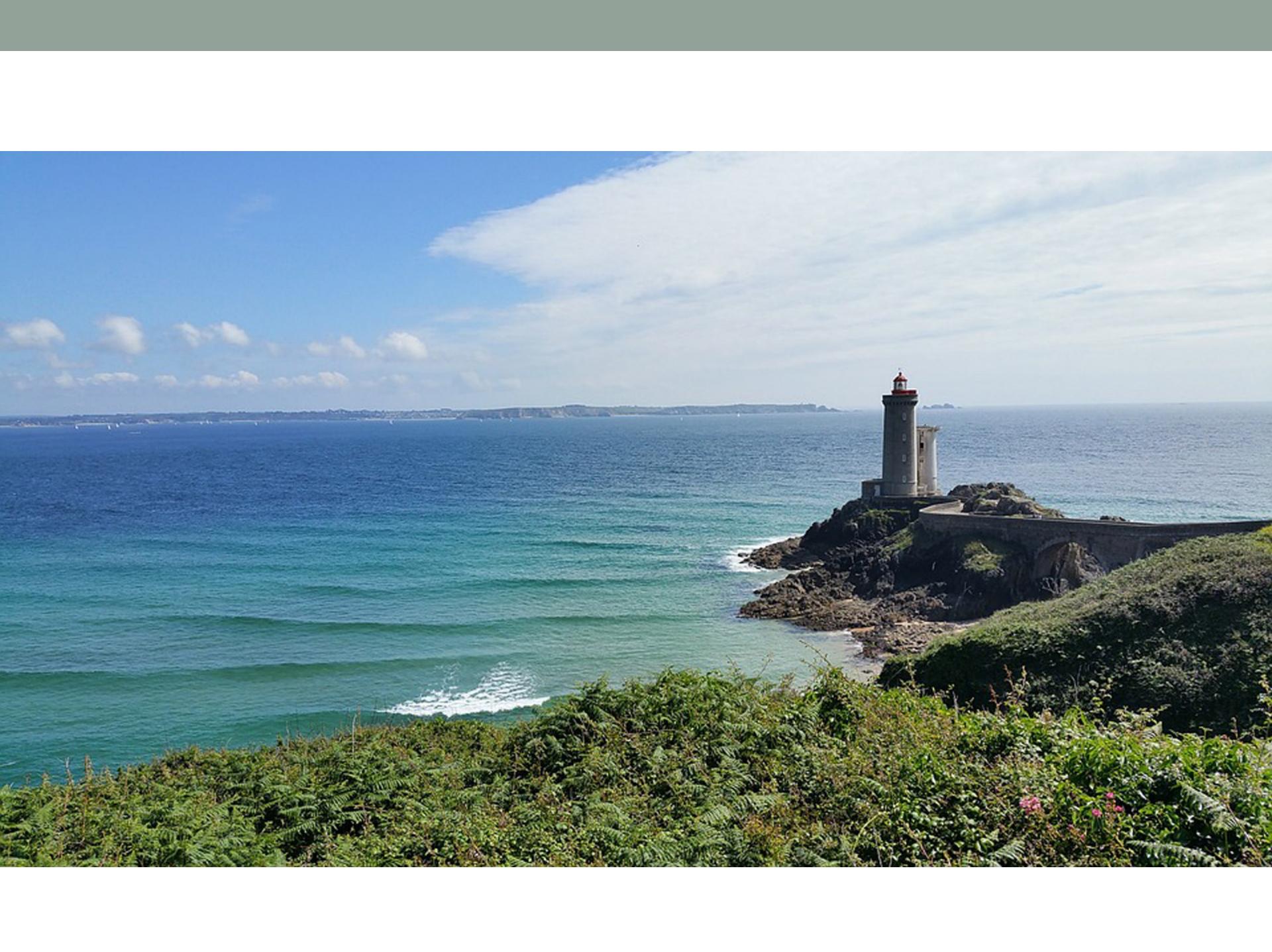


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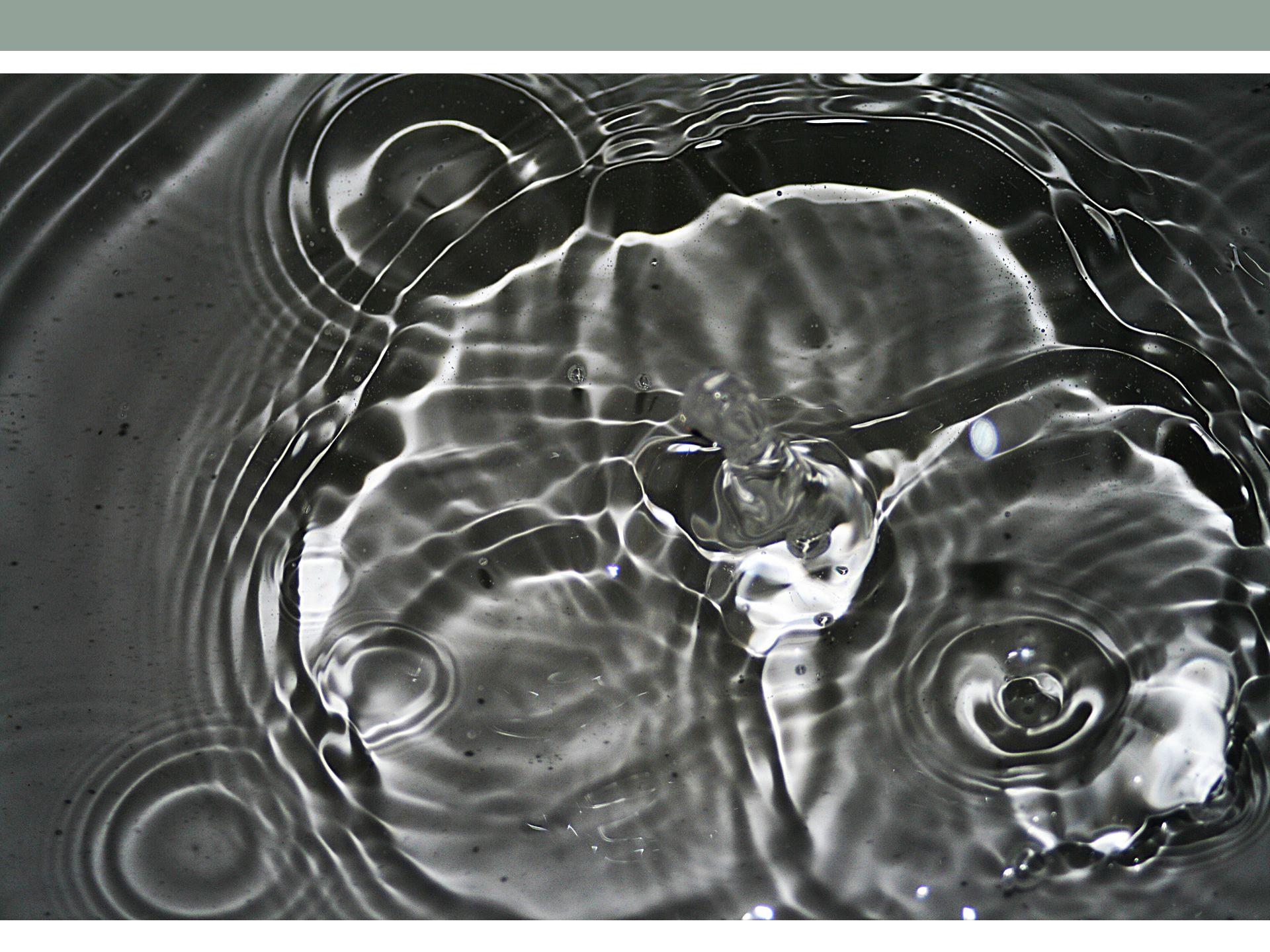
Jonathan GULA
gula@univ-brest.fr

