Predicting Mine Burial at the Martha's Vineyard Coastal Observatory

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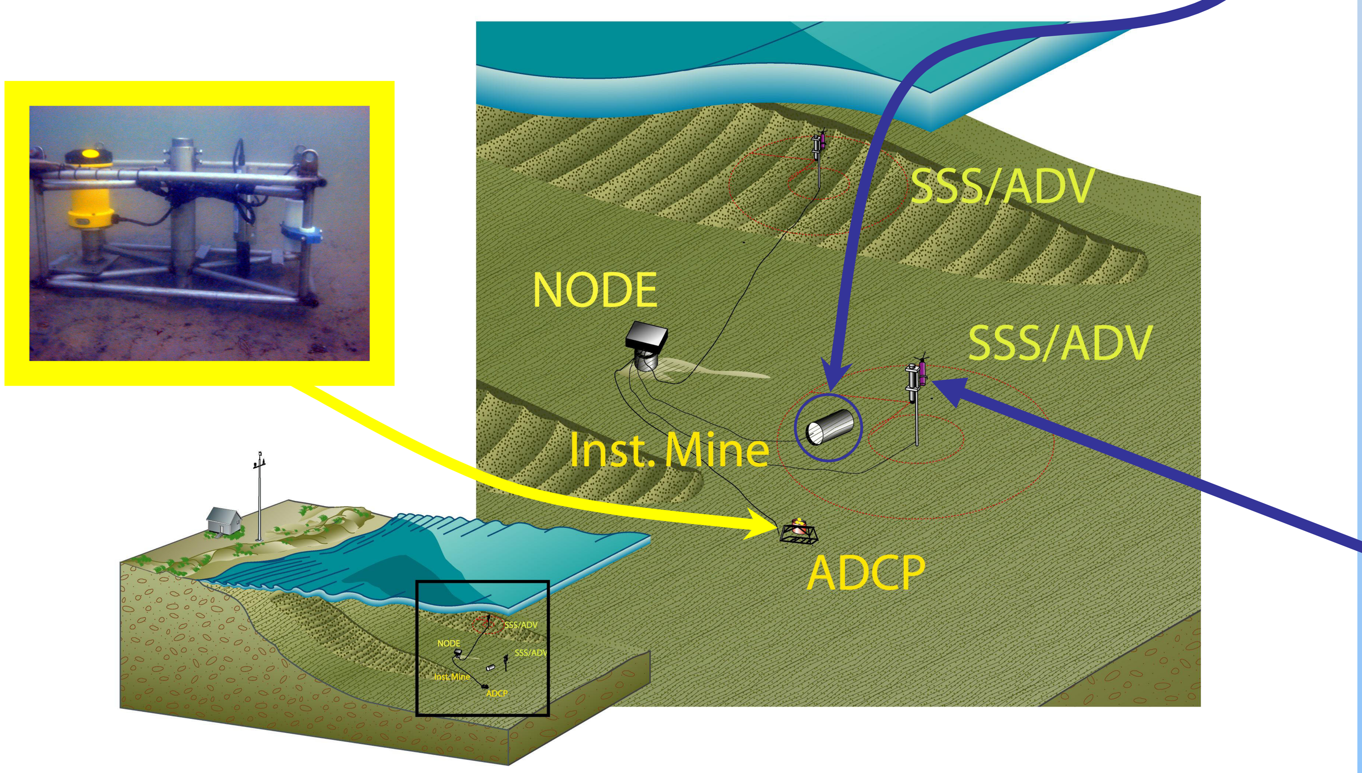
Abstract

