Investigation of moisture anomalies at the air-sea interface over the Mediterranean using MSG SEVIRI data

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Abstract

Within the frame of EU sponsored project MODOBS (www.windeng.net/ModObs/ModObs_Home_page.pdf) aimed to improve the capability to model Marine Boundary Layer (MBL) in coastal areas for different time and space scales, we investigate the information content of MSG SEVIRI observations that, due to their spatial resolution, temporal sampling and limited sounding capabilities, are expected to contain additional information, compared to observations from the previous generation of operational meteorological satellites, to study the MBL and related processes in coastal areas. Aim of the study is to find a SEVIRI based observable related to the moisture component of the latent heat turbulent flux focusing on the Mediterranean Sea.
We use two approaches to explore the MSG SEVIRI data with regard to spatial and temporal variability of moisture anomalies at the air-sea interface. First approach relies on the analysis of Total Precipitable Water vapor (TPW) derived from satellite data, using the ratio TPW/SST as an indicator of degree of decoupling between atmosphere and sea surface. Secondly, the moisture anomaly is defined as the difference between an estimated near-surface water vapour mixing ratio (*wh*) and the saturation value corresponding to an air temperature equal to the actual SST. Qualitative analysis of high resolution spatial and temporal variations of these parameters is encouraging, highlighting both large scale structures (e.g. the patterns of low TPW/SST ratio corresponding to known upwelling areas), as well as smaller scales features, like the expected correlation between high/low surface winds and decrease/increase of average *wh*, on a daily time scale.

INTRODUCTION

The global observation of surface latent heat flux (LHF) was significantly enhanced by the advance of satellite technology, which offers an unique way to remotely derive LHF estimates over open sea areas, thus complementing in-situ observations. Most of currently available LHF datasets (e.g. HOAPS-2 (Schulz et al 1997; Bentamy et al 2003), J-OFURO (Kubota et al, 2002), GSSTF-2 (Chou et al, 2003), OAflux (Yu et al, 2004, 2007)) contain accurate information at global spatial scales, and for timescales larger than 1 day. However, for certain applications (e.g. MPBL processes studies, forecast of sever weather events on costal areas) more detailed knowledge of LHF is needed. Standard measurements of observable of interest for LHF derivation, like synoptic observation, radiosounding datasets, etc, are available mainly on land regions, while on open-sea and even off-shore areas the information on variables of interest may be obtained, with the necessary temporal and spatial details, only from satellite measurements.
In this study, we focus on the moisture term that enter in the LHF definition (e.g Fairall et al, 1996), trying to determine if interesting details, for the characterisation of BL and coastal regions, may be derived from MSG SEVIRI data, limiting the study area at the Mediterranean Basin.

DATA AND METHODS

The satellite information used is provided by MSG-SEVIRI data, that have improved spatial, temporal and spectral capabilities and contains enough information to describe the sea surface temperature

(SST) and the total amount of water vapour (i.e. TPW). Due to the characteristics of the SEVIRI channels and the consequent shape of the weighting functions, it is not possible to separate atmospheric contributions in the lowest levels from that of the surface, therefore surface-variables (e.g. water vapour mixing ratio) may not be in principle retrieved without uncertainties. However, it might be possible to obtain statistical information about near-surface variables, using satellite data and surface observation climatologically relevant for the studied area.

Starting from these assumptions we use two approaches to investigate spatial and temporal variability of moisture anomalies at the air-sea interface.

Firstly, the moisture anomalies are investigated using indicators based on the satellite derived TPW. We estimated TPW using a Split-Window Differences algorithm developed at Spanish Meteorological Center (SCIESUM, 2007). The SST data used is a standard product of OSI-SAF (Ocean and Sea Ice Satellite Application Facility), available over the Atlantic and the Mediterranean with a spatial resolution of 0.1 degree and a temporal sampling of 3 h, which contains also the cloud mask adopted in the data analyses. As investigation tool, we use the ratio TPW/SST, assuming it may be an indicator of degree of decoupling between atmosphere and sea when certain threshold values are met. The thresholds values, chosen as the 10% and 90% percentiles of the distribution of this parameter over the Mediterranean basin for the periods analyzed, define cases of dry atmosphere, if the ratio is less than 0.7 mm/C and respectively wet atmosphere cases, if the ratio is larger than 1.2 mm/C.

