# Fluvial Anchor Ice/Sediment Dynamics and Ice Rafting

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## LONG-TERM GOALS

The long-term goals of our research are to understand the interactions between frazil, anchor ice, and sediment, and to determine how these interactions affect sediment dynamics in fluvial, marine, and lacustrine environments.

## OBJECTIVES

- Determine how sediment is incorporated into anchor ice masses

- Determine the thermodynamic conditions at the sediment/water interface leading to anchor ice formation

- Understand the initial stages of anchor ice and frazil formation, and how these ice types interact with sediment

## APPROACH

In order to understand how frazil formation and anchor ice formation and release affect sediment dynamics, it is necessary to know when and how dthe ice forms, how anchor ice is released from the bed, what type and how much sediment is ice rafted, and the distance that sediment is ice rafted. In this project we are working in Rocky Mountain streams and lakes to determine when and where frazil and anchor ice form, and to determine the interactions between ice and sediment. We collect field data in November, December, February, and March at times when anchor ice is most likely to form. We monitor river stage, water temperature, weather conditions, and ice conditions. During periods of frazil and anchor ice production, we make daily trips to map ice distributions, collect samples, collect underwater video, and observe flow conditions.

In addition to field observations, we create frazil and anchor ice in the lab using a race track flume in a freezer. The lab work allows us to control conditions and to view the initial stages of anchor ice formation on the bed.

Although our present research is focused on small streams, we are mostly interested in the processes that lead to sediment incorporation into ice and subsequent ice rafting. The insights we garner from this study are applicable to ice-sediment interactions in fluvial, lacustrine, and marine environments.

# Report Documentation Page

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## WORK COMPLETED

*Fluvial anchor ice rafting of large sedimentary clasts.* On 14 February 2005 we placed 24 marked cobbles (tracers), ranging in mass from 72 to 1269 g, on the bed of the Laramie River. This was a time when the surface ice cover had melted, and there was significant diel frazil and anchor ice formation. Over the next six weeks, we made daily trips to the river to monitor ice rafting of these tracers. We tracked the ice-rafted movement of these tracers with GPS.

*Suspension freezing.* Frazil, or small discs of ice suspended in the water column, is the first type of ice to form in turbulent freezing conditions. Frazil and sediment interact in a complex set of ways, known as suspension freezing, to form sediment-laden ice in rivers, lakes, and seas. Suspension freezing is a poorly-understood process. In November 2004, we conducted a series of experiments in Lake Hattie, Wyoming to determine if we could detect Langmuir circulation with an ADV during frazil formation events, and to see if Lc might play a role in bringing sediment and frazil into contact in the water column.

*Race track flume experiments.* A total of 10 laboratory frazil/anchor ice experiments were made using the race track flume described by Kempema *et al.* (1993). The purpose of these experiments was to study the initial stage of supercooling, frazil formation, and anchor ice formation in a controlled setting. We built on the observations of Kempema *et al.* (1993) by using gravel and cobbles from local streams as the substrate in these experiments.

*Development of frazil/anchor ice detectors.* During summer 2004 we revamped the relatively inexpensive frazil/anchor ice detectors we have been developing. The major revision include:

(1) switching from an 8-bit to a 12-bit data logger (Onset Hobo U-12) significantly improved the precision of stage and temperature measurements.

(2) The revamped detectors use an amplified pressure transducer for measuring stage.

This transducer significantly simplifies the detector circuitry and the interchangeability of individual components. The revamped detectors were deployed in the Laramie River in the fall of 2004 to monitor river conditions through the 2004-2005 winter and spring.

## RESULTS

During the six-week period when we monitored the tracers, a total of 19 of the 24 tracers were ice rafted downstream over distances ranging from 1 m to 145 m. Anchor ice formed at night, and the tracers were ice rafted downstream (Figure 1) in mornings when the anchor ice released from the bed. Some tracers were rafted only once, while others were rafted on up to four separate occasions. There is no clear correlation between size of the tracer and the distance it was ice rafted. For example, one of the heaviest tracers (1212 g) was rafted 125 m downstream in one event while the smallest tracer (72 g) was not ice rafted at all. 14 of the 19 tracers were ice rafted more than 40 m downstream. Of these, five were ice rafted more than 100 m downstream. Most of the ice rafted tracers were deposited in riffles when turbulence in broke up the released, floating anchor ice masses, which dropped the entrained sediment back to the river bed. During this period bed shear stress was not high enough to move any material larger than sand, so it appears that anchor ice rafting is an important process for moving coarse streambed material downstream during the winter. However, anchor-ice rafting is ‘spotty’, i.e. clasts are preferentially moved on different days, so the total amount of coarse material moved by anchor ice may be small relative to the amount moved hydraulically in a single large freshet when the entire bed may be in motion.

