FluViSat

Hydrological Flow Measurement from Satellite Video

Technical Note on the Opportunities for Hydrometric Monitoring

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Contents

1. Purpose

This note outlines the potential applications in hydrometry for the proven FluViSat method of measuring surface flow velocity from satellite video. It also covers the key limitations of the method and outlines what needs to be improved to enhance accuracy and application across the globe.

2. Summary of project achievements

The FluViSat project builds upon the now well-proven method for measuring river discharge using low-cost aerial camera drones (Acharya *et al* 2021) by exploring whether camera sensors on satellites can be used for the same optical surface velocimetry application.

Through the field validation exercises, the project has demonstrated that it is possible to accurately measure the surface flow speed of medium and large rivers and a fast tidal current using high resolution satellite videos. The resulting water speed information, when combined with data on the waterbody's cross-sectional area and velocity distributions, allows the calculation of discharge rates.

The high elevation of the satellites, some 400-450 km above the earth's surface, led the project team to target satellite acquisitions on rivers where surface features were likely to be relatively large and fast moving, and hence easy to detect. Furthermore, where possible, acquisitions were planned for periods when high flows were expected at the study sites, since the number and scale of the surface tracers is greatest in these conditions, further improving detectability and traceability of surface features.

In summary, despite unusually low flows in several sites, the FluViSat method delivered excellent results on:

- Moderate flood events on a large Australian river
- An 80-metre-wide UK river in relatively low flow conditions
- A large tidal race in Scotland
- The Zambezi River below Victoria Falls, where it is just 40 m wide
- The Indus River in Pakistan, during a major flood event
- The Uono River in Japan

The results from each of the sites were within the +/-10% bounds that the project had defined based on accepted hydrometric practice. In fact, where intercomparisons between field and satellite-derived data were closely synchronised, the results were within 1% of each other.

3. Exploring further opportunities for hydrometric applications

This section outlines the potential for the application of the FluViSat method for hydrometric applications.

3.1. Extreme event monitoring

Extreme flood events can happen anywhere in the world and bring huge – and very costly - impacts for people, agriculture, infrastructure and nature. When severe flooding occurs, monitoring capabilities may be inadequate, suffer damage or destruction, or simply be absent. Furthermore, access to impacted areas to make manual observations can be hazardous or even impossible. The FluViSat method allows observations of major floods with no need for people, infrastructure or equipment on site. The 21 satellites in the SkySat constellation can allow multiple observations to be made in a single day, offering the potential for near real-time surveillance of rapidly evolving flood events.

3.2. Sparsely monitored catchments

It is widely recognized that many of the world's major river systems are very poorly monitored, especially in less economically developed countries. With challenges ranging from poor availability of funding, equipment and skills to conflict and simple challenges relating to accessibility of sites, monitoring networks on many great rivers are inadequate, and often in decline.

FluViSat has great potential to help in these situations, since it can provide remotely sensed observations with no need for people or potentially expensive infrastructure and equipment on site. The method could also be combined with remotely sensed water surface altimetry information to further improve results in remote locations.

3.3. Operational monitoring

The FluViSat innovation offers considerable potential for long term operational monitoring of large river systems. The SkySat constellation has the potential to capture video imagery at any location on earth, and at sub-daily repeat times. Once field validation activities have been undertaken to calibrate the method for the site, repeat satellite observations would be expected to deliver high quality data on an ongoing basis.

3.4. Floodplain flows

One of the most damaging and dangerous aspects of major flood events can be water flowing on the floodplain and extending through populated areas. Recent flood events have shown the power of these floodplain flows to destroy infrastructure and threaten the lives of those living in impacted areas.

When trying to assess total river flow rates during flood events, quantifying volumes of water flowing outside of the normal river channel is difficult. With its wide spatial coverage, the FluViSat method has the potential to provide observations of water extent and flow speed beyond the confines of the main river channel.

3.5. Raising the profile of hydrometry

Hydrometry is the critical science that underpins all aspects of the management of inland water. It has however, always suffered from a very low profile, in many cases leading to underinvestment. Projects like FluViSat, and engagement with the satellite and EO communities can do a great deal to raise awareness of hydrometry as an important scientific discipline and critical monitoring service during hazardous floods.

4. Limitations

This section examines the current limitations of the FluViSat innovation.

4.1. Cloud cover

The single biggest limitation for the use of optical satellite remote sensing for hydrometric observations is the issue of cloud cover. In many regions of the planet, clouds can potentially obscure observations in any season, but will tend to be most problematic in times when flooding may occur. This will limit effectiveness for short-duration floods, where flood peaks can pass before any breaks in the cloud. The project has however proven its potential to provide valuable observations during floods which last longer, such as the case in Pakistan.

4.2. Tasking

A second major challenge is tasking of the satellites. The FluViSat project has helped inform not only the scientific potential of satellite-based observations, but also the practicalities of obtaining observations.

