Psychology Research, May 2017, Vol. 7, No. 5, 297-304
doi:10.17265/2159-5542/2017.05.005

Comparison of Long Term Turbidity Trends in Different Locations

Ilknur Tuncer
Dokuz Eylul University, Izmir, Turkey

Light passage through water is affected by suspended materials in water. Secchi depths are simply used for the measurement of water clarity, in other words turbidity. The purpose of the present study was to determine whether the turbidity trend in the Menai Strait, Wales, UK is a local or worldwide pattern by comparing Secchi depths in the Strait with the ones from Skomer MNR, Wales, UK and from L'Estartit, Spain. Therefore, the hypothesis that long term changes in Secchi depth are driven by long term changes in wind speed was tested using correlation and regression analyses. For the Menai Strait, a computer model based on the mathematical relation between turbulent kinetic energy and Secchi depth was constructed. There were significantly negative correlation between monthly Secchi depth—wind speed pairs of Menai Strait—Anglesey and Skomer MNR—Cardiff but no correlation between annual pairs of Menai Strait—Anglesey and L'Estartit—Barcelona. As a result, it was proposed that high turbidity in the Menai Strait could not be explained by only wind speed, moderate turbidity in Skomer MNR could be driven by moderate wind and clear water of L'Estartit could not be explained by wind speed. It was concluded that wind alone could not cause turbidity without suspended particles in water but if there was a source of suspended particles, the wind would make the water more turbid.

Keywords: Turbidity, Secchi depth, wind speed, turbulent kinetic energy, the Menai Strait

Introduction

The Menai Strait separating the Isle of Anglesey and the mainland of Wales, UK experiences elevated water turbidities. Long term turbidity trends in the Strait between 1961 and 1988 were studied by Lumb (1989; 1990) and then, Birkett and Maggs (2001) added Secchi disc data from 1989 to 1999. Seasonal variations were observed such that in winter (January, February, March) turbidity was highest, significantly less in spring (April, May, June), further decreased in summer (July, August, September, October) and significantly increased in early winter (November, December). Bowers (2006) examined the turbidity trends with the data obtained from optical backscatter sensors between 2003 and 2005 in addition to those Secchi depths. Clear water (Secchi depth > 4 m) is an unusual event for the Straitin in spite of the decreasing turbidity trend in recent years.

Long term trends in turbidity have also been studied in other parts of the world such that decreasing trends in water clarity were seen in Omura Bay, Japan between 1945 and 1975 due to rapid industrialization and population growth (Iizuka, 1976), in the Black Sea between 1960s and 1980s due to changes in food web (Zaitsev, 1992) and in the northern Adriatic between 1960 and 1982 due to increased phytoplankton biomass related to the Po River discharge (Justicet, Rabalais, Turner, & Dortch, 1995). On the other hand, increasing

Ilknur Tuncer, Ph.D., Dokuz Eylul University.

trends were seen in Norwegian coastal waters between 1960 and 1993 due to improvements in sewage treatment (Johanessen & Dahl, 1996) and similarly in Narragansett Bay between 1972 and 1996 due to the introduction of waste treatment plants (Borkman & Smayda, 1998). There were also reasons not related to anthropogenic activities. For instance, in Santa Monica Bay in the Southern California Bight an increasing trend in water clarity was observed between 1972 and 1987 due to long time-scale fluctuations in the intrusion of clear oceanic water into nearshore regions (Conversi & McGowan, 1992; 1994). White, Gaffney, Bowers, and Bowyer (2003) correlated the annual variations in turbidity of the Irish Sea between 1987 and 1997 with regional wind strength and suggested that the turbidity in coastal seas was controlled by climate.

