Accelerated wind conditions: spectral shape evolution and turbulent kinetic energy dissipation from laboratory and field measurements

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The air-sea fluxes of momentum, heat and mass in the marine atmospheric boundary layer are key boundary parameters for atmospheric, oceanic and wave models. With the recent efforts to couple ocean and wave information to atmospheric models [e.g., Hodur, 1997; Powers and Stoelinga, 2000], **accurate knowledge of the fluxes is increasingly important.**

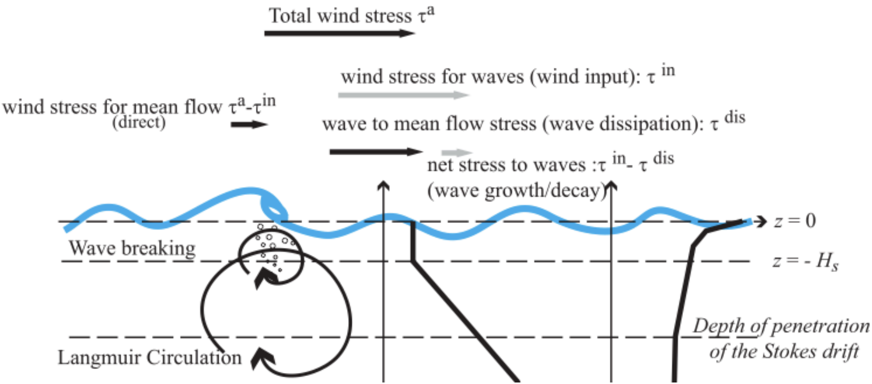


Figura 1: [Ardhuin et al., 2005]

Non-equilibrium conditions ? *Tehuano* winds? Hurricanes?

Introduction

Drag coefficient and sea state

- **Sea state - wave age** → direct influence roughness and C_D [Smith et al., 1992] [Donelan et al., 1993]
- **Young sea** → increase wind stress [Donelan, 1990] [Drennan, 2003]
- **Steep waves** → induce air flow separation, enhancing wind stress [Reul et al., 2008]

Accelerating/decelerating winds

- **Gustiness** → most distant ouliers in C_D [Babanin and Makin, 2008]
- **Response of wave spectra** → rising wind conditions [Toba et al., 1988]
- **Variation in roughness length** → changes the saturation level of wave spectrum [Toba and Ebuchi, 1991]
- **Delayed adjusting of wave spectra** → variations in wind stress [Uz et al., 2002]

Introduction

Need

- We do not fully understand how these fluxes are modified by complex (non-equilibrium) surface wave fields, including developing wind seas. Therefore, there is a remarkable need to study the first stages of wind-wave and surface drift current generation and evolution under accelerated wind conditions.

Task

- Several experiments were carried out in a large wind-wave facility in order to provide a wide range of wind conditions and wave development stages under different values of acceleration of wind velocity.

Main objective

Study the surface drift current generation and evolution process and its role in the momentum interchange through the air-water interface.

Specific objectives

- Study the early stages of the generation of the wind-wave field and surface drift current.
- Determine the influence of the sea state in the surface drift current.
- Analyse the vertical variation of the surface drift current.

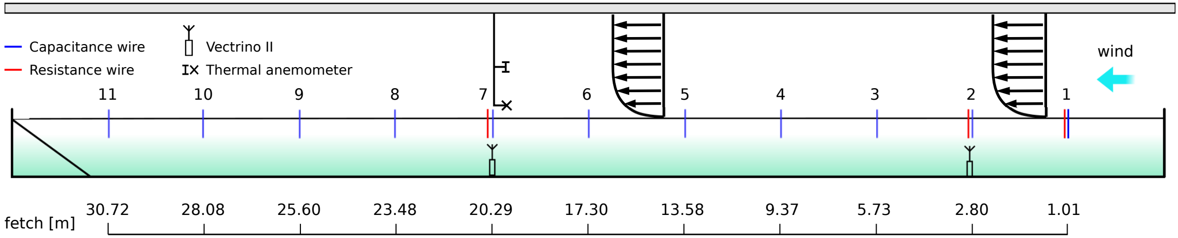
The main contributions:

- Moderated wind acceleration conditions induce a higher wave growth efficiency and a higher vertical shear of the surface drift current.
- This produces a higher production of turbulent kinetic energy and a non-equilibrium in the production-dissipation of turbulent kinetic energy.

