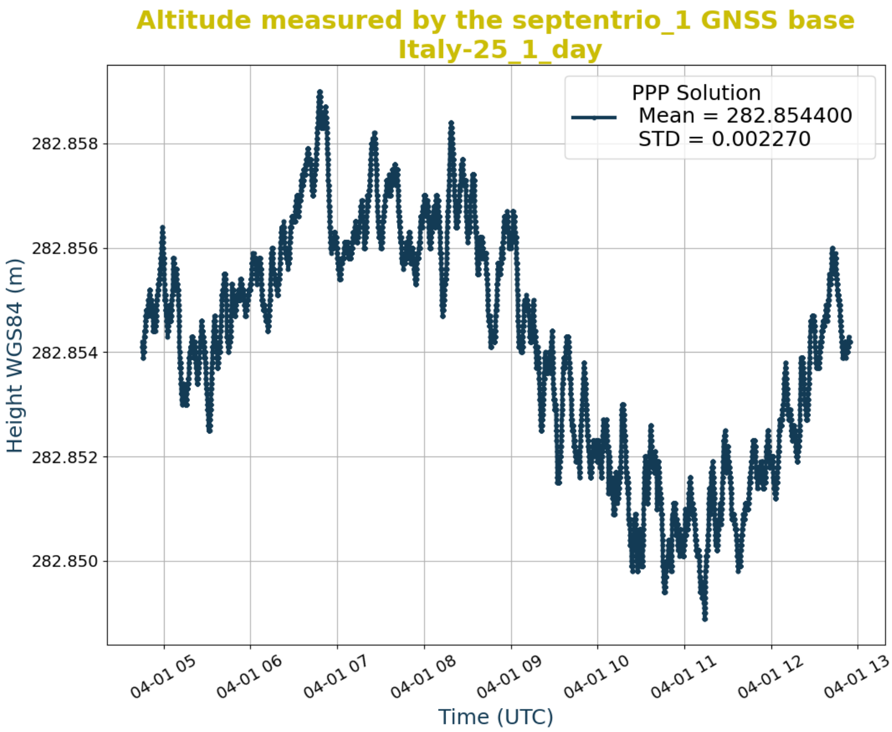

Figure 5: Altitude measured by the GNSS base on Tiber campaign.

3.2 Altimeter positioning

3.2.1 Po River campaign

3.2.1.1 Pontestura / Casale Monferrato super-site

On flight 139 on Pontestura super-site, we observe a very strong variability with an amplitude of approximately 60 cm in the GNSS solution, which does not reflect the altimeter displacement (Figure 6).

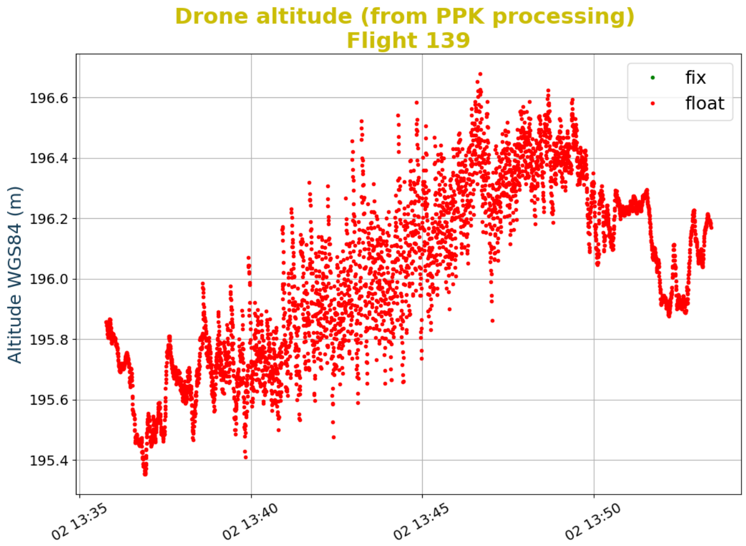

Figure 6: Drone altitude from PPK processing of flight 139.

For all the flights (from 139 to 144), the ambiguities are not fixed. The GNSS solution we obtain is not optimal and can generate height bias.

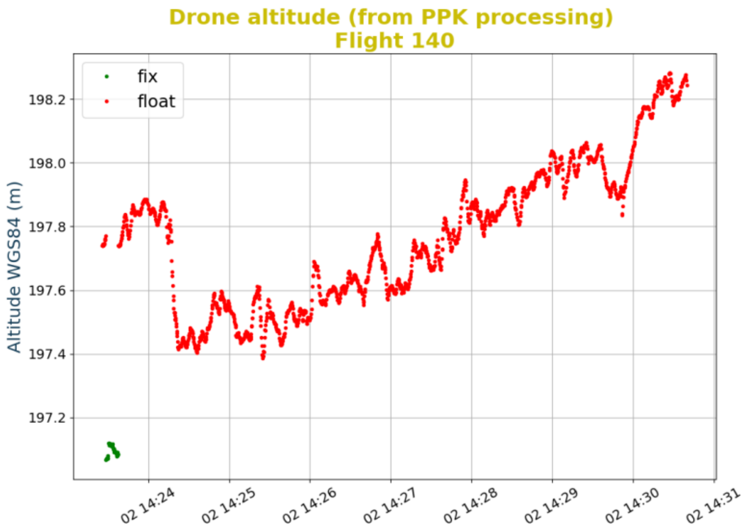

Figure 7: Drone altitude from PPK processing of flight 140.

Figure 8 shows in detail the position of flight 139 in Pontestura. Strong variability is observed in the middle of the flight, making real signal extraction impossible due to a low signal-to-noise ratio (SNR). This noise seems to be lower at the beginning and at the end of the flight positioning. The cause of this result is currently unknown. This behaviour has not been observed in GNSS solutions before the Italy campaign.

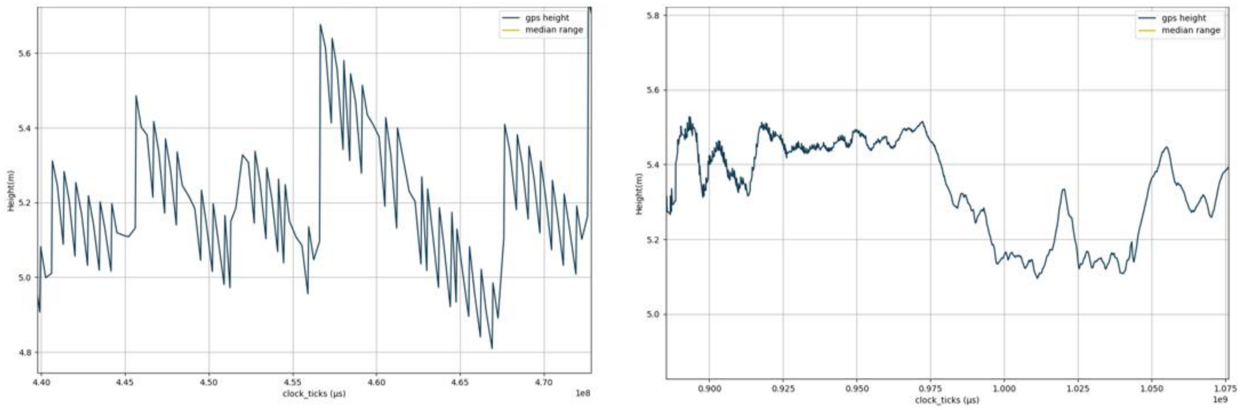

Figure 8: Altimeter positioning of flight 139 in Pontestura super-site.

The two other flights (140 and 144) over Pontestura are also affected, but with a significantly different magnitude (Figure 9). For these flights, we can extract the actual signal thanks to a higher SNR. We observe a similar pattern at the beginning and end of the flights, which appear cleaner. This may be due to a Kalman filtering effect from GNSS positioning or suboptimal GNSS measurement acquisition, which could lead to these poor solutions. Validating water height consistency between flights may provide further insights.

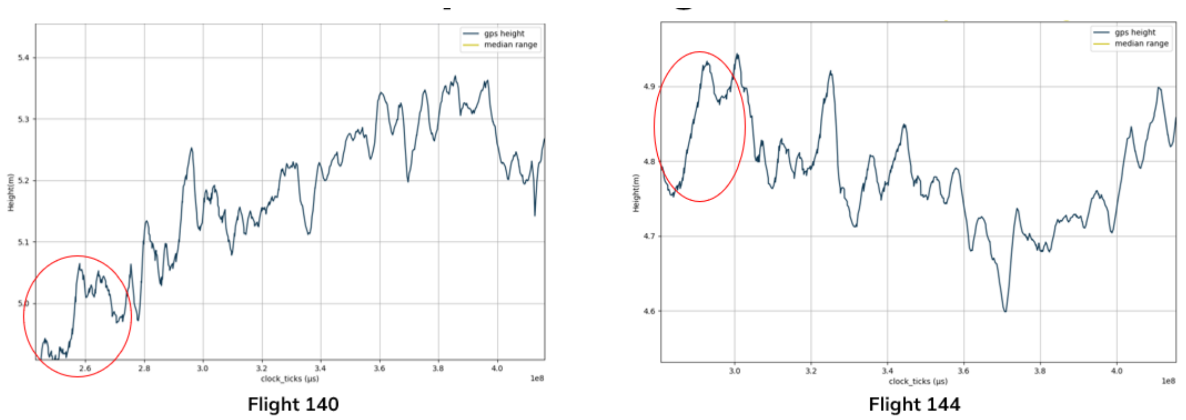

Figure 9: Altimeter positioning of flights 140 and 144 in Pontestura super-site.

3.2.1.2 Isola Pescaroli super-site

We obtained very different results for the Isola Pescaroli super-site compared to the Pontestura super-site. For Isola-Pescaroli, all ambiguities were resolved, and we have strong confidence in the GNSS positions computed for all these flights (Figure 10). For flight 131, the significant height variation within the flight is due to the flight plan designed to avoid power lines.

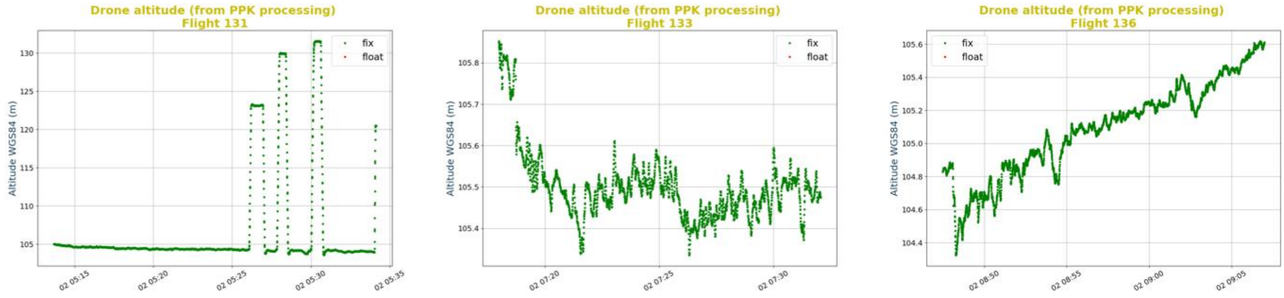

Figure 10: Drone altitude from PPK processing over Isola Pescaroli super-site.