Previous studies for the turbidity trends in the Menai Strait suggested that the changes in meteorological conditions and the sediment regime, sediment erosion, the changes in particulate supply from external sources, sewage discharge, dumping in Liverpool Bay, nutrient enrichment and mariculture as cultivation of mussels could be the possible reasons (Buchan, Floodgate, & Crips, 1967; 1973; Kenchington, 1970; Thompson, 1974; Hiscock, 1976; Lumb, 1993). However, recent studies showed that some of them could not cause turbidity. For instance, filter feeders coming from commercial mussel fisheries in the Strait did not have a major influence on turbidity and transportation of sediments and dumping of sewage sludge could also not be causes of the trends in the Strait due to the altered management practices by the Environmental Agency and the controls by the authorities (Birkett & Maggs, 2001). Finally, it was shown that the major factor of the turbidity trend in the Strait was not the anthropogenic input of organic material because the majority of the sediments were inorganic (Kratzer, Buchan, & Bowers, 2003). Thus, the suggestion of the fact that the turbidity changes in the Strait were driven by the changes in climate has become stronger (Buchan et al., 1967, 1973; Thompson, 1974, Lumb, 1993; Kratzer et al., 2003; Bowers, 2006) in addition to the consistent storm index over British Isles from 1960s to 1990s of Alexandersson, Tumenvirta, Schmith, and Iden (2000) with Secchi depths of the Strait (Bowers, 2006).

The aim of the present study is to determine whether the turbidity trend in the Menai Strait is a local or worldwide pattern and to test the hypothesis of the fact that the long term changes in Secchi depth are driven by long term changes in wind.

Methods

Study Area and Data Sets

The Menai Strait which has been selected as a potential Marine Nature Reserve is a narrow and shallow strait in North Wales, UK. Its length is approximately 25 km, width in the range of 200-2000 m and depth 18 m at maximum. The tidal range at spring tides is 6 m. Skomer Marine Nature Reserve (MNR) which is in south-western Wales has the tidal currents over 5.6 m/s and the tidal range as approximately 7.4 m. The area is monitored by the Countryside Council for Wales (CCW) in Skomer Oceanographic Monitoring Site (OMS) and Skomer Thorn Rock (TRK). L'Estartit protected by Natural Park status is located between Montgri Massif in the north-eastern coast of Spain and the Mediterranean Sea.

In the present study, monthly mean Secchi depth data of the Menai Strait between 1961 and 1999 was extracted from Birkett and Maggs (2001) and between 2003 and 2005 from Bowers (2006). Monthly mean Secchi depth data between 1992 and 2005 for Skomer OMS and also the data between 2004 and 2005 for Skomer TRK were obtained from Skomer MNR. And for L'Estartit, only annual mean Secchi depth data between 1975 and 2004 could be extracted from Marba and Duarte (1997). In addition, all wind speed data were taken from web addresses as for Barcelona (1996-2004) and Cardiff (1996-2005) from weather underground webpage as daily mean data, for Loughborough (1994-2003) from Loughborough University climate data webpage as monthly mean data and for Gwynedd (1961-2005) from BADC weather data webpage as hourly mean data.

Comparison of Turbidity Trends and Relation Between Secchi Depth and Wind Speed

The Secchi depths from the study area were compared by correlation analysis to determine whether turbidity trend in the Strait was local or worldwide pattern. Correlation and regression analyses were also performed to see the relation between Secchi depths and wind speeds. Then, a model designed by Bowers (2003) was used for better understanding of those relations. This model was based on turbulent kinetic energy (TKE) generated by tide and wind and was designed to be applied to a whole shelf sea area of the Irish Sea over time scales of a year or more. In this model, Bowers (2003) derived that for a well mixed water column in steady state, the homogenous concentration of fine suspended sediment is

$$c = P/(g'hw_s) \quad (1)$$

where $P = \gamma\,(4 / (3\pi)\, k_b\rho_w U^3 + k_s\rho_a W^3)$, W is wind speed and constant values were given in Table 1.