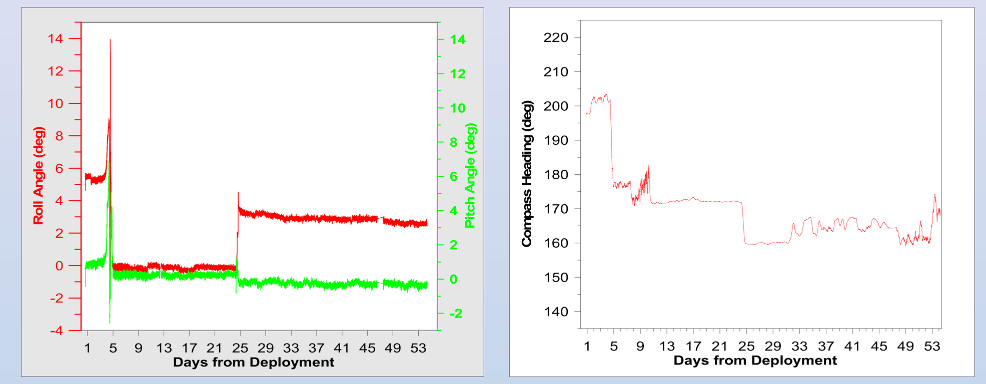
Mine burial by scour and fill was characterized in real-time on a fine sand substrate at the Martha's Vineyard Coastal Observatory using an optically instrumented mine, Acoustic Doppler Velocimeter (ADV), bottom-mounted pressure sensors, and a sector-scan sonar (*see poster by Traykovski and Richardson*). In two separate experiments, episodic scour and fill in response to surface gravity wave stress was responsible for mine burial. In the first experiment complete burial was achieved by changes in seafloor morphology. The mine did not completely bury in the second experiment. The effect of tidal currents on mine burial was minimal for both experiments. A time-scaling scour burial model based on amplification of sediment transport around the mine and modified by infilling was found to accurately predict mine burial. The wave orbital velocity measured at the sea floor using the ADV was similar to orbital motion predicted from wave height and period, which were derived from a NOAA regional wave model (WaveWatch III). These experiments and model comparisons suggest burial by scour can be accurately predicted from sediment type (mean grain size), bathymetry, mine characteristics, and measured or modeled wave statistics and bottom currents.

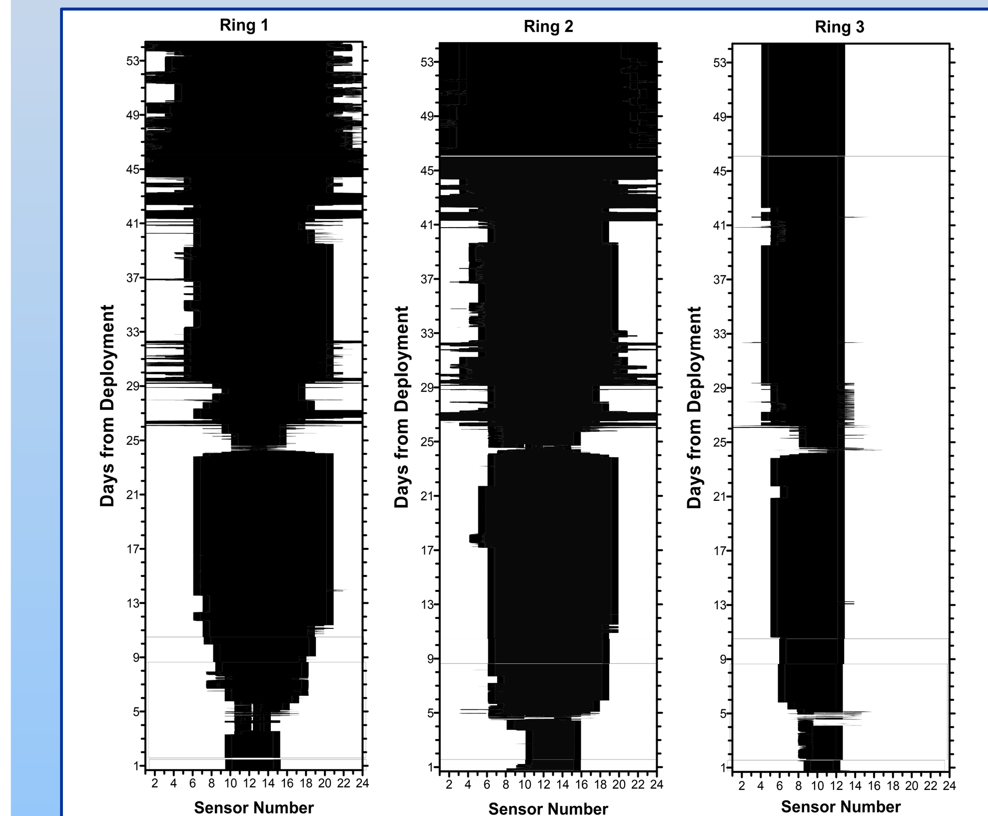
Martha's Vineyard Coastal Observatory Instrumented Mine Deployments



