EMSO TIME SERIES CONFERENCE
OBSERVING OCEAN SOUND
20-22 OCTOBER 2021
CANARY ISLANDS SPAIN

Incidental noise measurements from acoustic Doppler current profilers reveal the near-bed flow speed of oceanographic turbidity currents

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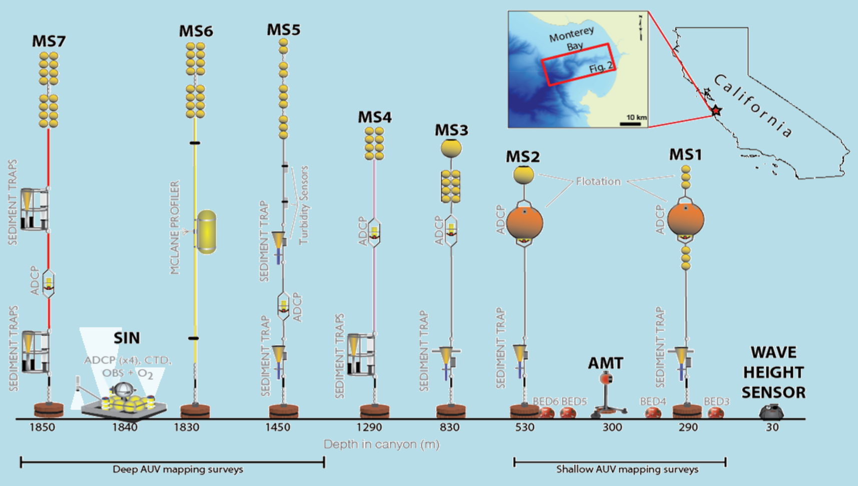
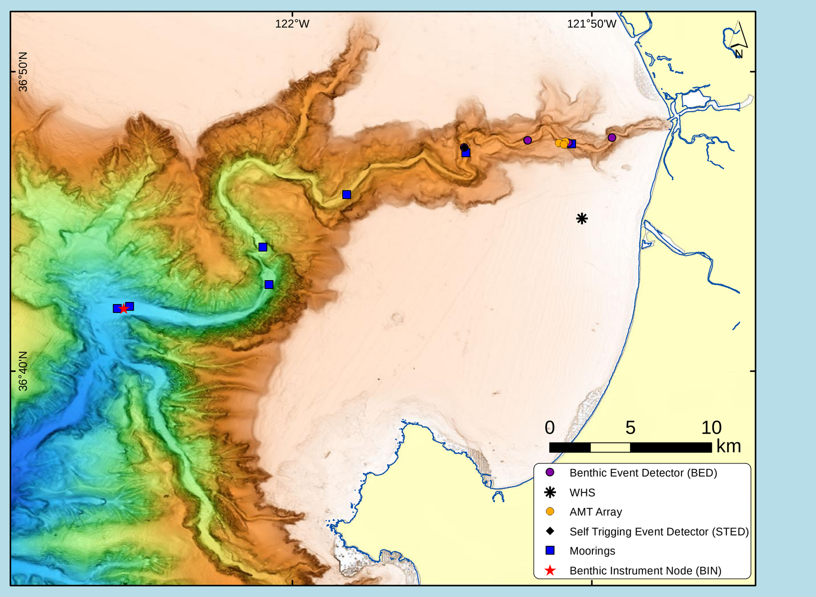
Turbidity currents are responsible for transporting and depositing the largest accumulations of sediment on Earth. Recent monitoring of these episodic flows, using acoustic Doppler current profilers (ADCP) deployed in submarine channels, has recently revealed their flow structure. However, acoustic measurements of flow speed in the near-bed region are often compromised by highly attenuating sediment concentrations and sidelobe effects. Here, we describe how incidental measurements of passive noise in the ADCP backscatter signal observed during the passage of turbidity currents through Monterey Canyon, offshore California, gives an indication of the flow speed in the compromised near-bed regions. We infer that the noise signal is generated by sand-sized particle collisions using the relationship between particle size and acoustic frequency developed for bedload sediment transport in rivers. The relationship between noise magnitude and flow sped is, however, similar to the relationship recently reported during the passive monitoring of turbidity currents using hydrophones in British Columbia. From this we infer that it is sand particle collisions in suspension that are principally responsible for generating the noise. This method opens up the possibility of re-examining existing data sets from multiple deployment locations worldwide to infer turbidity current flow speed and suspended particle grain size

