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Couette *vs.* Langmuir circulations: Comment on "On the helical flow of Langmuir circulation — Approaching the process of suspension freezing" by Dethleff, Kempema, Koch and Chubarenko

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ABSTRACT

This comment suggests that flow structures observed in the laboratory work of Dethleff et al., [Dethleff, D.E. Kempema, W., Koch, R. and Chubarenko, I., 2009. On the helical flow of Langmuir circulation — approaching the process of suspension freezing. Cold Regions Sci. and Tech., 56, 50–57.] and identified by the authors as Langmuir circulations may actually be Couette circulations, structures characteristic of the primary flow instability of a sheared channel flow. The difference between the two circulations has implications for the field conditions in which "dirty ice" forms.

The authors of this paper have carried out a series of interesting laboratory experiments applicable to the question of "dirty ice" formation. Wind is blown on the surface of a thin water layer under both non-freezing and freezing conditions and various tracers (paper dots, dye, sediment and frazil ice) are used to reveal circulation patterns consistent with those widely believed to be associated (only) with Langmuir circulations, which the authors denote *Lc*.

Unfortunately, the generally qualitative nature of the flow field measurements in this study makes it hard to distinguish between Langmuir circulations (in which the momentum equation is dominated by a surface-wave-induced Langmuir vortex forcing term (Craik and Leibovich, 1976) and the rather similar structures that are found in numerical simulations of purely surface-stress-driven flows (Lee and Kim, 1991; Papavassiliou and Hanratty, 1997; Tejada-Martínez and Grosch, 2007), flows in which the Langmuir vortex force is entirely absent. These "Couette circulations"[1], which I will denote as *Cc*, have the same downwind-elongated counter-rotating vortex pairs as do *Lc*, leading to identical patterns of surface and bottom convergences alternating with divergences. However Tejada-Martínez and Grosch (2007) show that they differ in crosswind wavelength (*Cc* are smaller) and intensity (*Cc* are weaker). When Langmuir vortex forcing is turned on in a vertically-bounded simulation that has reached steady state with *Cc* under pure stress forcing, the existing Couette structures eventually transition to larger (approximately double) scale, stronger Langmuir circulations. I would argue that the structures observed in the laboratory by Dethleff et al. (2009) may be *Cc* rather than *Lc*.

Dethleff et al. (2009) present two qualitative observations to support their claim that the structures observed in their tank are necessarily *Lc*. First, they state that the " first visible wave crests…" passed the test section just as the bottom dye began to evidence "*Lc* inhomogeneities", implying that forces associated with the appearance of surface waves (instantaneously) produced Langmuir circulations. However the appropriate causal interpretation of this observation is not clear. Faller and Caponi (1978) and Veron and Melville (2001) report similar data sets which instead exhibit significant lags between the onset of measurable surface waves and subsequent formation of instability structures (which both of these sets of authors also refer to as "Langmuir circulations"). Because an imposed surface stress acts simultaneously to accelerate a mean sheared flow and to generate surface waves, it seems possible that small nonlinearities of the surface waves act as trigger for the natural (*Cc*) instability of the increasingly sheared mean flow. Small differences in surface wave nonlinearities in different experimental configurations (along with different definitions of "visible" or "measurable" waves) among the three cited studies would then lead to differences in phasing between the appearance of surface waves and that of the instability structures. As a second piece of evidence, the authors point out later in the paper that in the grease ice experiments "No evidence of "*Lc* circulation" was observed in the water column under the continuous grease ice layer", with the implicit conclusion that this absence was due to the absence of surface waves in this region.

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[1] Couette flow is traditionally defined as that of a thin layer of fluid bounded (horizontally) by two differentially rotating cylinders. When this prototype is generalized to flow of a layer of fluid driven by stress at a boundary, the primary instabilities depend upon whether stress is applied at horizontal or vertical boundaries. As used in this Comment, "Couette circulations" are the instabilities of a flow forced by stress at vertical boundaries, what is termed "turbulent plane Couette flow" in the literature (Lee and Kim, 1991; Papavassiliou and Hanratty, 1997).

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However it could equally well result from disappearance of the (non-Langmuir) wind-imposed surface stress as that is absorbed by ice compaction forces, hence no longer transmitted to the fluid interior. I suggest that neither of these qualitative observations allows a firm decision about which type of structure is involved in the laboratory measurements.