When zooming in on the flight positions, the “noise” observed at Pontestura is never seen in the solution. This result is consistent with what we obtained during the previous campaign. There is no difference in data acquisition or processing between the Pontestura and Isola Pescaroli campaigns. Further investigation is required to determine the cause of this issue.

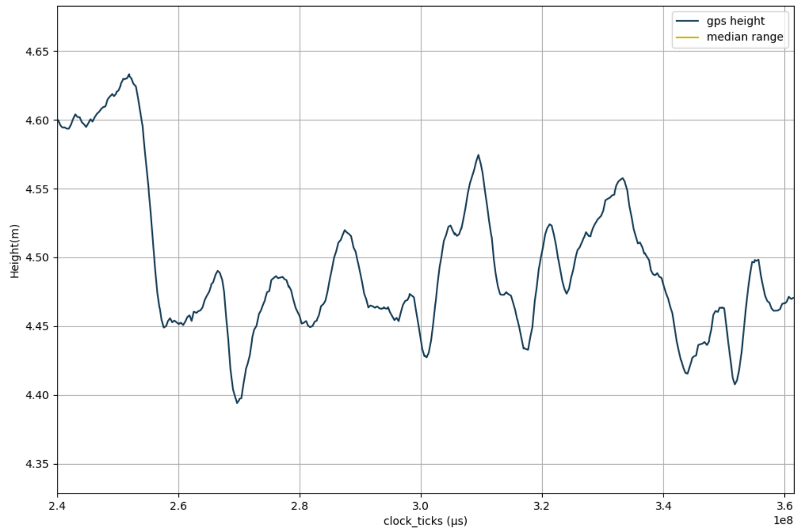

Figure 11: Zoom in on the altimeter positioning of flight 131 over Isola Pescaroli super-site.

During the measurements performed at Isola Pescaroli, we also observed a problem of missing LiDAR measurements (Figure 12), which is distinct from the previously discussed missing data percentage. When no LiDAR backscattered signal is detected, the system records a NaN value, and the missing measurements percentage corresponds to the proportion of NaN values in the LiDAR time series. In this case, however, the LiDAR failed to produce any record for the clock tick. Only flights 131 and 134 were affected by this issue.

Figure 12: LiDAR measurements displayed on the map for flight 131 (in green: area without any LiDAR missing measurements; in red: area with missing measurements).

3.2.2 Tiber River campaign

3.2.2.1 Deruta super-site

On Deruta flights (112 and 114), the ambiguities are not fixed as shown in Figure 13. We do not have strong confidence in the GNSS position obtained during these flights. On flight 112 (Figure 13, left panel), we observe very strong variability on the GNSS solution in the middle of the flight that does not describe the drone displacement.

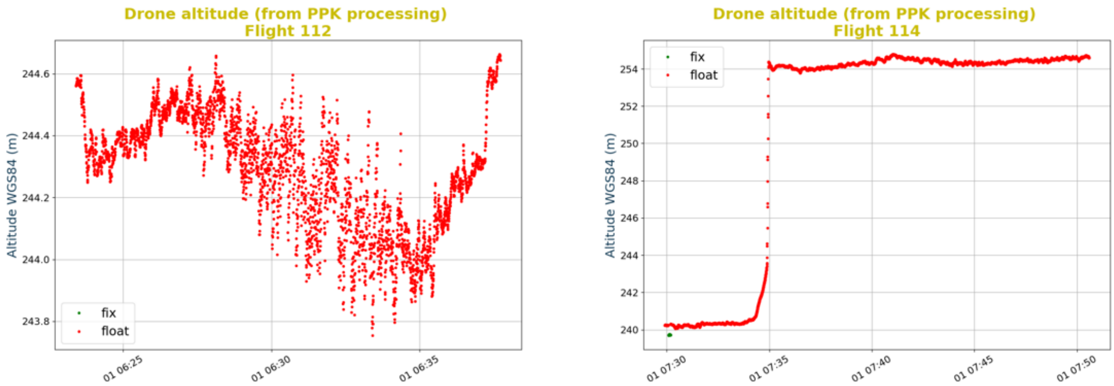

Figure 13: Altimeter positioning (from PPK processing) on Deruta super-site.

Due to a low SNR, it is impossible to extract the drone displacement signal from the time series (Figure 14). The noise is lower at the beginning and at the end of the flight. The cause of this result is currently unknown. This behaviour has not been observed in GNSS solutions before the Italy campaign.

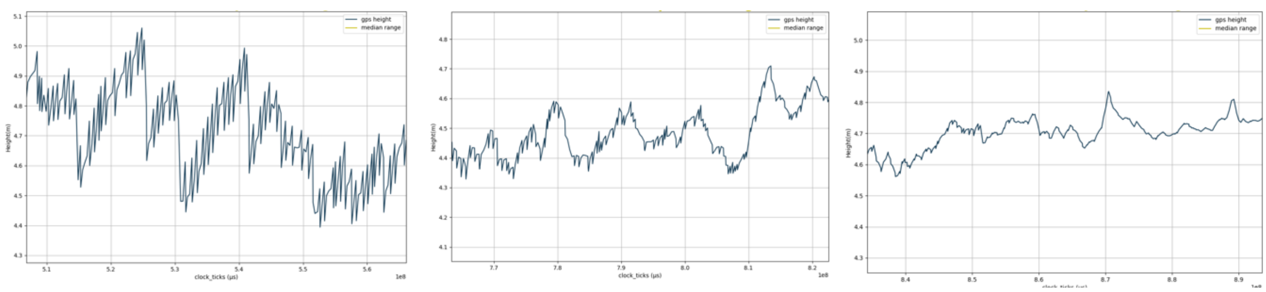

Figure 14: Altimeter positioning in Deruta in flight 112 for the middle part, the beginning, and the end of the flight (from left to right, respectively).

The second flight on this site is also impacted by this issue, but the amplitude of the noise is lower. The beginning and end of the flights seem to be cleaner than the middle of the flight. This noise can be induced by the Kalman filter of the

GNSS software because of issues in the raw data. We don't have strong confidence in this positioning. It creates noise and can create a height bias.

3.2.2.2 Santa Lucia super-site

On Santa-Lucia super-sites (flights 119 and 123), we have the same issue as seen in Deruta; the ambiguities are not fixed (Figure 15). We do not have strong confidence in the GNSS position obtained. On flight 119, the sudden change in altitude at the end of the flight is due to the drone landing. The drone pilot should have stopped the measurements before landing to avoid editing a part of the flight on our side.

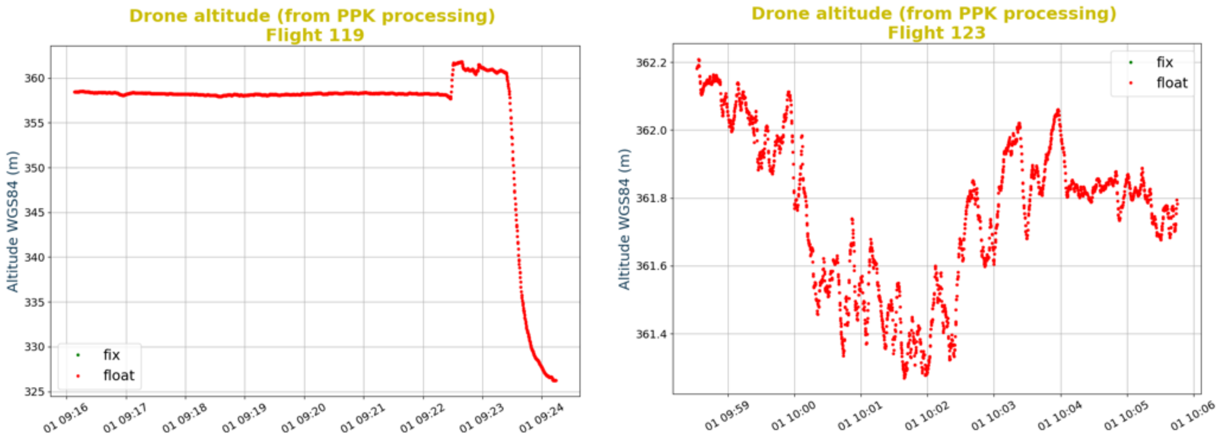

Figure 15: drone altitude (from PPK processing) on Santa Lucia super-site (flights 119 and 123).

As on the other flights, we observe the noise in the position of the time series on flight 119, whereas flight 123 is not impacted by this noise. The amplitude of the noise is lower than that for flight 112, but it impacts the accuracy of the water surface height measured by the altimeter (Figure 16).

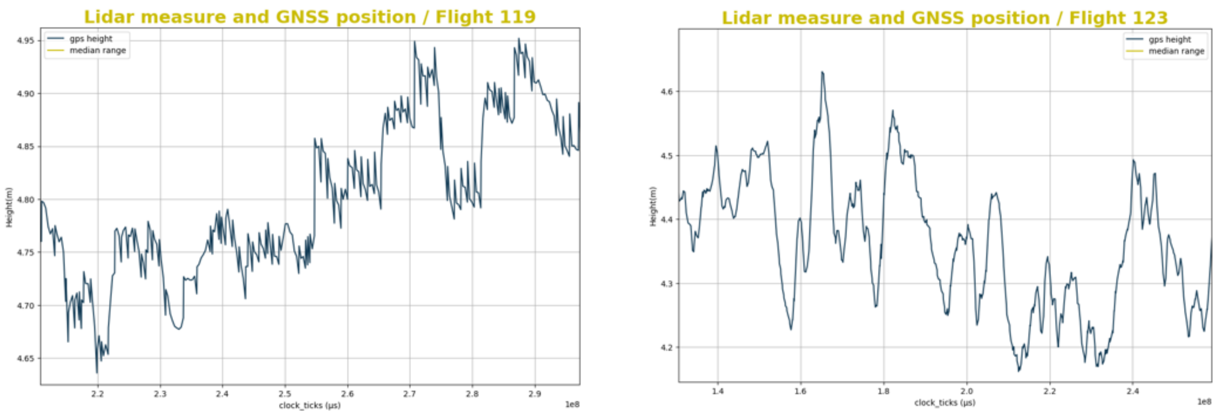

Figure 16: Lidar measure and GNSS position in Santa Lucia super-site (flights 119 and 123).

3.2.2.3 Pierantonio / Umbertide super-site

On the Umbertide / Pierantonio super-site (flights 127 and 128), we have a completely different behaviour than the one for the two other super-sites. On this super-site, the ambiguities are fixed for all the flights (Figure 17). The deployment on the Rhine River showed that when the ambiguities are fixed, the GNSS position of the altimeter is very accurate; therefore, we have strong confidence in the GNSS solution on these flights.

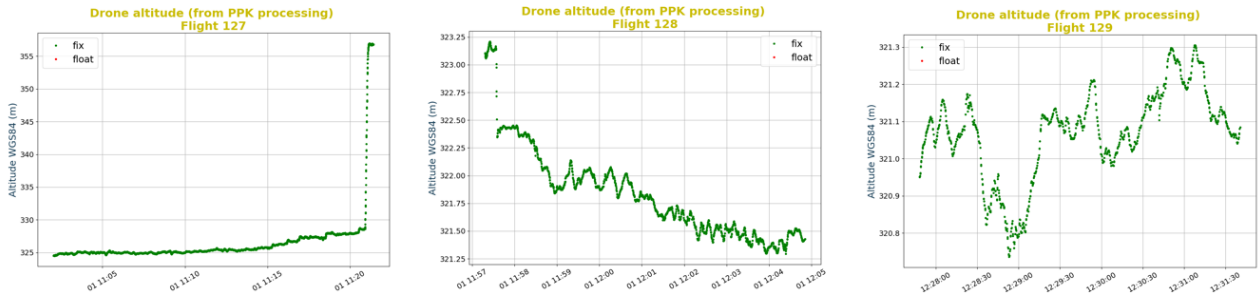

Figure 17: Drone altitude (from PPK processing) on Pierantonio / Umbertide super-site.