MONTEREY COORDINATED CANYON EXPERIMENT

- Most intensive monitoring of submarine canyon carried out to date with the purpose of monitoring of episodic sediment-laden avalanches of sediment referred to as turbidity currents
- 18 month experiment duration with instruments deployed from October 2015 to April 2017
- 7 moorings and numerous instruments deployed in channel axis including 6 downward-looking acoustic Doppler current profilers (ADCP) operating at 300 kHz that profiled flow velocity over a range of ~60 m above the channel floor
- 16 flow events observed during 18 month period
- 3 flows ran out through the entire instrument array over a distance of 50 km to depths of 2000 m
- Acoustic noise was observed in the backscatter recorded by the ADCPs. We relate the magnitude of this noise to the flow speed and infer that it was generated by sand-particle collisions in suspension within the flow
- The noise magnitude can be used as a proxy for flow speed. This helps to overcome problems with the Doppler method that arise from sidelobe interference in the near-bed region



Mooring and instrument array

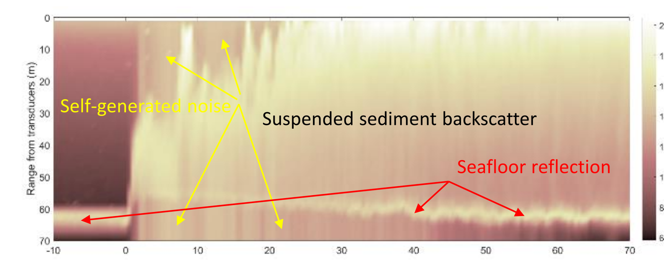


Monterey Canyon and mooring locations, offshore California

DETERMINING THE NEAR-BED FLOW SPEED OF THE TURBIDITY CURRENTS FROM THE PARTICLE COLLISION NOISE

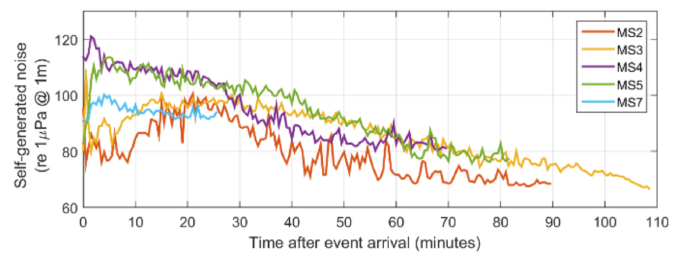
Incidental noise signal is recorded by ADCPs as the turbidity currents pass the moorings. The noise magnitude is related to flow speed.

Acoustic backscatter data show scattering by sediment within the turbidity current and also a noise signal generated within the faster-moving flow front



Received Signal Strength Indicator (RSSI) for mooring MS5 during passage of January 15 event

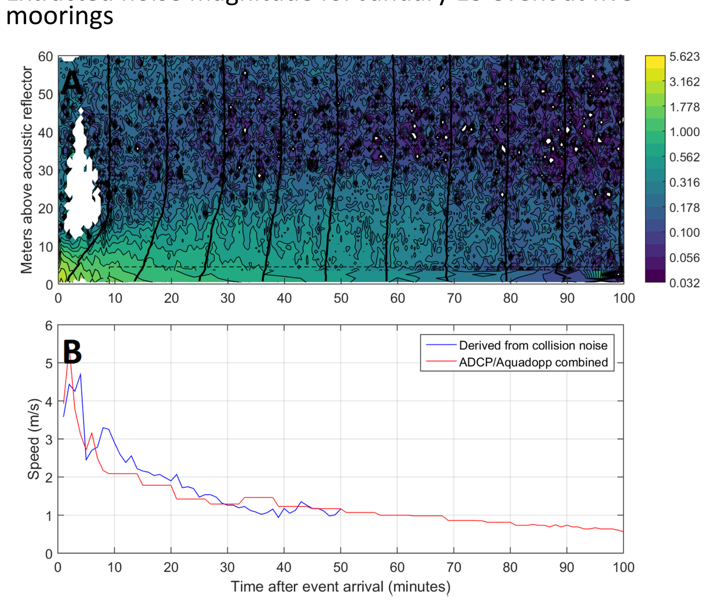
This noise signal is extracted here for five of the moorings for the largest event on January 15° 2016 that ran through the full mooring array



