Laboratory measurement of Langmuir circulations and turbulence

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INTRODUCTION

Streaks or windrows are frequently observed at the surface of the ocean or lakes. Irving Langmuir was the first to report a series of experiments on the phenomenon which now bears his name: Langmuir Circulations (1938). He determined that the surface streaks are the signature of subsurface vortex pairs with their axis aligned with the wind direction. The streaks are visible when foam or other tracers are swept by the vortices and accumulated above downwelling regions.

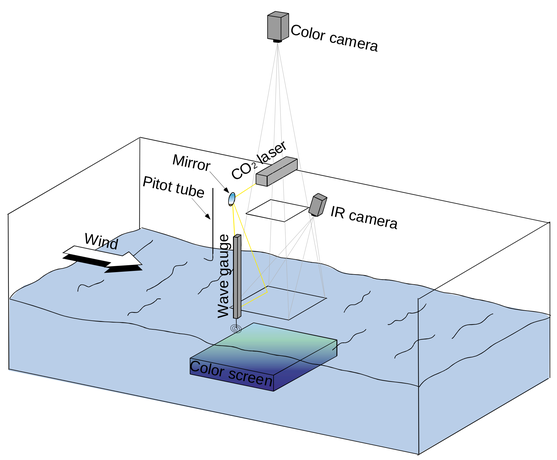
A rational theory was later proposed by Craik and Leibovich (1976) who showed that the interaction of the Stokes drift associated with the surface waves and the wind-driven current could lead to unstable conditions and generate Langmuir circulations.

(photo P. Matusov, 1999)

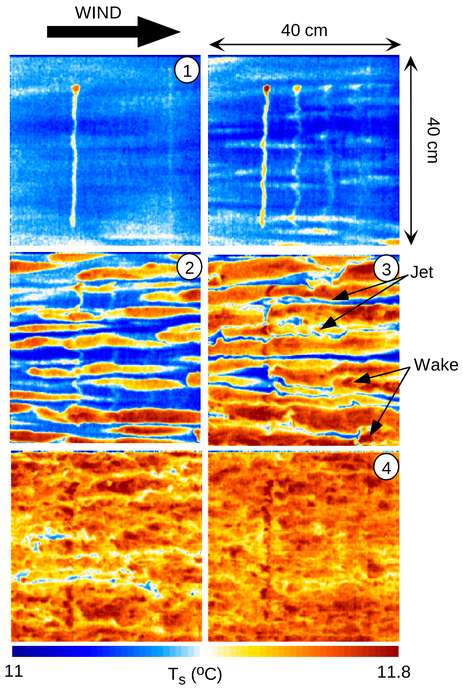
We present a series of laboratory experiments on the generation of Langmuir circulations. We show that Langmuir circulations appear as an instability of the wind driven shear layer.

EXPERIMENTS

The experiments were conducted in the large wind wave channel at Scripps Institution of Oceanography, University of California, San Diego. The wind was started from rest above a quiescent water surface and monitored using a Pitot static tube placed in the center line of the air flow. The wave height was measured using a wire wave gauge and the wave slope was retrieved using a digital color imaging slope gauge. The surface temperature was monitored with a calibrated infra-red camera. A thermal marker laid down by a CO_2 laser was used to measure the Lagrangian surface drift.



SURFACE FLOW VISUALISATION

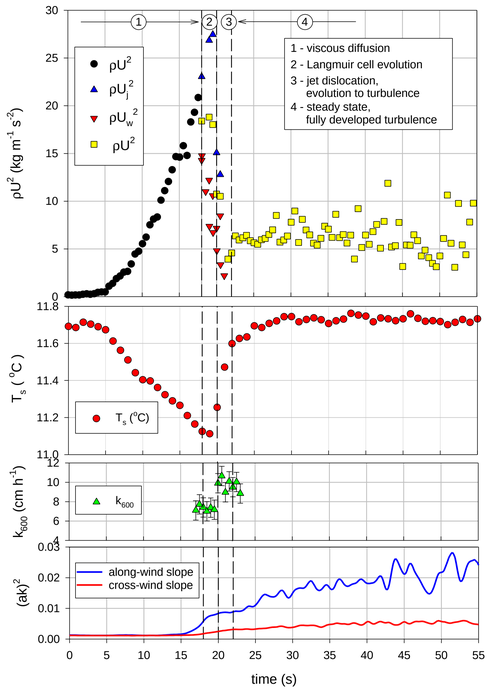


Surface temperature evolution for a wind speed of 5 ms^{-1}. Times shown are t=16.8, 18.3, 19.8, 21.3, 22.8, 24.3 s after the start of the wind.

