Lagrangian transport by breaking surface waves

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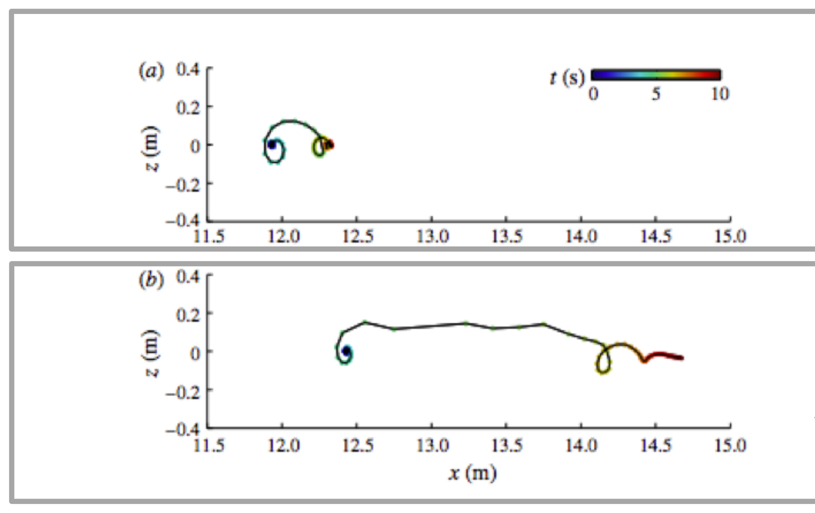
1. Introduction

We report on a theoretical and numerical study of the Lagrangian transport by deep-water breaking waves.

Breaking waves transport up to an order of magnitude more mass than non-breaking waves.

Important for enhanced models of upper ocean dynamics.

DNS of Particle trajectories in non-breaking and breaking waves



Particles in breaking waves can travel **up to order of magnitude further**.

Background

Effects of waves on upper ocean processes usually enters through **Stokes drift** (i.e. through the vortex force).

Crucial component of models of Langmuir circulations and upper ocean turbulence.

Lagrangian drift can significantly affect these upper ocean processes, especially at submesoscales, and should be considered in further developments of coupled ocean–atmosphere models.

2. Surfing surface gravity waves♯

Derive a criterion for particles to *surf* an underlying surface gravity wave and establish a surfing "sweet spot".

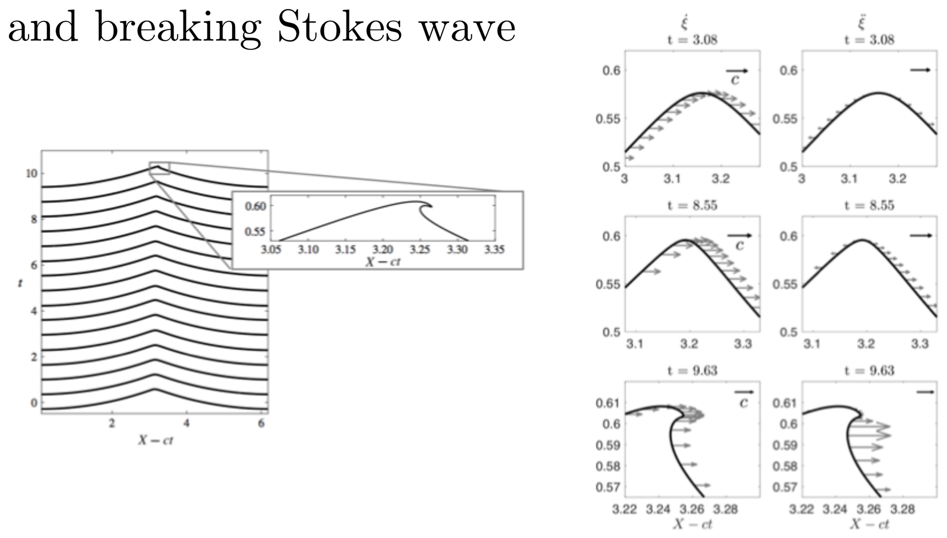
It is found that particles travelling near the phase speed of the wave, in a geometrically confined region on the forward face of the crest, increase in speed.

Helps us better understand geometry and kinematics of steep and breaking deep-water surface gravity waves.

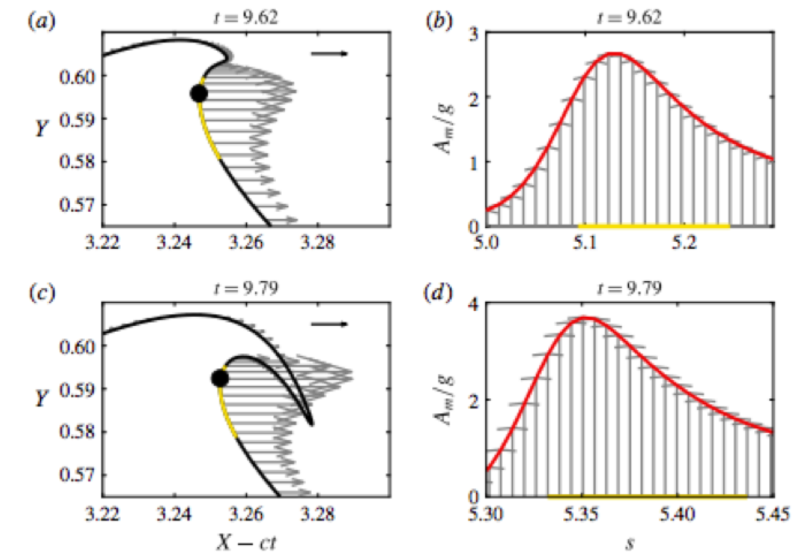
Theoretical/Numerical Results

Surfing criterion: Speed of particle matches speed of wave

Numerical simulations of geometry and kinematics of steep and breaking Stokes wave



- Velocities are largest in jet
- Accelerations largest just below crest



Red: theoretical prediction
Arrows: Numerical results

Horizontal accelerations exceeding 3g on forward face of wave near crest.
Theory accurately describes numerical observations.