As expected, we do not observe the noise present in the flight in Deruta (Figure 18). When the ambiguities are fixed, the GNSS solution is clean. The GNSS solution seems to describe the drone height displacement precisely.

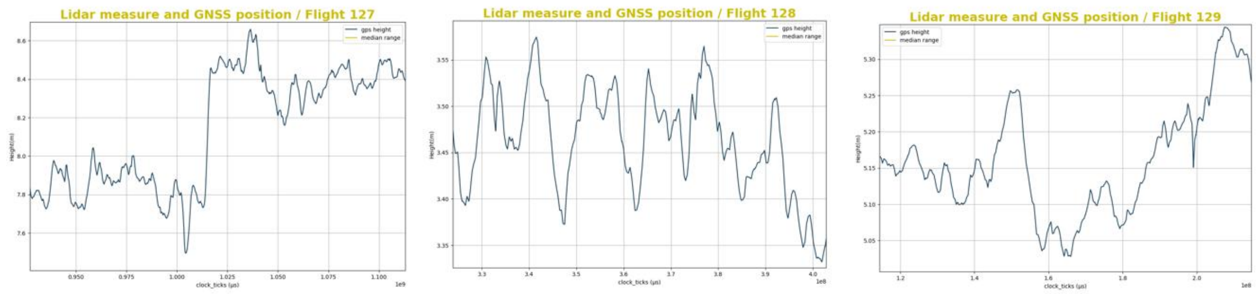

Figure 18: Lidar measure and GNSS positioning in Pierantonio / Umbertide super-site.

3.3 Quality of the lidar measurements

3.3.1 Po River campaign

3.3.1.1 Pontestura / Casale Monferrato super-site

Excellent results were obtained from the LiDAR measurements. We observed a high percentage of missing data on the two central beams, which is expected over hydrographic water bodies. On flight 144, we obtained poorer results than on the two other flights for LiDAR measurements, but still enough to produce good measurements.

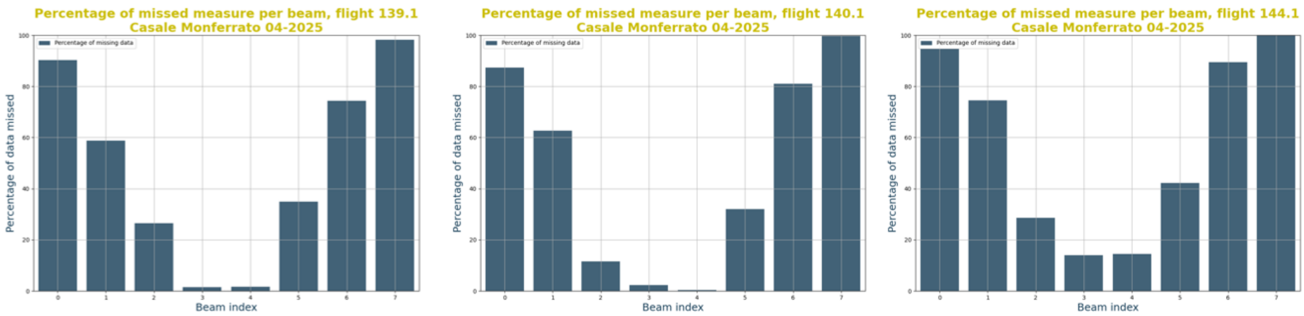

Figure 19: percentage of missed measures per beam on Casale Monferrato super-site (flights 139, 140, and 144).

Pitch mispointing can lead to missing data as the geometry of the 8 beams is on a line on the roll axis. Pitch analysis shows that for the three flights, the pitch is not centred, and we have around 3° variability (Figure 20).

The stabilization is better than on the previous version of the altimeter, thanks to the use of the DJI X-Port gimbal (from pitch STD around 10° to 3°). We must improve the initialization of the gimbal to better center the pitch and the altimeter center of mass to make the stabilization easier for the gimbal. This initialization must be done at every flight.

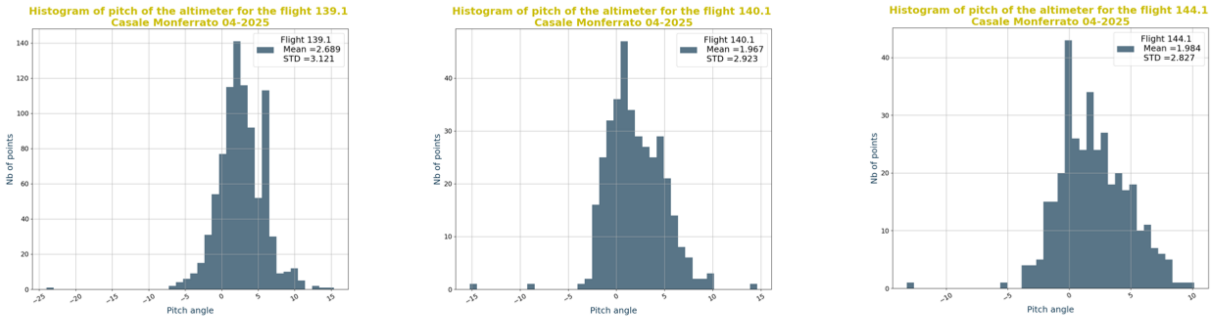

Figure 20: Pitch mispointing on Casale Monferrato super-site.

Roll mispointing analysis shows better results. The gimbal is exactly centred with a mean roll of around 0.3° for all flights (Figure 21). The stabilization is also better with a STD of 0.6° on this axis. We can explain the difference in pitch by the flight condition. As the drone goes forward, the constraints are more on the pitch than on the roll.

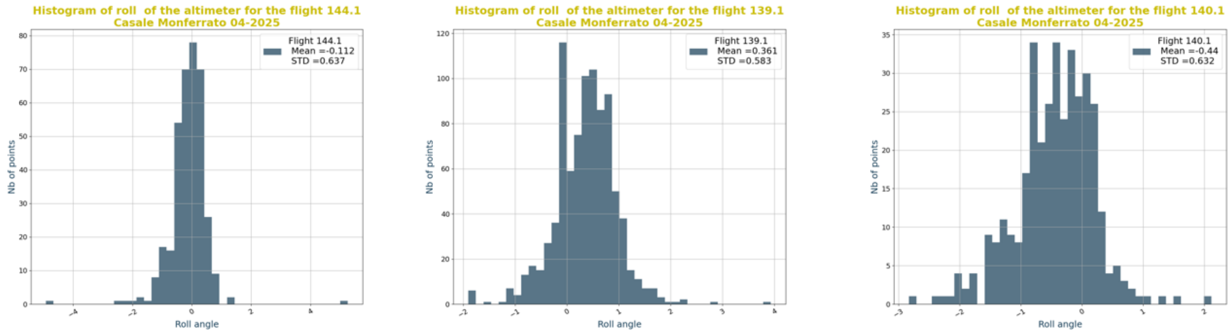

Figure 21: Roll mispointing on Casale Monferrato super-site.

3.3.1.2 Isola Pescaroli super-site

Excellent results were obtained from the LiDAR measurements. We obtain a good percentage of missing data on the 2 central beams, which is the expected result on Hydro waterbodies.

On flight 131, we have a strange behaviour with 80% missing measurements on the two external beams. Due to the measurement geometry, we should have 100% of missed data. This is due to pitch mispointing from a gimbal error.

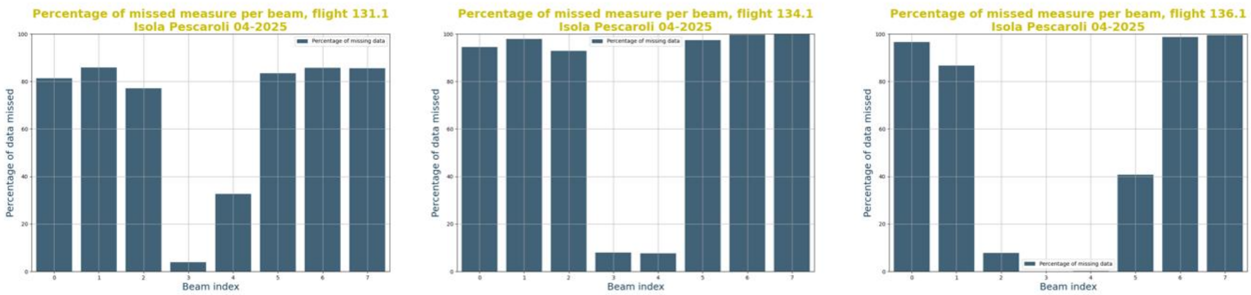

Figure 22: percentage of missed measures per beam on Isola Pescaroli super-site (flights 131, 134 and 136).

On flights 134 and 136, the pitch is well-centred. The high variability on flight 134 is due to some gimbal issues. On flight 131, we had strong gimbal issues with a pitch of around -80° for a part of the flight.

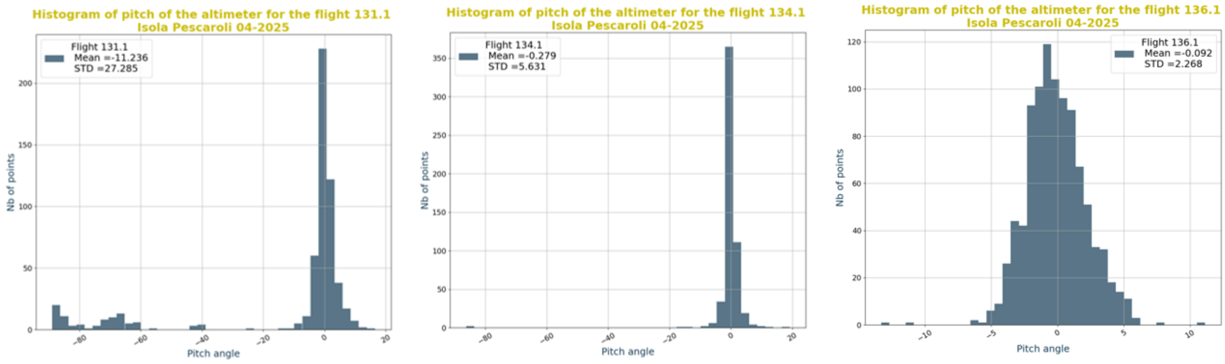

Figure 23: Pitch mispointing on Isola Pescaroli super-site.

The issue with the gimbal has been seen in the images measured by the altimeter (Figure 24). The picture was taken during one of these gimbal issues. We suspect that the gimbal is in error and blocks itself at the maximum pitch. We need to understand what causes the gimbal issue. The drone pilots should have seen it on their radio and reset the gimbal with the mispointing indicators we developed. We must continue to develop the procedure with the drone pilots to ensure better deployments.