In addition to this model, Kratzer et al. (2003) found the linear relation between the concentration of suspended sediment c (mg/L) and the Secchi depth in meters(Z_{SD}) for the Menai Straitas

$$c = -3.09 + (17.9/Z_{SD}) \quad (2)$$

Therefore, Eqs. (1) and (2) were combined to show that inverse Secchi depth in the Menai Strait is linearly related with the cube of wind speed

$$1/Z_{SD} = a + b\,W^3 \quad (3)$$

where a and b are constants, $a = (3.09 + (\gamma\,(4 / (3\pi)\, k_b\rho_w U^3/g'hw_s))/17.9$ and $b = \gamma k_s\rho_a/17.9g'hw_s$.

Table 1

Constant Values Used in the Model for Turbidity (Bowers, 2003)

Constant	Explanation	Value
γ	Efficiency of sediment re-suspension	0.00006
π	Pi	3.142
k_b	Bottom drag coefficient	0.0025
ρ_w	Density of water	1025 kg/m^3
w_s	Settling speed	10 m/day
k_s	Surface drag coefficient	0.0012
ρ_a	Density of air	1 kg/m^3
g'	Gravity	5 m^2/s
h	Water depth	13 m for the Menai Strait
U	Tidal current	0.7 m/s for the Menai Strait

In the present study, the subsequent analysis was based on Eq. (3). In the computer model, Secchi depths of the Strait were calculated using observed wind speeds and constants a and b in Eq. (3) and then observed and computed Secchi depths were compared.

Results

In the study area, the Menai Strait had the highest turbidity (2.06 ± 0.79 m) and Skomer MNR had moderate turbidity (5.51 ± 1.86 m and 5.58 ± 0.93 m for Skomer OMS and TRK, respectively) but L'Estartit had very clear water (16.99 ± 0.93 m) (Figure 1). On the other hand, Gwynedd was very windy (6.61 ± 1.63 m/s) compared with the other sites as Loughborough, Cardiff and Barcelona having approximately 2.5-3.5 m/s wind speeds (Figure 1).

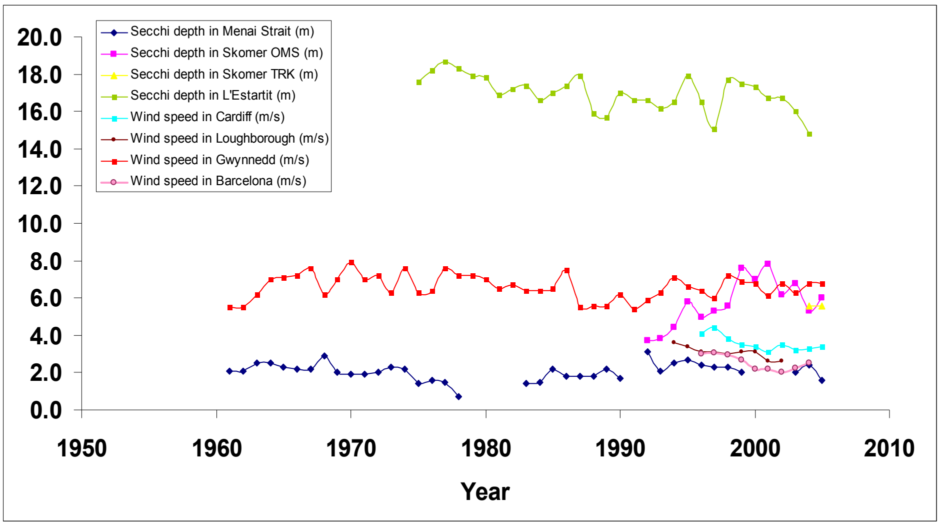


Figure 1. Annual Secchi depths in the Menai Strait (1961-2005), Skomer OMS (1992-2005), Skomer TRK (2004-2005) and L'Estartit (1975-2004) and annual wind speeds in Cardiff (1996-2005), Loughborough (1994-2002), Gwynedd (1961-2005) and Barcelona (1996-2004).

Starting with the time series of Secchi depths at different locations, only one significant correlation was obtained between the Strait and L'Estartit (Pearson correlation = -0.465, $P < 0.05$, $R^2 = 0.216$). Other pairs of places (L'Estartit—Skomer OMS and Menai Strait—Skomer OMS) had no statistically significant correlation.

