# Investigating marine shallow waters dynamics to explore the role of turbidity on ecological responses

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## ABSTRACT
The ecological tangible effect of the complex interaction between sediments and water column in shallow waters is represented by turbidity which is a common feature of most aquatic ecosystems: it varies both temporally and spatially. Turbidity can cover large areas and persist for long periods or it can be very localized and temporary. Among many factors able to generate turbidity, wind generated wave action and water mass movements due to tides seem important in causing resuspension of sediments. Although there is much research spent in last decades on this topic and many models to explain the complexity of the wind-water-sediment interaction, some interactive aspects are highly site specific and then still poorly understood. On the other hand, this interaction involves many physical, chemical and trophic aspects like water flow velocity, turbulence, boundary layer thickness, environmental stresses and, in turn, resuspension, transport, and deposition of particulate matter, mechanical limits to size, larval dispersion, food availability.

## KEYWORDS
Biological-physical interaction, ecological responses, hydrodynamics, resuspension, shallow water, turbulent kinetic energy, turbidity.

## INTRODUCTION
In shallow waters, seagrass beds may exert strong effects on hydrodynamics extracting fluid momentum due to roughness of vegetation and enhancing turbulence levels at the canopy-water interface. This process create two dynamically different environments: the first, called vegetated layer (i.e., below the canopy) which is characterized by low flow velocity, a vertical gradient and turbulence (Gambi *et al.*, 1990) and the second over the interface which is characterized by greater velocity and higher degrees of turbulence (Ciraolo *et al.*, 2004; Nezu and Sanjou, 2008). Under these conditions, turbulence is not only generated at the canopy-water interface but also by wind-induced-shear-stress at the surface. Thus, turbulence controls resuspension intensity and the residence time of suspended matter in the water column whose presence substantially affects biological and ecological responses of aquatic organisms. Hydrodynamic variables as flow and shear velocities, turbulence kinetic energy (TKE) depict the behaviour of the non-vegetated layer often characterised by a boundary layer (i.e. that layer with a logarithmic velocity profile expressed by a modified von Karman Prandtl law) according to Hendriks *et al*. (2005): $u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z-d}{z_v}\right)$ (1)

where *u(z)* is the velocity at height above bottom, $u^*$ is the shear velocity, $\kappa$ is the von Karman constant (~0.41), *d* is the displacement height (i.e. the height above bottom where the log velocity profile goes virtually to zero) and $z_v$ is the vegetation roughness (Klopstra *et al.*, 1997). Although there is much research spent in last decades on these topics and many models have been formulated to explain the complexity of the wind-water-sediment interaction, some interactive aspects are too highly site-specific and then still poorly understood. On the other hand, this interaction involves many physical, chemical and trophic aspects like water flow velocity, turbulence, boundary layer thickness, environmental stresses and, in turn, resuspension, transport, and deposition of particulate matter, mechanical limits to size, larval dispersion and food availability for secondary consumers. In the present paper, the effect of vegetation coverage on water column behaviour was studied with a long-continuous experiment in a Mediterranean shallow area (the Stagnone di Marsala, Western Sicily) with the main aim of exploring the relative importance of resuspension throughout the water column in comparison of a lateral advective transport.

## MATERIALS AND METHODS

### The study area

The study was carried out in a semi-enclosed marine system, the Marsala lagoon (western Sicily, the Mediterranean Sea; Figure 1). The basin is shallow (~1.5m) and the seagrass are particularly luxuriant in the basin, especially in the southern part where they are able to affect currents and silting. Water exchanges with the open sea are ensured by currents (a mean speed between ~ 5 cm $s^{-1}$ and ~ 3 cm $s^{-1}$, respectively in the Southern in the Northern areas). Geographical and environmental details are extensively reported in Pusceddu et al. (1997, 1999) and Sarà (2006).