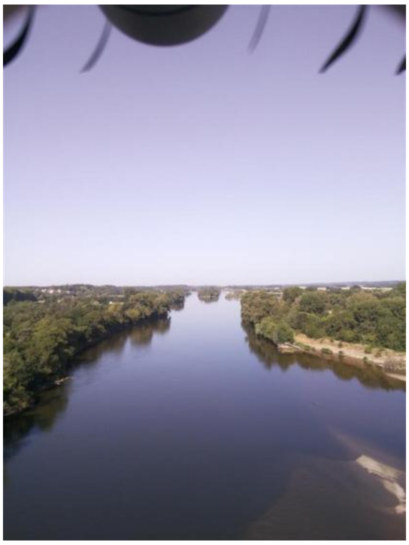

Figure 24: Picture taken by the altimeter during a gimbal issue.

3.3.2 Tiber River campaign

3.3.2.1 Deruta super-site

The LiDAR measurements show good results in Deruta, with a low percentage of missing data on the two central beams. For both flights, we observe a slightly higher percentage of missing data compared to other river flights (Figure 25). This discrepancy may be due to pitch misalignment or LiDAR backscatter originating from targets higher than the river surface.

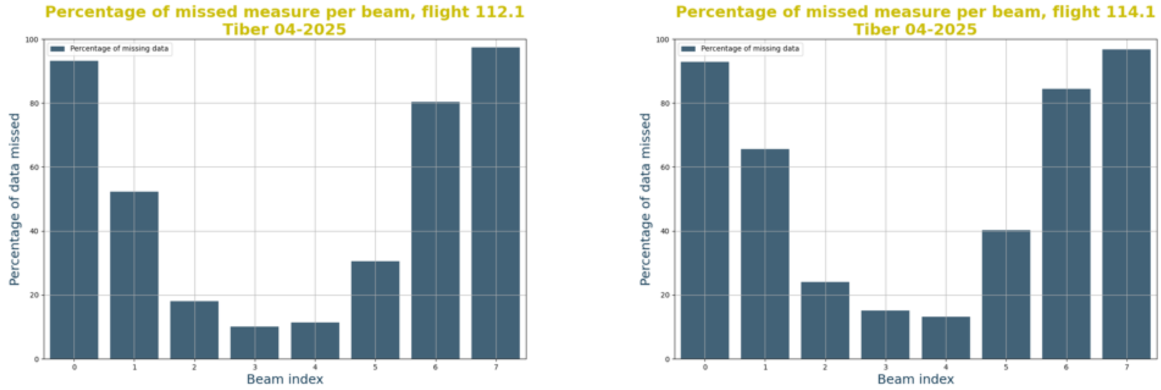

Figure 25: percentage of missed measures per beam in Deruta super-site.

On both flights, the pitch is well-centred (Figure 26). The high variability in the flights is due to gimbal issues. We suspect that the gimbal can have some errors and block the stability to the min pitch (~ -80°), which is the same behaviour as the one observed at Isola Pescaroli super-site.

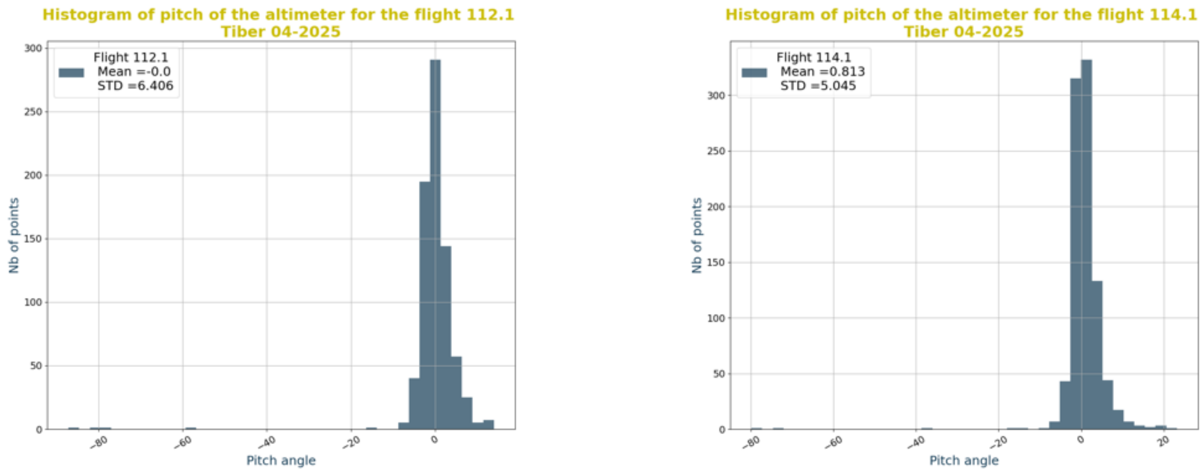

Figure 26: Pitch of the altimeter in Deruta super-site (flights 112 and 114).

The images acquired by the altimeter illustrate the significant mispointing that can occur when the gimbal is malfunctioning (right panel of Figure 27). For comparison, the left panel shows the altimeter when the gimbal is operating nominally. When we have this strong mispointing, we can see that the altimeter is not pointing to the nadir and does not have any back-scattered signal.

Figure 27: Pictures taken by the altimeter when the gimbal has a normal position (left) and a wrong one (right).

3.3.2.2 Santa Lucia super-site

The LiDAR measurements show good results, with a low percentage of missing data on the two central beams (Figure 28). The higher percentage observed on flight 123 is due to the initial editing performed during processing, which excludes some outliers and counts them as missing data.

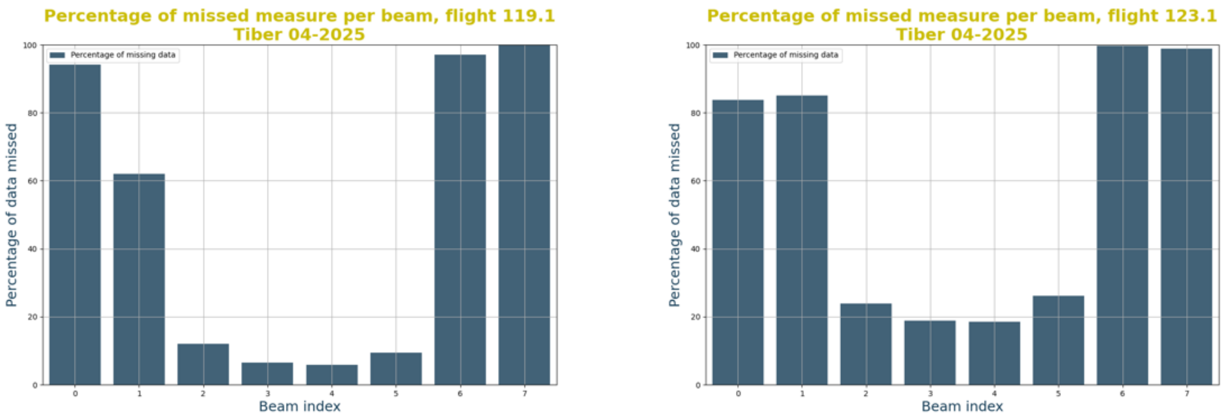

Figure 28: Missed measures per beam in Santa Lucia super-site (flights 119 and 123).

On both flights, the altimeter is well-centred regarding the pitch. The pitch standard deviation is a good information on the quality of the stabilization. This value is much lower than with the previous gimbal and is especially excellent on flight 123. On these flights, we do not have the gimbal issue seen on the Deruta super-site.

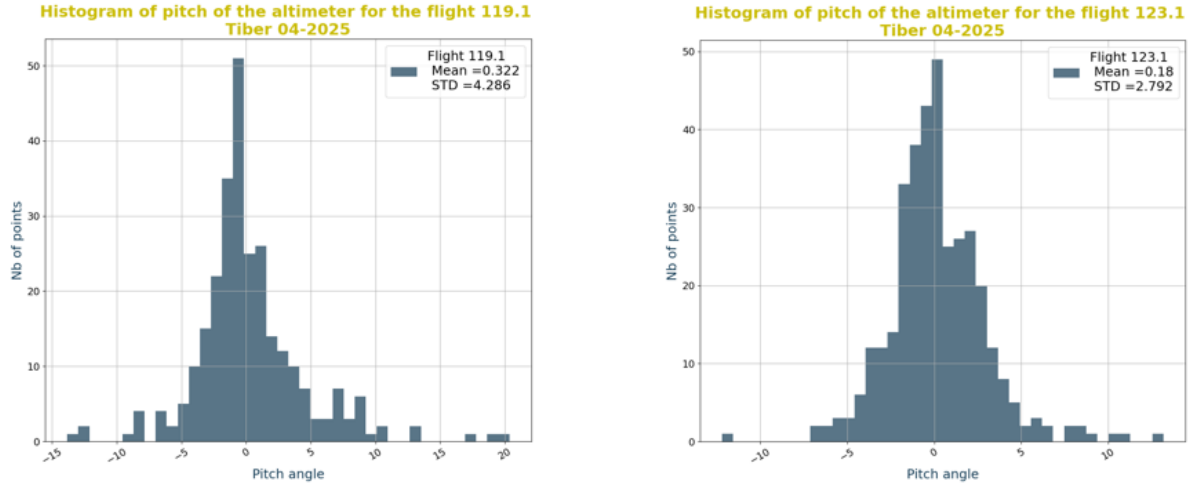

Figure 29: Pitch of the altimeter in Santa Lucia super-site (flights 119 and 123).

3.3.2.3 Pierantonio / Umbertide super-site

We have excellent results concerning the percentage of missing data (Figure 30). We have almost all the expected back-scattered signal on the 2 central beams for the flights 128 and 129. On flight 127, we have a slightly higher percentage of missing data. This comes from the pitch mispointing.

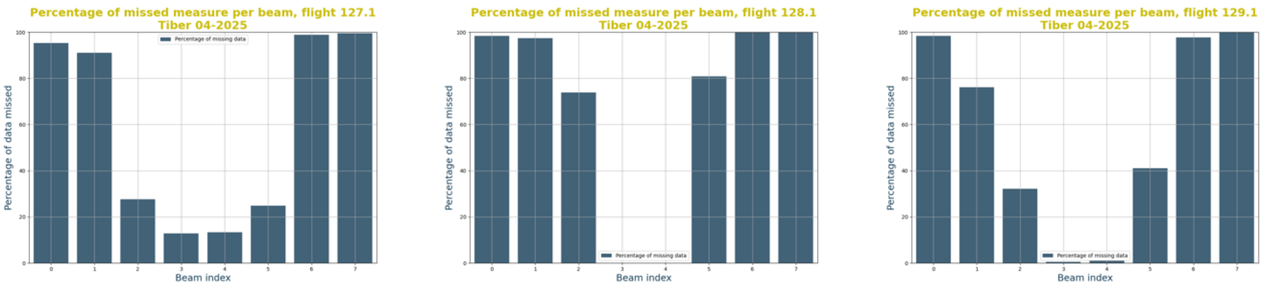

Figure 30: Percentage of missed measures per beam in Pierantonio / Umbertide super-site.

On flights 128 and 129, the altimeter is well-centred regarding the pitch. The stabilization seems to work well regarding the standard deviation of the measured pitch. For flight 127, the altimeter is not well-centred regarding the pitch. This is due to the drone set up before the flight. We need to improve this procedure with the drone pilot to avoid this issue. We assume that this issue led to the higher percentage of missing measurements.

