Quantifying the journey of a turbidity current: How water and sediment discharges vary with distance in Monterey Canyon

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Abstract

Turbidity currents transport vast quantities of sediment across the seafloor and form the largest sediment accumulations on Earth. These flows pose a hazard to strategically important seafloor infrastructure and are important agents for the transport of organic carbon and nutrients that support deep-sea ecosystems. Therefore, it is important to quantify the scale of these flows, the amount of sediment they transport, and the evolution of their discharge over time and space along their flow path. Two modes of flow evolution have been proposed based on experimental and numerical models. The first is termed ignition, where flows entrain seafloor sediment, becoming more voluminous and powerful and increasing their discharge. In the second mode of evolution, called dissipation, sediment falls out of suspension, so flows decelerate and lose discharge. Thus far, field-scale turbidity currents have only been measured at a handful of sites worldwide, and never in detail at multiple locations along their full course. Therefore, it has not yet been possible to determine when, where, and why flows diverge into these two modes in the deep sea, or how flow discharge varies. The ambitious multi-institution Coordinated Canyon Experiment measured turbidity currents at seven instrumented moorings along the Monterey Canyon, offshore California. Fifteen flows were recorded, including the fastest events yet measured at high resolution (>8 m/s). This remarkable dataset provides the first opportunity to quantify down-channel sediment and flow discharge evolution of turbidity currents in the deep sea. To understand whether flows ignite or dissipate, we derive total and sediment discharges for each of the flows at all seven mooring locations down the canyon. Discharges are calculated from measured velocities, and sediment concentrations are derived using a novel inversion method. We observe two distinct flow modes, as most flows rapidly dissipated in the upper reaches of the canyon, while three ran out for the full 50 km array length. We then explore why only these three flows ignited and discuss the implications for canyon and channel capacity and evolution.

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1.0. Motivation

Turbidity currents transport vast quantities of sediment across the seafloor and form the largest sediment accumulations on Earth (Talling *et al*., 2012). The power of these flows is driven largely by their speeds >4m/s (Fig.1) and as such they pose a significant hazard to underwater infrastructure including seafloor cables that carry >95% data traffic (i.e. internet and financial markets) (Carter et al., 2012). It is therefore important to quantify the scale of these flows in terms of how their discharge evolves along their course in order to progress towards characterising a flow beyond its velocity. The variability of these flows can be classified by two modes of flow evolution, which have been proposed based on experimental and numerical models (Piper, Cochonat and Morrison, 1999). The first of which is termed ignition, where flows entrain seafloor sediment and become more voluminous and powerful and increase in discharge. Secondly dissipation can occur, where sediment falls out of suspension, flows decelerate and lose discharge.

2.0. Dataset

- Multi-institution Coordinated Canyon Experiment (Oct 2015-Apr 2017) measured turbidity currents at 6 moorings along the Monterey Canyon, offshore California.
- The dataset used was recorded on 15th Jan, which was an ignitive event that ran out the entire 50km mooring array (MS1,MS2,MS3,MS4,MS5,MS7).
- Discharges have been calculated from velocities recorded by a series of 300kHz Acoustic Doppler Current Profiler (ADCP) fitted to each mooring station.
- ADCP's are down-ward looking and have been suspended above the seabed at heights ranging from 65m (MS1) to 74m (MS7).