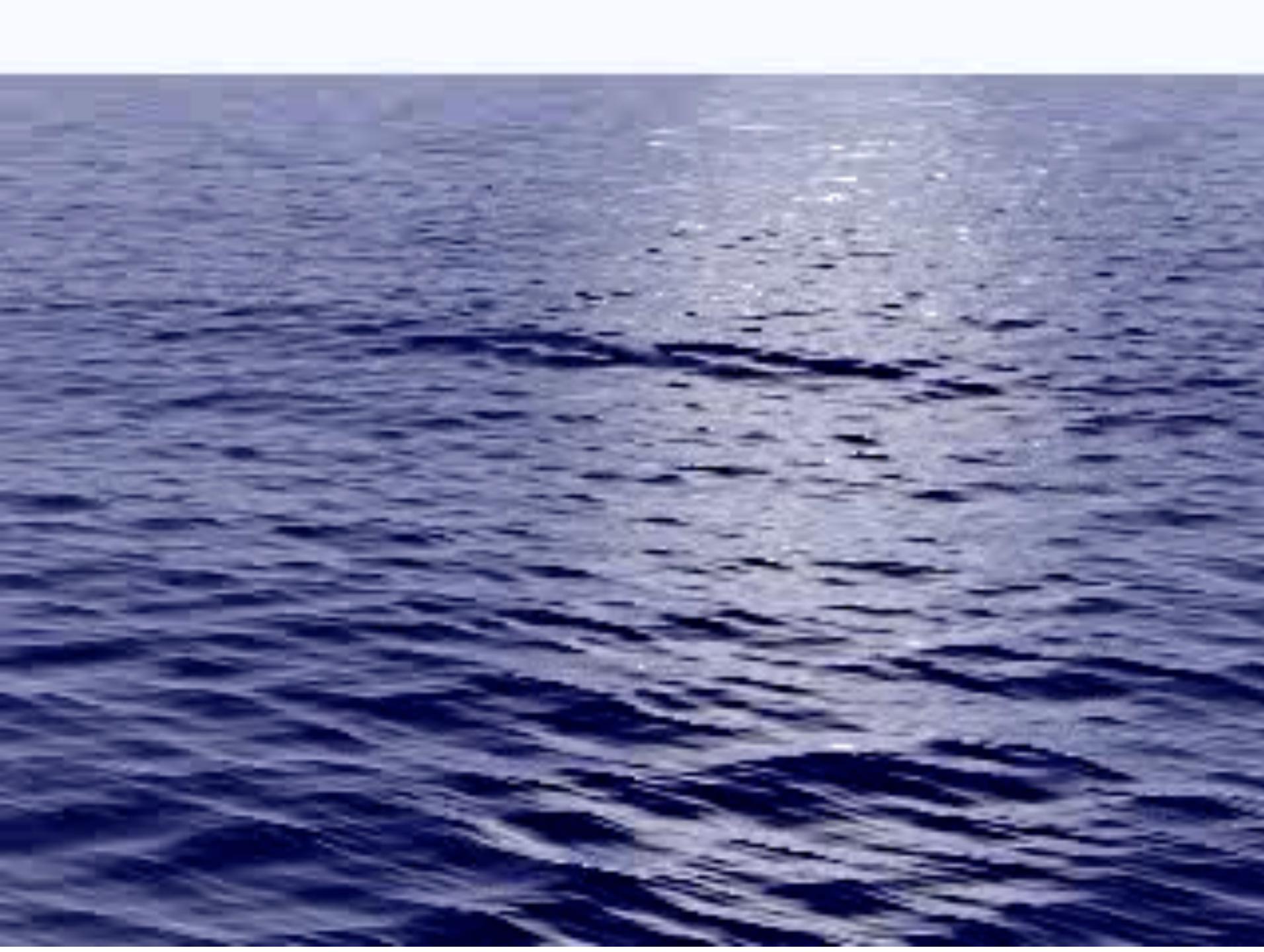


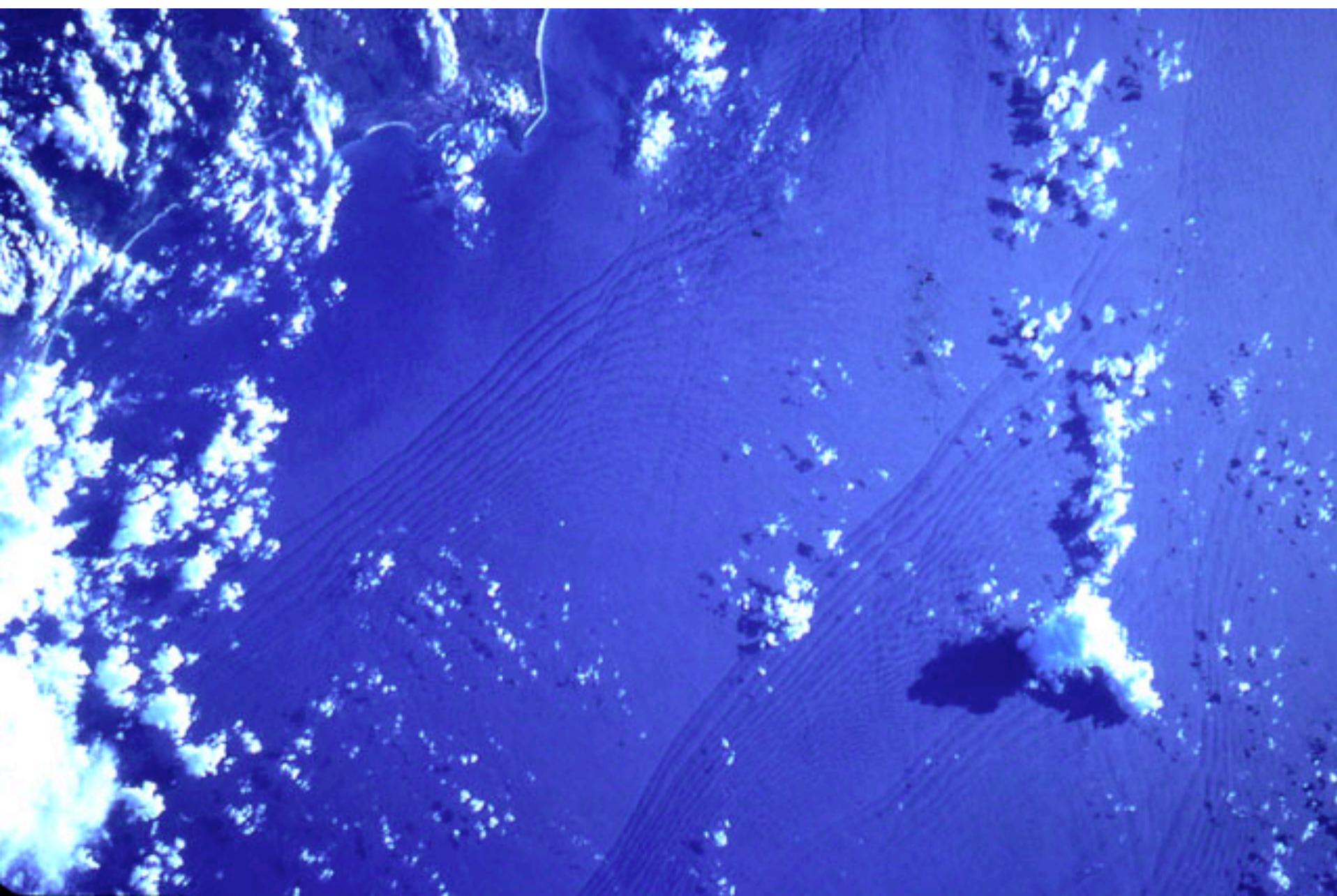




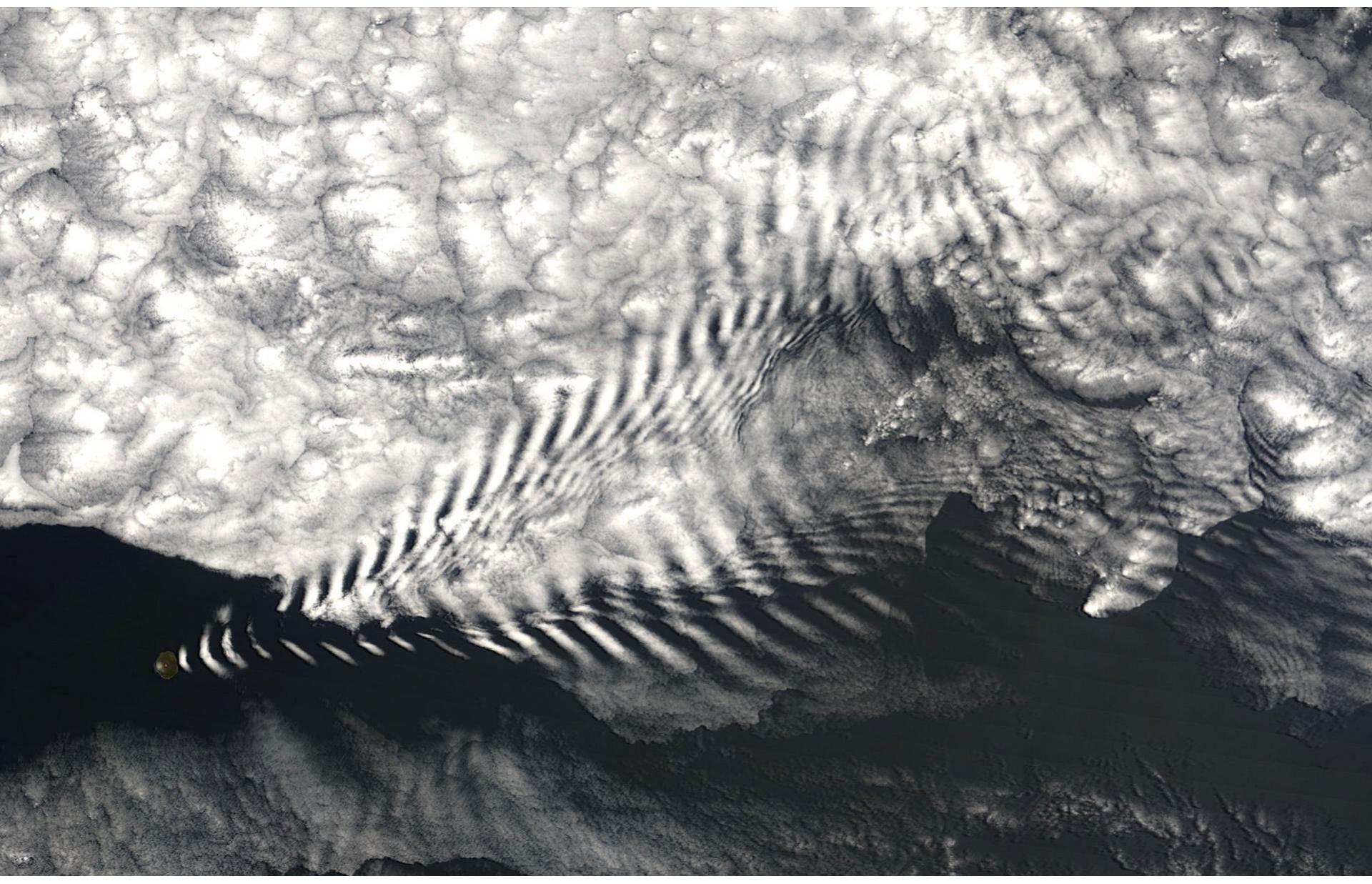






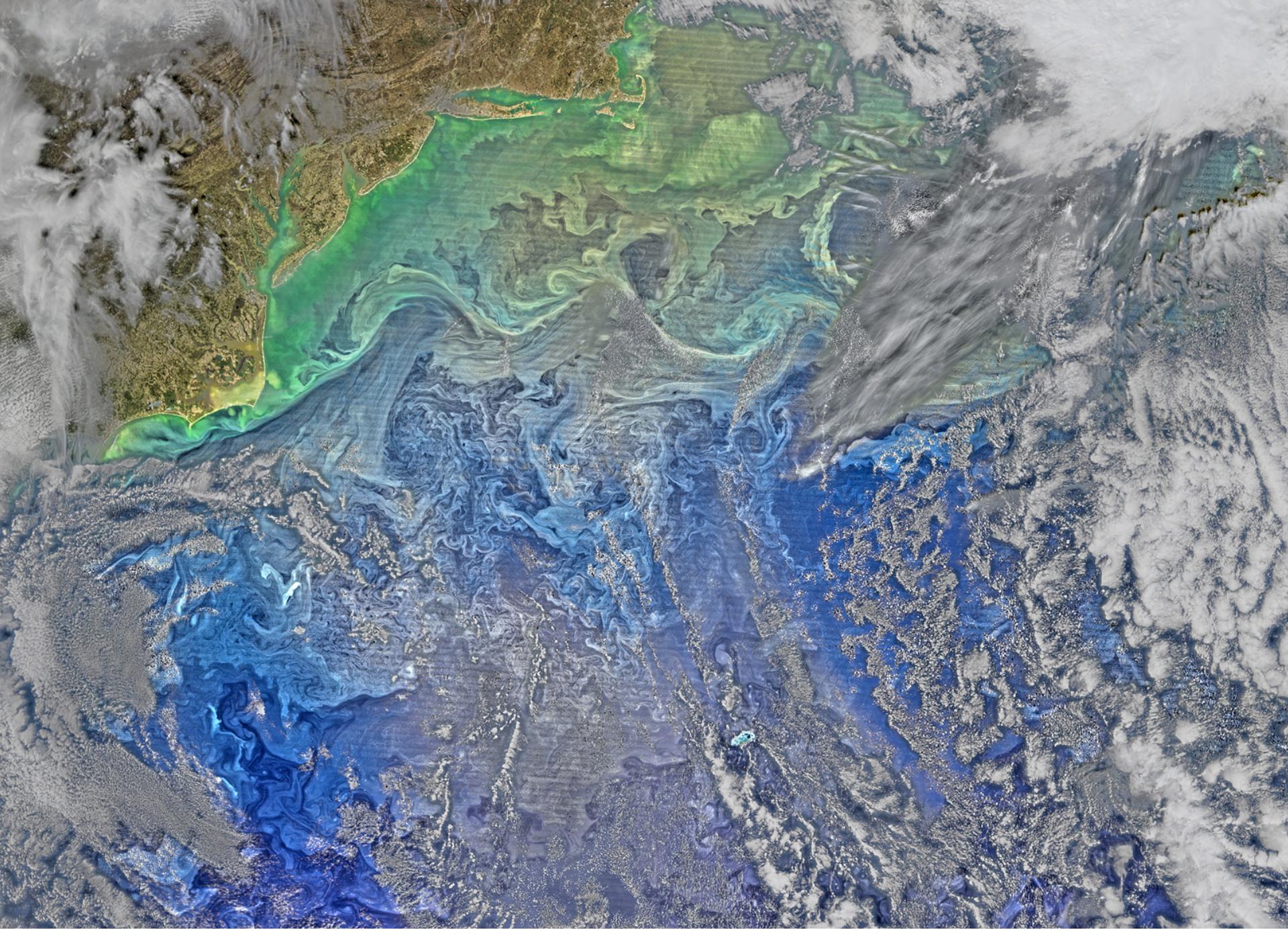


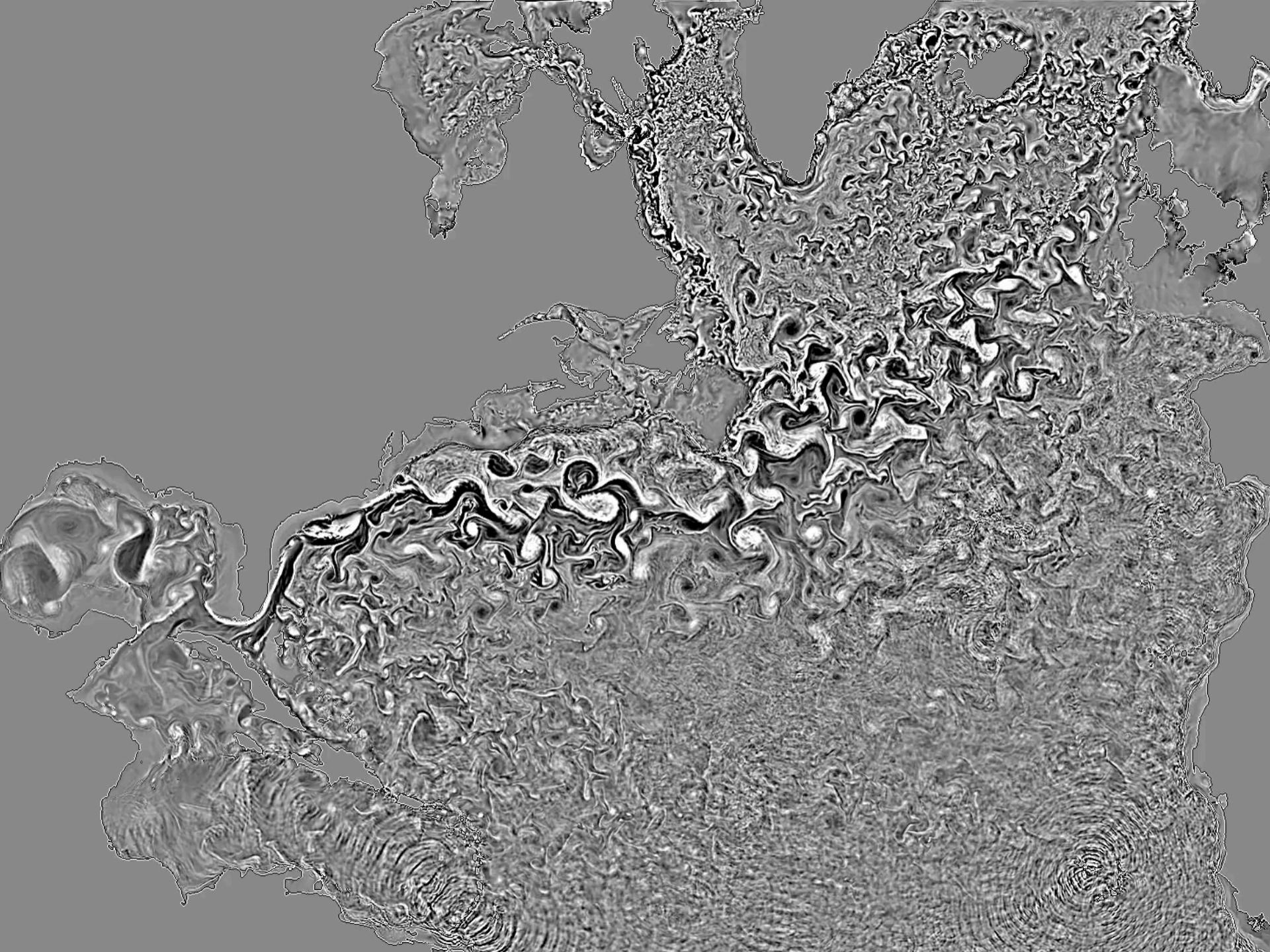






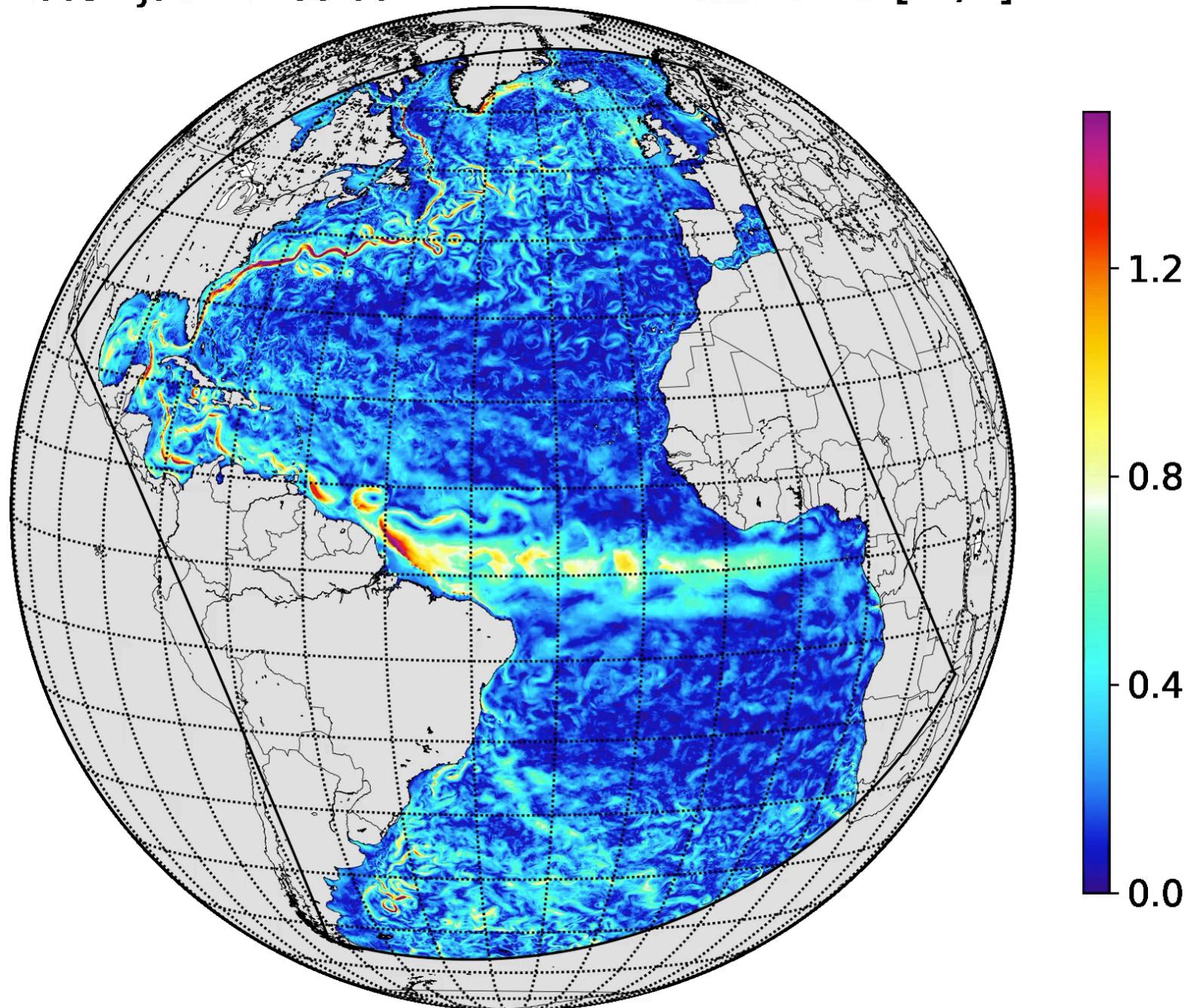
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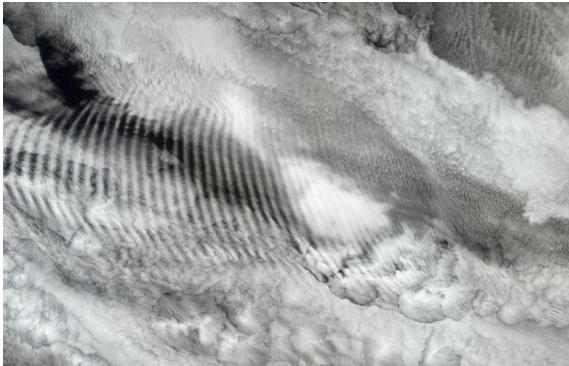
2005 - Jan 14 - 00:00

currents [m/s]

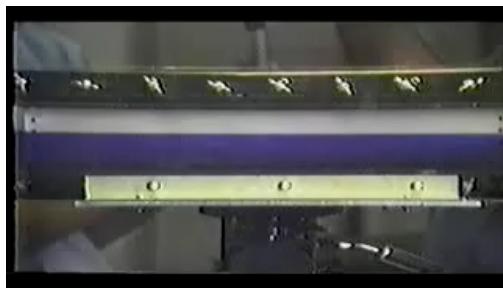


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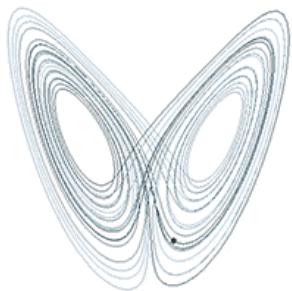
1. Waves



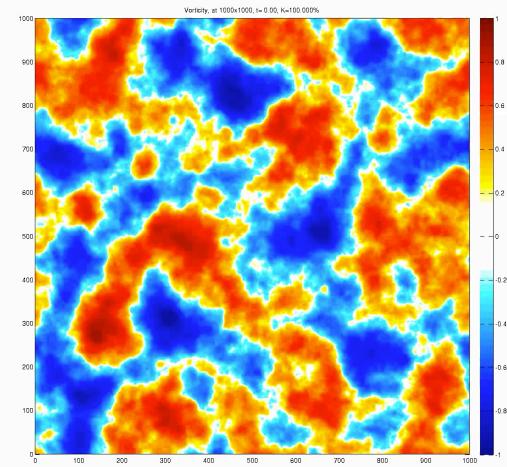
2. Instabilities



3. Chaos



4. Turbulence



I. WAVES

Jonathan GULA
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I. WAVES

I.1. Introduction

I.2. General properties of Waves

I.3. Different type of ocean waves

I.3.1 Surface Gravity Waves

I.3.2 Internal Waves

I.3.3 Acoustic Waves

I.4. Ray Theory

Bibliography

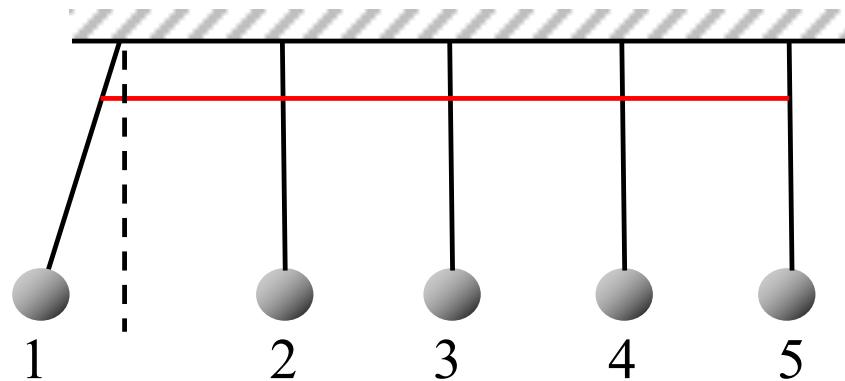
- Whitham (1974) : *Linear and nonlinear waves*
- Leblond-Mysak (1977) : *Waves in the ocean*
-

Definition of a wave:

- A wave is a recognizable signal that is transferred from one part of the medium to another with a recognizable velocity of propagation. The signal may be any feature of the disturbance, such as a maximum or an abrupt change in some quantity, provided that it can be clearly recognized and its location at any time can be determined. [Whitham: « Linear and nonlinear waves »]
-

Definition of a wave:

- Restoring force and a continuous medium to transport oscillation



Definition of a wave:

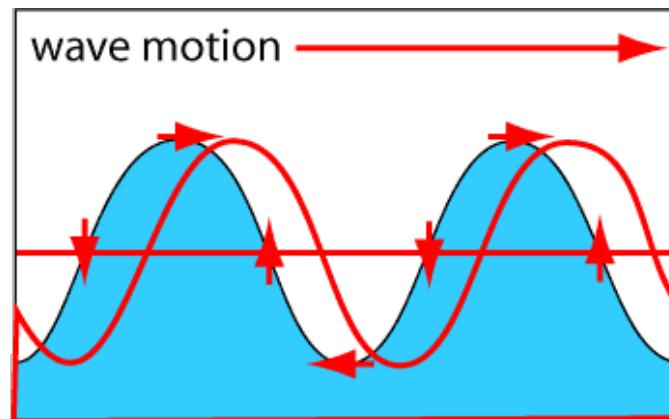
- Restoring force and a continuous medium to transport oscillation



<http://hal.elte.hu/fij/wave/pmwiki.php?n>Main.Model>

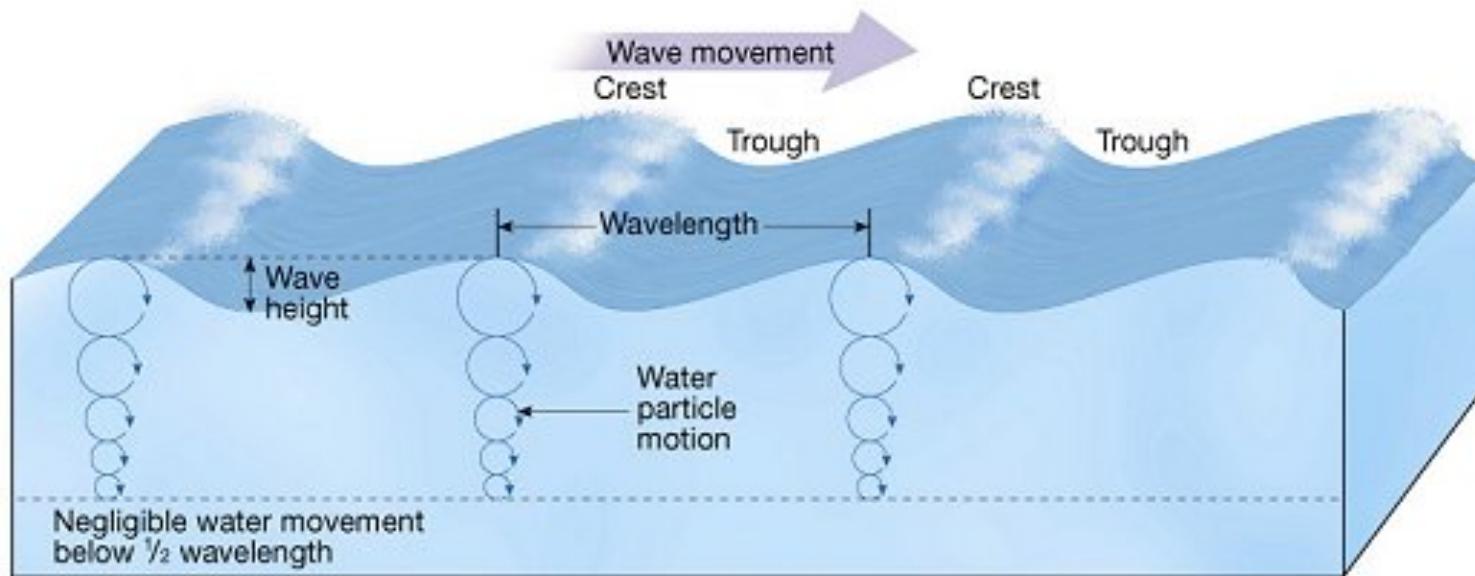
Ocean Waves

- A wave results when fluid is displaced from a position of equilibrium.
- The restoration of the fluid to equilibrium will produce a movement of the fluid back and forth, called a wave orbit.



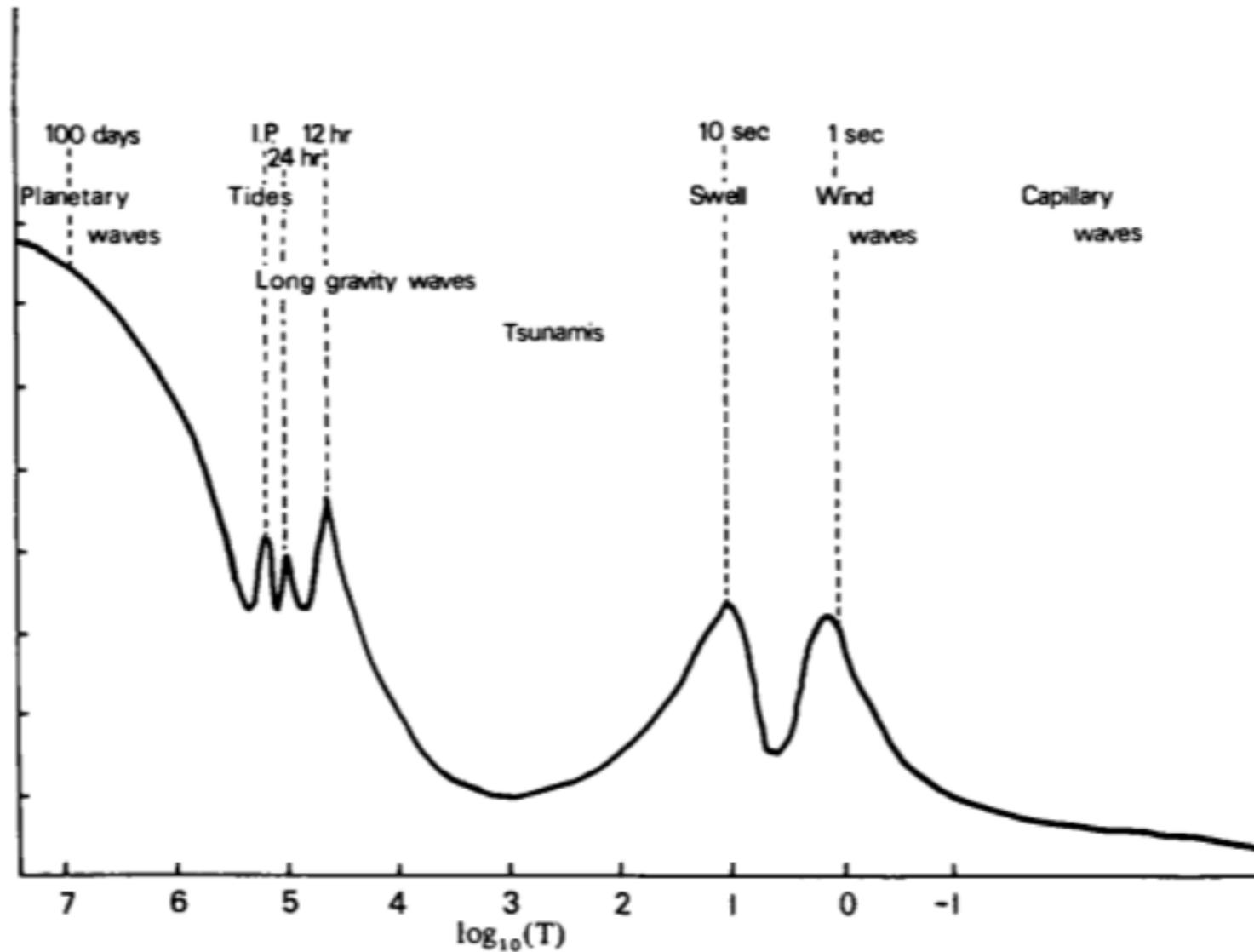
Ocean Waves

- Waves propagates energy but do not transport water



I.1. Introduction

Ocean Waves



Schematic energy spectrum of ocean variability [Leblond & Mysak]