In addition to the potential issues with cloud cover already discussed, competition for satellite time can be an issue. This is particularly the case for video, as it requires the precise targeting of the satellite, and so precludes the capture of the still imagery more commonly required by other customers.

4.3. Stabilisation

The raw video files received by the project team suffered from very significant wandering of the imaged scene, as well as perspective based distortion as a result of the satellite's changing viewpoint as it captures the 30-second video clips while passing overhead at around 27,000 km/h. It is essential that both of these factors are resolved prior to attempting velocimetry processing.

At present, stabilisation and rectification is a manual process, which requires relatively intensive manual intervention in order to define the processing parameters and the water's surface as an AOI. Further work will be required to streamline the rectification and stabilisation workflow and processing tools.

4.4. Image quality

With favourable river flow conditions and illumination, the quality of the video imagery provided by the SkySat satellites is remarkably good. However, to successfully undertake accurate optical velocimetry measurements requires tracking the movement of sometimes quite small and indistinct visible features on the water's surface. Where surface features are less clear, and illumination is less optimal this can make processing difficult or impossible.

In summary, while the SkySats provide a superb introduction to satellite-based velocimetry, it is hoped that future satellite constellations will bring significant improvements in image quality and in particular, the provision of higher quality video imagery.

5. Opportunities for improvements

As well as demonstrating the significant potential for satellite-based river velocimetry, the FluViSat project has helped to illustrate some areas where further research is required to improve results and applicability of the method.

5.1. Radar based velocimetry

To overcome issues with cloud cover preventing observations with the FluViSat optical method, research into the potential of radar-based velocimetry is needed. As an example, SAR microsatellite operator ICEYE is able to rapidly obtain very high-resolution Synthetic Aperture Radar (SAR) observations regardless of cloud cover or illumination through its 20-strong constellation of small radar satellites. ICEYE's satellites have the potential to deliver SAR video products, which could potentially provide water speed information for times and locations where optical coverage is denied.

5.2. Enhancements to hydrometric Software

Manual processing in HydroSTIV

In addition to several automatic processing options, a manual re-processing option is offered in HydroSTIV software to refine results in difficult conditions, such as where water speed is not uniform along a search line, or the video imagery is not fully stable (Figure 1). In these cases, a manual visual correction is made by the operator. This is time-consuming and introduces the potential for different results to be obtained by different users. Since the FluViSat method requires long search lines, and can be susceptible to unstable imagery, optimization of the HydroSTIV software for satellite remote sensing applications should be undertaken.

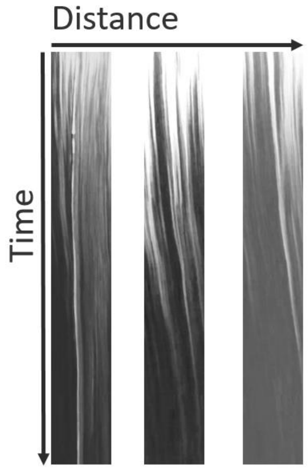

Figure 1 Inconsistent STIV angles as a result of spatially varying water speed along search lines and minor instability of imagery

QRev ADCP software

The open source QRev (for Q (discharge) Review) software is very widely used to aid in the processing and validation of ADCP river flow data. Additionally, QRev analysis of the vertical discharge profile in the ADCP data provides a robust method for determining the appropriate Surface Alpha coefficient for the accurate calculation of discharge for all surface velocimetry techniques, including EO based methods.

The application of this ADCP data tool to surface velocimetry techniques, highlights two significant development needs:

1. QRev does not currently report the surface alpha value directly, leaving the user to derive it manually from the discharge profile extrapolation plot. ***Recommendation:*** Reporting of surface alpha should be added.
2. The QRev discharge profile plot provides an automated assessment of the vertical discharge profile, and suggests an appropriate extrapolation to the surface, but these do not always appear to be optimized. The software also permits user intervention to adjust the extrapolation, which can change the value of the surface alpha by anything up to 5% (Figure 2). For ADCP discharge calculations the impact on total reported discharge is minimal, as only the top, unmeasured slice of the water column is affected. However, for surface velocimetry, the surface alpha value selected is applied to the entire cross-section, greatly increasing sensitivity to this parameter. ***Recommendation:*** Algorithms should be optimized to report the correct surface alpha value automatically.

In conclusion, the QRev software should be refined to inform the surface alpha values more robustly and consistently, recognizing the relatively large impact of any error on surface velocimetry techniques.