Preview

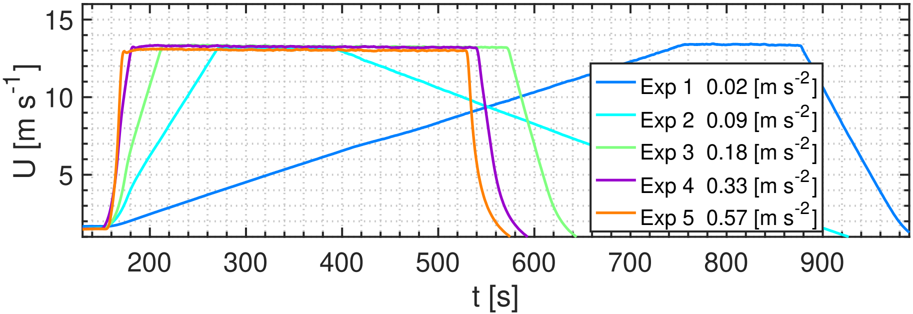
- Experimental set-up
- Air boundary layer development and wind-wave growth
- Early stages of the wind-wave generation through spectral analysis
- Surface drift current and turbulent kinetic energy

Facility and measuring devices

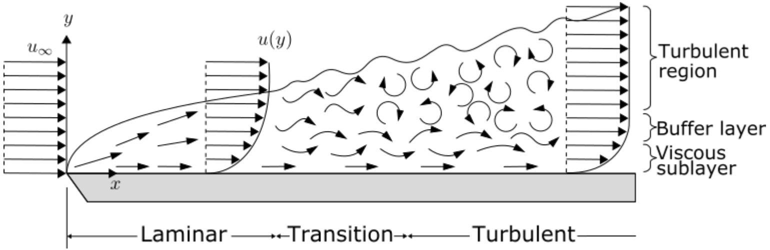


- Resistance and capacitance wire probes [256 Hz].
- Thermal anemometers [256 Hz].
- Acoustic profiler, *Vectrino II* [100 Hz]. $\Delta z = 1$ mm; column height = 3.5 cm