- Establish a surfing "sweet spot" for particles traveling near the phase velocity of the underlying wave.
- Elucidates particle kinematics in steep/breaking waves

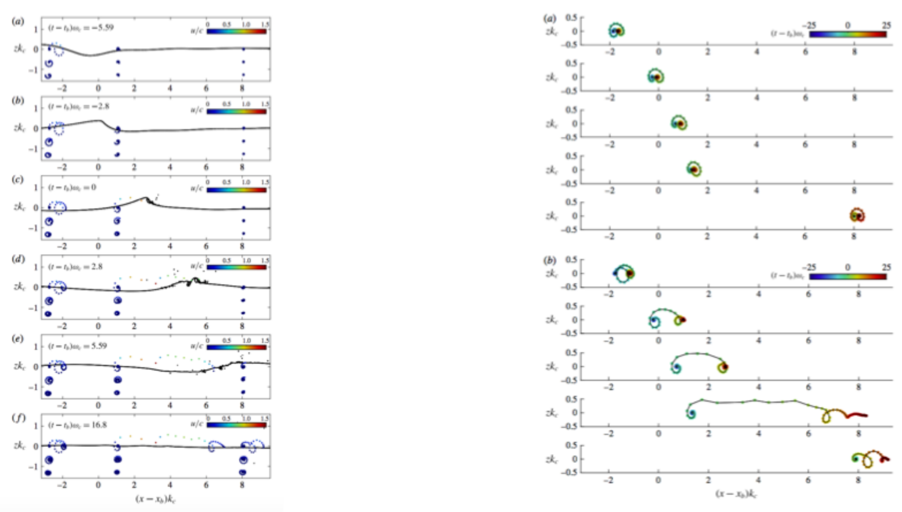
3. Lagrangian transport by breaking surface waves♮

Characterize drift due to non-breaking and breaking deep water wave packets.

Use direct numerical simulations (Gerris flow solver) of breaking deep-water surface gravity waves.

Theoretical predictions for non-breaking packets and scaling argument of drift due to breaking examined.

DNS of focusing wave packets

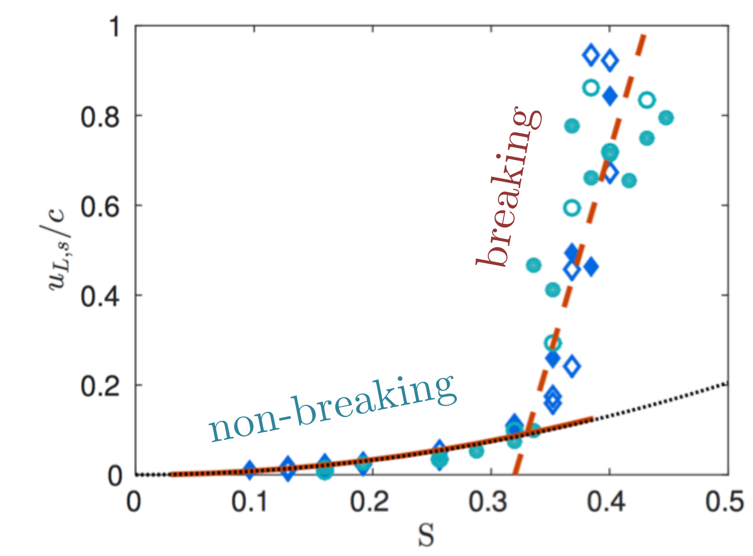


Scaling argument based on Section 2 implies the Lagrangian drift, u_L, goes like

$$u_L/c=\beta\, S,$$

S: slope of packet, β a scaling constant, c phase speed.

Results



Added drift at the surface is up to an order of magnitude larger than the drift obtained for non-breaking packets.

4. Conclusions

Theoretical criterion for particles to surf underlying wave.

Scaling argument for drift induced by breaking.

Breaking waves transport up to an order of magnitude more mass than non-breaking waves.

Important for understanding wave induced currents (mass transport, upper ocean processes).

Enhancement of models of upper ocean dynamics.

5. Future work

From breaking statistics can extend scaling model to ocean.

No account has been made of the contribution of surface wave breaking to the surface drift, or surface current.

Examine contribution to drift due to breaking versus classical Stokes drift using existing field data.

References:

♯: Pizzo, N.E. 2017 Surfing surface gravity waves. Journal of Fluid Mechanics. **823**, 316-328.

♮: Deike, L., Pizzo, N.E., & Melville, W.K. 2017 Lagrangian transport by breaking waves. Journal of Fluid Mechanics. **829**, 364-391.