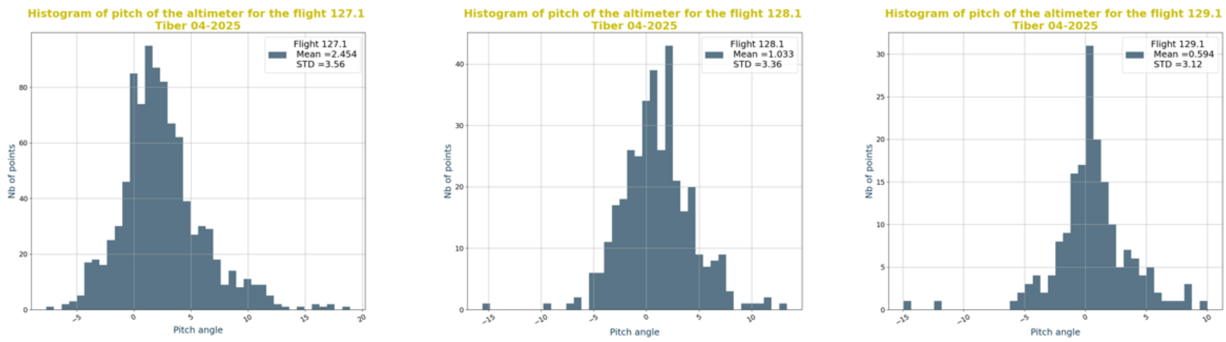

Figure 31: Pitch of the altimeter in Pierantonio / Umbertide super-site.

4 Data acquisition and processing report

4.1 Processing and results

The main processing steps for the vorteX-io drone altimeter measurements are:

- The positioning of the base by Precise Positioning Pointing (PPP).
- Positioning of all the flights by PPK with the base as reference.
- Combining all the acquired data (GPS, IMU, and lidar) to obtain raw water surface height (WSH) per flight.
- Processing the full reach by combining all the flights to obtain the linear.

4.1.1 Po River campaign

4.1.1.1 Pontestura / Casale Monferrato super-site

On flights 140 and 144, we obtain good results (Figure 32). The WSH obtained is similar to what we obtained before in terms of noise. The artifact at the beginning of flight 140 comes from the GNSS positioning. As expected, flight 139 is very noisy due to the noise in the GNSS solution computed.

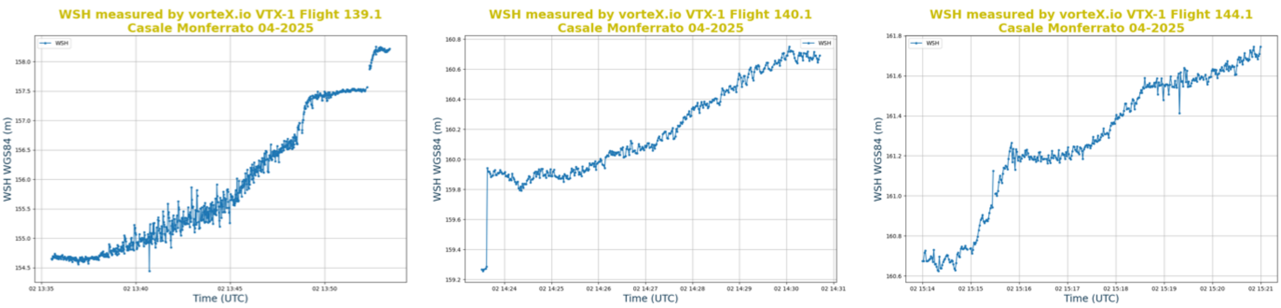

Figure 32: Water Surface Height measured by vorteX-io drone altimeter in Casale Monferrato super-site.

There is a good continuity between flights 140 and 144, with a difference of approximately 10 cm and a 100 m curvilinear break caused by a bridge (Figure 33). However, there is no continuity between flights 139 and 140, showing a 2.5 m difference despite only a 20-minute break between the two flights at the same location. As expected, the GNSS issue on the altimeter introduces significant bias between flights. Even though flights 140 and 144 appear consistent, there may still be a height bias affecting these flights as well.

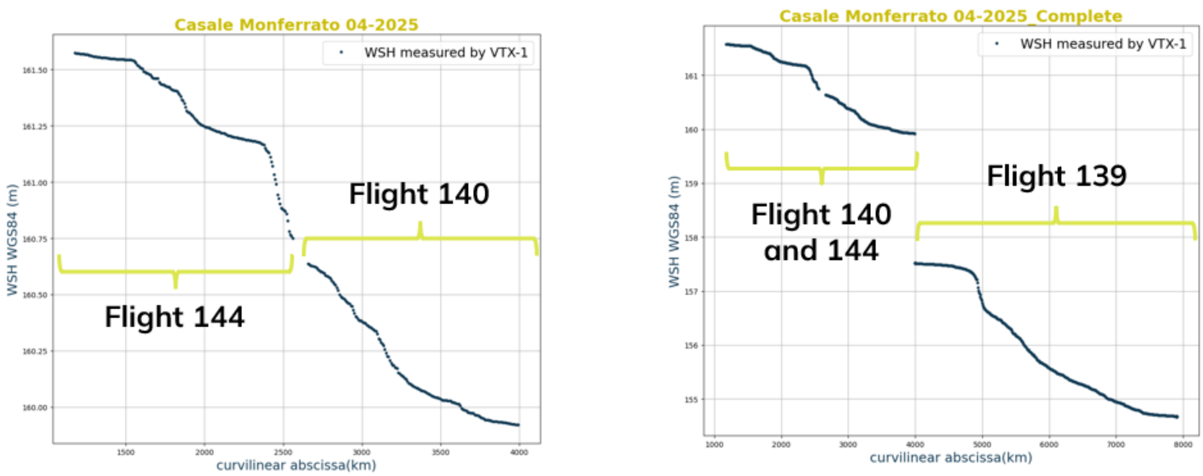

Figure 33: Hydrological topography profiles in Casale Monferrato super-site.

The water height difference between flights 139 and 140 cannot come from the evolution of the water level during the deployment. The micro-station installed on Pontestura measured only a centimeter of water level evolution during the day of the flight.

4.1.1.2 Isola Pescaroli super-site

We obtain the raw water surface height for all the flights (Figure 34). We removed the portions of the time series where the pitch exceeded 10°, as the backscattered signal originated from part of the drone itself. This explains the presence of measurements on the outer beams. The raw water surface height obtained is consistent with the results of the previous campaigns.

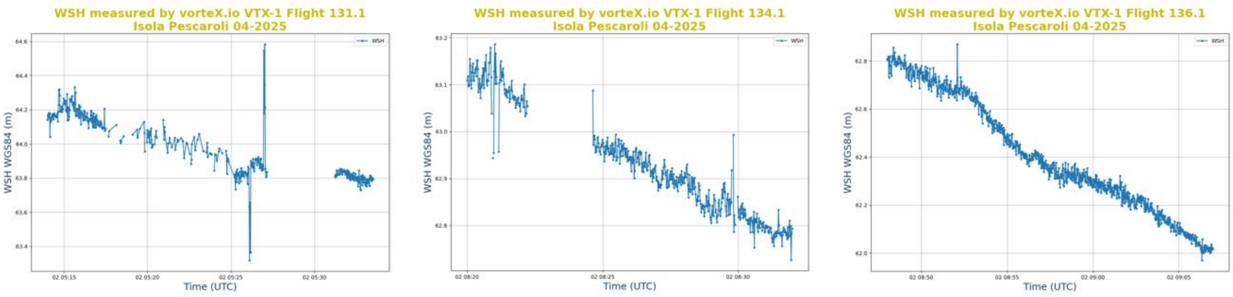

Figure 34: Water Surface Height measured by vorteX-io drone altimeter in Isola Pescaroli super-site.

A very good level of agreement was observed among all flights performed during the Isola Pescaroli campaign. The water height continuity is excellent between all the flights, with a difference of around 1 to 3 cm, as shown in Figure 35. The result is excellent, and it shows that we can have strong confidence in the GNSS solution when all the ambiguities are fixed.

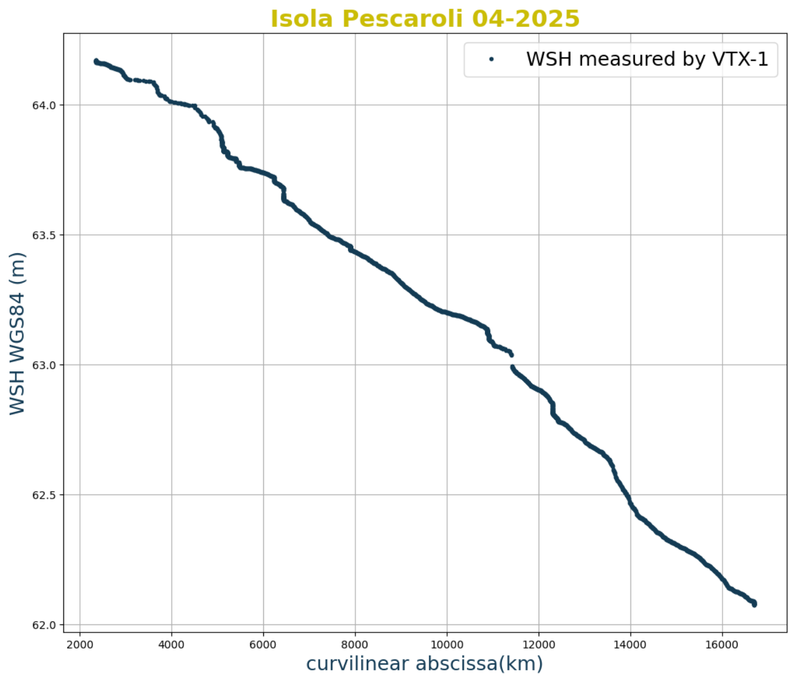

Figure 35: Hydrological topography profiles in Isola Pescaroli super-site.

4.1.2 Tiber River campaign

4.1.2.1 Deruta super-site

On flight 114, we observe a strong noise due to the error in the GNSS solution (Figure 36). On both flights, we observe outliers that we suspect are due to the vegetation that is important on this river.

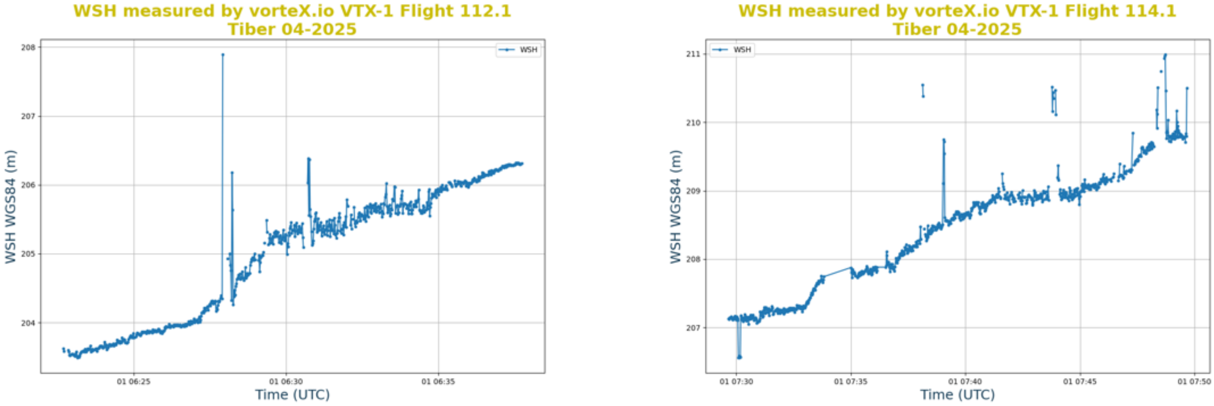

Figure 36: Water Surface Height measured by vorteX-io drone altimeter in Deruta super-site.