The flow evolves in four distinct stages:

- 1-Acceleration of the surface; viscous diffusion of momentum.
- 2-Appearance of longitudinal vortices, and surface streaks.
- 3- Appearance of secondary instabilities and bifurcations.
- 4-Fully developed turbulence.

From the displacement of the thermal marker, it is possible to measure the surface wind drift.
The decay of the laser spot permits the calculation of the gas transfer velocity with the CFT technique (Jahne and Hauβecker, 1998). The surface wave slope and average temperature are also available.



Time series of the surface momentum flux, average surface temperature, gas transfer velocity (normalized to a Schmidt number of 600), and rms surface wave slope. The four stages of the evolution of the flow are clearly visible.

The IR camera and the imaging slope gauge are collocated and synchronized. This allows the study of the interaction of the wave field with the Langmuir circulations.

CONCLUSIONS

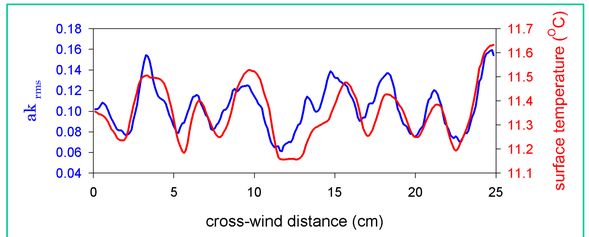
We have shown that the classical wave generation problem is accompanied by the formation of Langmuir circulations, which:

- Disrupt the momentum boundary layer and rapidly mix the energy provided by the wind in the water column.
- Modify the thermal boundary layer, and rapidly replace a large fraction of the surface skin layer enhancing heat and gas transfers.
- Interact with the growing wave field.

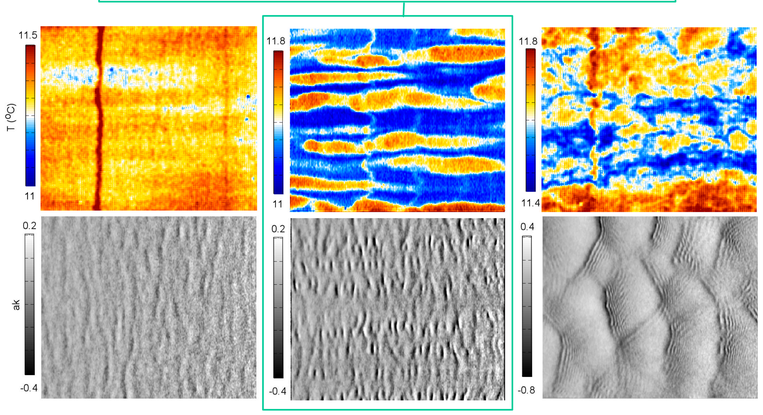
REFERENCES

Langmuir, I. 1938 Surface motion of water induced by wind. Science **87**, 119-123.
Craik, A. D. D. and S. Leibovich, 1976: A rational model for Langmuir circulations. *J. Fluid Mech.*, **73,** 401-426.
Jahne B. and H. Hauβecker, 1998: Air water gas exchange. *Annu. Rev. Fluid Mech.*, **30,** 443-468.

The patches of warm water are associated with upwelling regions. This newly formed surface water has been exposed for only a short time to the cooling and accelerating effect of the wind. Hence, the upwelling patches are warmer and their along-wind velocity is less that the average surface drift.
The surface waves appear steeper while propagating over warm (slow) water. This is consistent with the behavior of a wave train propagating over an adverse current.



Cross-wind variation of the surface temperature and rms surface waves slope for a final wind speed of 5 ms^{-1}.



Simultaneous measurements of the surface temperature (top) and surface wave slope (bottom) for a 5 ms^{-1} wind speed and at t=16.8, 19.8, and 41 s from the start of the wind. Image size is 36.8 cm x 27 cm.