Extracted noise magnitude for January 15 event at five moorings

The ADCPs had difficulty measuring flow velocities accurately in the near bed region of the flows due to sidelobe interference

An Aquadopp on one mooring succesfully measured near-bed velocities. The velocity magnitude maxima are correlated with the seventh power of flow speed, enabling estimation of flow speed from noise magnitude alone

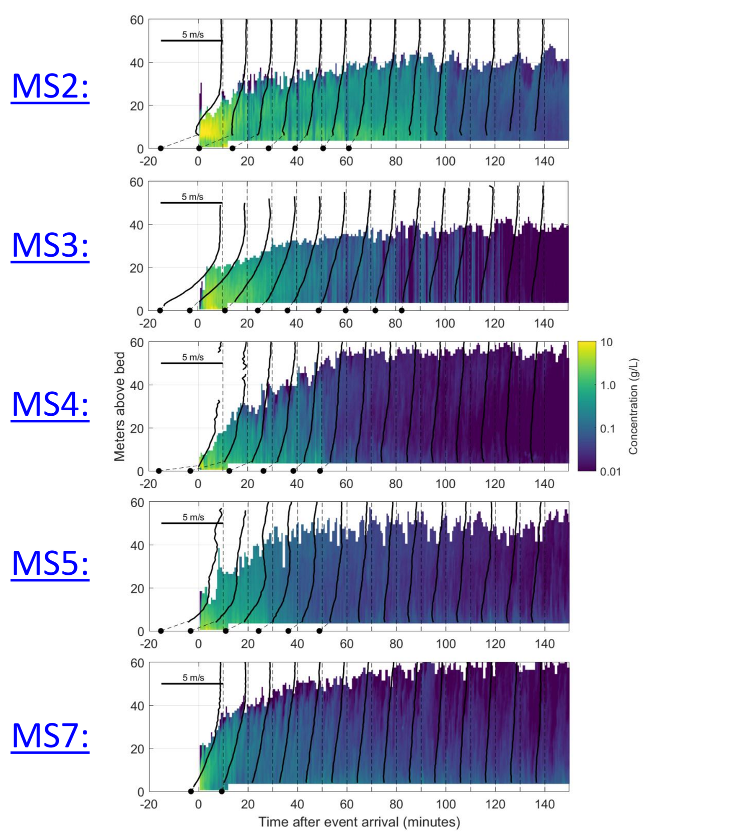


A composite image of flow velocities recorded by mooring MS3 during the passage of a flow by a 300 kHz ADCP at 60 m above the channel floor and a 2 MHz Aquadopp at 10 m above the channel floor. **B** velocity magnitude maximum as a function of time from the ADCP/Aquadopp flow data and flow speed derived from the noise magnitude

ADCP-derived flow structure of January 15 event at multiple moorings compared with noise-derived flow speed

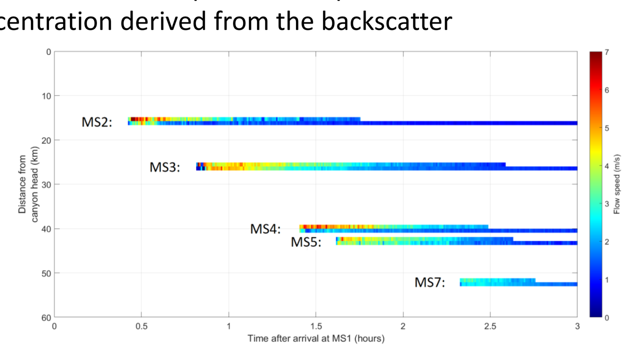
Using the calibration of the noise magnitude to flow speed maxima obtained with the Aquadopp, flow speed as a function of time is derived for each of the individual moorings during the January 15 event

Noise-derived flow speeds tend to be slightly faster than the maximum of the ADCP-derived flow profiles and this is likely due to sidelobe interference relating to the channel floor, bedforms and channel flanks