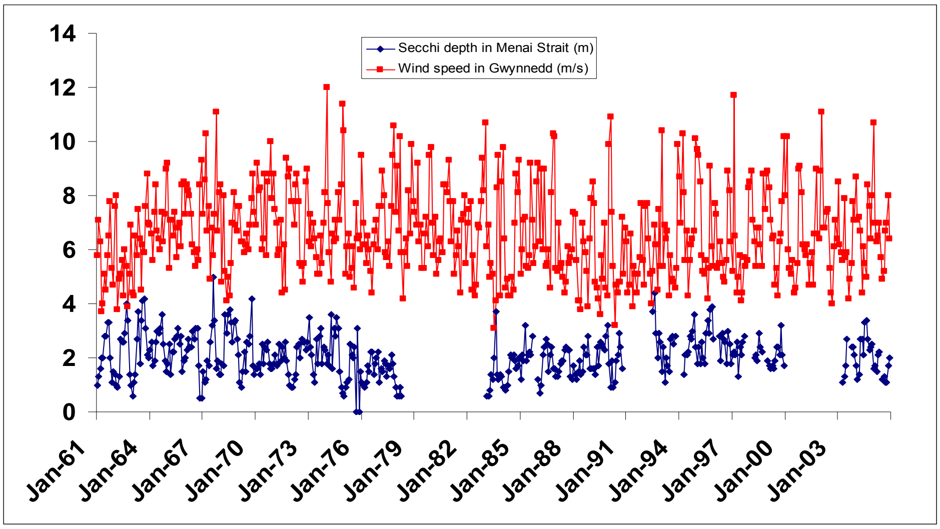
Table 2

Correlation and Regression Analysis Results

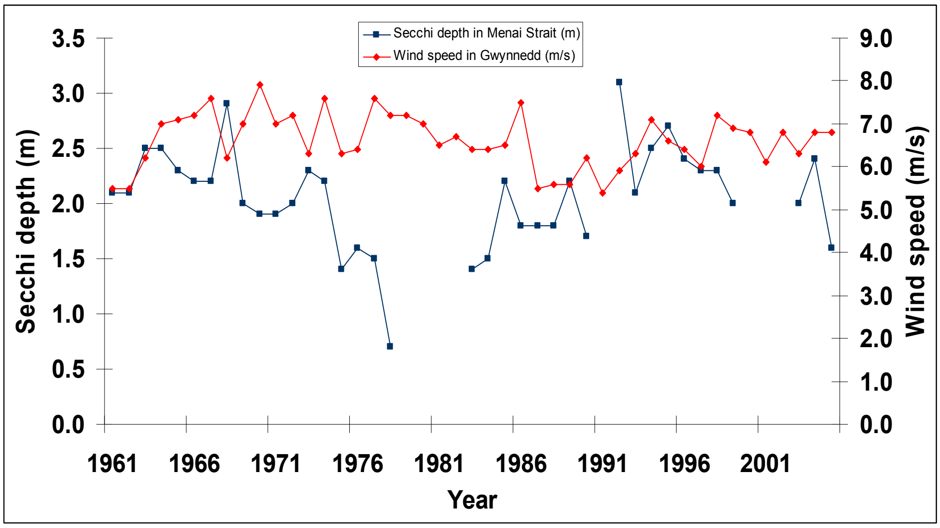
Secchi depth (m)—Wind speed (m/s)	Pearson correlation (r)	$1/Z_{SD} = a_0 + a_1W$			$1/Z_{SD} = a_0 + a_1W^3$		
		a_0	a_1	R^2	a_0	A_1	R^2
[a]Monthly data pairs							
[b]Menai Strait—Gwynedd	-0.233	0.334	0.036	0.045	0.491	0.00024	0.052
		0.057	0.008		0.022	0.00005	
[c]Skomer OMS—Cardiff	-0.696	-0.028	0.064	0.511	0.115	0.00168	0.541
		0.029	0.008		0.010	0.00019	
[d]Skomer TRK—Cardiff	-0.779	-0.019	0.065	0.646	0.117	0.00205	0.677
		0.054	0.017		0.018	0.00050	
[e]Annual data pairs							
[f]Skomer OMS—Cardiff	-0.665	0.011	0.043	0.478	0.117	0.00098	0.459
		0.057	0.016		0.019	0.00038	