The NRL design is based on an instrumented mine developed by Ingo Stender of Forschungsanstalt der Bundeswehr für Wasserschall- und Geophysik (FWG) in Kiel, Germany [4]. Heading (+/- 1°) is measured with three solid-state compasses and roll and pitch (+/- 1°) of the mine are measured with a three-axis accelerometer. Burial is measured by three rings of paired optical sensors externally mounted at 15° intervals around the mine. Transmitting optical sensors are LED's and receiving sensors are phototransistors. Burial is measured by blockage between these sensors. The mine above is made of aluminum and is 1.5 m long and 0.47 m in diameter. The weight in air is 619 kg and in water is 357 kg but these weights are adjustable. During the experiments, measurements were made every 2-5 minutes and transmitted to a shore-side computer at MVCO.

Instrumented Mine Data April 5-May 28, 2002





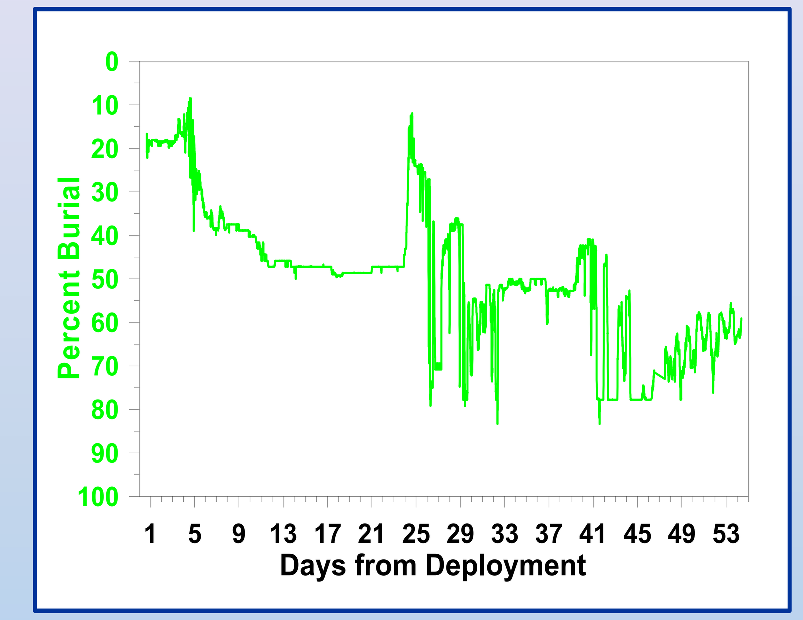
Observations

Based on the sensors of the mine:

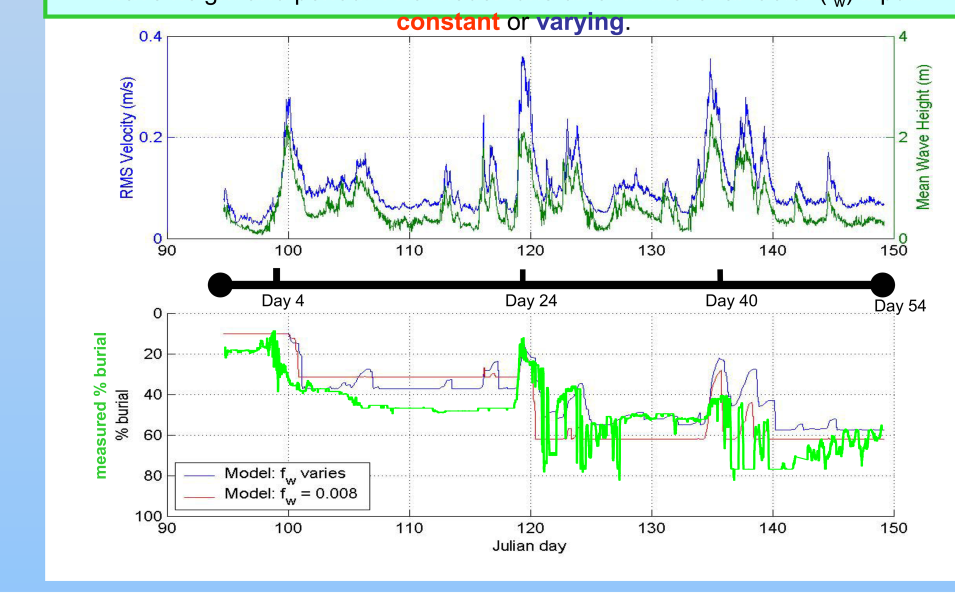
- During the second deployment complete burial did not occur.
- On days 32 and 41, percent burial was maximum at 82% (*right, above*), with one end of the mine exposed.
- Changes in roll and pitch of the mine were coincident, during days 4 and 24 (*left, above*). On day 4 the mine rolled 9° clockwise, then 15° counterclockwise; on day 24 the mine rolled 4° clockwise, then 1° counterclockwise.
- The orientation of the mine changed 35° during day 4 and 12° during day 24; the same days the mine rolled and pitched.
- Coincident changes in roll, pitch, and orientation on days 4 and 24 are likely due to the mine rolling into its scour pit. Evacuation of sand from around the sensors (*left*) on days 4 and 24 (and to some lesser extent on day 40) is an indication of large amount of scour from around the ends of the mine.