The only *quantitative* information available on the flow structure observed by Dethleff et al. (2009) is the ratio of L, the crosswind length scale of a vortex pair, to fluid depth H. From the reported measurements, $L/H\sim 10$ cm/4 cm~ 2. This value is consistent with the computational results of Lee and Kim (1991, $L/H\sim 2$), Papavassiliou and Hanratty (1996, $L/H\sim 1.5$), and Tejada-Martínez and Grosch (2007, $L/H\sim 2$) for Cc. In addition, the value agrees with earlier laboratory results of Faller and Caponi (1978) who found $L/H\sim 2$ for circulations arising from the stress of a “rake” dragged along the surface of a long, shallow laboratory tank. Although Faller and Caponi (1978) refer to the rake-induced structures as “Langmuir circulations”, the reported cell width to height ratio, coupled with generation of the structures in the absence of surface waves, implies that they too are Couette circulations. The value of $L/H\sim 2$ found by Dethleff et al. (2009) is *in*consistent with larger values typical of Lc in shallow-water oceanic observations (observations summarized in Gargett and Wells (2007) range from 3–10: in particular, Langmuir supercells (Gargett et al., 2004) are associated with $L/H\sim 5$–6) and with Langmuir-forced LES which exhibits $L/H\sim 4$ (Tejada-Martínez and Grosch, 2007).

Is there observational as well as the cited computational and laboratory evidence of the existence of Cc? Kenney (1993) reports highly coherent bands of algae in the upper few centimeters of lakes under the influence of breezes so weak as not to generate even capillary waves. These bands can only result from the large-eddy structures characteristic of a purely stress-driven surface boundary layer, i.e. from Cc. Other evidence of the reality of Cc comes from the Ross Sea, Antarctica, where “ice lines”, banded patterns of grease ice, tiny ice chunks, and snow are a familiar sight in open water leads of all sizes. In large leads with long fetches, the effects of wind waves through the Langmuir vortex force cannot be discounted. However ice lines are observed in even the smallest leads, with characteristics that cannot always be explained by wind/wave forcing. The example shown in Fig. 1a is a minor lead (estimated downwind width < 100 m) that was being opened by the forward progress of an icebreaker.