Notes. a: Monthly data pairs of the Menai Strait with Cardiff and Loughborough have *p*-value > 0.05. The pairs of Skomer OMS with Loughborough and Gwynedd have *p*-value < 0.05 but low R^2. And since the data of Skomer TRK is only for 2004-2005 and very similar to Skomer OMS, the latter is considered. b, c: $p < 0.001$ and d, f: $p < 0.05$; e: Annual data pairs of the Menai Strait with Gwynedd, Cardiff and Loughborough and also the pairs of Skomer OMS with Loughborough and Gwynedd have p-value > 0.05; L'Estartit – Barcelona pair which has only annual data has also p-value > 0.05. a_0 and a_1 are the coefficients of the above equations and the top line represents their value and the lower one is their standard error. Z_{SD} is used forSecchi depth and W is forwind speed.

By the analysis of possible relation between Secchi depths and wind speeds, significantly negative correlations were found for monthly data of Menai Strait—Gwynedd (r = -0.233, *P* < 0.001), Skomer OMS—Cardiff (r = –0.696, *P* < 0.001) and Skomer TRK—Cardiff (r = -0.779, *P* < 0.05) and also for annual data of Skomer OMS – Cardiff (r = -0.665, *P* < 0.05) (Table 2). Negative correlation indicated that the more wind speed the more turbidity. For monthly Secchi depths of the Strait, there was no statistically significant correlation (*P* > 0.05) with other wind speeds which were in Cardiff and Loughborough but negative correlation with Gwynedd was clearly seen in Figure 2a. However, all correlations of annual Secchi depths of the Strait with wind speeds in UK, even with Gwynedd (Figure 2b) were not statistically significant (*P* > 0.05). Annual Secchi depths of Skomer OMS did not give statistically significant correlations with wind speeds in Gwynedd and Loughborough. On the other hand, both monthly and annual Secchi depths of Skomer OMS are consistent with wind speeds of Cardiff (Figure 3). However, there was no statistically significant correlation for annual L'Estartit Secchi data with Barcelona wind speeds (*P* > 0.05) (Figure 4).

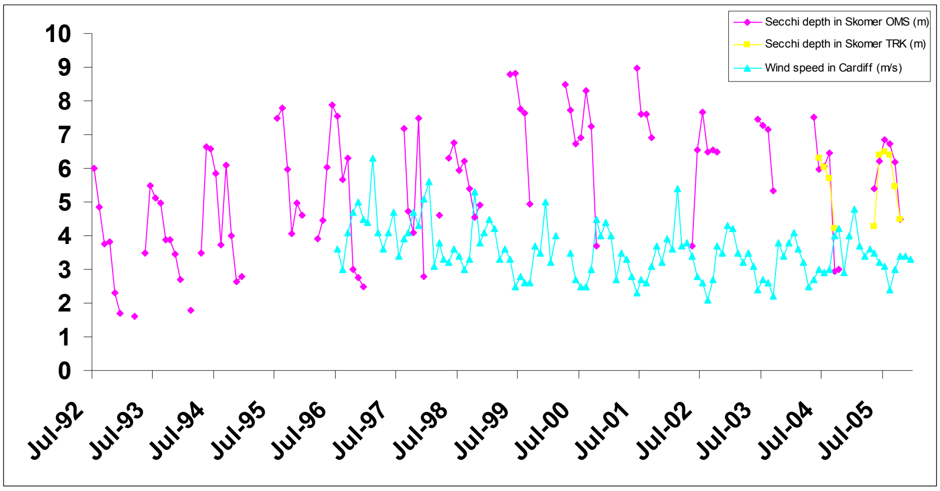


(a)