Based on the environmental inputs and scour burial modeling:

- High bed stress, indicated by the orbital velocities and mean wave height (*right, below*) coincided with the mine movement on days 4 and 24 and scour/burial on day 41.
- Predictions of mine burial due to scour are made with the Wallingford equations (*right, below*). These predictions are compared with burial estimated from the optical sensors on the mine (in green, right, below).
- The models initially underestimate burial, but by day 24 (and two significant bed stress events) agree with measurements. However, after the third significant bed stress event on day 41 the model has again diverged toward underestimating burial.
- Bed friction does matter; two predictions indicated by red (constant friction factor) and blue (friction factor varying with current speed) are similar, but not identical. The model with constant friction tends to over-predict burial as time progresses.



ADV data and estimated current stress between April 5, 2002 and May 28, 2002. Burial is predicted from models run using orbital velocity calculated from mean wave height and period. Two model runs differ in frictional factor (f_w) input: constant or varying.



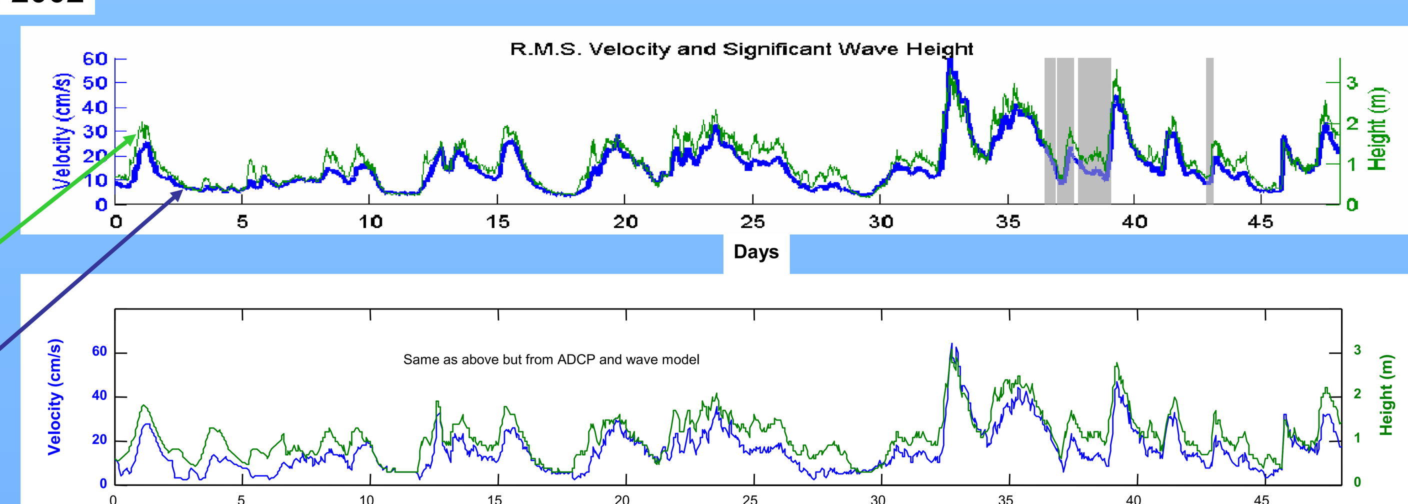
First Experiment (Dec 5, 2001 to Jan 22, 2002)