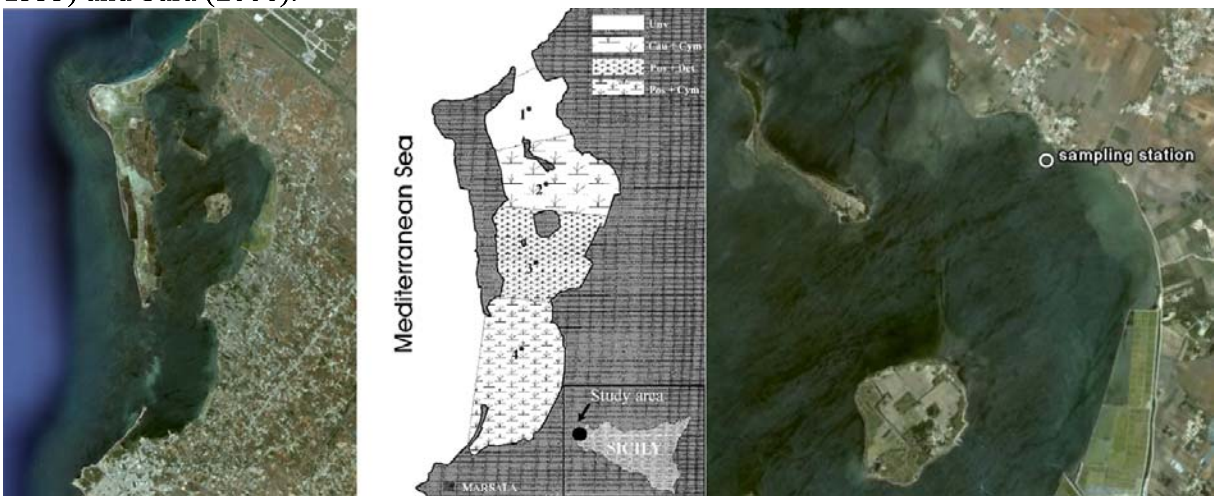


**Figure 1** From the left side: Marsala lagoon (image from *Google Earth*); a schematic image that illustrate the spatial distribution of different algal and vascular plant coverage types (1. Unv = unvegetated; 2. Cau + Cym = *Caulerpa prolifera* + *Cymodocea nodosa*; 3. Pos + Det = *Posidonia oceanica* + detritus of *Posidonia*; 4. Pos + Cym = *Posidonia oceanica* + *Cymodocea nodosa*) (image from Pusceddu *et al.*, 1999), the study area and the sampling station (image from *Google Earth*).

### Field mesurements

The experiment was carried out between the 14 and 19 March 2007 for 5-continuous days in the north-eastern area of the Stagnone di Marsala characterised by 70% bottom coverage of seagrasses *Cymodocea nodosa* and *Ruppia maritima*. The sampling station was located at 100 m from the east coast (37°52’55.14’’ N, 12°28’40.71’’ E) and had a depth of ~0.9 m with a tidal amplitude of 0.25 m. The experiment consisted in collecting data (see Tab. 1 for details) on wind speed and direction, water velocity at two different heights of the water column to understand the contextual response as turbidity and chlorophyll-a under conditions of seagrass coverage and flow regime driven by tides and wind events.

| Instruments | Variables | Frequency | Positioning |
|---|---|---|---|
| *Meteorological station* Oregon Scientific WMR928X | Wind velocity (m s$^{-1}$) Wind direction (° from North magnetic) | 1 data per minute | ~ 2 m above sea surface |
| *Multiprobe* YSI 6600 | Turbidity (NTU) | 1 data per minute | Sensor at 30 cm above bottom |
| *Acustic doppler velocimeter (ADV)* Nortek | East ($x$ – *axis*), North ($y$ – *axis*) and Up ($z$ – *axis*) component of flow velocity, respectively $u$, $v$, $w$ (cm s$^{-1}$) | 8 data per second (8 Hz) | Sampling volume at 40 cm above bottom |
| *Electromagnetic current meter (ECM)* Valeport 808 EM | Magnitude of flow velocity in $x$-$y$ plane (cm s$^{-1}$) Flow direction (° from North magnetic) | 3 data per minute (0.05 Hz) | Sampling volume at 20 cm above bottom |

**Table 1**

We used the linear wave theory and the empirical equations according to Carper and Bachmann (1984) and Demers *et al*. (1987) under the hypothesis that local resuspension was related to wind induced waves. In the linear wave theory the wavelength of a deepwater wave is related to its period by the well-known equation: $L = \frac{gT^2}{2\pi}$ (2)

where $L$ is the wavelength, $T$ is the wave period and $g$ is the gravitational acceleration. In shallow waters like small lakes and lagoons, the wave period is related to wind velocity and effective fetch by the following equation (U.S. Army Coastal Engineering Research Center, 1977): $\frac{gT}{2\pi W} = 1.20 \tanh\left[0.077\left(\frac{gF}{W^2}\right)^{0.25}\right]$ (3)

where $W$ is the wind velocity and $F$ is the effective fetch.