Temporal variation of mean wind speed



Air boundary layer development and wind-wave growth

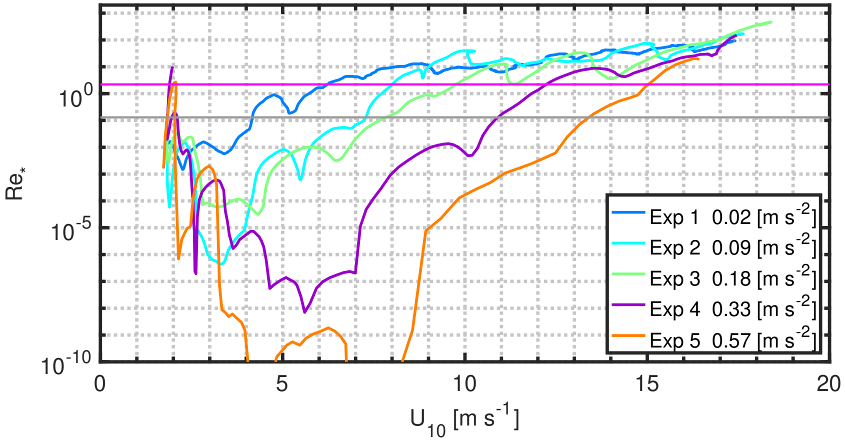


Roughness Reynolds number

$$Re_* = u_* z_0 / \nu \quad (1)$$

$$z_0 = \frac{z}{e^{\left(\kappa / \sqrt{C_D}\right)}} \quad (2)$$

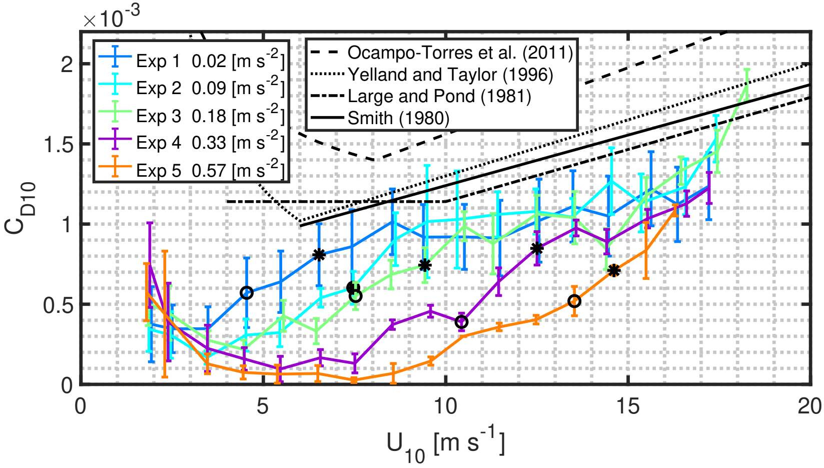
- $Re_* < 0.13$
  smooth flow regime
- $Re_* > 2.2$
  rough flow regime



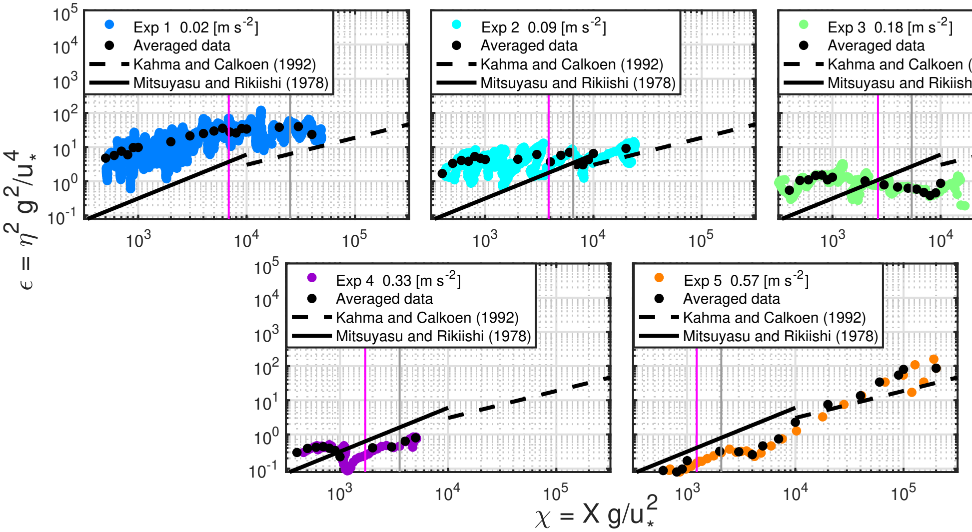
$$\tau = -\rho \left(\overline{w'u'} \right) \quad (3)$$