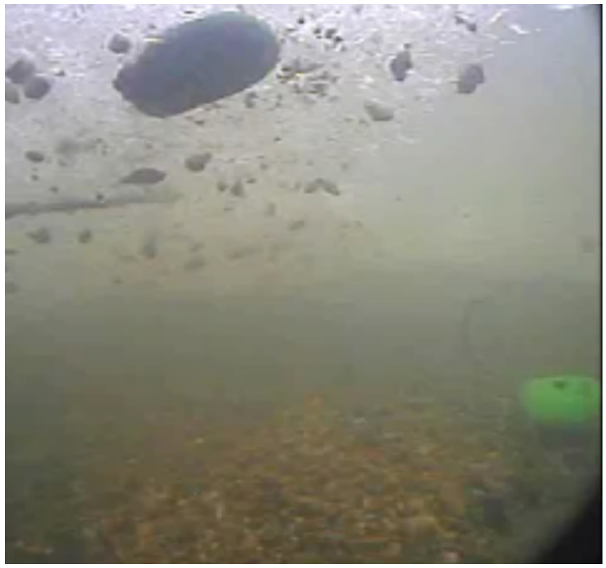

***Figure 1. Still image from an underwater video showing two of the tracer cobbles used to monitor ice rafting in the Laramie River, WY. One bright-green tracer (mass: 263 g) is visible on the bed in the lower right portion of the image. The other tracer (830 g, at the top center of the image), along with assorted gravel, is suspended 30 cm above the river bed in a recently released anchor ice mass. The video clip can be viewed at http://faculty.gg.uwyo.edu/kempema/vidtour.html***

We observed frazil in Langmuir cells in a lake during two mornings in November. These observations consist of water, interstitial water, and frazil ice samples, and of ADV measurements made at 70 cm above the bed in a 1 m deep water column. At the time we made the observations, floating frazil delineated undulating Lc convergence zones on the water surface. The distance between convergence zones was roughly twice the water depth. The ADV time series show a complex, rotating velocity structure in the water column at the ADV position. The time series shows reversing cross stream and vertical velocity components as Lc cells migrate past the ADV position (Figure 2). Downward directed vertical velocities ranged up to 9 cm $s^{-1}$, more than enough to overcome the buoyant rise velocity of individual frazil crystals (Gosink and Osterkamp, 1983) and entrain frazil down into the water column. Both interstitial and frazil samples are enriched in sediment compared to the water column samples (Dethleff and Kempema, submitted), which suggests that frazil was filtering or scavenging sediment from the water column at the time the observations were made.

The flume experiments showed that the initial anchor ice that forms in a gravel- or cobble-bedded stream consists of masses of frazil crystals that are deposited in the interstices between bed particles. As anchor ice growth continues, these initial crystals ‘grasp’ or ‘surround’ bed material, so it is effectively lifted from the bed and ice rafted when the anchor ice is released from the bed (Figure 1). It is not clear why the initial frazil adhesion occurs in the space between cobbles, but anchor ice formation there implies that there may be water flow though the pore spaces in bed gravel.