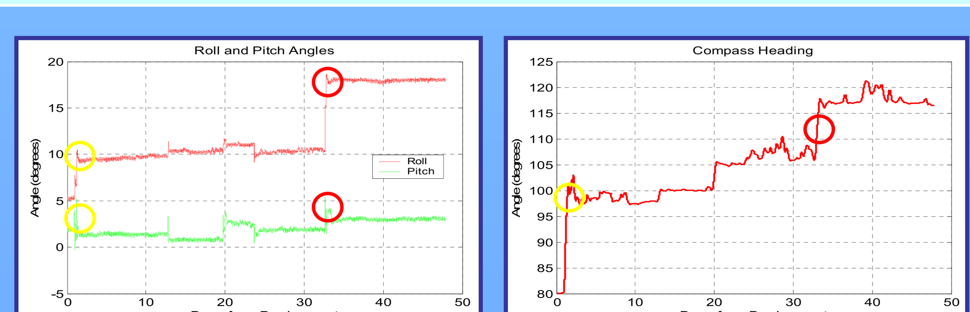
Geological, Meteorological, and Oceanographic Results

Sediment in the vicinity of the experiment was a moderately well sorted, fine quartz sand with a mean grain size of 0.18 mm (2.5 phi), average grain density of 2661 kg m^{-3} (SD = 11 kg m^{-3}), porosity of 38.5% (SD = 0.7 %) and bulk density of 2042 kg m^{-3} (SD = 11 kg m^{-3}). An average of 95% (by weight) of the sediment was sand sized with most grains between 0.1 and 0.35 mm.

Several weather systems passed through the region between deployment days 31 and 45, resulting strong southerly winds which produced large waves. Significant wave heights were calculated from pressure spectra measured by the Nortek Vector ADV. Significant wave heights reached just over 3 m during the stormy period between deployment days 31 and 42 with larger waves having periods between 8-12 seconds.

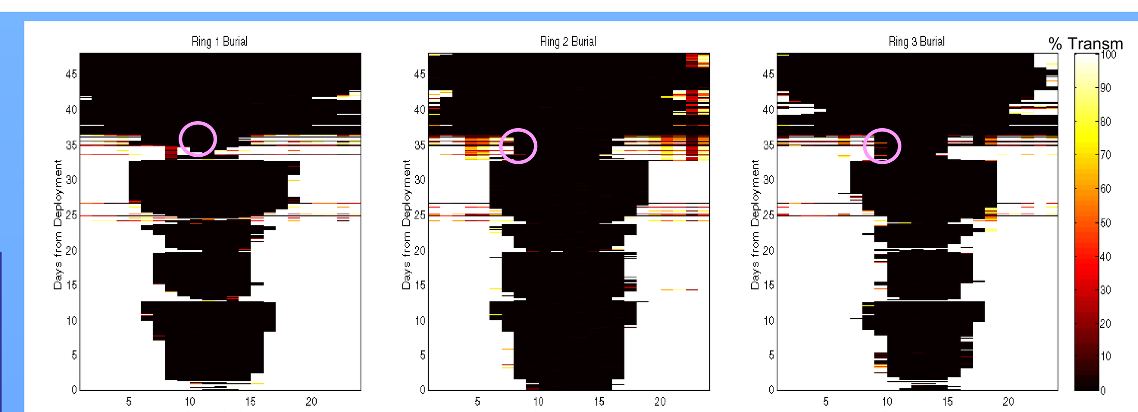
Tidal flows are semidiurnal and ranging between 0.5 and 1.4 m and have magnitude of +/- 20 cm s^{-1}. During the deployment period one significant wind forced event (deployment day 39) resulted in an additional 20 cm s^{-1} of current for a maximum current speed of 40 cm s^{-1}.