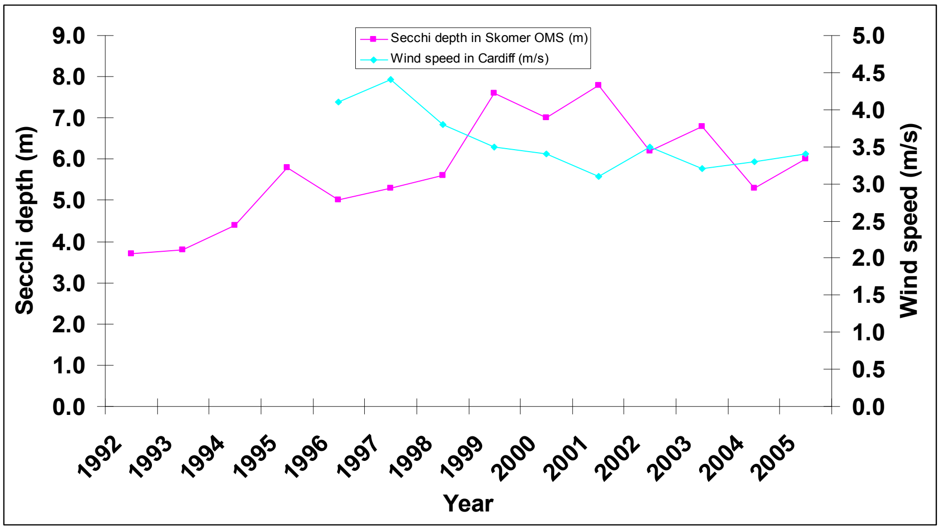


(b)

Figure 2. Monthly and annual mean Secchi depths of Menai Strait and wind speeds of Gwynedd (a and b, respectively).



(a)



(b)

Figure 3. Monthly and annual mean Secchi depths of Skomer OMS and wind speeds of Cardiff (a and b, respectively).

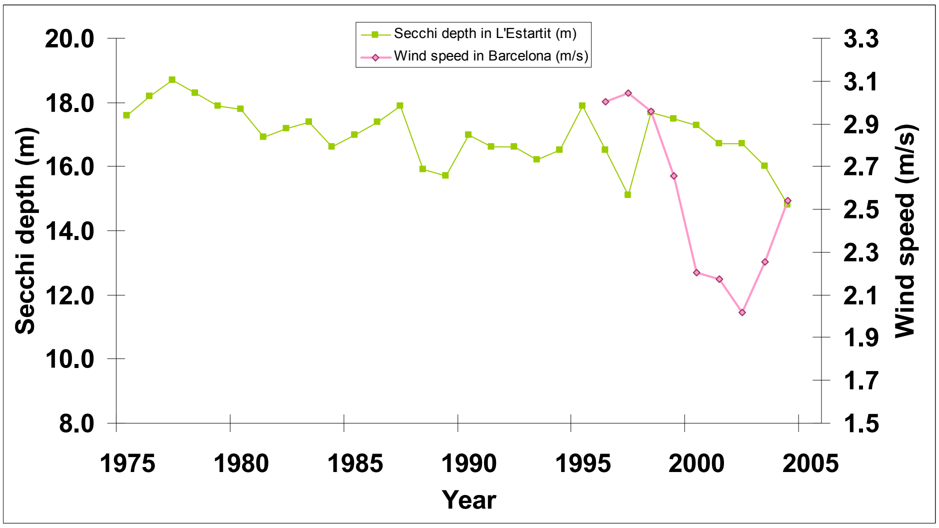


Figure 4. Annual mean Secchi depths of L'Estartit and wind speeds of Barcelona.

When Eq. (3) was considered, regression analysis of inverse Secchi depths with the cube of wind speeds were obtained and very similar results were found such that for monthly data Menai Strait—Gwynedd and Skomer OMS—Cardiff pairs had R^2 values as 0.052 and 0.541, respectively and for annual data Skomer OMS—Cardiff pair had R^2 value as 0.459 (Table 2).