3.0. Method

3.2. Down canyon changes in velocity magnitude and cross section at each mooring station

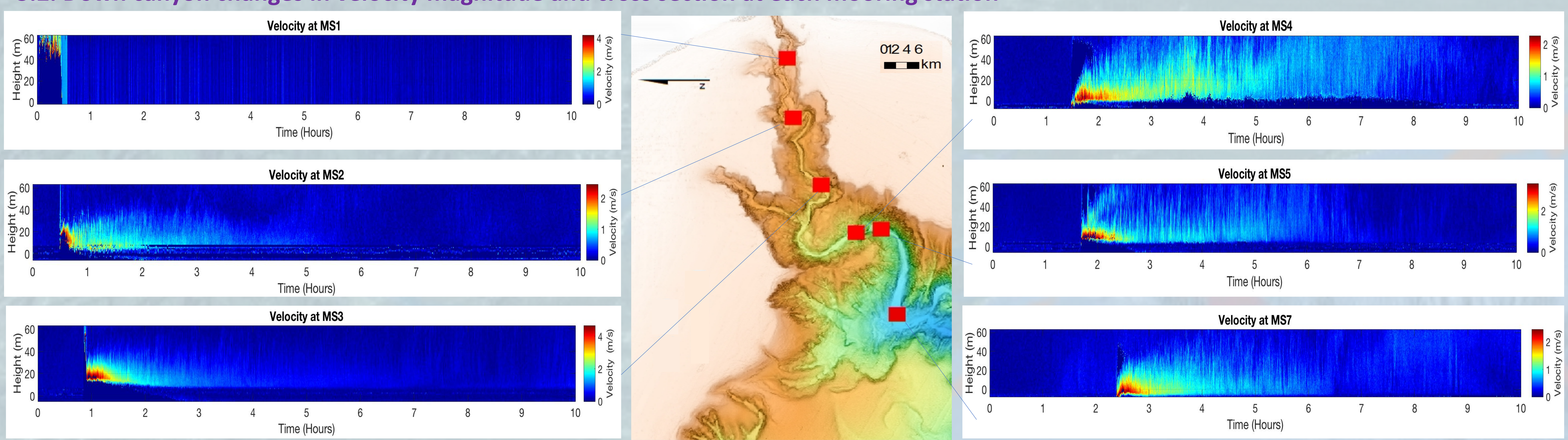

Fig.1. ADCP measured velocity profiles at each mooring site showing head, body and tail regions of a turbidity current. The head and body regions represent the fastest velocities (red) ; the tail is associated with the slowest velocities (light blue), while ambient/surrounding water is stationary (0 m/s) and represented by the darkest blue.

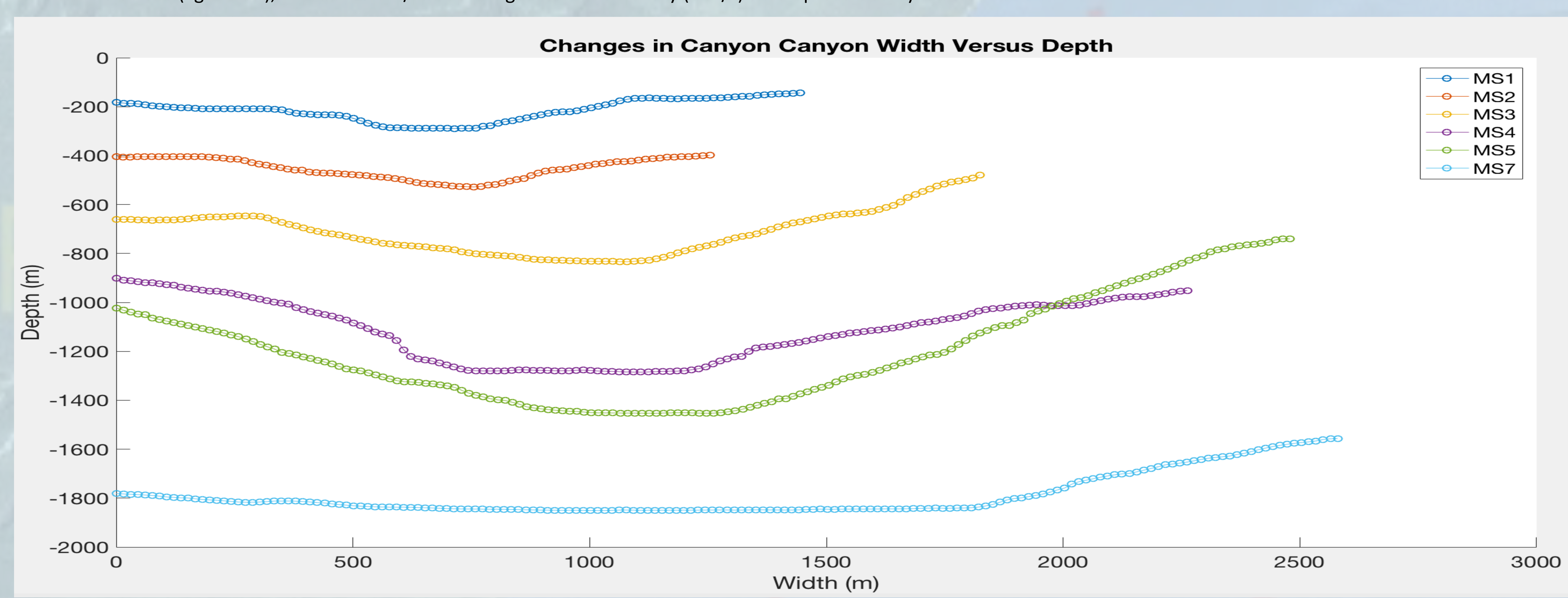

Fig.2. Changes in canyon cross-sectional area down-canyon, from the head (MS1) towards the fan (MS7). At increasing depths ranging from 143m (MS1) to 1850m (MS7) canyon width is increasing from 184m at MS1 to 1540m at MS7 after interpolating the points on the curve and subtracting data points on the left hand side from the right hand side.