There is no continuity between the two flights on Deruta (see Figure 37 and Figure 38). There is a significant bias of 87 cm between the flights. The two flights were performed one after the other with a 15 min break. No water level evolution can explain this bias. This lack of agreement between flights is attributed to poor GNSS positioning at this site.

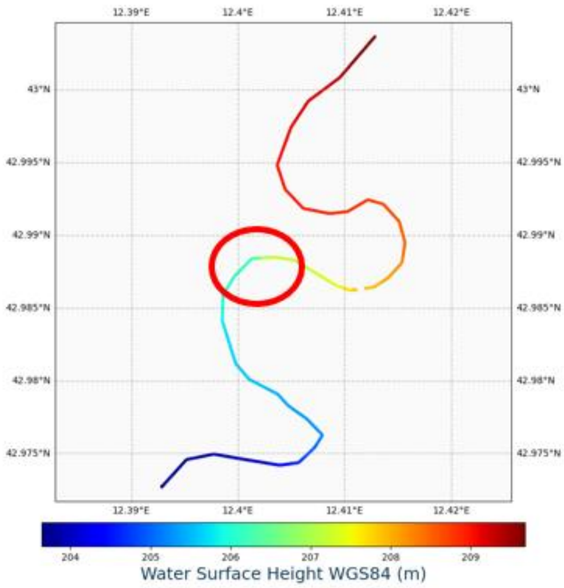

Figure 37: Water Surface Height along the Deruta linear. The bias between the two flights is indicated in the red circle.

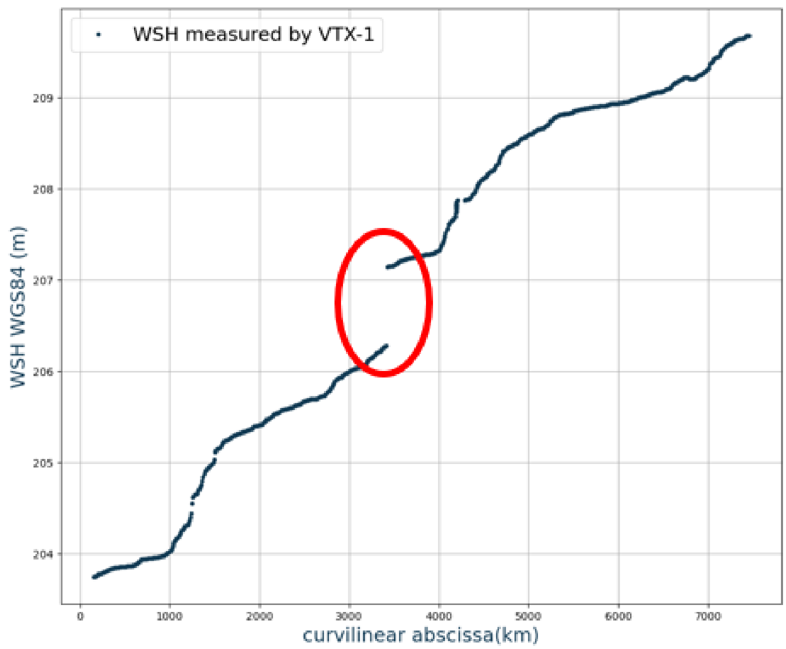

Figure 38: Hydrological topography profile in Deruta super-site.

4.1.2.2 Santa Lucia super-site

The computation of the raw water surface height gives us mixed results with several outliers and parts of the flights already edited (Figure 39). On flight 119, there is a strange behaviour with a stabilization of the water surface height that does not seem to follow the water level evolution. The noise on the water surface height seems to be quite high. On flight 123, there is a height gap in the flight. This gap seems to be physical and located before a small waterfall.

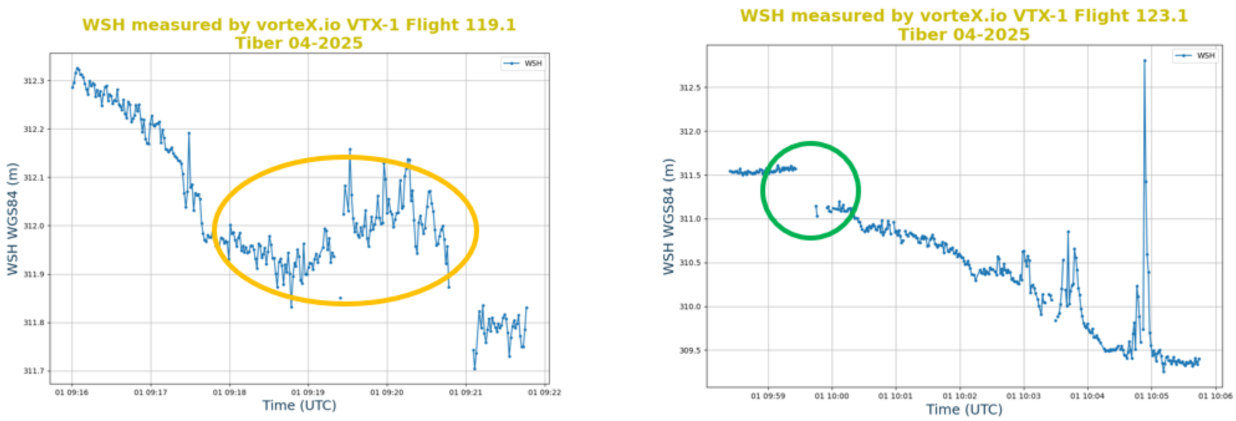

Figure 39: Water Surface Height measured by vorteX-io drone altimeter in Santa Lucia super-site.

There is a 90 m curvilinear distance between the two flights due to two bridges. Even with this break, we do not have continuity between the two flights on Santa Lucia. There is a bias of 27 cm between the flights (Figure 40). We assume that this bias is due to the bad GNSS results. We will check if the flight's position is coherent with the micro-station.

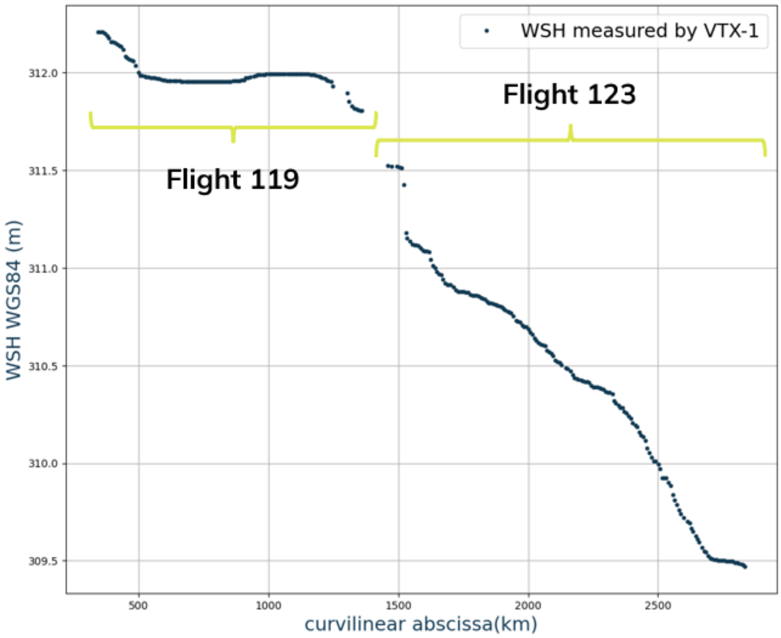

Figure 40: Hydrological topography profile in Santa Lucia super-site.

4.1.2.3 Pierantonio / Umbertide super-site

The obtained results are excellent (Figure 41). The noise on the raw water surface height is coherent (around 5 cm amplitude). Flights 128 and 129 are very stable with no river topography evolution. This can be explained by the presence of a dam between flights 127 and 128 and a stable water level upstream of the dam. There are some outliers on flight 127 with a water level lower than the river. We need to check what phenomenon can generate such outliers. They will be edited during the topography computation.

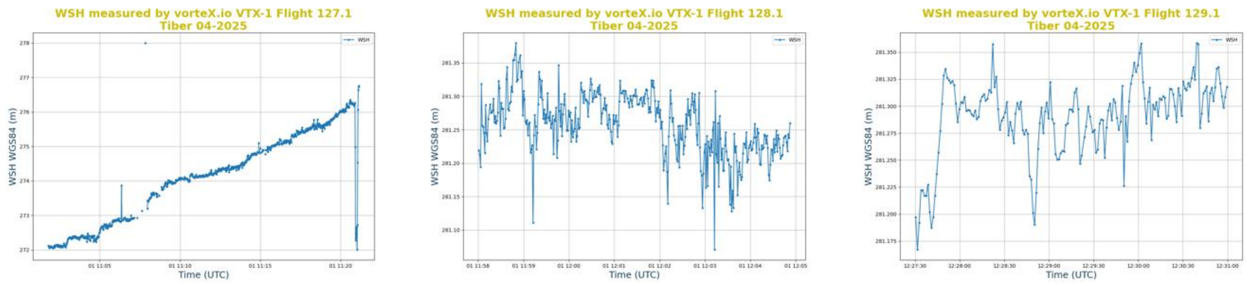

Figure 41: Water Surface Height measured by vorteX-io drone altimeter in Pierantonio / Umbertide super-site.

There is no bias between flights 128 and 129 (only a 2 cm difference) (Figure 42). The water level continuity is very good when the GNSS solution for all the drone flights is good. It is not possible to evaluate the continuity between flights 128 and 127 because of the dam. The heights of the two flights are very different.

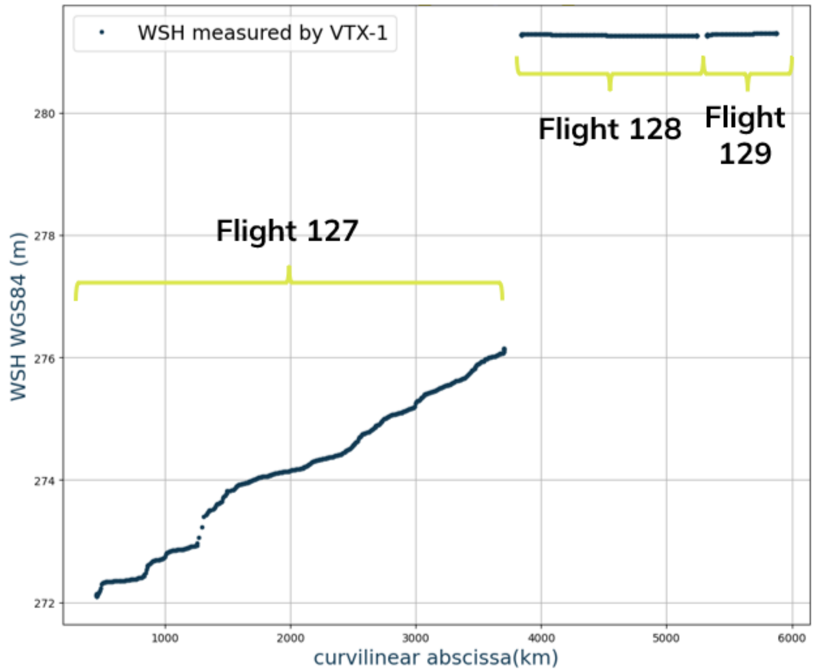

Figure 42: Hydrological topography profile in Pierantonio / Umbertide super-site.