Ocean Waves

Different type of waves are classified on the basis of:

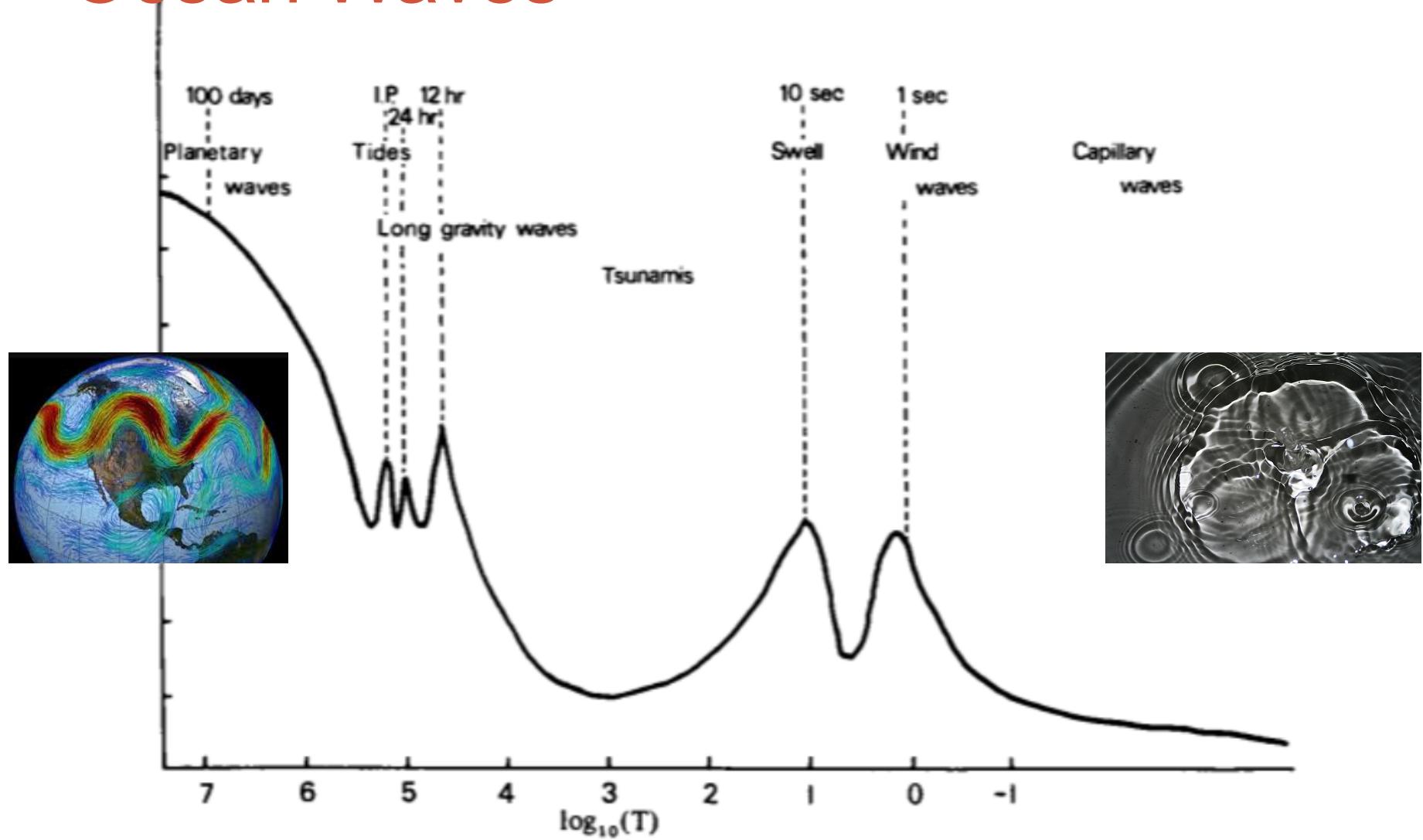
- Disturbing force
- Restoring force
- Wavelength
- Free wave Vs forced wave

Ocean Waves

	Disturbing Force	Restoring Force	Wavelength	Periods
Acoustic waves		Pressure (compressibility)	1 mm - 10 km	< 1 s
Capillary waves		Surface tension	1 mm - 1 cm	< 1 s
Surface gravity waves	Wind, boat, earthquake, etc.	Gravity	1 cm - 100 km	1 s - 1 day
Internal waves	Tides, Wind, Topography, etc.	Gravity (stratification) + Coriolis	1 m - 100 km	1 s - 1 day
Rossby waves		PV (variation of Coriolis with latitude)	100 km - 1000 km	Days - Months
Kelvin wave		Pressure gradient + Coriolis	10 km - 100 km	Days - Months
Equatorial Waves		Pressure gradient + Coriolis	10 km - 1000 km	Days - Years

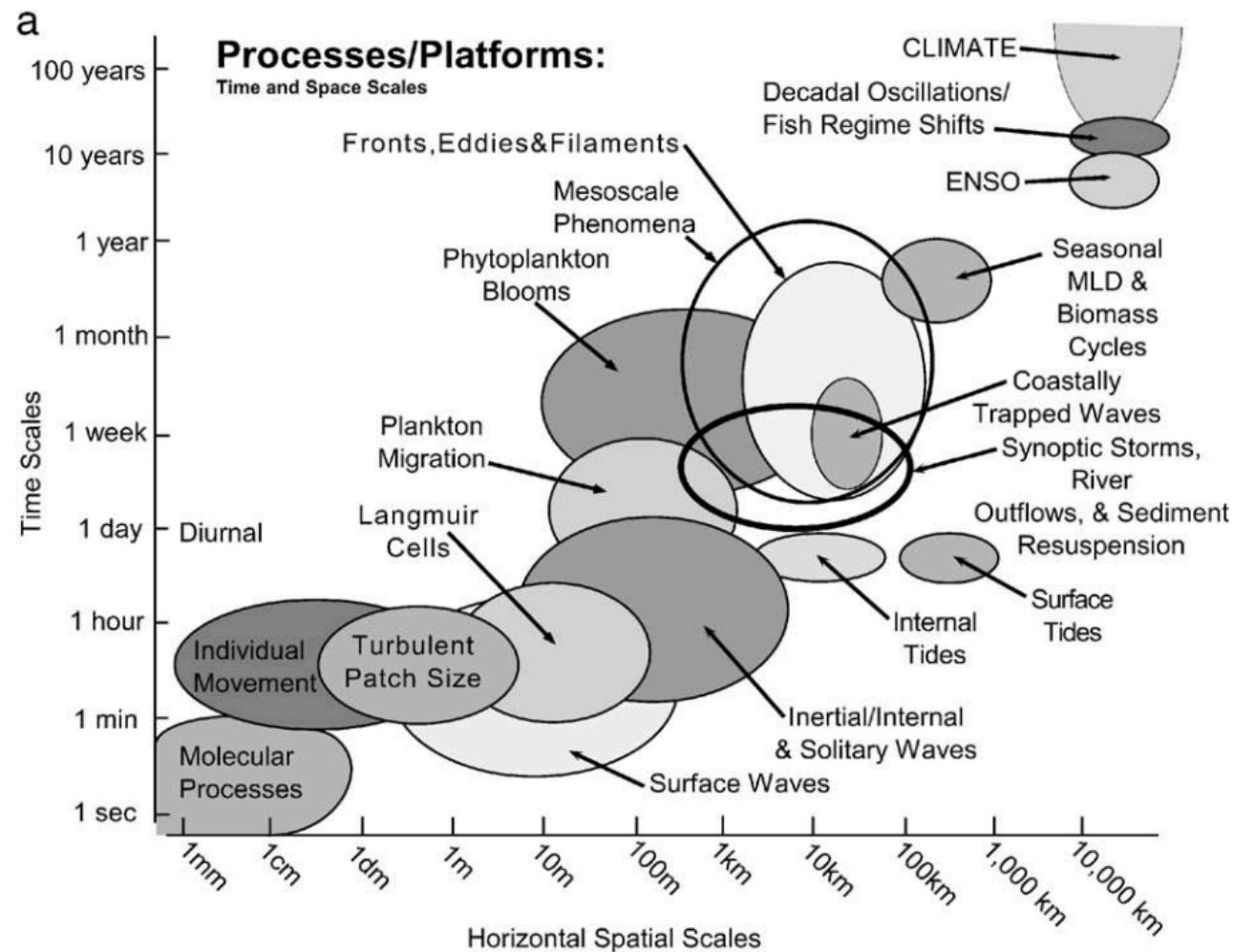
I.1. Introduction

Ocean Waves

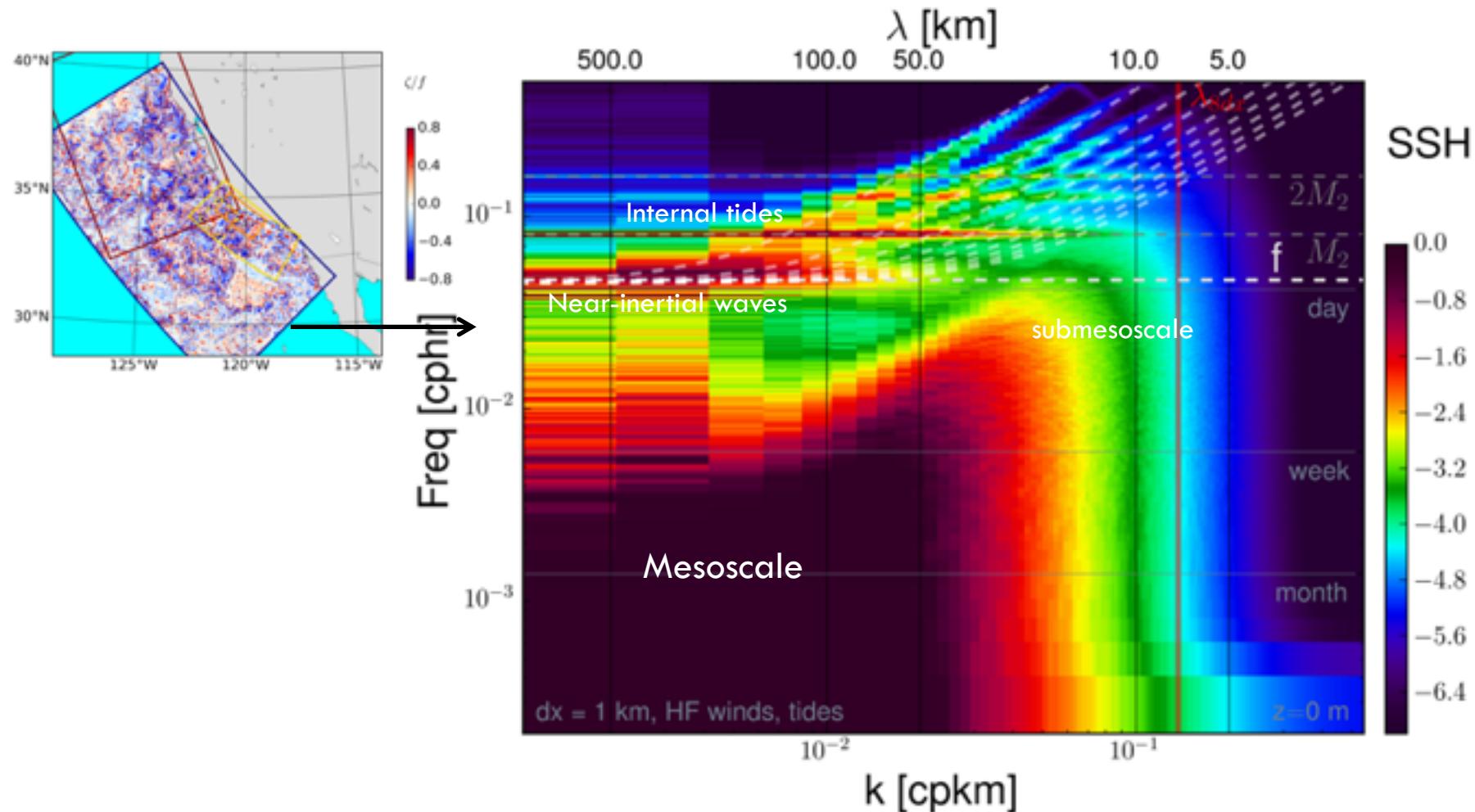


Schematic energy spectrum of ocean variability [Leblond & Mysak]

Ocean Waves



Ocean Waves



Azimuthally-averaged 2D frequency-wavenumber spectra for SSH in California Current

I.2. General properties

I.2.1 Simple Wave example

I.2. General properties

- Mathematically two main classes of waves:

Hyperbolic waves and dispersive waves

Hyperbolic waves

1. **Hyperbolic waves** are formulated in terms of hyperbolic partial differential equations, for example:

$$\eta_t + c\nabla\eta = 0$$

$$\eta_{tt} - c^2\nabla^2\eta = 0$$

Hyperbolic waves

1. **Hyperbolic waves** are formulated in terms of hyperbolic partial differential equations, for example:

$$\eta_t + c\nabla\eta = 0$$

$$\eta_{tt} - c^2\nabla^2\eta = 0$$

- With general solutions in the form:

$$\eta = f(x - ct)$$

$$\eta = f(x - ct) + g(x + ct)$$

- Very frequent in acoustics, elasticity, electromagnetism, etc.