$$u_*^2 = \frac{|\tau|}{\rho} \quad (4)$$

$$\rho \overline{u'w'} = \rho u_*^2 = \rho C_D U_{10}^2 \quad (5)$$



Non dimensional wave growth

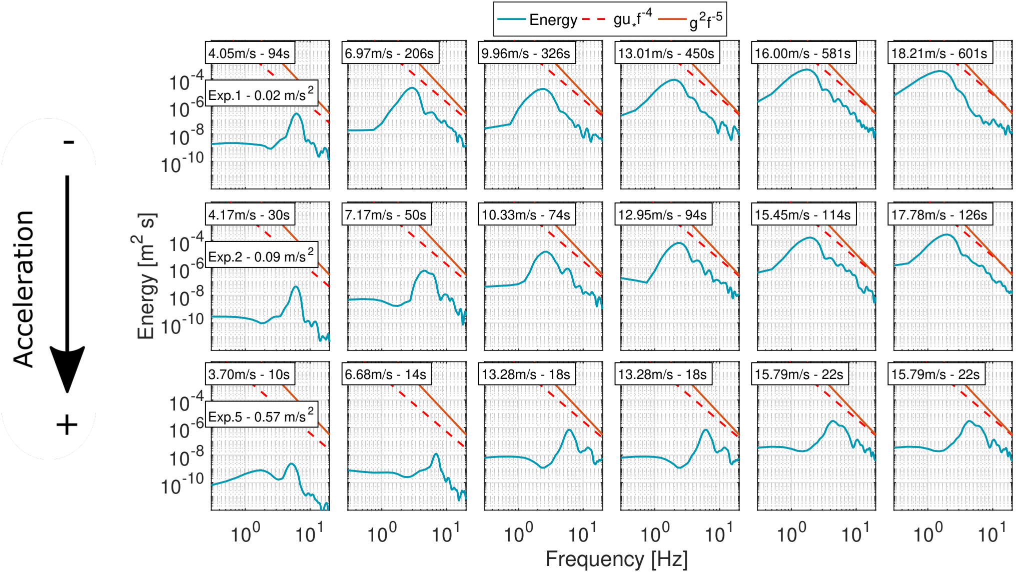


More results at:

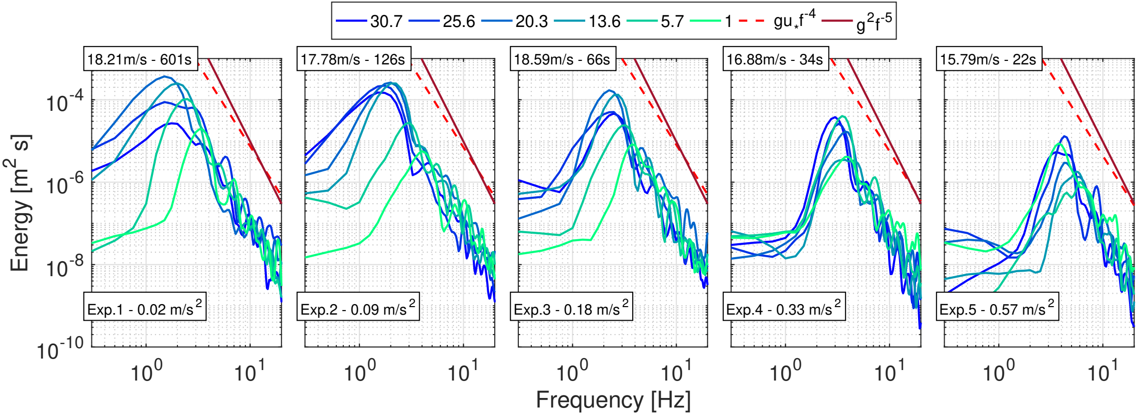
- Robles-Diaz, L., Ocampo-Torres, F.J., Branger, H., Garcia-Nava, Osuna, P., Rascle, N., **“On the early stages of wind-wave generation under accelerated wind conditions”**, *European Journal of Mechanics - B/Fluids*, Vol. 78, pp. 106-114, 2019.
  DOI: https://doi.org/10.1016/j.euromechflu.2019.06.007

Early stages of the wind-wave generation through spectral analysis

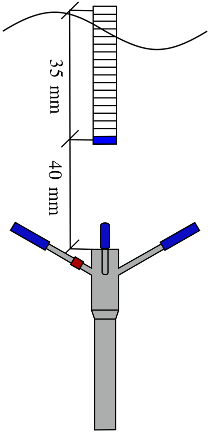
Wave energy spectrum evolution with wind speed