For the Strait, computed Secchi depths obtained by the computer model using wind speeds of Gwynedd and the constants from Bowers (2003) and Kratzer et al. (2003) had no best fits with observed Secchi depths despite they were consistent with each other.

Discussion

Secchi depths are simply used for turbidity analysis. To compare the long term turbidity trends in the Menai Strait, there were Secchi depths from Skomer MNR, UK and L'Estartit, Spain. The only significant correlation which was negative was obtained between the Strait and L'Estartit. In other words, the decreasing trend from 1960s to 1980s and then the increasing one to the end of 1990s in the Strait were seen in reverse for L'Estartit in the period of 1975-2004.

To explain the reason(s) of turbidity trends, wind speeds which were local to those three sites were used. Gwynedd, UK was the windiest site whereas the Strait had the highest turbidity. Cardiff, UK had moderate wind speeds while Skomer MNR had moderate turbidity. It was therefore expected that wind speeds in Barcelona, Spain were much less than the ones in UK since L'Estartit had very much clear water when compared to high turbidities of other sites. However, despite Barcelona had the smallest mean of wind speed, it was windier than expected whereas L'Estartit had the clearest water.

Likely, correlation and regression analyses indicated the Secchi depth and wind speed pairs such that Skomer MNR—Cardiff was statistically significant for both monthly and annual data, Menai Strait – Gwynedd was statistically significant only for monthly data but not for annual data and L'Estartit—Barcelona was not statistically significant. Based on the Eq. (3) as the combination of the model derived by Bowers (2003) and the Eq. (2) derived by Kratzer et al. (2003), regression analyses of the Secchi depths and the cube of wind speeds also gave similar results. In addition, for the Strait there was no best fit between the observed Secchi depths and the computed ones obtained by the computer model using the Eq. (3).

Based on all those analyses, three different situations were concluded for those three pairs of Secchi depths and wind speeds. First, the clear sea water seen in L'Estartit was not driven by the local wind speed in Barcelona. Since there was insufficient amount of particles, the energy coming from wind and tide needed for the suspension was not crucial. Even with high wind speeds as seen in Barcelona, turbidity was therefore not observed in L'Estartit. Second, moderate turbidity in Skomer MNR could be explained by moderate wind speeds in Cardiff because the wind having enough energy could spin the particles in sufficient amount. Third, the Menai Strait had the highest turbidity which could not be driven only wind speed since the Strait had much more particles than the local wind in Gwynedd having energy needed for their suspension despite Gwynedd was very much windy. Therefore, in addition to the wind speed there would be other factors to explain this very high turbidity in the Strait.

When those three situations were generalized, it was claimed that high turbidity could not be explained by only wind speed and clear sea water, unlike moderate turbidity, could not be driven by wind speed. In further studies, computerized models like the one used in the present study as Eq. (3) were suggested for other sites.

References

Alexandersson, H., Tumenvirta, H., Schmith, T., & Iden, K. (2000). Trends of storms in NW Europe derived from an updated pressure data set. *Climate Research*, *14*, 1-73.

BADC weather data webpage for Anglesey. The British Atmospheric Data Centre, Oxford shire. Retrieved from: http://badc.nerc.ac.uk/data/ukmo-midas/

Borkman, D. G., & Smayda, T. J. (1998). Long term trends in water clarity revealed by Secchi-disk measurements in lower Narragansett Bay. *ICES Journal of Marine Science*, *55*, 668-679.

Bowers, D. G. (2003). A simple turbulent energy-based model of fine suspended sediments in the Irish Sea. *Continental Shelf Research*, *23*, 1495-1505.

Bowers, D. G. (2006). Menai Strait turbidity and co-variate surveillance. Marine Monitoring Report No. 22.

Birkett, D. A., & Maggs, C. A. (2001). Analysis of water turbidity and microalgal depth distributions on a transect in the Menai Strait. CCW Contract Science Report No. 468.