## Data processing

From the whole dataset we obtained and calculated: ***Flow velocity: F (cm s$^{-1}$)*** where $F_1$ i.e. $F$ at 20 cm above bottom, is given from dataset of ECM; $F_2$ i.e. $F$ at 40 cm above bottom, from datasets of ADV, calculated according the following equation: $F_2 = \sqrt{u^2 + v^2}$ (4)

***Flow direction: $\alpha$ (°)*** where $\alpha_1$ i.e. $\alpha$ at 20 cm above bottom, is given from dataset of ECM; $\alpha_2$ i.e. $\alpha$ at 40 cm above bottom, from dataset of ADV, calculated according the following equation: $\alpha_2 = \arccos\left(\frac{v_2}{F_2}\right)$ (5)

***Turbulent kinetic energy: TKE (cm$^2$ s$^{-2}$)***: From dataset of ADV only, calculated according the following equation (Pope *et al*. 2006): $TKE = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$ (6)

***Shear velocity [TKE]: u$_*$ (cm s$^{-1}$)***. From dataset of ADV only, calculated according the following equation (Pope et al. 2006): $u_* = \sqrt{\frac{1}{2}C\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)}$ where $C$ = 0.2 (7)

***Shear velocity [cov]: $u_*$ (cm $s^{-1}$)***. From dataset of ADV only, calculated according the following equation modified after (Boudreau and Jørgensen, 2001): $u_* = \sqrt[4]{\left(\overline{u'w'}\right)^2 + \left(\overline{v'w'}\right)^2}$ (8)

***Shear velocity [log]: $u_*$ (cm $s^{-1}$)***. From dataset of ECM and ADV, when $F_2 > F_1$ and $|\alpha_1 - \alpha_2| < 30°$ hypothesizing a log profile. Is given a value with linear regression according the following equation: $u_* = \frac{\kappa(F_2 - F_1)}{\ln\left(\frac{z_2}{z_1}\right)}$ (9)

***Displacement height + roughness height: $d + z_v$ (cm)***. At the same condition above mentioned, is given a value of the sum $d + z_v$ according the following equation:

$$d + z_v = \exp\left[\ln z_2 - \left(\frac{F_2 \ln \frac{z_2}{z_1}}{F_2 - F_1}\right)\right] \quad (10)$$

It is well-known that $z_v$ is negligible in comparison with $d$ and for that the values obtained represent roughly 0.6 times the height of the inflection vegetation (Denny, 1986).

# RESULTS AND DISCUSSION

## Analysis of the velocity profile

Data coming from two different current meters allow us to deduce that the water column, during the big semidiurnal tidal transitional phase, had a flow field described the logarithmic layer following the wall law. In figures 2-5, we report some features of water column behaviour.