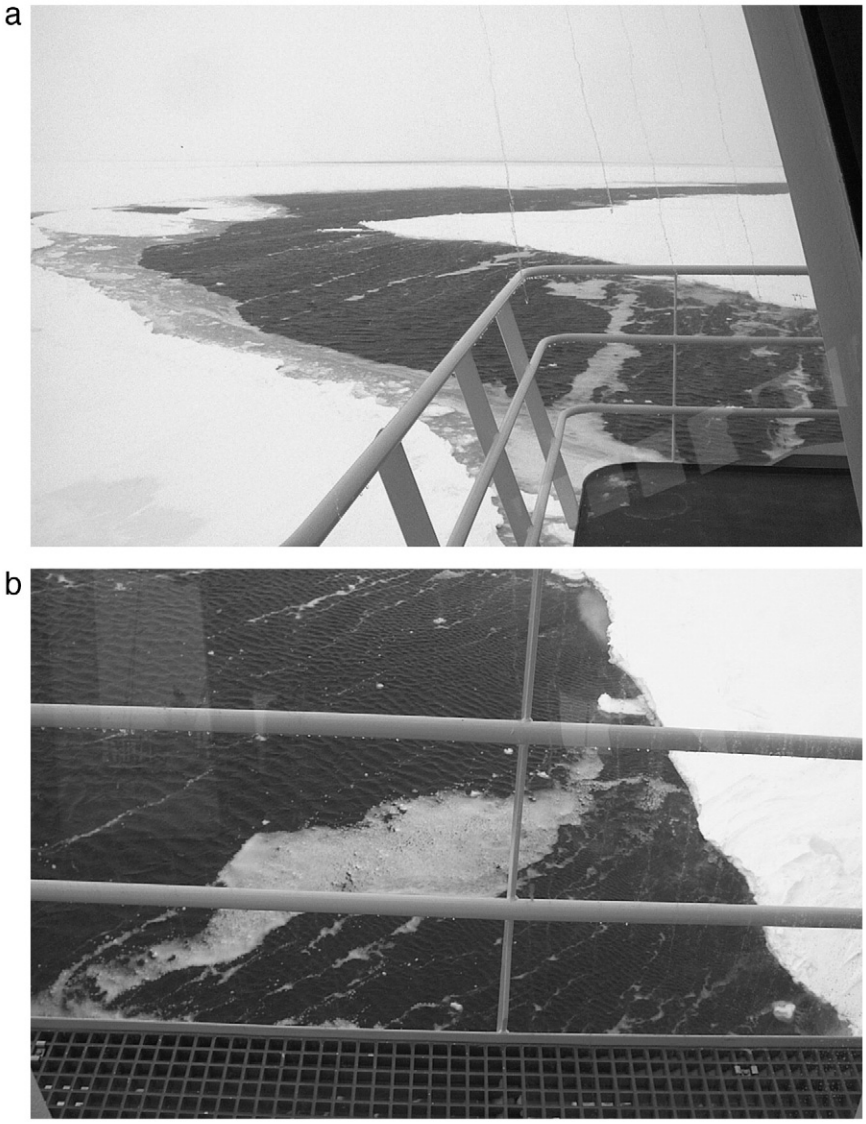

Fig. 1. (a): Photograph taken from the bridge of the icebreaker N. B. Palmer in October 2003, during the MIXURS (Mixing and Ultraviolet Radiation in the Ross Sea) expedition to the Ross Sea, Antarctica. “Ice lines” of various scales extend across the full downwind extent (< 100 m) of an opening lead. (b) Detail of both large and small scale “ice lines” at the upwind edge of the lead shown in (a). The existence of strong convergences at the upwind ice edge, before the growth of surface waves and their associated Langmuir vortex forces, suggests that the “lines” are associated with Cc, the basic instability structure of a purely surface-stress-driven flow, rather than with Lc.

Irregular ice lines of various scales are visible over the entire surface. Although they are roughly wind-aligned, these lines do not develop downwind along with the surface wave field, as would be expected of structures associated with Langmuir vortex forcing. Instead, lines of all scales exist right up to both downwind and *upwind* boundaries (see detail, Fig. 1b). This feature strongly suggests that the lines are associated with *Cc*, existing turbulent structures that are characteristic of the purely stress-driven boundary layer under pack ice drifting approximately downwind. In the situation pictured, these underlying boundary layer structures are simply being exposed to view by the opening of the lead.

The question of which structure, *Cc* or *Lc*, is actually being documented by the observations of Dethleff et al. (2009) is not a merely academic one. The answer could be particularly important in the context of conclusions drawn from the study, since if Couette structures exist in the absence of open water as a result of stress exerted by moving ice, sediment could enter forming ice in *ice-covered* shallow shelves, not just those with open water, surface waves, and Langmuir circulations[2].

The point of this comment is not to claim that the structures observed by Dethleff et al. (2009) cannot be Langmuir circulations. It is instead to point out the existence of other structures, Couette circulations, that have broadly similar qualitative features but do not involve surface waves through the vortex force predicated to produce Langmuir circulations. Distinction between the two structures requires more quantitative measures than those provided by the present study. It is recommended that subsequent laboratory studies of "Langmuir circulation" report the value(s) of the turbulent Langmuir number $La_t \equiv (u_\tau/u_s)^{1/2}$ (McWilliams et al., 1997: $u_\tau = (\tau_s/\rho_o)^{1/2}$ is the friction velocity associated with surface wind stress magnitude τ_s, ρ_o is water density, and u_s is the surface Stokes drift velocity) that gauges the relative importance of the surface stress and the Langmuir vortex force. In addition, for cases that involve surface heat loss, the buoyancy Langmuir number ($La_b \equiv (4B_o/\beta u_s u^2_\tau)$, where B_o is the destabilizing surface buoyancy flux and β is the e-folding depth of the Stokes drift (Li and Garrett, 1995; Gargett and Wells, 2007) should also be reported, since sheared unstable convection can also exhibit Langmuir-like roll structures with $L/H \sim 2$ (Furbish, 1996).

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[2] Unless, as suggested by Sherwood (2000) and Gargett et al. (2004), high shear associated with the thin (Trowbridge and Agrawal, 1995) surface wave boundary layer is required to resuspend bottom sediment prior to its movement away from the boundary by weaker turbulent flows.