4.0. Results: Total discharge at each mooring

- Velocity (Fig.1) and total discharge (Fig.2) are much higher in the mid canyon due to mixing caused by entrainment.
- Between MS3 to MS4 there is a significant decrease in discharge is possible due to sediment settling very quickly out of suspension could which is suggestive of flow dominated by coarse sediment.

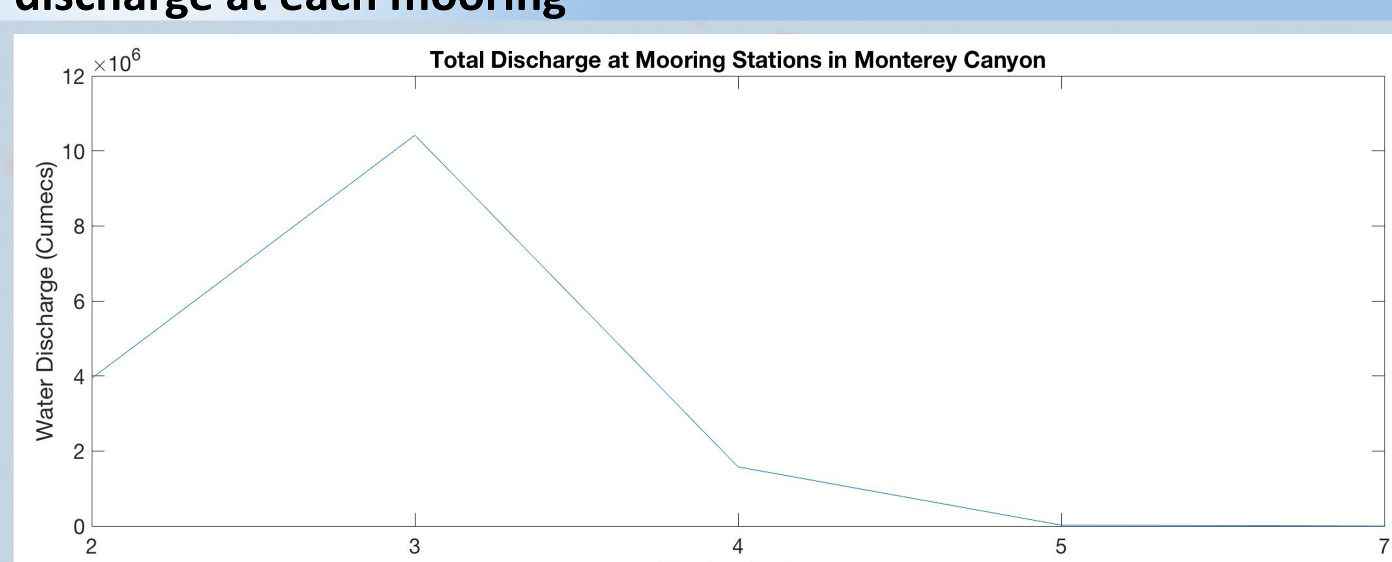

Fig.3. Total Water discharge in Monterey Canyon during 15th Jan turbidity current event, where discharge increases by more than double initially from 3.9 million Cumecs at MS2 to 10.4 million Cumecs at MS3. Discharge rapidly decreases by over a factor of 4 declining to 1.6million Cumecs (MS4) and 23,900 Cumecs, (MS5).