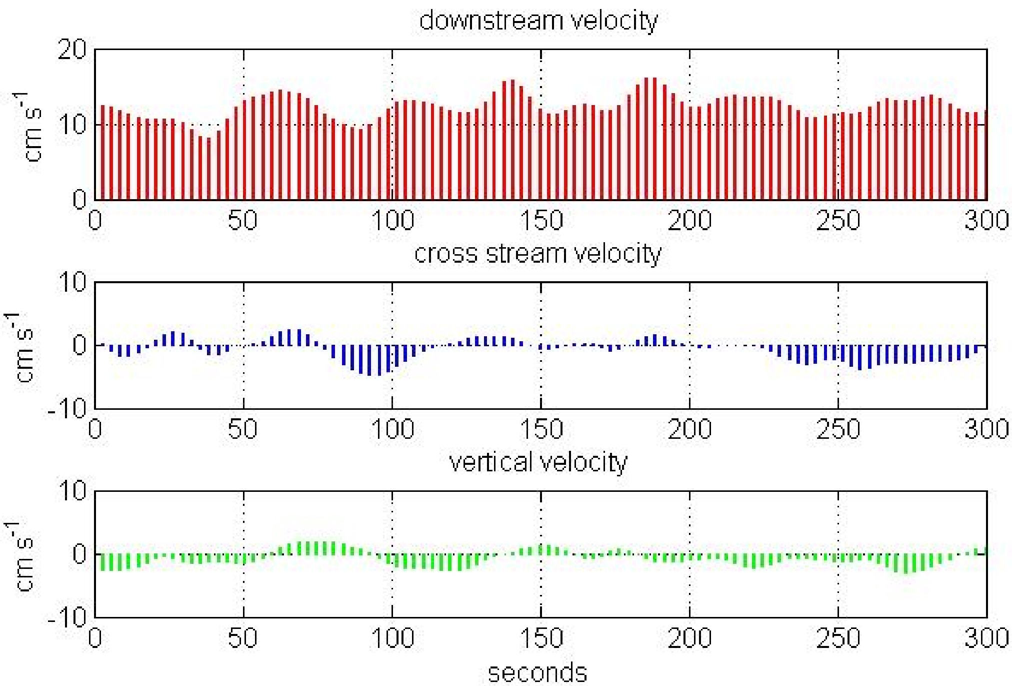


***Figure 2. A typical five minute time series record showing ADV-measured downstream, cross stream, and vertical velocity components in Lake Hattie, WY, on November 27, 2004. Floating frazil formed windrows on the water surface at this time, indicating active Langmuir circulation. The Langmuir circulation is visible in the alternating cross stream and vertical velocity components in this record.***

## IMPACT/APPLICATIONS

Sediment-laden sea ice is widespread in the Arctic (Eicken *et al.*, in press), but the mechanism of entraining sediment into ice (suspension freezing) is poorly understood. Our Lake Hattie observations suggest that Lc may be an important condition for suspension freezing, and that ADV measurements may be effectively used to study the relationship between Lc and suspension freezing in shallow seas.

## REFERENCES


Dethleff, D. and Kempema, E.W., submitted. Langmuir circulation driving sediment entrainment into newly forming ice - tank experiment results with application to nature (Lake Hattie, U.S.A.; Kara Sea, Siberia. Journal of Geophysical Research.

Eicken, H. et al., in press. Sediment transport by sea ice in the Chukchi and Beafort Seas: increasing importance due to changing ice conditions. Journal of Geophysical Research.

Gosink, J.P. and Osterkamp, T.E., 1983. Measurements and analyses of velocity profiles and frazil-ice crystal rise velocities during periods of frazil ice formation in rivers. Annals of Glaciology, 4: 79-84.

Kempema, E.W., Reimnitz, E., Clayton, J.R. and Payne, J.R., 1993. Interactions of frazil and anchor ice with sedimentary particles in a flume. Cold Regions Science and Technology, 21: 137-149.

**PUBLICATIONS**

Dethleff, D. and Kempema, E., 2005. Particle entrainment into newly forming ice in Lake Hattie, WY (USA), Institut fur Polarforschung (Institute for Polar Ecology), Kiel, Germany, p. 18-22 [published].

Dethleff, D. and Kempema, E.W., submitted. Langmuir circulation driving sediment entrainment inot newly forming ice - tank experiment results with application to nature (Lake Hattie, U.S.A.; Kara Sea, Siberia. Journal of Geophysical Research: [refereed].

Kempema, E.W. and Dethleff, D., submitted. The roll of Langmuir Circulation in initial ice formation and suspension freezing., Annals of Glaciology: [refereed].

Kempema, E.W. and Konrad, S.K., 2004. Anchor ice and water exchange in the hyporheic zone, Proceedings, of the 17th International Symposium on Ice. IAHR, St Petersburg, Russia, pp. 251-257 [published, refereed].

Kempema, E.W., McGee, B.W. and Pueblitz, L., 2004. Video observations of anchor ice/sediment interactions in two Rocky Mountain streams. EOS Transactions, AGU, 85(47): Fall Meeting Supplement, Abstract C43C-0241.