I.2. General properties

Hyperbolic waves

1. Examples of **Hyperbolic waves**

- Flood wave, tidal bores



- Shock wave



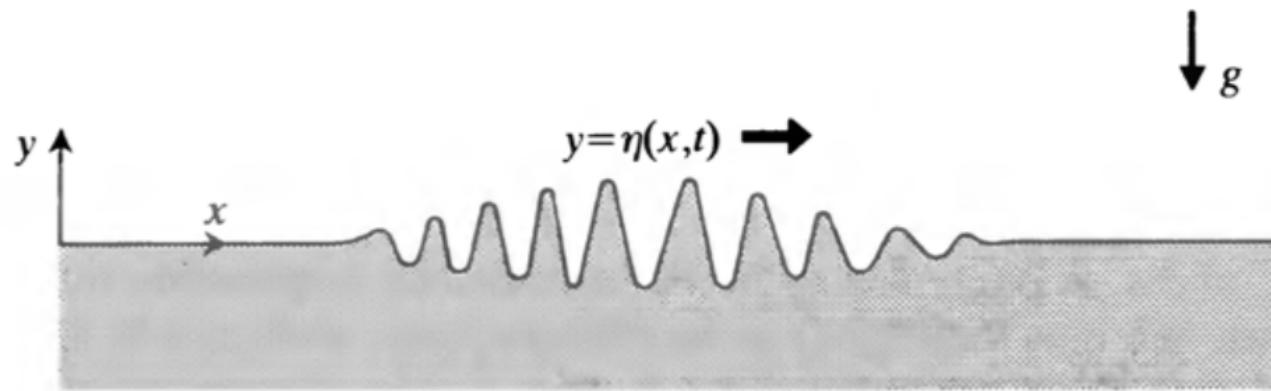
Dispersive waves

2. Dispersive waves come from a variety of partial differential equations, they are characterized principally by their dispersion relation:

$$\omega = f(k)$$

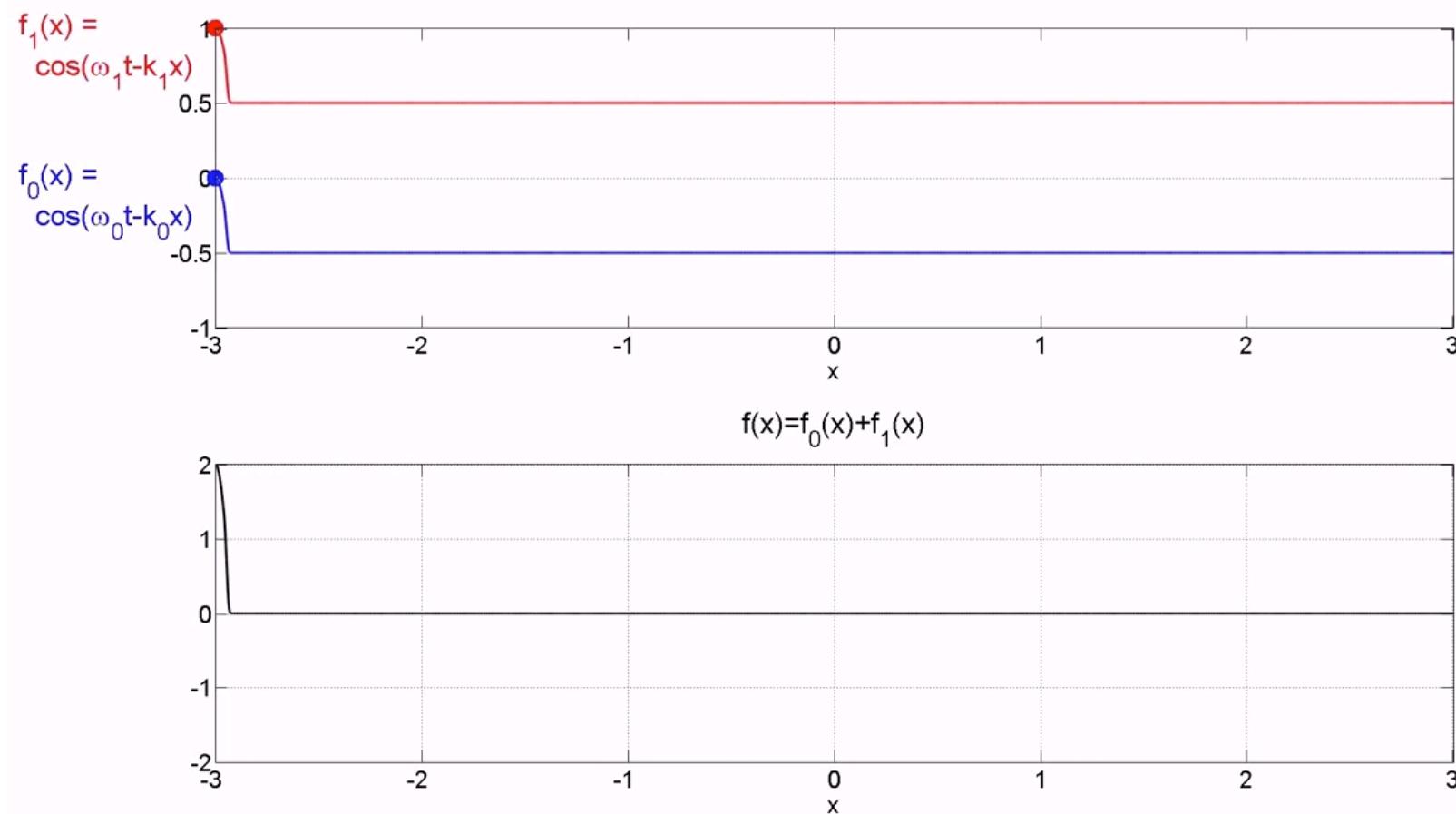
Connecting the frequency and the wave number.

They are visualized as a group of waves where the different Fourier components propagate at different speeds



