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Particle entrainment into newly forming ice in Lake Hattie, Wyoming (USA)

Introduction

The entrainment of particulate material into newly forming ice was investigated on different shallow circum-Arctic Arctic shelves and in Lakes (Osterkamp and Gosink, 1984; Kempema et al., 1989; Reimnitz et al., 1991; Kempema & Reimnitz, 1991; Reimnitz et al., 1998; Eicken et al., 2000; Dethleff, 2005). Among processes like tidal pumping, wave action, floe-bulldozing, near shore seabed freezing of grounded ice floes, and beach-ice formation, the principle mechanism of 'suspension freezing' was proposed to be the most effective mechanism to entrain fine-grained particulate material into newly forming ice (Reimnitz et al., 1992). Accordingly, driven by cold and stormy weather conditions, the water column mixes down to the bottom at shallow locations in open water areas. Super cooling of the water leads to frazil ice formation, and subsequent turbulent scavenging and filtration of suspended particulate matter by rising ice crystals as well as uplifting of anchor ice promote the entrainment and enrichment of particles in the ice cover (Osterkamp & Gosink, 1984; Reimnitz et al., 1993).

Many of the above studies revealed that the particle content in ice by far exceeded the suspension load of the underlying water column, so that turbulent enrichment processes like Langmuir circulation (Lc) were proposed to form sediment-laden ice rather than simple freezing of the particle laden water (Dethleff, 2005).

The aim of our study in Lake Hattie, Wyoming (USA), during fall freeze-up in late November 2004 was to investigate the entrainment of particles into newly forming lake ice in the presence of water column turbulence.

Environmental Settings, Material and Methods

Lake Hattie (Fig. 1), a shallow reservoir used for local farmland watering, is situated about 25 km west of Laramie at the foothills of the Medicine Bow Mountains, western Rocky Mountains, on an altitude of about 2,200m. The lake covers an area of few square km. The investigations were carried out on the southern shore of the lake.

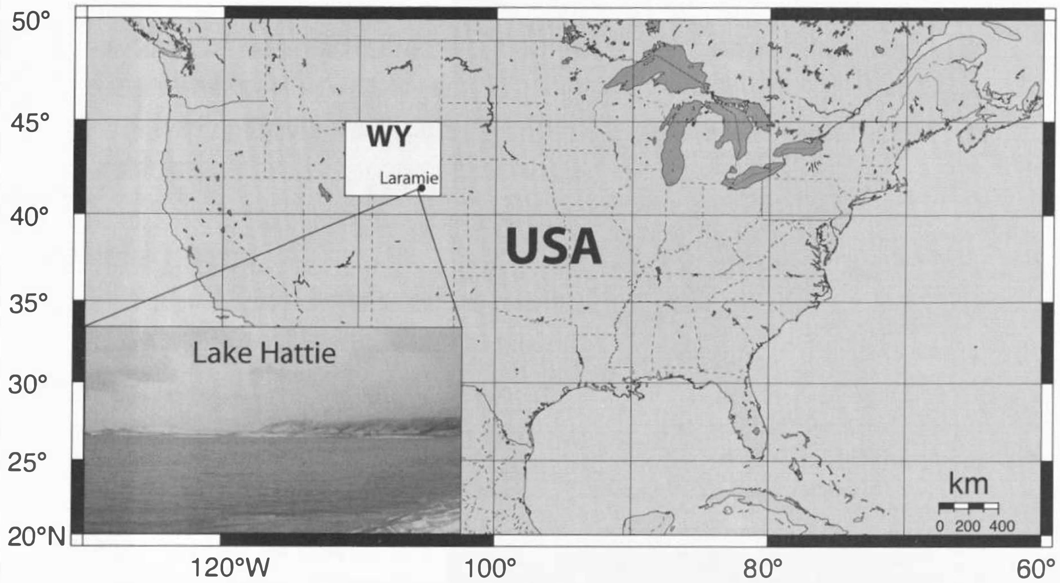

Figure 1 *Location and photo of Lake Hattie, WY, USA. View is from the southern lake-shore.*

During the freeze-up period of Lake Hattie, we conducted two sampling cycles of suspended particulate material (SPM), ice interstitial water (IW) and newly forming lake ice (Fig. 2). The north-easterly wind varied between 3-4 m/s (wave height: ~10cm) and 5-6m/s (wave height: ~15-30cm). The lake surface water (SPM) was sampled using 1l PE-bottles. Newly forming ice was taken from the ice streaks on the lake surface by a plastic net, and the IW was dropped from the net into a beaker immediately after ice sampling (Fig. 2). Due to temporary snowfall, we sampled slush ice with a roughly 5-10% portion of frazil crystals rather than pure frazil ice (grease ice).

Preliminary Results and Discussion

During freeze-up of Lake Hattie we observed the development of parallel new ice streaks on the water surface (Fig. 3). According to various investigations (e.g. Langmuir, 1938; Weller et al., 1985; Faller & Auer, 1988; Zedel & Farmer, 1991), wind parallel surface streaks of floating material in lakes and oceans may reflect the convergent zones of counter-rotating pairs of circulation cells (Lc), where the water is transported downward and floating particles are collected on the surface. The downwind propagating cell rotation is induced by a combination of wind, cross-wave action and current (e.g. Uzaki & Matsunaga, 2000).