Flow velocities and suspended sediment concentrations at five moorings during the January 15 event. The noise-derived flow speeds are represented by the solid dots and solid lines represent the ADCP flow speeds through the water column. The colorbar scale represents suspended sediment concentration derived from the backscatter

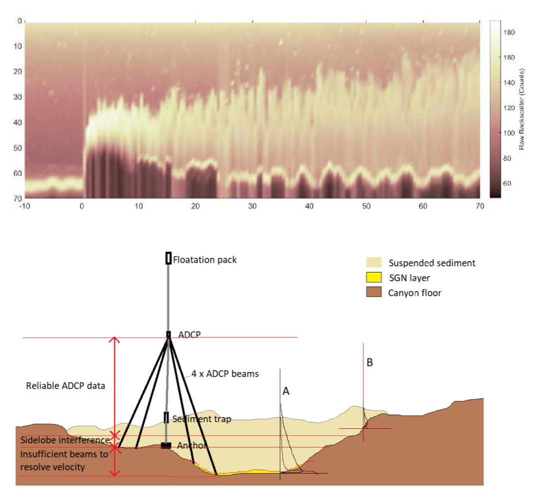
This plot of noise-derived and ADCP maximum flow speeds demonstrates how the noise signal is being picked up simultaeously at multiple moorings over a distance of ~25 km along the channel



Noise-derived flow speeds (above) and ADCP maximum flow speeds (below) plotted as function of time

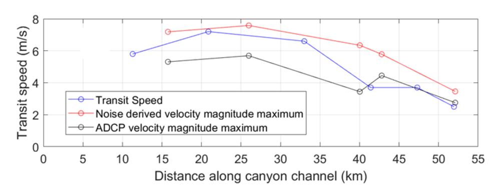
Noise-derived flow speeds show better agreement with the flow front speed than the ADCP Doppler measurements

Sidelobe interference in the near-bed region is a significant issue for ADCP flow measurements, particularly when there is an irregular seafloor topography. This issue was acute for some of the moorings in the canyon that landed in positions close to the channel flank during deployment. As the ADCPs are free to rotate on the mooring, the noise signal fluctuates as the individual beams are steered alternately between the dense flow within the channel and the channel flanks. This effect can be mitigated by selecting the beam that is steered towards the deepest part of the channel, thus providing a flow speed measurement method that overcomes the sidelobe interference issue associated with the Doppler method



Upper plot shows the backscatter from a single beam at MS2 during the passage of the January 15 event. As the instrument rotates on the mooring the beams are steered in and out of the deepest part of the channel. The particle collision noise thus varies with compass heading

The noise-derived flow speeds are generally greater then the maximum flow speeds recorded by the ADPCs using the Doppler method and show a better relationship with the transit speeds calculated by using the arrival time at each mooring and the distance between the moorings



Comparison of the transit velocities between the moorings determined by the arrival team at each ADCP and the maximum velocity recorded by the Doppler method and the noise-derived flow speeds

RELATING THE PARTICLE COLLISION NOISE TO TURBIDITY CURRENT FLOW SPEED

The downward-looking ADCPs on a frequency of 300 kHz with a 75 kHz bandwith pick up a clear particle collision noise signal from the deepest parts of the channel. The noise magnitude is related to the flow speeds using a relationship previously observed in Howe Sound, British Columbia using a hydrophone mounted above passing turbidity currents (Hay et al, JASA Express Letters 1, 070801 (2021)). The ADCPs pick up this noise signature as incidental data but it can be used to determine flow speed in regions of the flow near the seafloor in which Doppler measurements are compromised by sidelobes and reflections from the canyon flanks. This method gives an indication of likely flow speeds that better match the transit speeds derived by examining the arrival times of the flows at the different moorings. The acoustic frequency of this noise suggests that it is generated by sand particle collisions. This matches the sediment samples in the sediment traps on the moorings 10 m above the seafloor. The relationship between noise magnitude and flow also suggests that the particle collisions are occuring in suspension within the water column rather than as bedload traction. Similar noise is observed in two upward-looking ADCPs on 600 kHz and 1200 kHz which helps to verify that the noise generation mechanism is related to suspension collisions. Noise is similarly seen in a 2 MHz Aquadopp that is pulled close the the base of the flow. These higher frequencies suggest that smaller-sized sediment particles are also colliding