The Wind-Wave Tank of Univ Hamburg

An Overview of Four Decades of Studies of Air-Sea Interactions

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Outline

Wind Wave Tank

70s and 80s:
• monomoleculare surface films
• Gas transfer

80s and 90s:
• Wave damping
• Radar backscattering
• Rain

Recent Work:
• Small-scale phenomena
• Gas transfer

Summary
Remote Sensing of the World's Oceans

Global wind fields from QUIKSCAT satellite data
Remote Sensing of the Sea

Observation of river outflow using ERS-2 SAR imagery
Wind Wave Tank

26 m × 1 m × 1.5 m
Fresh water @ 0.5 m
2 - 20 m/s Wind speed
0.7 - 2 Hz mech. waves
Slicks @ 5.5 m
Rain @ 12.5 - 14.8 m
Air re-circulation (2006)
1970s and 1980s
70s and 80s: Monomolecular Surface Films

Dedicated substances to represent main compounds of marine surface films

Hydrophobic part (long alkyl chain) - hydrophobic head group

Substances accumulate on water surface as monomolecular film

(a) \[
\begin{align*}
\text{CH}_3 & \quad \text{O} \\
\text{H}_3\text{C} & \quad \text{O} \\
\end{align*}
\]

(b) \[
\begin{align*}
\text{HO} & \quad \\
\text{CH}_3 & \\
\end{align*}
\]

(c) \[
\begin{align*}
\text{CH}_3 & \quad \text{O} \\
\text{H}_3\text{C} & \quad \text{O} \\
\text{HO} & \quad \text{O} \\
\text{CH}_3 & \quad \text{O} \\
\text{H}_2\text{C} & \quad \text{O} \\
\end{align*}
\]

(a) PME

(b) OLA

(c) TOLG
70s and 80s: Monomolecular Surface Films

Horizontal surface tension gradients!
Longitudinal surface waves as additional solution of the Navier-Stokes-Equations ("Marangoni waves")

Fig. 4. Horizontal velocity (a) and force (b) components acting on the surface of a gravity water wave propagating from left to right.

Lange & Hühnerfuss, 1984
70s and 80s: Monomolecular Surface Films
70s and 80s: Monomolecular Surface Films

Theory of (relative) wave damping by monomolecular surface film
Characteristic damping maximum at 4-5 Hz
70s and 80s: Gas Transfer

Wolfgang Siems, Dissertation, 1980
70s and 80s: Gas Transfer

Gas transfer velocity of $O_2$ (o) and $CO_2$ (+) at filmfree water surface. Characteristic kink between 10 m/s and 14 m/s: Generation of bubbles by wave breaking

Siems, 1980
70s and 80s: Gas Transfer

Gas transfer velocity of $CO_2$ at filmfree (+) and film covered (o) water surface

Strong reduction in gas transfer in the presence of surface films

Siems, 1980
70s and 80s: Gas Transfer

Size distribution of gas bubbles derived with optical methods

Size distribution of gas bubbles in water at 13 m/s (o), 15 m/s (Δ), 17 m/s (+), 19 m/s (x)

Siems, 1980
Summary: 70s and 80s

Thorough studies of physico-chemical properties of monomolecular surface films

Particularly of the influence of film coverage on wave damping and gas transfer from water into the air

Important basics for later field experiments and for the interpretation of satellite data
1980s and 1990s
Reduced energy input by the wind, because of reduced friction velocity ($u_*$)

Influence of film coverage on all source terms of Action Balance Equation!
80s and 90s: Wave Damping

1st visits of S.A. Ermakov
80s and 90s: Wave Damping

Generation of bound (parasitic) waves at the wave crests (high local "pressure")

Critical amplitude (steepness)
80s and 90s: Radar Backscattering

Measured radar contrast at X band (9.8 GHz, $\lambda_B = 3$ cm) and Ka band (37 GHz, $\lambda_B = 0.8$ cm) cannot be explained by pure Marangoni damping!
Analyses of radar Doppler shifts to derive propagation speed of scatterers:

At low wind speeds (up to approx. 5 m/s) bound waves are dominating the radar backscattering.
80s and 90s: Radar Backscattering

Strong wave damping at moderate wind speeds (7 m/s - 9 m/s) through reduced generation of bound waves!
80s and 90s: Rain