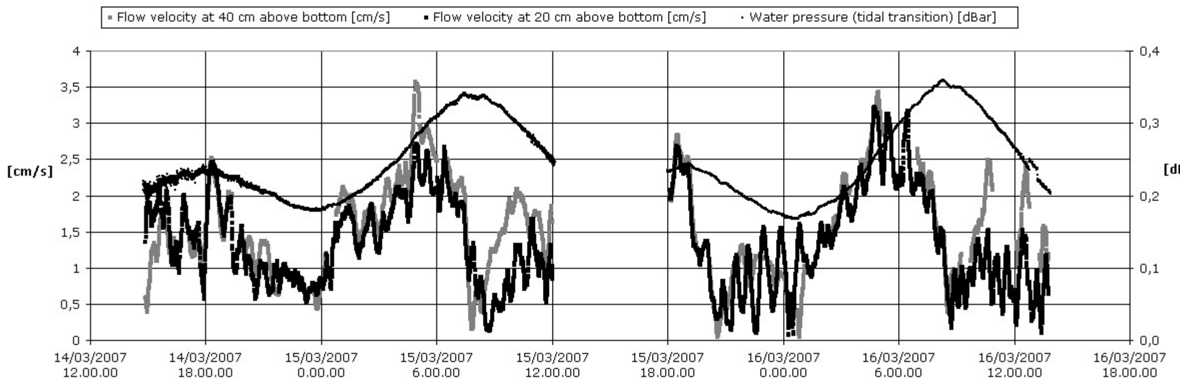


**Figure 2 –** Measured velocities and pressures

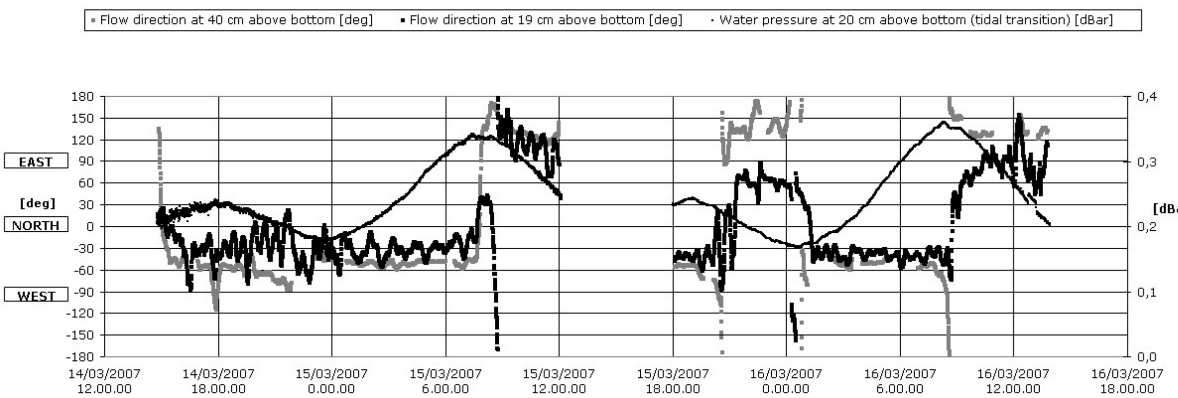


**Figure 3–** Measured flow directions and pressures

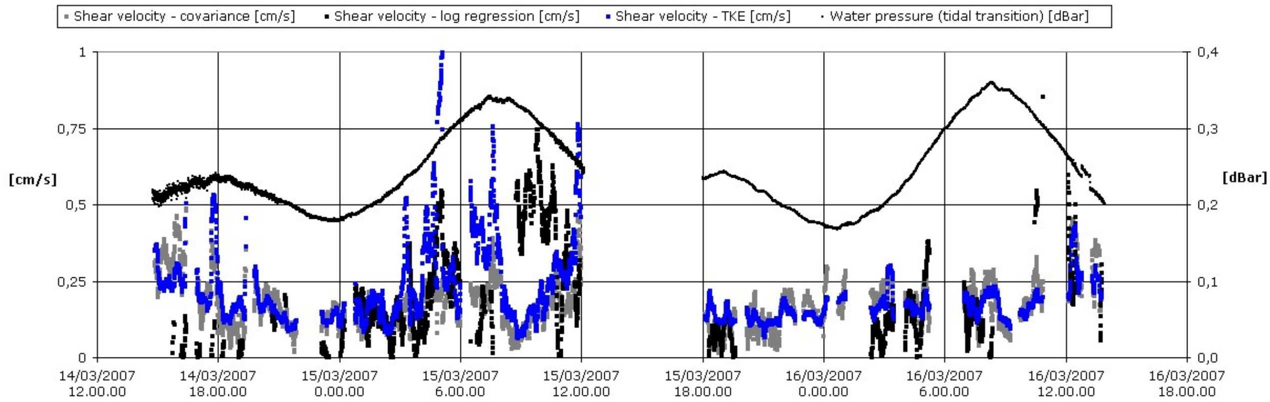


**Figure 4–** Shear velocities and pressures

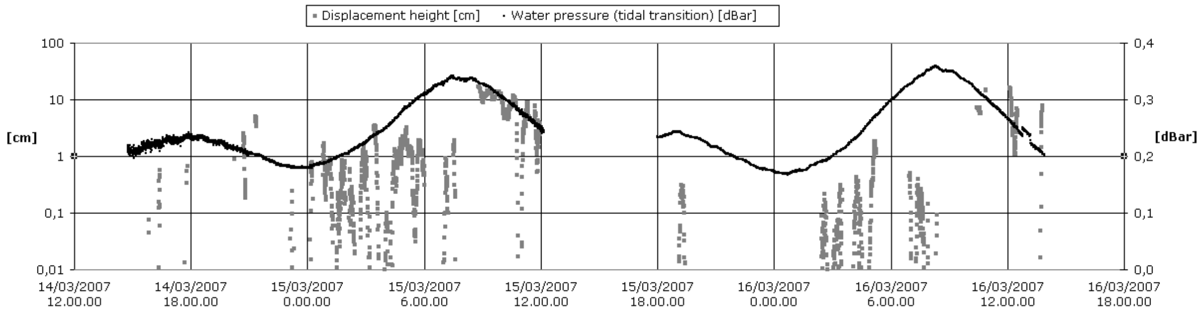


**Figure 5–** Displacement height and pressures

## Analysis of interactions

Flow field was tidally driven (Figure 6), the wind and the turbulent kinetic energy (TKE) were in phase (Figure 7) while the CERC expected wave impact on the bottom (shadowed areas) and TKE were significantly correlated (Figure 8). These results suggested that, in terms of kinetic energy, the water column response to the wind action was substantially immediate (i.e., a few minutes). Nevertheless, the increase of water turbidity (and the concentrations of total suspended matter) and chlorophyll-a (as a proxy of food availability for consumers) (Figure 9) in the water column raised significant peaks with 8-hours shifts from the peaks in kinetic energy.