Wave energy spectrum evolution with fetch

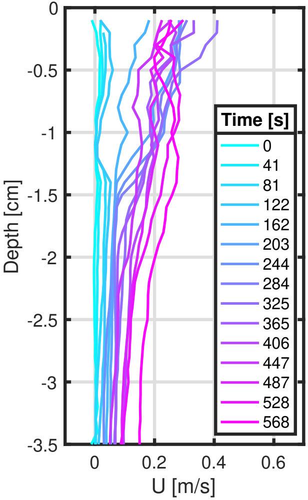


Surface drift current and turbulent kinetic energy

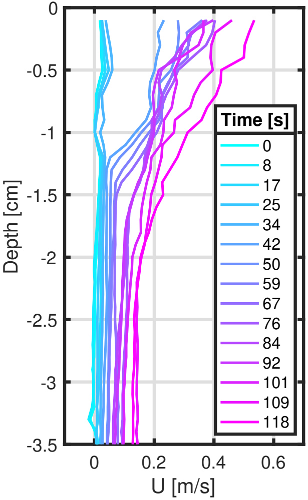


Total surface drift current

Experiment 1 (0.02 m s^{-2})

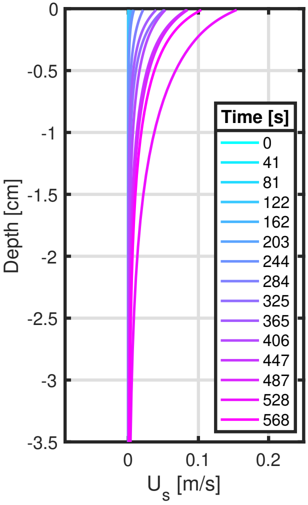


Experiment 2 (0.09 m s^{-2})

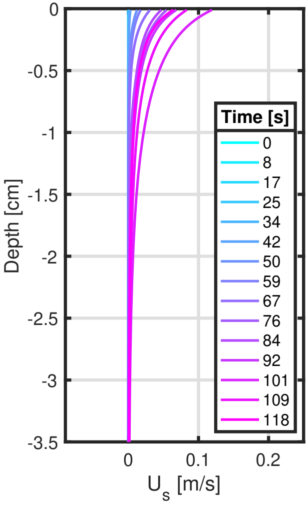


Stokes drift

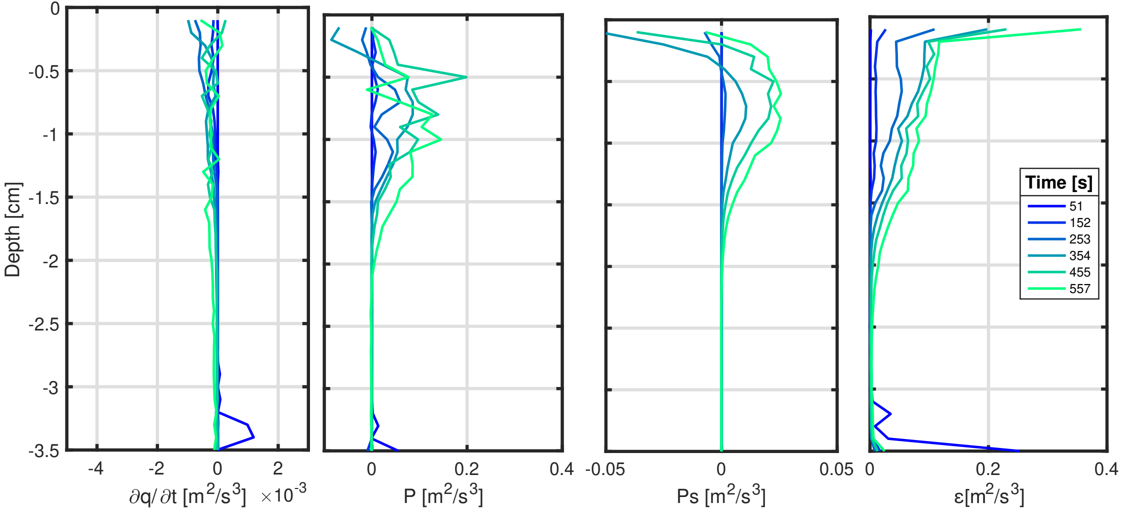
Experiment 1 ($0.02\ m\ s^{-2}$)