Buchan, S., Floodgate, G. D., & Crips, D. J. (1967). Studies on the seasonal variation of the suspended matter in the Menai Straits: The inorganic fraction. *Limnology & Oceanography*, *12*(3), 419-431.

Buchan, S., Floodgate, G. D., & Crips, D. J. (1973). Studies on the seasonal variation of the suspended matter in the Menai Straits. II: Mid-stream data. *Deutsche Hydrographische Zeitschrift*, *26*, 74-83.

Conversi, A., & McGowan, J. A. (1992). Variability of water column transparency, volume flow and suspended solids near San Diego sewage outfall (California): 15 years of data. *Chemistry and Ecology*, *6*, 133-147.

Conversi, A., & McGowan, J. A. (1994). Natural versus human-caused variability of water clarity in the Southern California Bight. *Limnology and Oceanography*, *39*, 632-648.

Hiscock, K. (1976). The influence of water movement on the ecology of sublittoral rocky areas. Ph.D. Thesis. University of Wales.

Iizuka, S. (1976). Succession of red tide organisms in Omura Bay with relation to water pollution. *Bulletin of the Plankton Society of Japan*, *23*, 31-49.

Johanessen, T., & Dahl, E. (1996). Declines in oxygen concentrations along the eastern Skaggerak coast, 1927-1993: A signal of ecosystem changes due to Eutrophication? *Limnology and Oceanography*, *41*, 776-778.

Justice, D., Rabalais, N. N., Turner, R. E., & Dortch, Q. (1995). Changes in nutrient structure of river dominated coastal waters: Stoichiometric nutrient balance and its consequences. *Estuarine, Coastal and Shelf Science*, *40*, 339-356.

Kenchington, R. A. (1970). An investigation of the detritus in Menai Straits plankton samples. *Journal of the Marine Biological Association UK*, *50*, 489-498.

Kratzer, S., Buchan, S., & Bowers, D. G. (2003). Testing long-term trends in turbidity in the Menai Strait, North Wales. *Estuarine Coastal and Shelf Science*, *56*, 221-226.

Loughborough University climate data webpage. Loughborough University, Leicester-shire. Retrieved from: http://www.lboro.ac.uk/departments/gy/ climate/index.html

Lumb, C. M. (1989). Algal depth distribution as an indicator of long-term turbidity change. In J. McManus & M. Elliot (eds.), *Development in Estuarine and Coastal Studies Techniques*. EBSA 17 symposium (pp. 69-74). Denmark: Olsen & Olsen.

Lumb, C. M. (1990). Algal depth distributions and long-term turbidity changes in the Menai Strait, North Wales. *Progress in Underwater Science*, *15*, 85-99.

Lumb, C. M. (1993). Turbidity monitoring in the Menai Strait, North Wales. Report to the Countryside Council for Wales. Incomplete first draft.

Marba, N., & Duarte, C. M. (1997). Interannual changes in sea grass (*Posidonia oceanica*) growth and environmental change in the Spanish Mediterranean littoral zone. *Limnology & Oceanography*, *42*, 800-810.

Thompson, J. C. (1974). Short term fluctuations of transmittance in the Menai Strait. MSc Thesis, University of Wales.

Weather underground webpage for Barcelona. The Weather Underground, Inc., Michigan. Retrieved from http://www.wunderground.com/history/ airport/EGFF/2007/6/28/DailyHistory.html

Weather underground webpage for Cardiff. The Weather Underground, Inc., Michigan. Retrieved from: http://www.wunderground.com/history/ airport/LEBL/2007/7/11/DailyHistory.html

White, M., Gaffney, S., Bowers, D. G., & Bowyer, P. (2003). Interannual variability in Irish Sea turbidity and relation to wind strength. *Royal Irish Academy*, *130B*, 83-90.

Zaitsev, Y. P. (1992). Recent changes in the trophic structure of the Black Sea. *Fisheries Oceanography*, *1*, 180-189.