I.2. General properties

Dispersive waves



Source: https://www.youtube.com/watch?v=uui9clp_DSg

I. WAVES

I.1. Introduction

I.2. General properties of Waves

I.3. Different type of ocean waves

I.3.1 Surface Gravity Waves

I.3.2 Internal Waves

I.3.3 Acoustic Waves

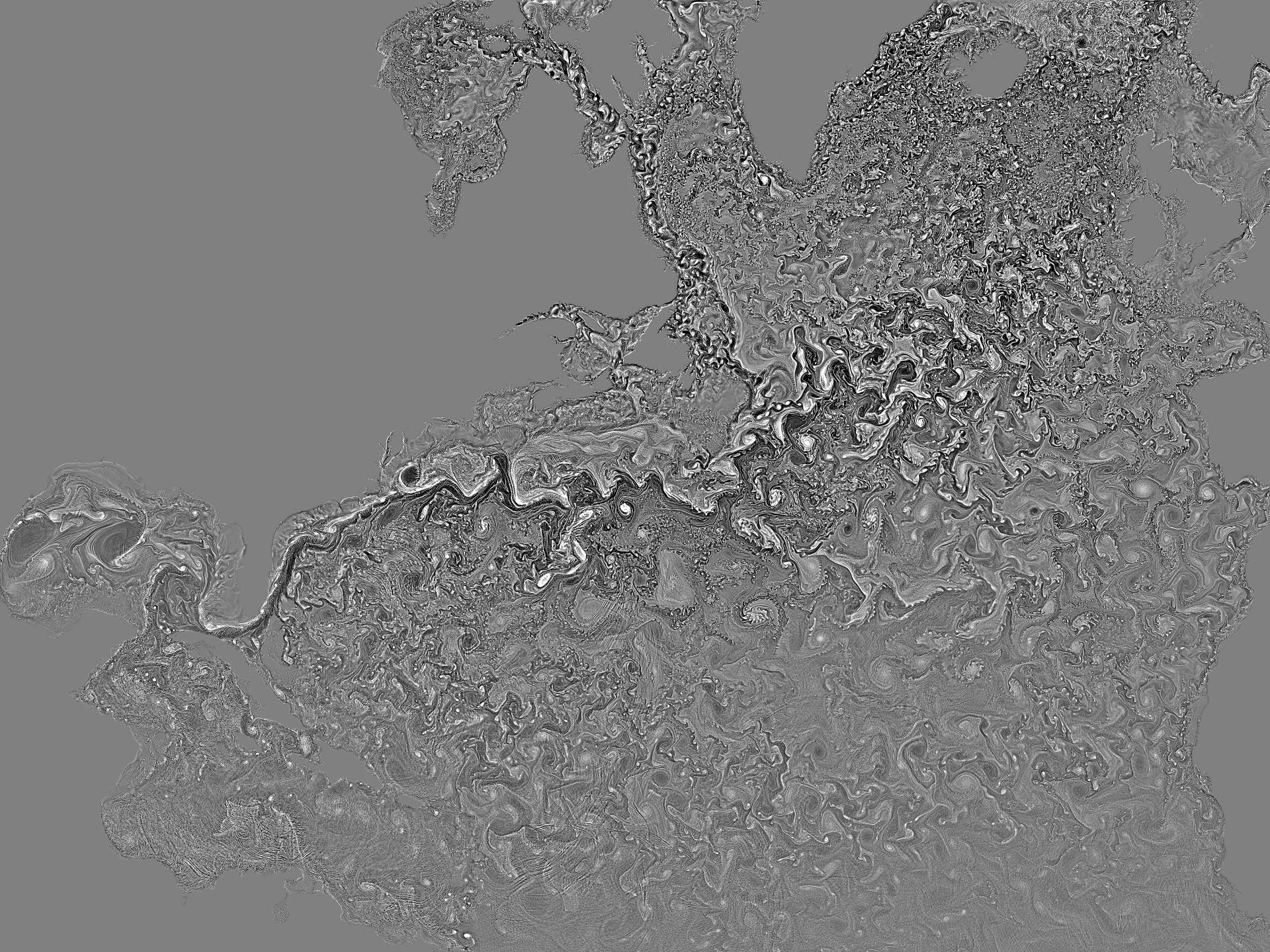
I.4. Ray Theory

I.2. General properties

I.2.2 Planar Wave example

I.2. General properties





I.3. Different type of ocean waves

I.3.1 Surface gravity waves

I.3.1.1 Long waves

I.3.1.2 Short waves

I.3.1.3 The general case

I.3. Different type of ocean waves



I.3. Different type of ocean waves

I.3.1 Surface gravity waves

I.3.1.1 Long waves

I.3.1.2 Short waves

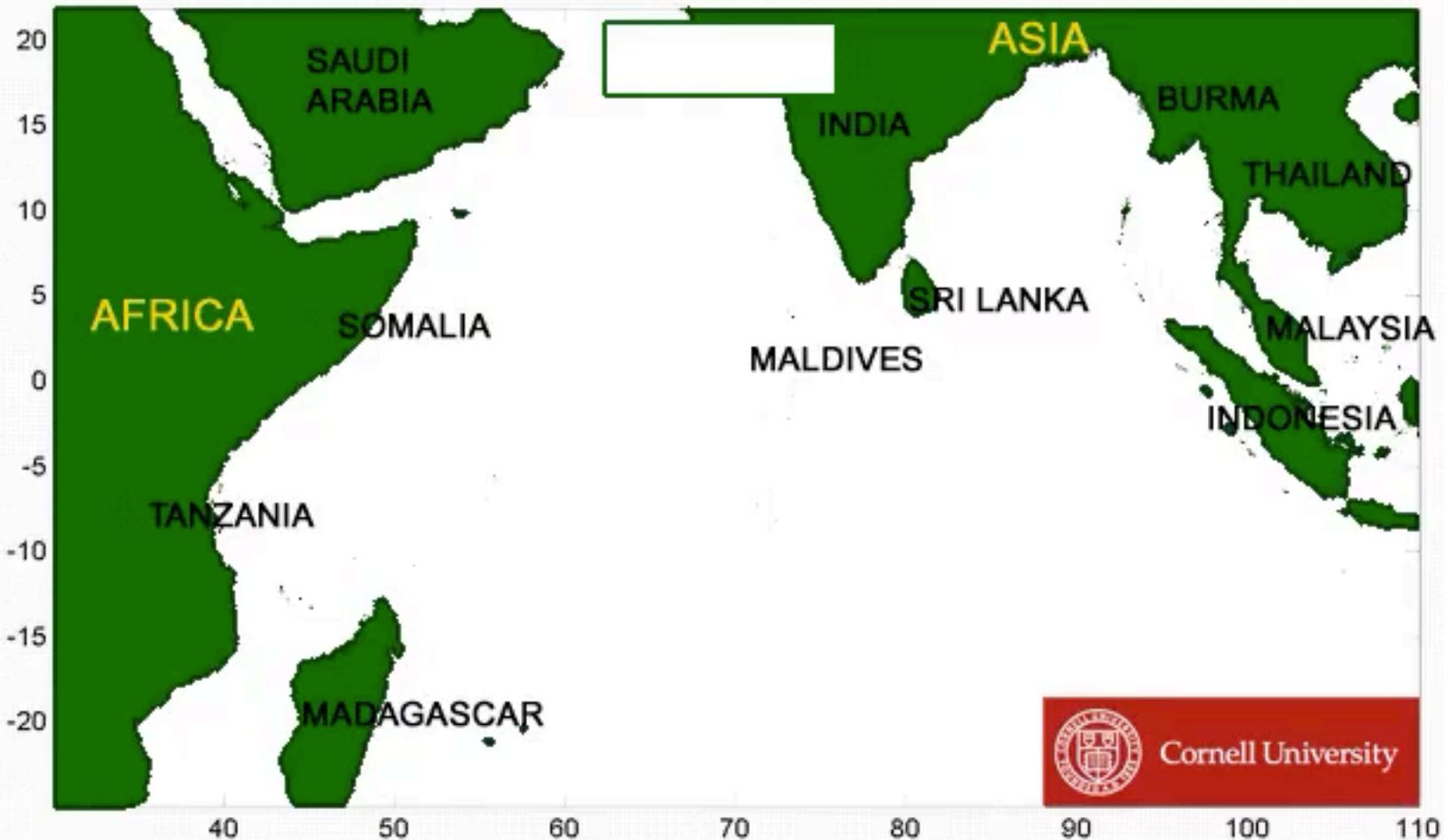
I.3.1.3 The general case

I.3.1.1 Long waves

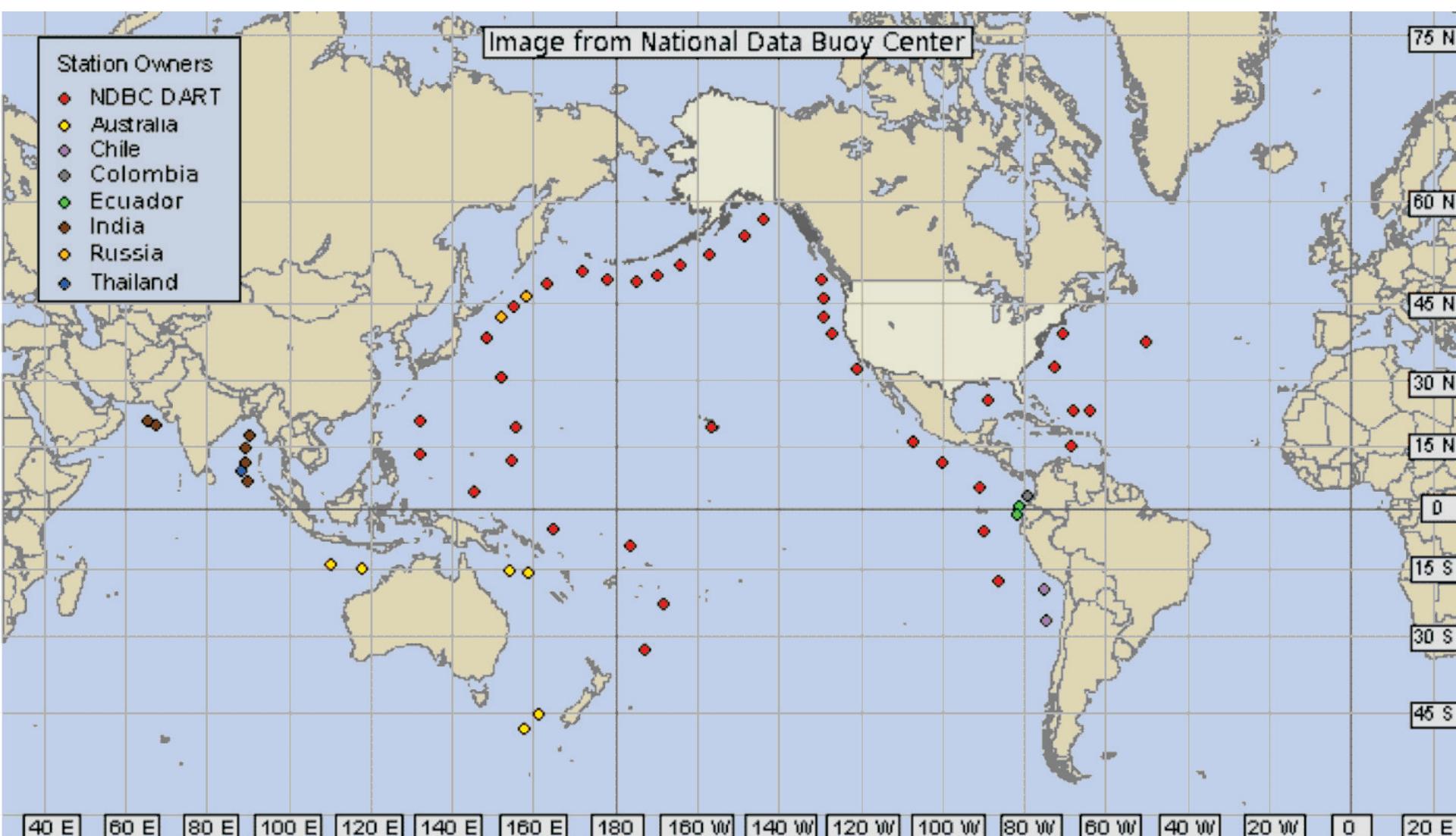
Example of long waves:

- **Tsunamis**
- **Tidal bores**

I.3.1.1 Long waves



I.3.1.1 Long waves



Tsunami detection buoys have been placed around many tectonically active locations. Map is from NOAA Tsunami Detection website <http://www.ndbc.noaa.gov/dart.shtml>

I.3.1.1 Long waves

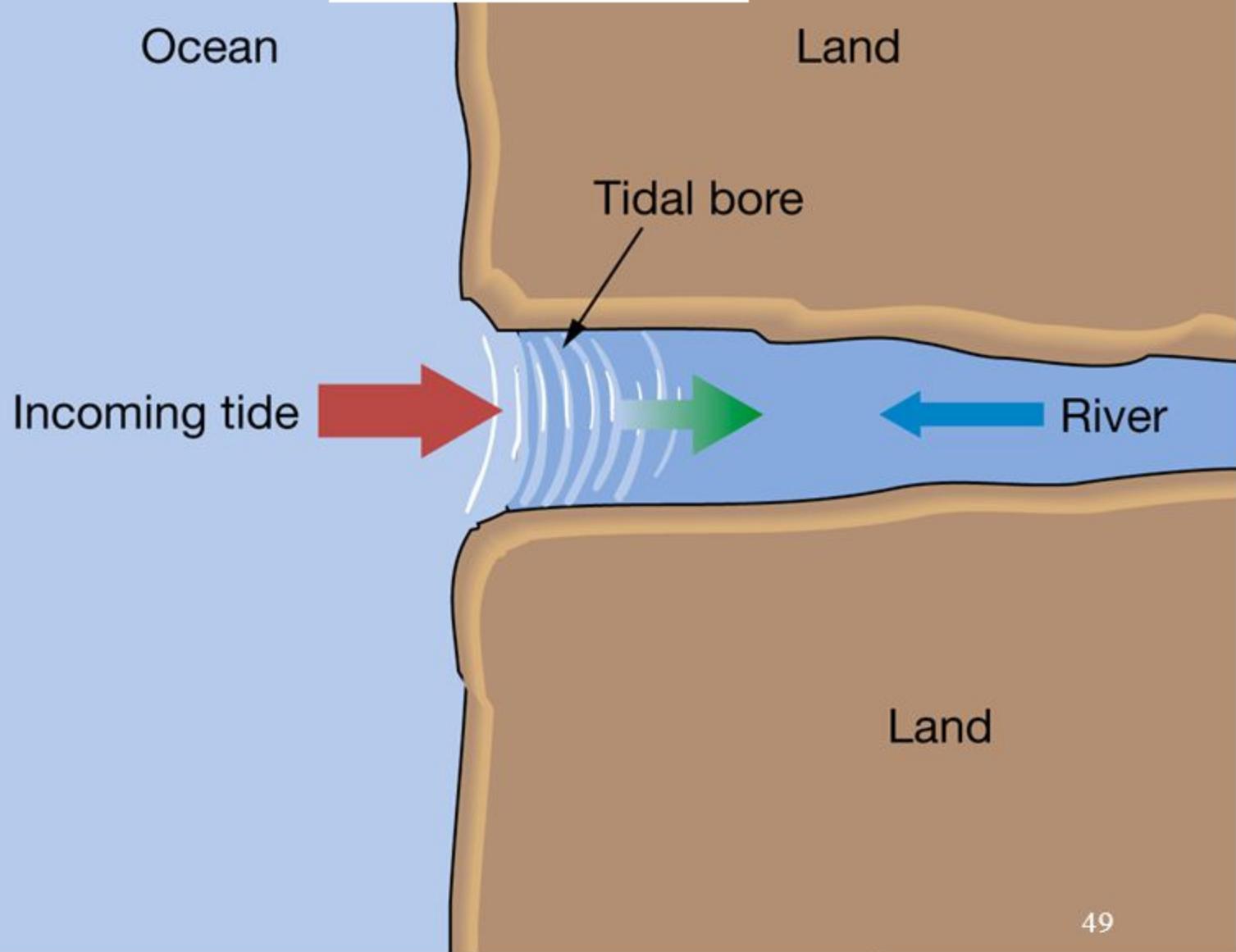
I.3.1.1 Long waves

Example of long waves:

- **Tsunamis**
- **Tidal bores**

Tidal Bore

A tidal bore is a wall of water that surges upriver with the advancing high tide.