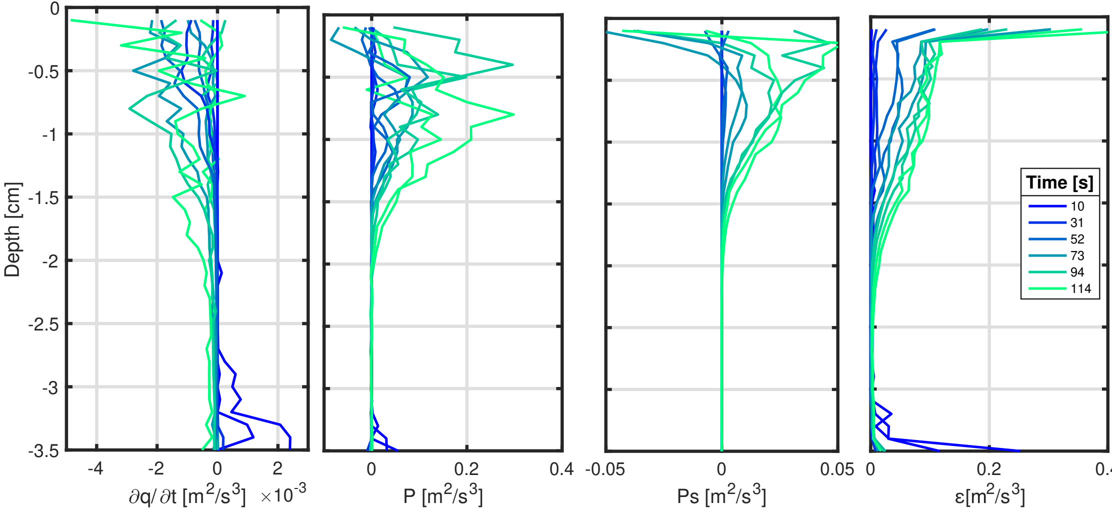
Experiment 2 ($0.09\ m\ s^{-2}$)



Experiment 1 ($0.02\ \mathrm{m\ s^{-2}}$)



Experiment 2 (0.09 m s^{-2})



Air boundary layer development and wind-wave growth

- It was possible to establish a relationship between momentum availability and wave growth efficiency.
- Under the **smooth flow regime**, the wind acceleration directly affects the turbulence generation and the magnitude of the drag coefficient. This fact implies that the amount of available momentum for wave generation is modified.
- Under the **rough flow regime**, also the state of development of the wave field has a direct influence on drag coefficient behaviour with wind speed.
- A less developed wave field induces a higher increase in drag coefficient with wind speed.

Early stages of the wind-wave generation through spectral analysis

- The spectral shape evolution is more remarkable under low acceleration conditions.
- Although the time is a determining factor in wind-wave development, the fact that the wind is accelerated induces a higher wind-wave field development under moderate acceleration conditions.

Surface drift current and turbulent kinetic energy

- A detailed description of the mean surface drift current associated with wind-wave generation process under accelerated wind conditions is presented.
- The higher the wind acceleration the higher the vertical shear of the surface drift current. That produces that a higher level of turbulence and promotes a higher production of turbulent kinetic energy due to the shear of the mean flow.
- The higher equilibrium between turbulent kinetic energy production and dissipation is observed under lower acceleration wind conditions.

Acknowlegments

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Thank you very much