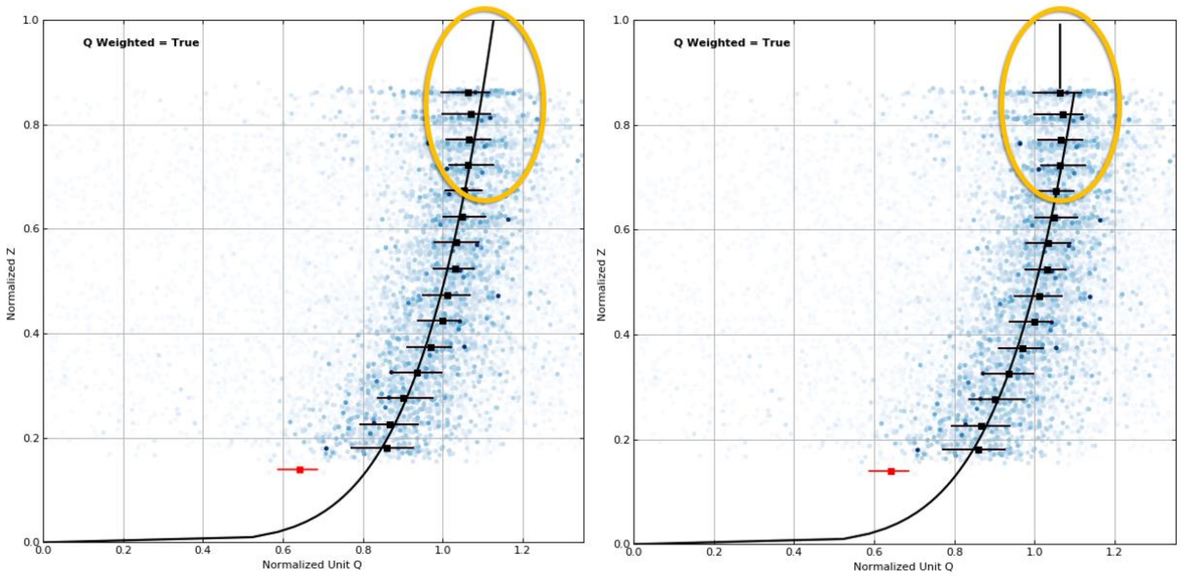

Figure 2 QRev vertical discharge profile analysis, River Tay at Ballathie, showing automatic top extrapolation (left) and manual (right). In the above case, the impact on ADCP reported discharge will be around 0.5%, but for surface velocimetry techniques, around 5%.

5.3. Satellite altimetry

Understanding the height of the water's surface is critical to accurately reporting river discharge. Research is needed to assess options for obtaining this information via remote sensing technologies.

Existing SAR satellites could have the potential to provide this information, and the potential of NASA's soon-to-launch Surface Water and Ocean Topography (SWOT) mission should be explored.

5.4. Site metadata

For FluViSat, as for all non-contact discharge measurement techniques, to calculate river discharge, certain metadata is required. Effectively obtaining and utilising this information is crucial to this method, but also to other measurement methods employed by the hydrometry community.

River cross-sectional area – The cross-sectional area of the river at the location of the velocimetry measurement must be known in order to calculate discharge. This information could be provided by means of a cross-sectional survey with an ADCP or other suitable depth mapping sensor such as an acoustic sonar. For FluViSat validation activities, an ADCP was used wherever possible.

Stability of river cross-section – Rivers will exhibit varying degrees of morphological stability. In some cases, the physical characteristics of the channel, including the cross-section, will be subject to very little change over time, while in others significant change can occur more or less continually. Optimally, surface velocity measurement sites (whether measured by drone, ground-based camera or satellite) will be chosen where morphological change is minimal, or at least predictable. Failing this, understanding the scale, drivers and timing of morphological change will be important to ensure the accuracy of observations over time.

Vertical velocity profile – To enable the accurate determination of river discharge, the surface alpha coefficient representing the relationship between the speed of the water's surface and the mean speed throughout the water column is required. A standard approach, including for FluViSat validation activities, is to analyse ADCP data to inform the correct surface alpha coefficient wherever possible.

Water surface height – Once a morphologically stable measurement location has been selected, variation in cross-sectional area will be driven by changes in the height of the water's surface. Water surface height can be obtained by local observations at the site, either manually or using water level sensors. To fully realise the potential of FluViSat for remote unsupervised observations, water surface height could potentially be provided by satellite altimetry, as discussed above.

6. Building the community

Refinement and uptake of this new hydrometric approach is dependent on building a community of practice that brings together a network of global experts from both the EO and hydrology sectors. This approach has proved successful in previous 'revolutions' in hydrometric technologies – for example, the uptake of ADCPs in the

1990s and early 2000s. ADCPs are now the benchmark for field-based measurements.

In addition to this, there is need to actively engage with relevant potential user sectors, such as hazard management agencies, reinsurance companies etc., in order to create a user community and have real-world applications for the technology.

7. References

Acharya, BS, Bhandari, M, Bandini, F, Pizarro, A, Perks, M, et al. 2021. Unmanned aerial vehicles in hydrology and water management: Applications, challenges, and perspectives. *Water Resources Research*, 57, e2021WR029925. https://doi.org/10.1029/2021WR029925

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