I.3.1.1 Long waves



I.3.1.1 Long waves

I.3. Different type of ocean waves

I.3.1 Surface gravity waves

I.3.1.1 Long waves

I.3.1.2 Short waves

I.3.1.3 The general case

I.3. Different type of ocean waves

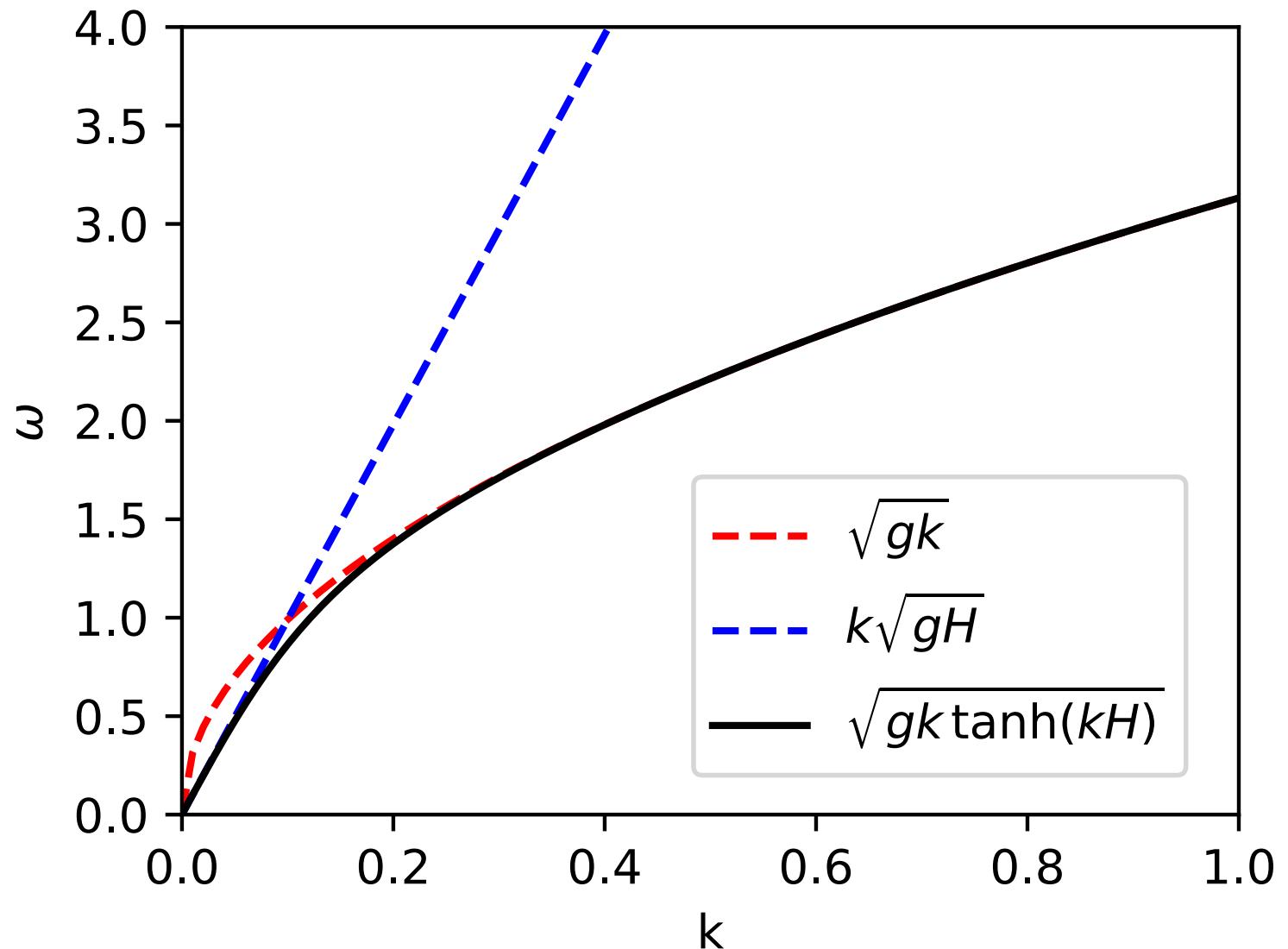
I.3.1 Surface gravity waves

I.3.1.1 Long waves

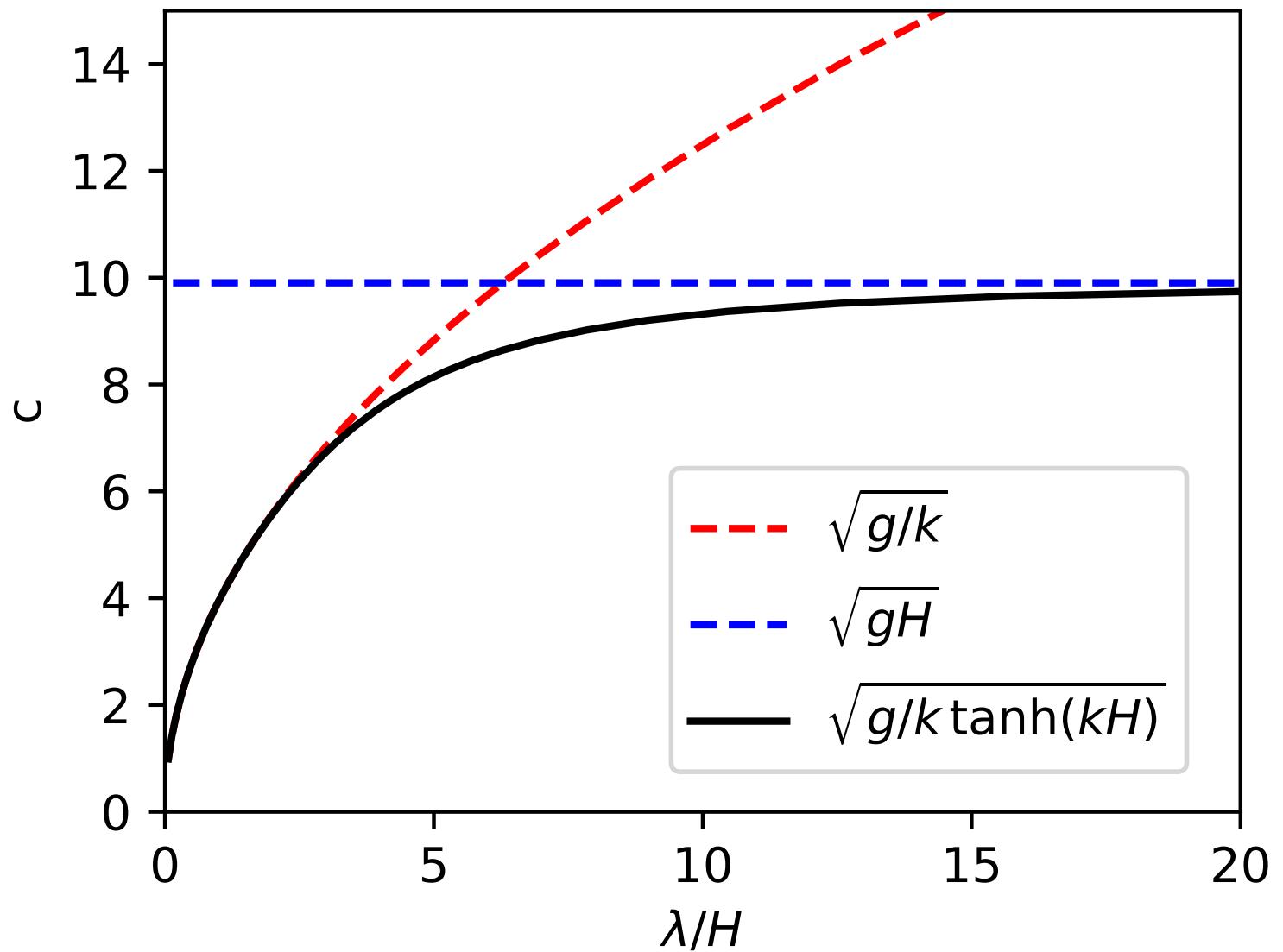
I.3.1.2 Short waves

I.3.1.3 The general case

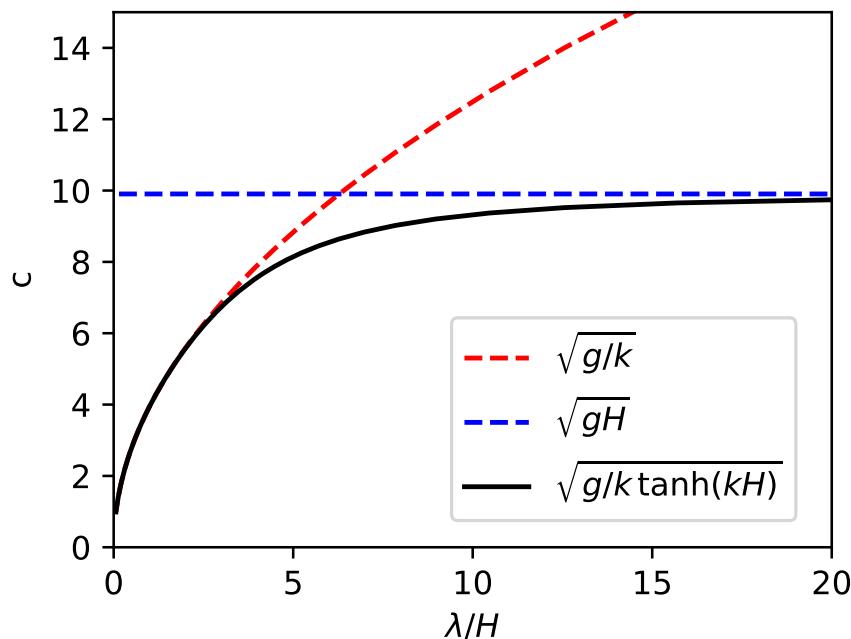
I.3.1.3 The general case



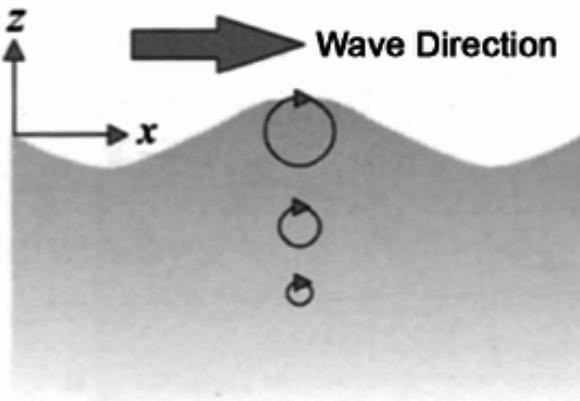
I.3.1.3 The general case



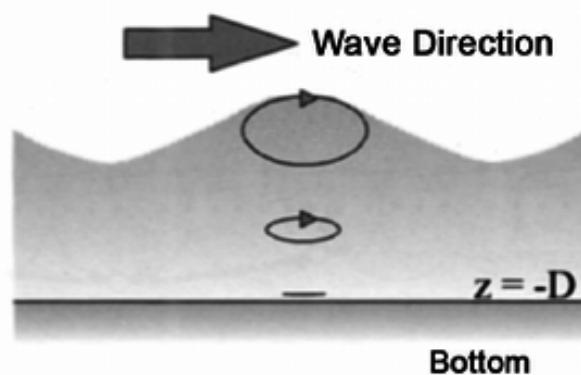
I.3.1.3 The general case



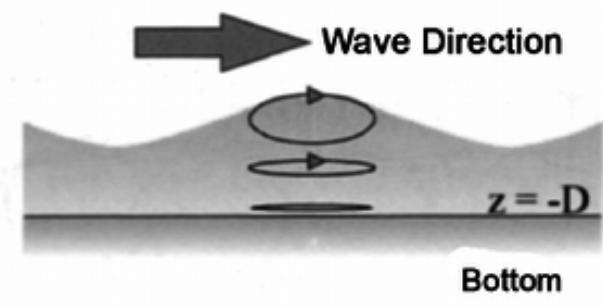
Deep Water



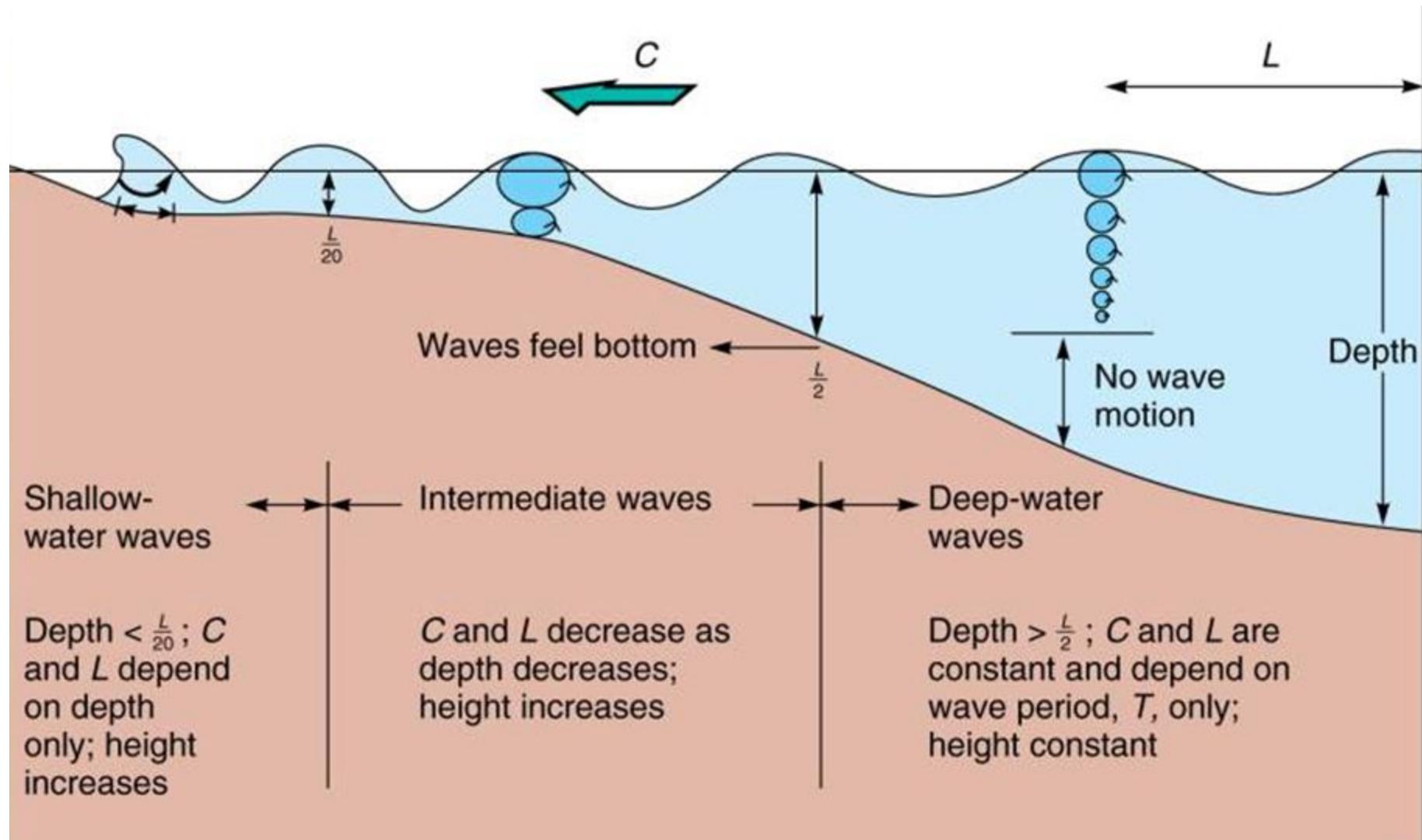
Intermediate Depth



Very Shallow Water



I.3.1.3 The general case



I.3.1.3 The general case

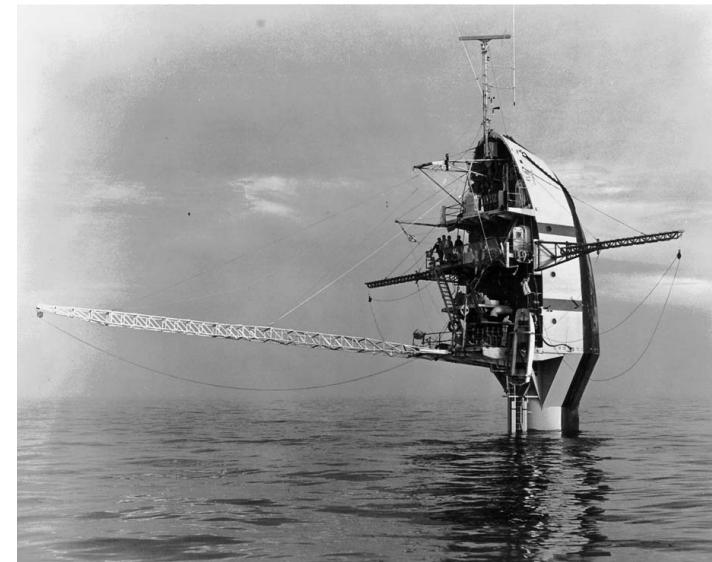
Munk's experiment in 1963: "**Waves Across the Pacific**"