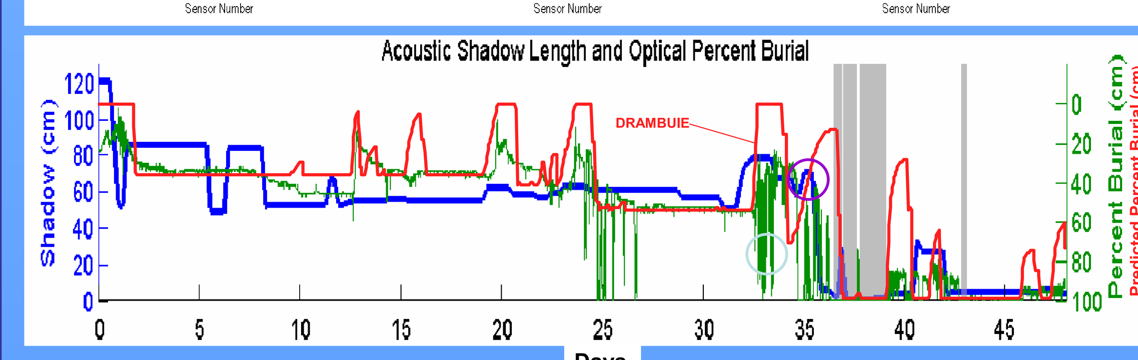




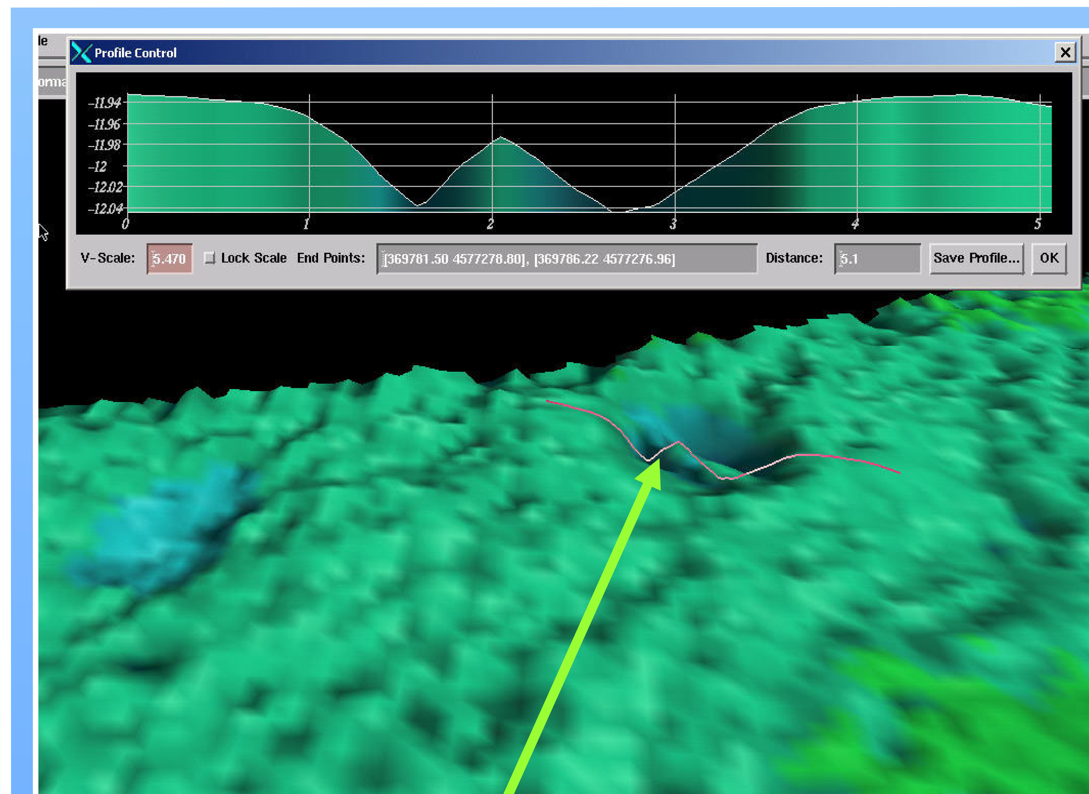
Instrumented Mine Data

- Initially, the mine had an azimuthal heading of 80°, was rolled clockwise on its long axis at 5.5° from vertical, and was pitched upward at 2.0° (*above*). Approximately 25% of the 72 sensors were blocked with sediment. Both ends of the mine (rings 1 and 3) were progressively scoured until only 5-10% of the sensors were blocked at day 0.96 (*right and below*).
- During the next 10 hours the mine pitched up and down 4 times, rolled clockwise 5°, ultimately ending up at nearly 10°, and rotated clockwise to a heading of 100°. These data suggest the mine progressively pitched on it long axis, eventually rolling into its own scour pit and reorienting to a heading perpendicular to the incoming swell.
- During the days 24 to 27, the percentage optical sensors blocked varied rapidly between 30% and 100%, with oscillations of high indicated burial occurring over periods of 15 minutes to 3 hours. Average burial increased from 30% to 55% while no change in pitch or roll angle was noted.
- At day 32.5, the percentage of blocked optical sensors began to oscillate wildly, with short bursts of a high percentage of sensors blocked (up to 80-90%) for the next 24 hours.
- At day 32.67 and 32.74 the mine pitched through 2-3°, rolled clockwise 5° then again 3° ending up at 18° and the mine rotated clockwise 10° with the heading ending at 116°. This was the last significant roll or pitch of the mine for the remaining period of deployment.
- Rapid infilling began at day 34.6 and the entire mine was apparently buried in less than 3 hours. The mine remained buried for the next 5 hours (day 34.7-34.9).
- Two short additional periods of complete burial occurred between day 35.3 to 35.5 (3 hours) and day 35.90 to 36.05 (3.5 hours) with no apparent change in orientation of the mine.