4.2 Data quality – overview

This section provides an overview of the data quality obtained during the drone campaigns at each site. For each flight, we indicate whether the data are fully usable. When a flight is not exploitable, the issue that caused this is described. Other minor issues that affected the flight are also reported.

Super site	Flight ID	Exploitable flights	Main issue identified	Minor issue identified
Po River – Pontestura / Casale Montferrato	139	No	GNSS issue	-
	140	No	GNSS issue	-
	144	No	GNSS issue	-
Po River – Isola Pescaroli	131	Yes	No major issue	Mispointing from gimbal error that led to ~30% of missing RAW data
	132	Yes	No major issue	-
	133	Yes	No major issue	-
	134	Yes	No major issue	Mispointing from gimbal error that led to ~10% of missing RAW data
	136	Yes	No major issue	-
Tiber River - Deruta	112	No	GNSS issue	-
	114	No	GNSS issue	-
	119	No	GNSS issue	-

Tiber River - Santa Lucia	123	No	GNSS issue	Mispointing from gimbal error that led to ~20% of missing RAW data
Tiber River – Pierrantonio / Umbertide	127	Yes	No major issue	-
	128	Yes	No major issue	-
	129	Yes	No major issue	-

5 Data quality assessment and evaluation through maturity matrix

This section will be completed in the final version of the report.

5.1 Po River campaign

5.1.1 Pontestura / Casale Monferrato super-site

The comparison with the micro-station shows a 28 cm bias with the drone flights (Figure 43). This bias seems to come from the bad GNSS positioning of the altimeter flights, likely due to an issue with the GNSS acquisition parameter of the micro-station in Pontestura. The GNSS has been turned off after the first altimetric position computation. We have one computation of the altimetric reference for the micro-station. We need more position results to conclude on the accuracy of the altimetric reference of the micro-station. Once the position quality study has been conducted, we will check the GNSS accuracy of the drone flights.

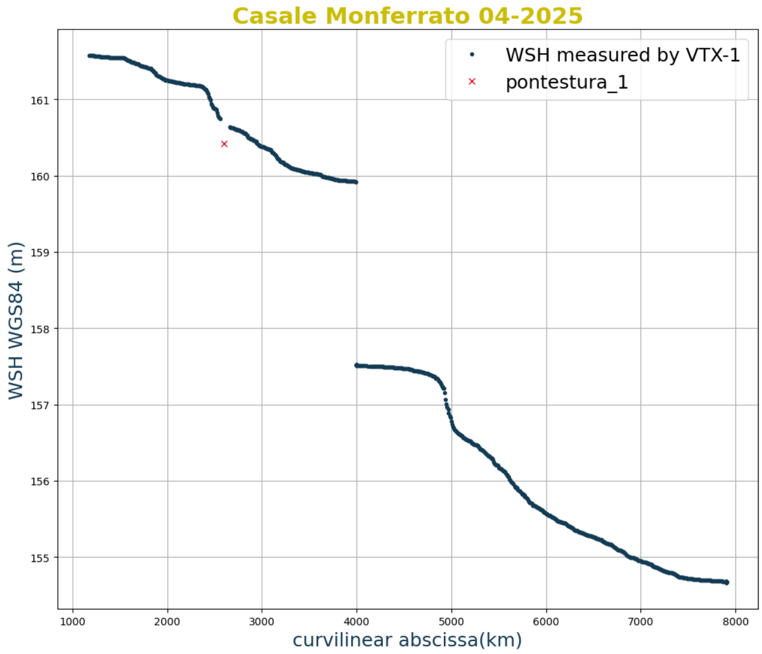

Figure 43: Comparison between WSH linear and micro-stations over Pontestura / Casale Monferrato super-site.

To obtain a coherent and usable drone profile, we propose to shift all the flights on the micro-station altimetric reference with a continuity between flights (Figure 44). We have low confidence in the downstream part (Flight 139). It is more a tendency than a precise topography measurement. There can be some bias in height due to the poor GNSS positioning. We can produce FRMs with this drone profile, but with **low confidence**.

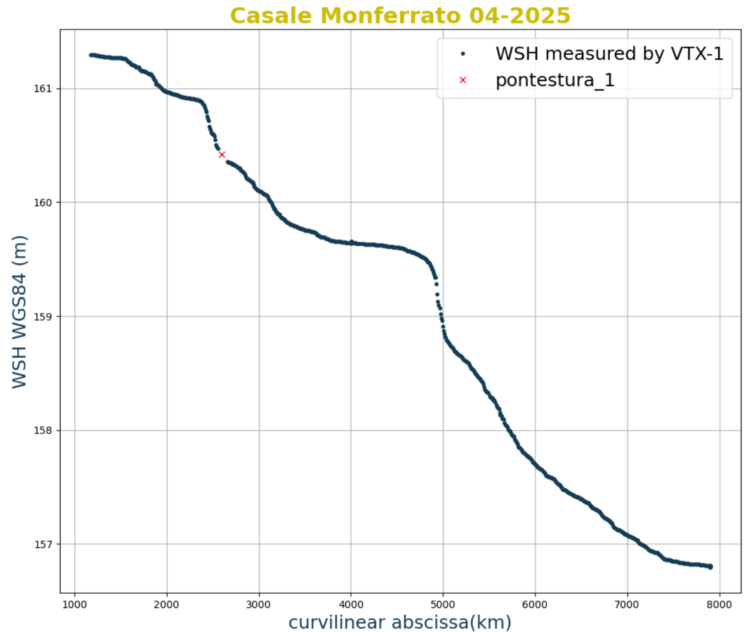

Figure 44: Corrected linear of Pontestura / Casale Monferrato super-site.

5.1.2 Isola Pescaroli super-site

The comparison with the station in Isola Pescaroli is very poor with around 15 cm difference (Figure 45). The station was impacted by the same issue as in the Pontestura super-site. We only have one altimetric position. With this low confidence, we suspect that the altimetric reference of the station is not good. We switched on the GNSS to allow us to compute many other altimetric references for the station and analyse its quality. Once the analysis is done, we will conclude on the accuracy of this part of the campaign.

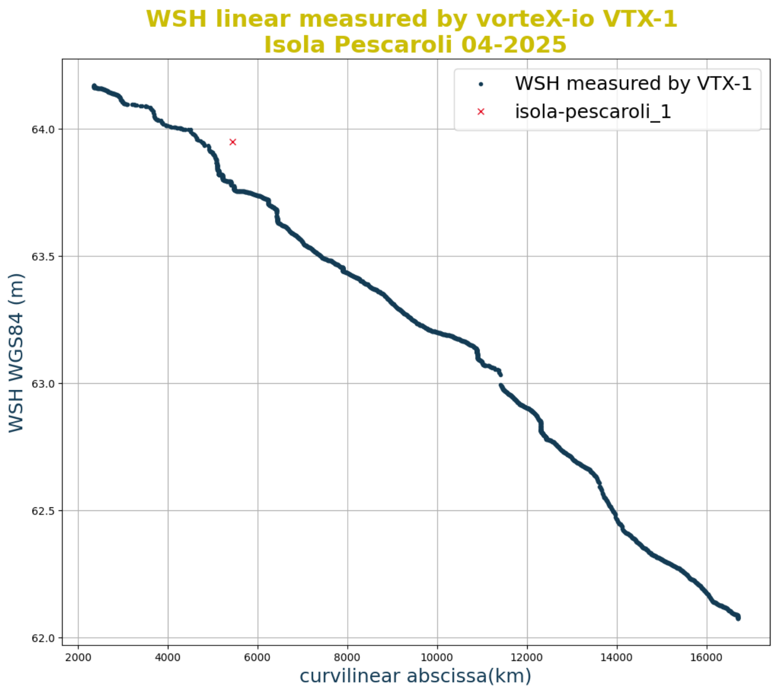

Figure 45: Comparison between WSH linear and micro-stations over Isola Pescaroli super-site.

5.2 Tiber River campaign

5.2.1 Deruta super-site

To validate the drone flights, we need to have a strong confidence in the altimetric reference of the micro-station installed on the super-site. As we have the embedded GNSS system on the micro-station, we can compute several altimetric references to ensure that the one applied to the LiDAR time series is correct. We computed 9 positions for the micro-station Deruta_1 and the quality indicators associated (Figure 46). We have a strong agreement between all the positions, with less than a centimeter difference between the positions for which the quality indicators are good. These quality indicators are explained in the altimetric reference deliverables (TD-13.1).

human_name	height	alt_std	sdu	resc_q75
deruta_1	217.243	0.0	0.002	0.021
deruta_1	217.24	0.002	0.003	0.018
deruta_1	217.239	0.0	0.002	0.021
deruta_1	217.246	0.002	0.01	0.02
deruta_1	217.217	0.011	0.007	0.02
deruta_1	215.559	0.161	0.122	0.015
deruta_1	217.248	0.0	0.002	0.021
deruta_1	217.242	0.0	0.002	0.021
deruta_1	217.242	0.0	0.002	0.021

Figure 46: Altimetric references of the deruta_1 micro-station with quality indicators.

There is a bias between the water surface height measured by the micro-station ''deruta_1'' and the water surface height measured by the altimeter VTX-1. There is a bias of 43 cm between the measurements of the two sensors (Figure 47). The GNSS position computed for those flights cannot give us confidence in the resulting river topography. We have low confidence in this river topography measurement due to the GNSS issue.

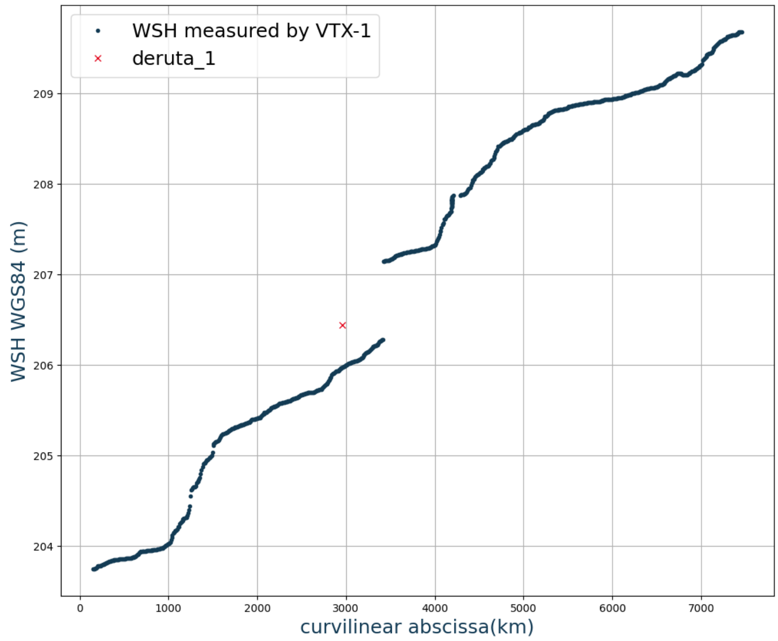

Figure 47: Comparison between WSH linear and micro-stations over Deruta super-site.