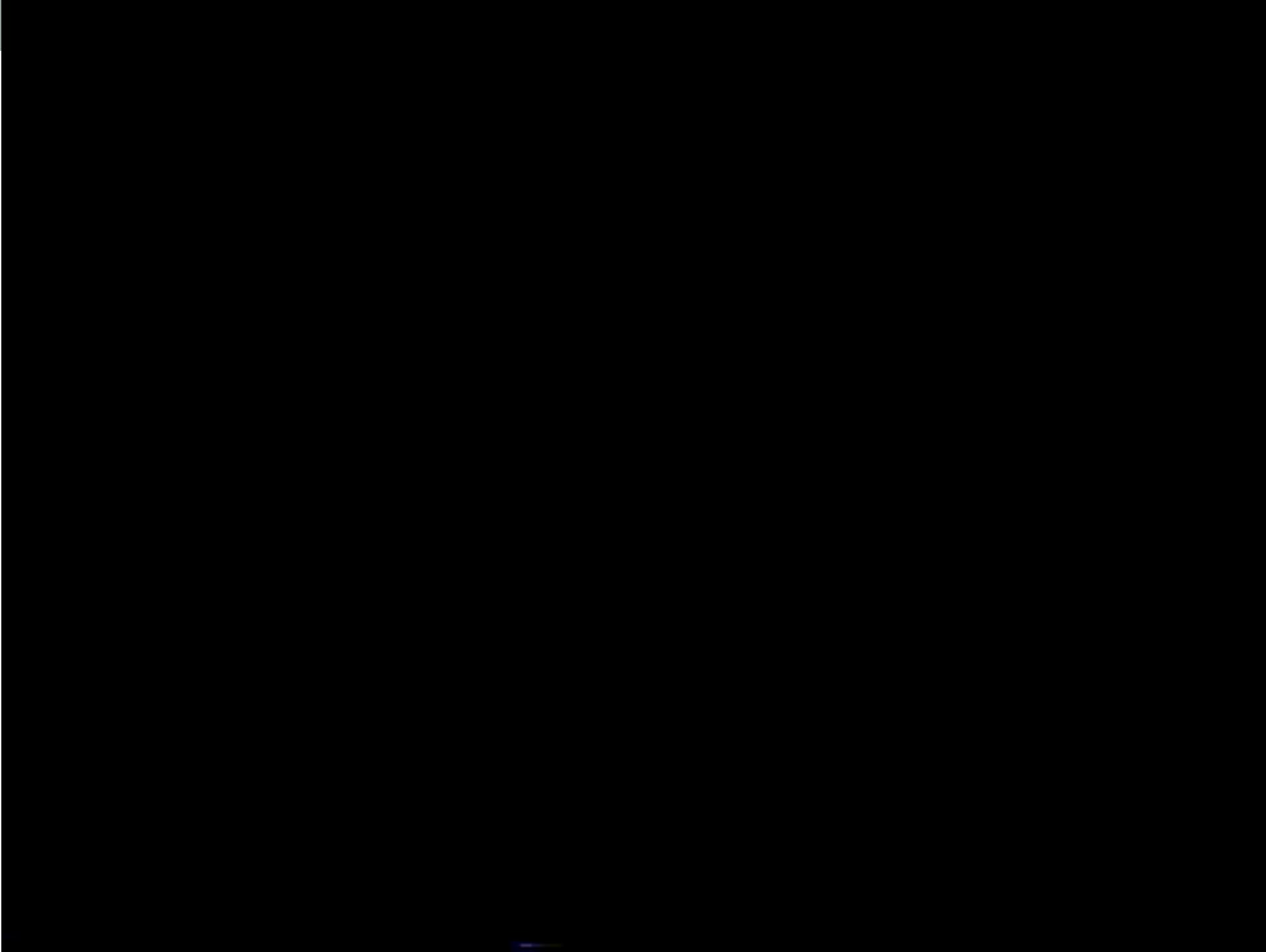
His equations said that the swells hitting beaches in Mexico began some 9,000 miles away — somewhere in the southern reaches of the Indian Ocean, near Antarctica.

"Could it be?" he wrote in an autobiographical sketch. Could a storm halfway across the world produce a patch of moving water that traveled from near the South Pole, up past Australia, then past New Zealand, then across the vast expanse of the Pacific, arriving still intact — at a beach off Mexico?

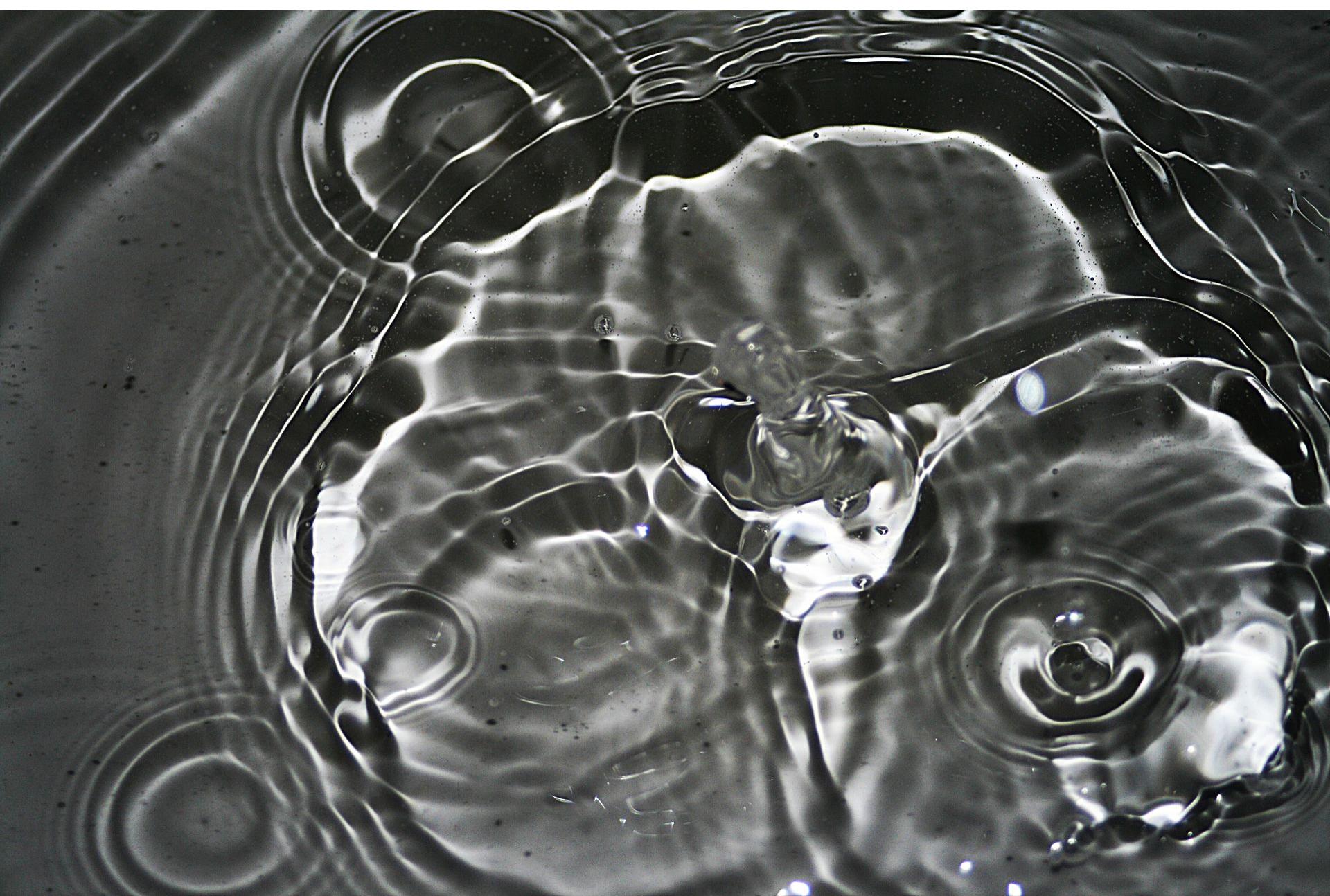
He decided to find out for himself.

That is why, in 1957, Walter Munk designed a global, real-life wave-watching experiment.



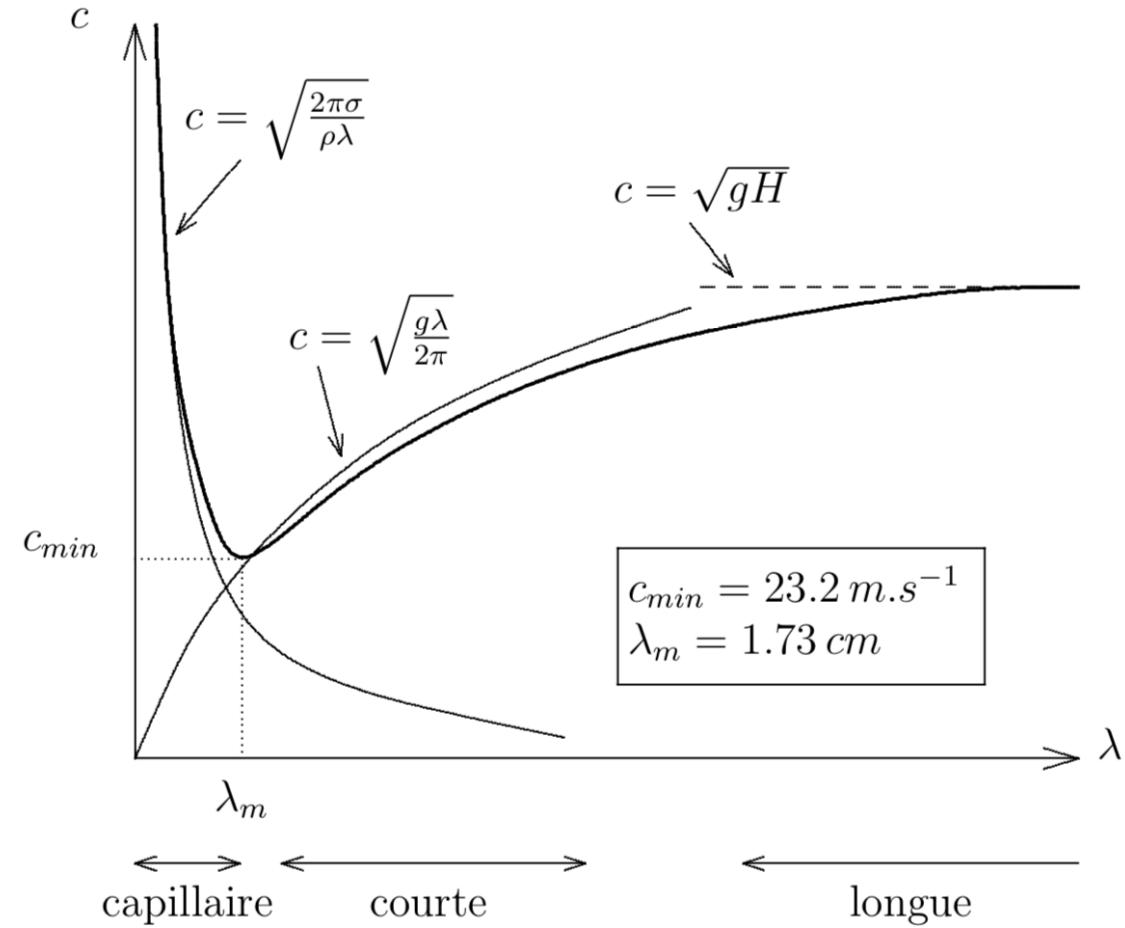


I.3.1.4 Capillary waves

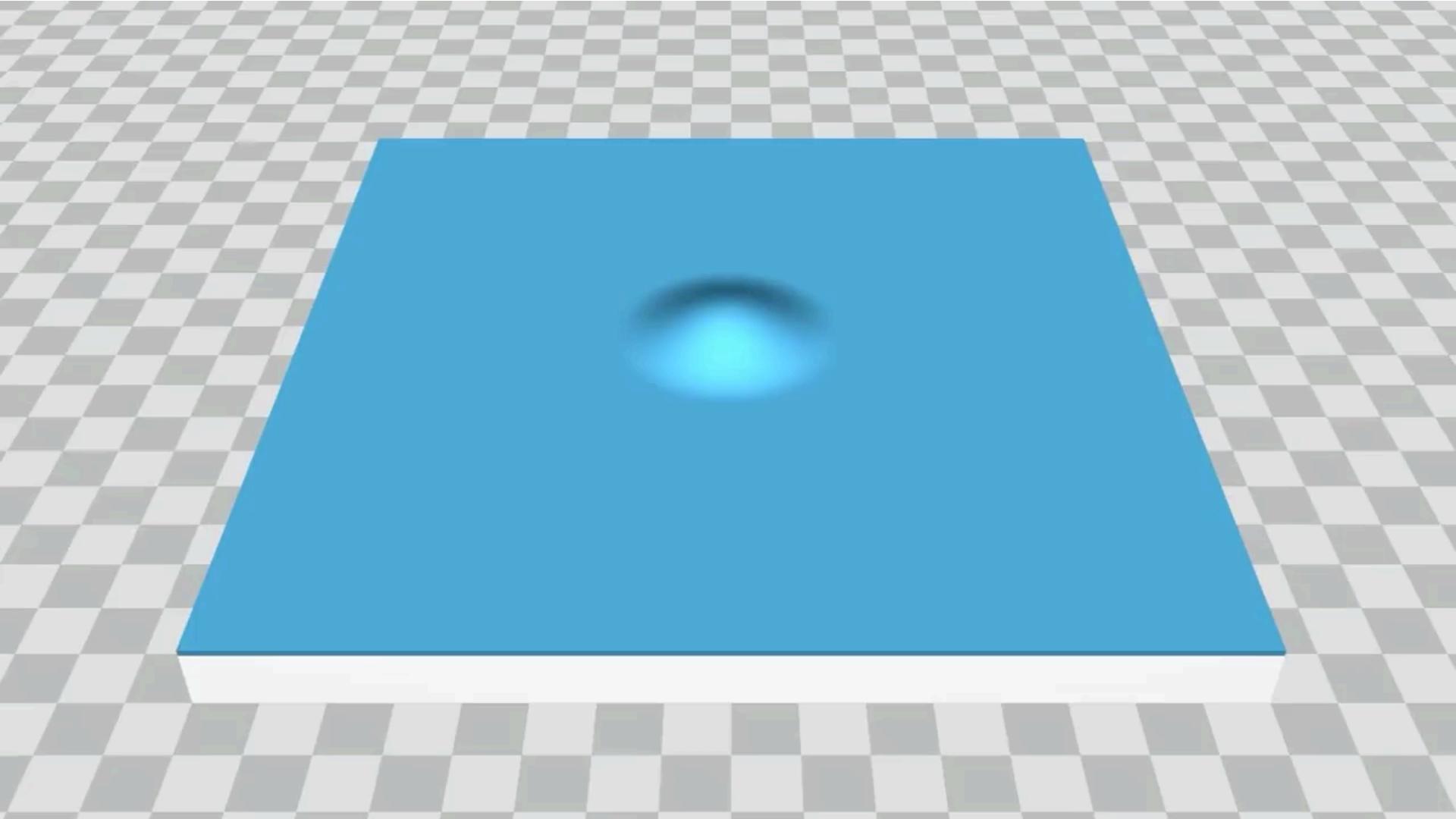


1. Surface waves

With surface tension effects:



I.3.1.4 Capillary waves



https://www.youtube.com/watch?v=BCW6_LAq6qs