Particle concentrations in the streaks of newly forming lake ice and in the IW exceeded the SPM load of the water column by to as much as 80%. All IW and ice samples contained extremely high percentages of fine-grained particles (silt and clay fractions). Qualitative particle compositions in SPM, IW and ice mostly resemble well in the Lake Hattie samples.

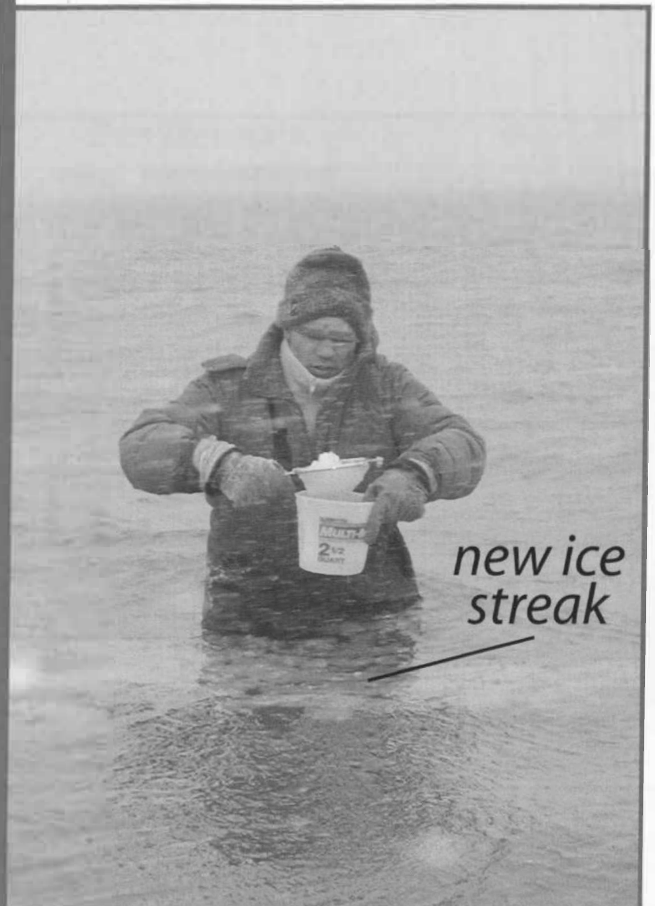

Figure 2 *Sampling in Lake Hattie roughly 30m from the shore in about 1m water depth.*

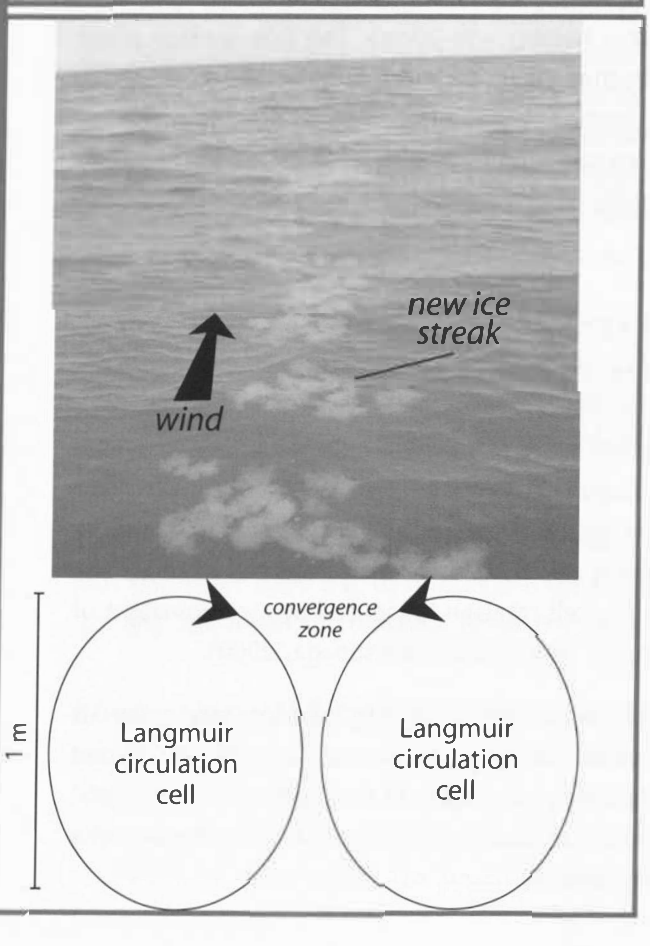

Figure 3 *Surface streak of slush and frazil ice in Lake Hattie indicating a convergent pair of Lc vortices in the underlying shallow water column.*

We suggest that the turbulent mechanism of Lc affects the re-suspension, collection and entrainment of particulate material into the newly forming grease ice cover of Lake Hattie. Turbulent convergent water flow through the parallel surface streaks of new ice - consisting of a net of frazil and slush crystals - may particularly promote the filtration enrichment of extremely fine grained particles in the ice.

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