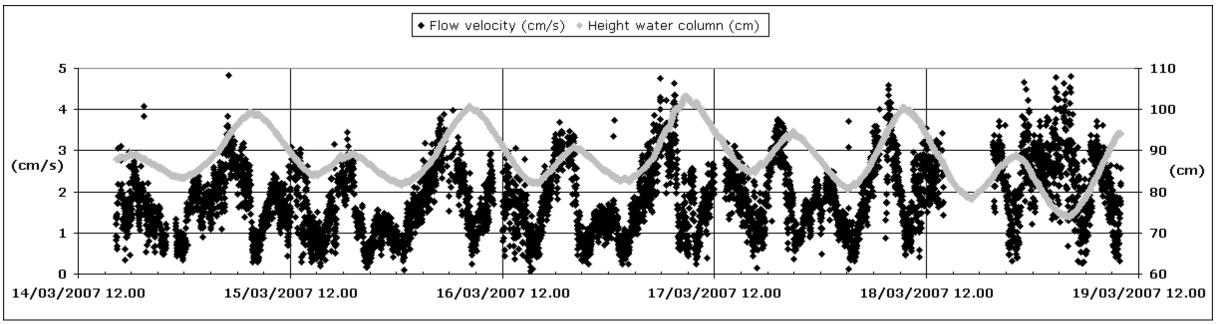


**Figure 6 –** Flow velocities and water level oscillations (tidally driven)

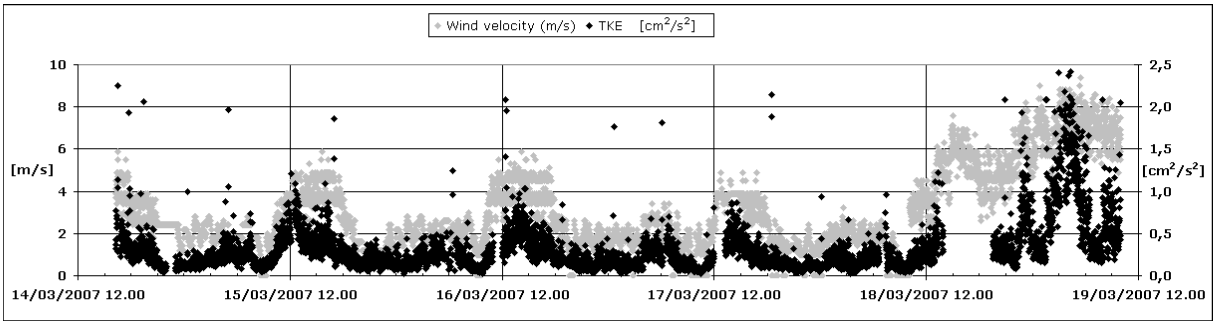


**Figure 7 -** Wind and the turbulent kinetic energy (TKE)

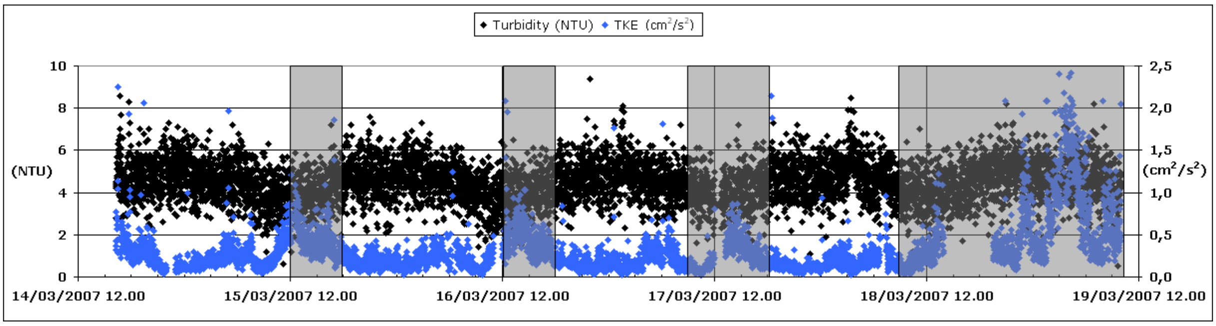


**Figure 8 –** Turbidity and turbulent kinetic energy (TKE)

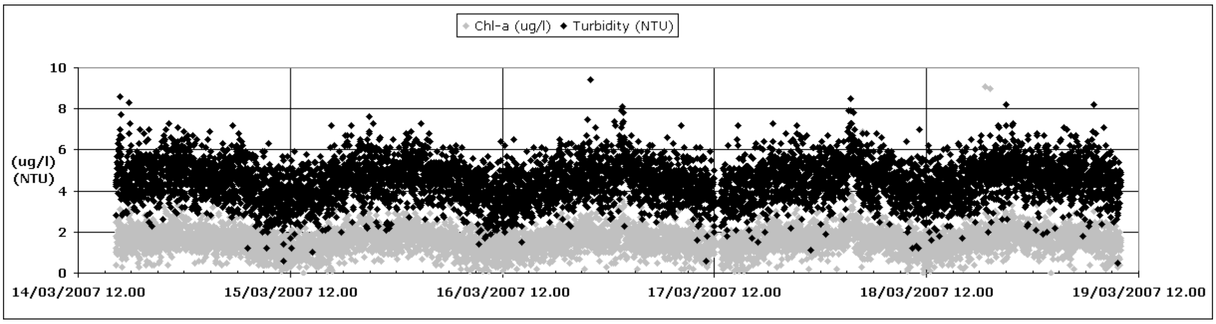


**Figure 9 –** Turbidity and Chl-a concentrations behaviour

The above figures indicates that vegetation play an important role as it influenced flow fields and sedimentary resuspension. Such a fact was pointed out by differences between observed and expected CERC patterns. Present results suggested that, through the turbulent motion, winds triggers effects on small scale (in the order of some meters) consisting in daily combined occurrence of wind events followed by turbidity peaks while. On larger scale (e.g., basin), winds induced a sort of inertial conveyor belt at surface after some hours of the starting of wind blowing. Thus, present preliminary data seems to confirm that the presence of the seagrass beds significantly attenuated wind-induced wave stress and such a fact should have important repercussions on ecological behaviour of pelagic species like resident fish and their main preys like zooplankton.

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