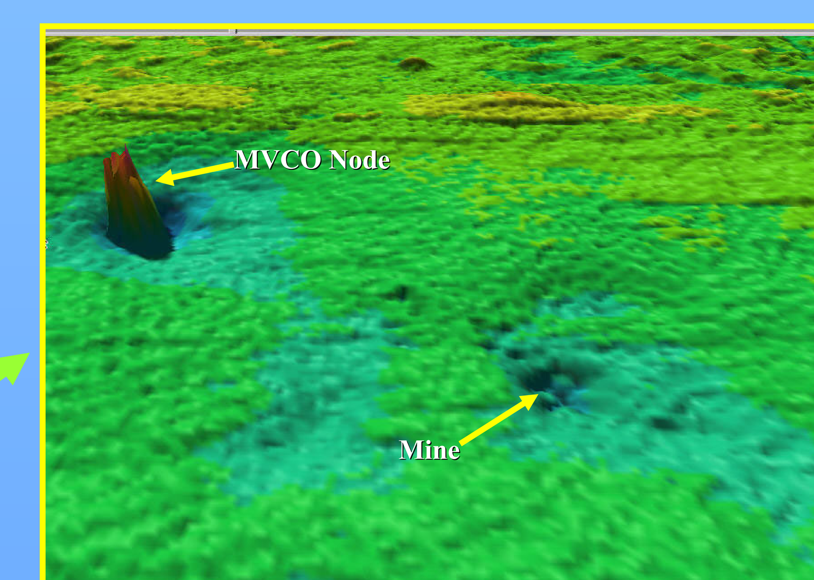




The gray shaded regions indicate periods when fine sediment had infilled the scour pit.



Current scour models (DRAMBUIE) are tracked by our measurements with our mine with optical sensors. There are, however, 10-20% discrepancies between model predictions and data. We need to examine the relationship between the RMS velocity and the orbital velocity because the RMS velocity probably contains both orbital velocity and current components. It would be better to have these components decoupled so that the stresses can be computed more accurately. The scour model, as written, does not account for boundary layer depth changes as the mine buries. Obviously, this is a shortcoming that should be addressed. Once these problems are rectified we will be better able to evaluate the models for mine scour burial. Another deployment of the optical sensor mine at MVCO was made in December 2002.



Seafloor microtopography from towed multi-beam sonar (*courtesy SAIC, UNH, and Reson, Inc.*) shows exposure of the top of the mine within a depression. This depression is likely to have resulted from scour. Turbulence has prevented the mine from being totally buried, but because the top of the mine is below the sediment-water interface it may be difficult to detect.

Summary

- These detailed observations suggest mine burial is not a continuous process but consists of episodic events of scour and fill:
  - Both ends of the mine rapidly scour (1-6 hours) in response to increases in significant wave height leaving the mine perched on a central pedestal.
  - When this pedestal is insufficient to support the mine, the mine rapidly pitches and rolls into the scour pit, possibly changing heading to match the incoming swell. This action can occur within a few minutes.
  - The scour pits around the mine slowly fill with the next few days and the mine is more deeply buried. These events are repeated until the mine is completely buried.
- Scour around the mine tends to occur when significant wave heights exceed 1.5 m and resulting in bed stresses exceeding 5-8 dynes cm^{-2} from bottom wave orbital velocities in excess of 30 cm s^{-1}.
- In order for the mine to fall into the scour pit, the pit must become deeper than the lowest surface of the mine. Thus, it requires at least as much energy than was in a previous storm to enlarge the scour pit to the point where additional elevation changes of the mine are possible.

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