To obtain a coherent and usable drone profile, we propose to shift all the flights on the micro-station altimetric reference with a continuity between flights (Figure 48). We have low confidence in these river topography measurements due to the bias and the noise of the GNSS position. We can produce FRMs with this drone profile, but with **low confidence**.

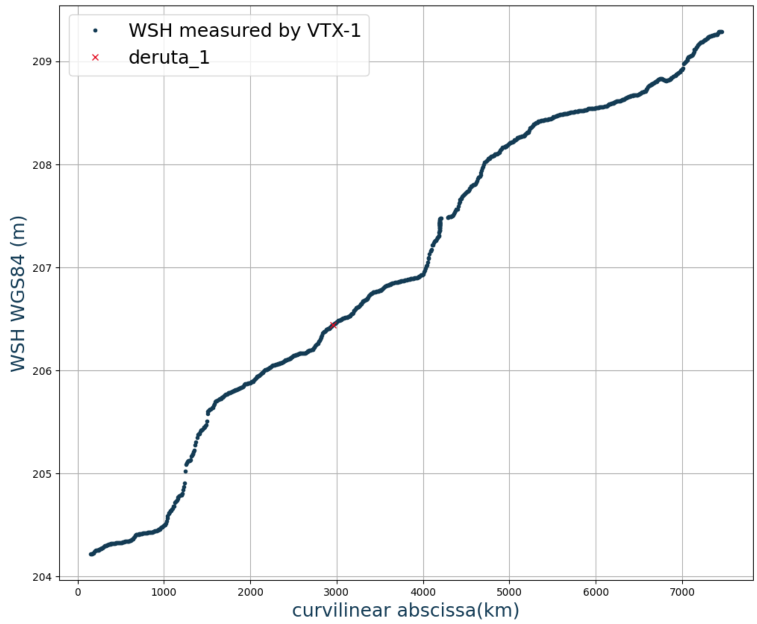

Figure 48: Corrected linear of Deruta super-site.

5.2.2 Santa Lucia super-site

To validate the drone flights, we need to have a strong confidence in the altimetric reference of the micro-station installed on the super-site. We computed 9 positions for the micro-station Santa-lucia_1 and the quality indicators associated (Figure 49). We have a strong agreement between all the positions with less than a centimeter difference between the positions, for which the quality indicators are good. We have a strong confidence in the altimetric reference of the station in Santa-Lucia.

human_name	height	alt_std	sdu	resc_q75
santa-lucia_1	327.705	0.0	0.002	0.017
santa-lucia_1	327.61	0.02	0.042	0.01
santa-lucia_1	327.721	0.001	0.004	0.017
santa-lucia_1	327.697	0.003	0.005	0.016
santa-lucia_1	327.708	0.001	0.01	0.015
santa-lucia_1	327.706	0.0	0.002	0.016
santa-lucia_1	327.7	0.0	0.002	0.017
santa-lucia_1	327.706	0.0	0.002	0.017
santa-lucia_1	327.709	0.0	0.002	0.017

Figure 49: altimetric references of the santa-lucia_1 micro-station with quality indicators.

There is no bias between the water surface height measured by the micro-station ''santa-lucia_1'' and the water surface height measured by the altimeter VTX-1 during flight 119 (Figure 50). Even with the poor GNSS results for the altimeter, we obtain a very good agreement with the micro-station. With the noise, the outliers, and the poor GNSS positioning, we have low confidence in these river topography measurements, even if flight 119 agrees with the micro-station.

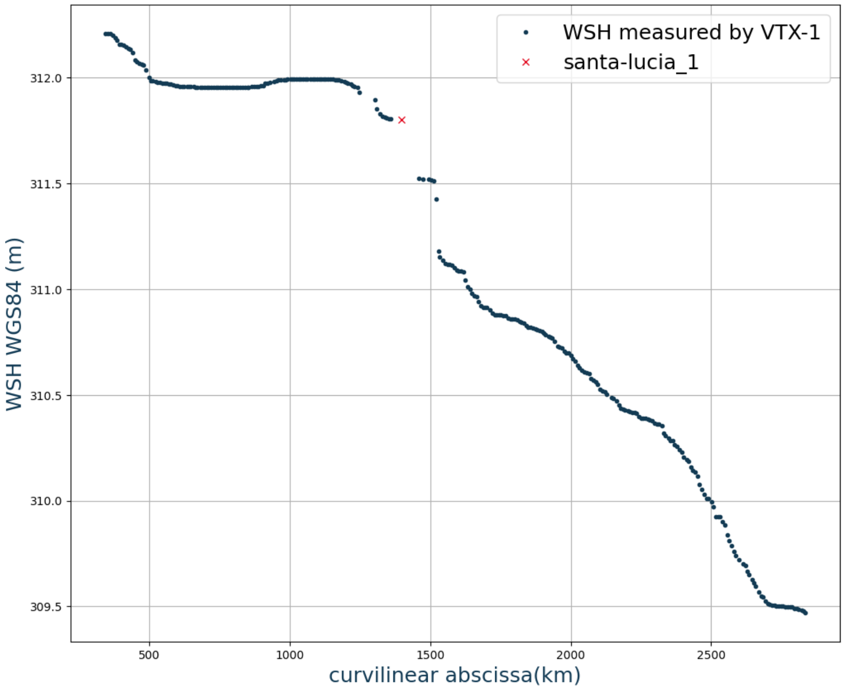

Figure 50: Comparison between WSH linear and micro-stations over Santa Lucia super-site.

To obtain a coherent and usable drone profile, we propose to shift the flight 123 to flight 119 and the micro-station (Figure 51). We have low confidence in these river topography measurements due to the water level effect on flight 119 and the GNSS position errors. We can produce FRMs with this drone profile, but with **low confidence**.

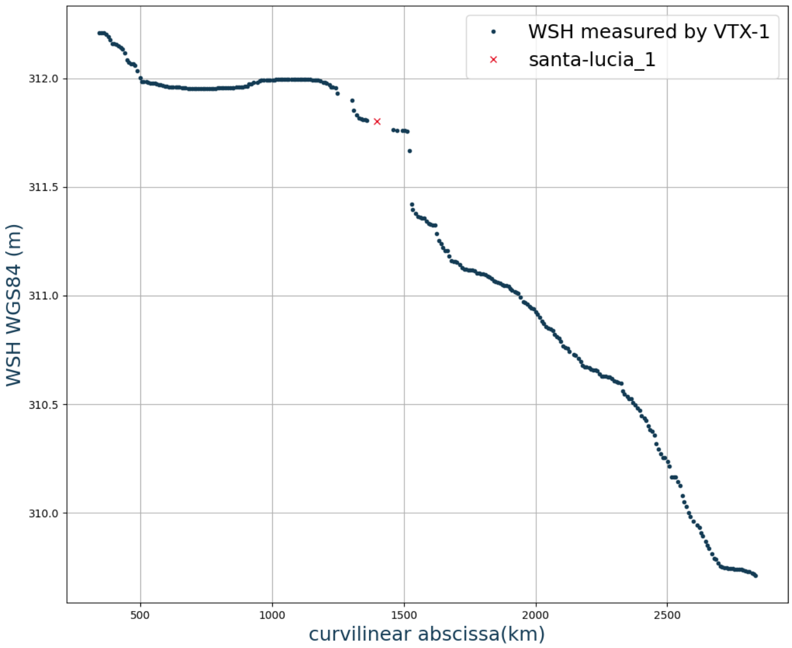

Figure 51: Corrected linear of Santa Lucia super-site.

5.2.3 Pierantonio / Umbertide super-site

We computed 9 positions for the micro-station umbertide_1 (Figure 52) and 4 positions for the station pierantonio_1 (Figure 53). For both micro-stations, we have strong confidence in the altimetric position. The positions with the best values for the quality indicators show around 1 centimetre agreement. We use the position closest to the median of the ‘’good positions’’ as the altimetric reference of the station.

human_name	height	alt_std	sdu	resc_q75
umbertide_1	289.314	0.031	0.014	0.024
umbertide_1	289.275	0.001	0.004	0.022
umbertide_1	289.273	0.001	0.003	0.022
umbertide_1	289.235	0.007	0.009	0.022
umbertide_1	289.179	0.007	0.017	0.023
umbertide_1	289.283	0.001	0.003	0.022
umbertide_1	289.284	0.0	0.003	0.022
umbertide_1	289.289	0.001	0.005	0.021
umbertide_1	289.271	0.001	0.004	0.022

Figure 52: altimetric references of the umbertide_1 micro-station with quality indicators.

human_name	height	alt_std	sdu	resc_q75
pierantonio_1	284.018	0.002	0.006	0.02
pierantonio_1	283.983	0.0	0.002	0.022
pierantonio_1	283.992	0.0	0.003	0.022
pierantonio_1	283.985	0.0	0.002	0.022

Figure 53: altimetric references of the pierantonio_1 micro-station with quality indicators.

There is an excellent agreement between the heights measured by the micro-stations and the drone flights. For Umbertide, we observe a difference of only 2.5 cm between flight 128 and the micro-station measurements. For Pierantonio, the agreement between flight 127 and the micro-station is 3.5 cm. When the GNSS solutions are of good quality, there is no bias between the micro-stations and the drone flights. We have strong confidence in these drone flights for producing FRMs at these supersites.

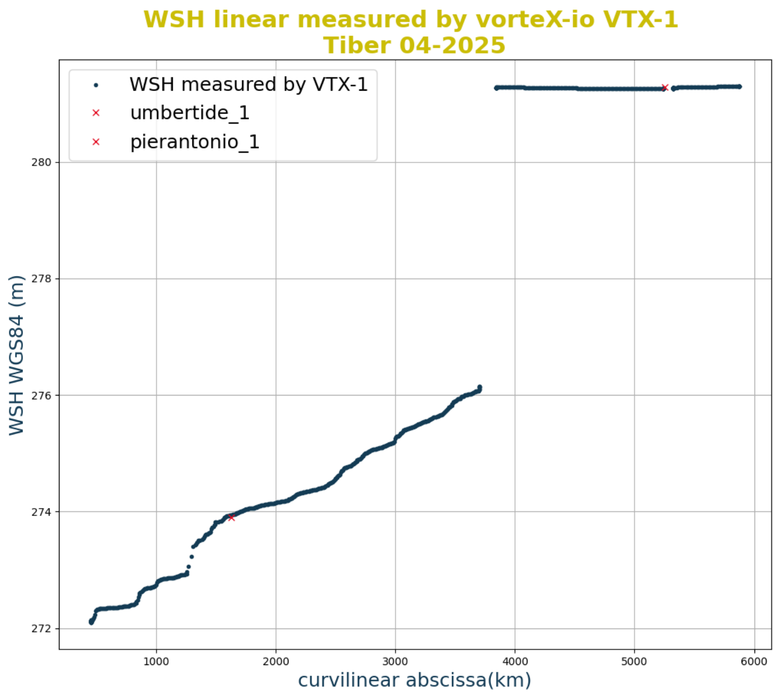

Figure 54: Comparison between WSH linear and micro-stations over Pierantonio / Umbertide super-site.