Rain area: 2.3 m x 1 m
Fall height: 4.5 m
Drop size: 2.1 - 2.9 mm Ø
Rain rates: bis 300 mm/h
> 80% of terminal velocity

It’s raining in here !!!
Investigation of rain-induced turbulence in the upper water layer using Particle Image Velocimeter (PIV) and Acoustic Doppler Velocimeter (ADV) sensors
80s and 90s: Rain

Top: development of ring vortex by dyed rain drop. Time difference between pictures: 0.12, 0.36 and 1.12 seconds.
Bottom: similar ring vortex, observed with PIV. Time differences 0.125, 0.125 and 0.25 seconds.
80s and 90s: Rain

- Damping of long waves \( (f < 5 \text{ Hz}) \)
- Generation of short waves \( (f > 5 \text{ Hz}) \)

Wave damping coefficient

- Only wind
- Wind and Rain

Braun, 2002
Local, rain-generated products (stalks, secondary drops, etc.) cause a strong dependency of the cross-pol radar backscattering on rain rate.
Summary: 80s and 90s

Further investigations of damping characteristics of monomolecularen surface films

New insights on the influence of the local wave field on the radar backscattering

First laboratory experiments in the presence of wind and rain
2000s: Recent Work
Experiments with small slick patches consisting of oleyl alcohol (OLA) and palmitic acid methyl ester (PME)

Purpose: study the wave field at slick edges; deliver data for EU project dealing with automated detection of sea (surface) pollution
Recent Research: Small-Scale Phenomena

Short-term deployment of substances to study phenomena at slick edges

- Front edge: sharp
- Rear edge: tethered

e.g. OLA @ 5 m/s

Universität Hamburg
Gade: Windwellenkanal
Recent Research: Small-Scale Phenomena

Entfernungsauflösendes W-Band 94 GHz ($\lambda_B = 3$ mm) z.B. OLA @ 9 m/s

Beobachtung von kleinskaliger Phänomenen (Mikrobrechen) an der Wasseroberfläche
Recent Research: Small-Scale Phenomena

Beobachtung der raumzeitlichen Entstehung und Verteilung von kleinskaligen Phänomenen
Gas Transfer

Greenhouse Gas $CO_2$

Takahashi et al [2002]
Gas Transfer

$CO_2$ invasion in the presence of artificial rain
Gas Transfer

1: no rain, no turbulence
2: turbulence
3: rain 180 mm/h
4: rain 270 mm/h
5: rain switched off
Gas Transfer
Gas Transfer (UHH + IOW)

7-Mar-07: 4 m/s, 110 mm/h

CT [µmol/k] vs. Elapsed Time [hh:mm]

CT [µmol/k] vs. Sample Location

0 min
90 min.
180 min.
270 min.
360 min.
450 min.
Rain
Gas Transfer (UHH + IOW)

9-Mar-07: 4 m/s, 160 mm/h

3-Apr-07: 8 m/s, 160 mm/h
WiSSCy: Joint Experiments with U Heidelberg

Schematic of ACFT (Active Controlled Flux Technique)
WiSSCy: Joint Experiments with U Heidelberg

IR Image Sequence of Water Surface

Wind speed: 1.45 m/s

15.2 °C  SST  15.7 °C
40 cm  60 cm
WiSSCy: Joint Experiments with U Heidelberg

2d measurements on water surface

Wind speed: 4 m/s
image rate: 312 Hz

11 cm

24 cm
Measurements of 3d Current Profiles

ADV gauge:
NORTEK Vectrino+
Measurement volume: \( \sim 1 \text{ cm}^3 \)
Sample rate: < 200 Hz
Depths: < 1 cm .. 23 cm
Current profiles: 4 m/s, 160 mm/h Rain

Cross:

Along:

Vertical:

Vertical:
Current Profiles: Wind Influence

4 m/s, 160 mm/h

10 m/s, 160 mm/h

cross

along

vertical

vertical
Current Profiles: Rain Influence

4 m/s, 0 mm/h

4 m/s, 160 mm/h

cross
along
vertical
vertical
Summary

WWT of Uni HH since early 1970s
(Inst. f. Organische Chemie & Inst. f. Meereskunde)

Basics for improved interpretation of remote sensing data

Measurements with wave, gas and radar sensors

- Wave damping by surface films
- Influence of heavy rain
- Gas transfer between water and air
- Recently: influence of small-scale phenomena (turbulence) on gas transfer and radar backscattering
Благодарю за внимание!

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