Results: Average discharge at each mooring

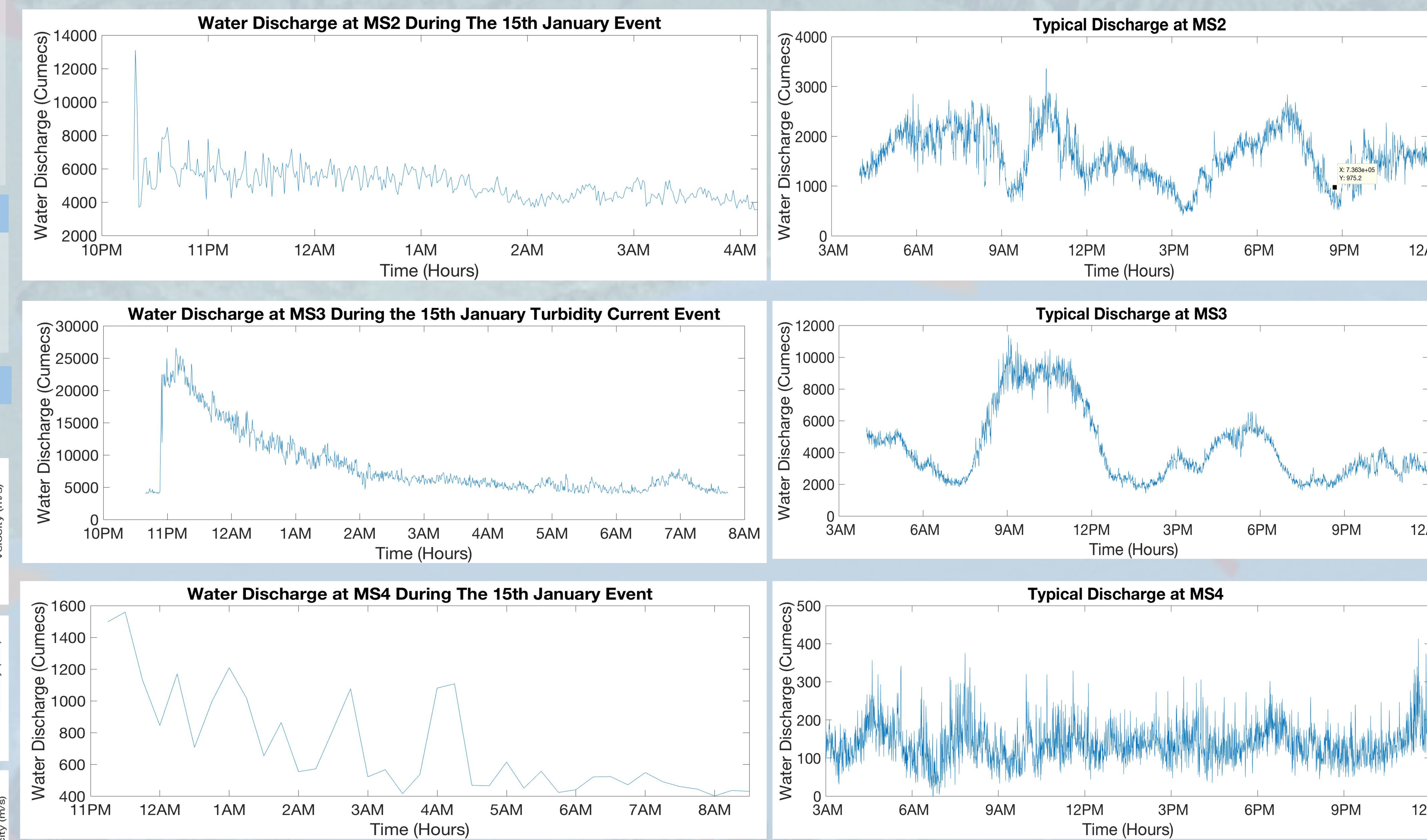

Fig.4. Average water discharge at each mooring in Monterey during the January 15th Event (left hand side, where the discharge data shown has been defined by threshold values based upon the average water discharge present at each location under normal conditions. (right hand side).

6.0. Uncertainties

- Side lobe interference due to acoustic signals reflecting off the side of the canyon below the ADCP and causes data loss, however can be mitigated by extrapolation.
- Effects of Internal tides specifically at MS4 where the data seems to indicate a normal discharge of 10,000 Cumecs which suggests they are slow but thick and that perhaps the tides have more strength further up the canyon.
- Changing mooring height, which occurred at MS1 where mooring was dragged almost parallel to the seabed due to initial force of turbidity current and data was lost as a result at MS1.

7.0. Conclusion

- Discharge increases as flow velocity increases, with peak velocities occurring in the Mid Canyon (MS3) where average discharge also peaks at an average of 27,000 Cumecs and a total discharge of 10.6 million Cumecs.
- At MS3 average discharge is almost twice that of the Mississippi river and significantly higher than other submarine environments including the Congo canyon (~16,000 Cumecs) (Azpiroz-Zabala et al., 2017).
- The rapid decline of discharge is an entirely unexpected result as discharge in theory should continue to rise or plateau.
- Suggests mixing is somehow turned off as sediment settles out and de-entrains water such that it becomes static and is no longer in the flow
- One explanation is that coarse sediment is present and settles quickly out of suspension however sediment trap data shows fine sediment and mud are present in turbidite deposit.

8.0. Future Research

- Quantifying the discharge will form the basis of other models including those that address how much sediment these events transport, using a novel entrainment method.
- This will allow for greater insight into why these flows entrain and de-entrain so rapidly, and as a result it will be possible to isolate which mechanisms are responsible for controlling these internal flow processes.
- Overall, by studying sediment and water discharges our understanding of the wider context of why these flows vary significantly from one to another will be greatly improved.

References

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