In the second approach, the moisture anomaly is defined as the difference between an estimated near-surface water vapour mixing ratio *wh* and the saturation value *whsst* corresponding to the actual SST. For the estimation of *wh* we developed a look-up table (LUT) method, based on information from 6 SEVIRI infrared channels (IR6.2, IR7.3, IR8.7, IR10.8, IR12.0, IR13.4) and radiosoundings from coastal stations. Taking into account that, for the nature of the SEVIRI channels weighting functions, it is not possible to separate near surface water vapor mixing ratio from SST contribution, the retrieval procedure was designed to give for each pixel a statistical description of all possible solutions that fill the match-up criteria.The simulated databases of brightness temperature (TB) vectors, which provides the LUT, are built using as input for the RTTOV8 package radiosounding profiles from long term and quality checked Integrated Global Radiosounding Archive (IGRA) (Durre et al, 2006), for 5 classes of satellite zenith angles. About 50 000 profiles from radiosounding data from two coastal stations in the Mediterranean (Adana (WMO #17351),Trapani (WMO #16429)) and one from North Atlantic (Valentia (WMO #3953)), were used, data from the latest station being included in order to test the behaviour of the retrieval algorithm. In order to simulate the observed SEVIRI channels, in addition to the temperature and humidity profile, provided by the radiosounding dataset RTTOV requires also the profile of O_3 and the SST. For the O_3 profile because of the lack of both temporally vertically detailed information at the radiosounding sites the standard climatological profile included in RTTOV package was used. Except for the IR9.6 channel the remaining IR channels have little sensitivity to the O_3 vertical distribution therefore the inversion algorithm does not include the observations from IR9.6 channel. SST is a fundamental geophysical variable in our study. In order to cover a large range of possible ocean-atmosphere situations, for each radiosounding simulations with different values of SST were performed varying its vales in such a way that if it was the air temperature, given the water vapor mixing ratio at the surface level of the radiosounding would correspond to relative humidity varying in the range [40, 110] %, with a step of 10%.

The criterion for selecting the possible solutions is related to the difference between observed and simulated TB for each channel considered. There are retained, as possible solutions, all *wh* values associated to the simulated TB vector which is sufficiently similar with the observed TB vector, thus their difference is less than a given threshold, chosen to be 1K. The output of the retrieval procedure is, for each pixel, a statistical description of distribution of *wh* solutions (Table 1). Also, two indices, related to the comparison of intermediate *wh* solutions with independently retrieved SST, are defined and evaluated for each pixel: the percent of possible *wh* solutions that have values smaller than the mixing ratio amount corresponding to an air temperature at the actual SST value and a relative humidity (RH) of 50%, denoted as *pc50* and respectively, the percent of possible *wh* solutions that have values larger than the mixing ratio amount corresponding to an air temperature at the actual SST value and RH of 80%, denoted as *pc80.* The SST data used to evaluate these indices was provided by the standard SST product from OSI-SAF.

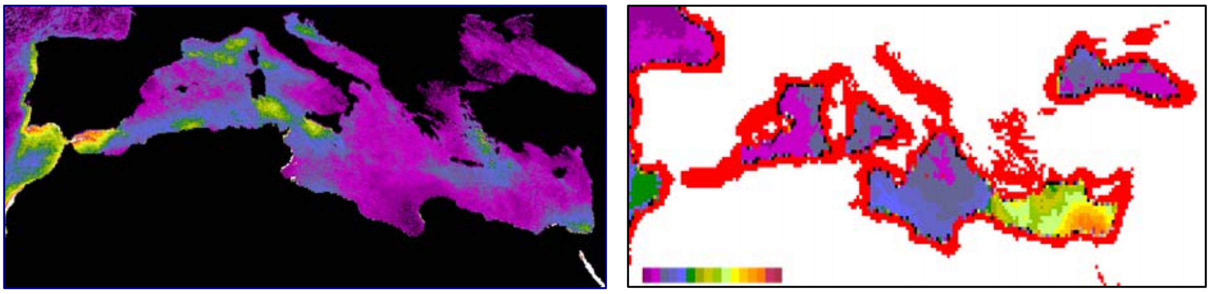
Satellite observations for a period of about 6 months, sampling mainly summer and winter seasons, but also corresponding to periods with available measurements campaign in Mediterranean region (e.g. September 2006) are analysed using the tools described, searching for both large and small scale features of moisture anomalies at the air-sea interface.

Statistical parameters for WH	***Statistical parameters for SST corresponding to WH intermediate solutions***	***Comparison with independently derived SST***	***Monitoring of intermediate solutions***
average (**AV**)	average (**AV**)	**pc50** = percent of intermediate solutions WH that are less than $WH_{sst}=f(SST_{GOES},RH=50\%)$	number of intermediate solutions (**NRS**)
percentiles: 10% (**p10**) 50% (**p50**) 90% (**p90**)	percentiles: 10% (**p10**) 50% (**p50**) 90% (**p90**)		
moda (**MDA**)	moda (**MDA**)	**pc80** = percent of intermediate solutions WH that are greater than $WH_{sst}=f(SST_{GOES},RH=80\%)$	dominant station (**NST**)
Standard Deviation (**STD**)	Standard Deviation (**STD**)		
Extreme values: maximum (**MAX**) minimum (**MIN**)	Extreme values: maximum (**MAX**) minimum (**MIN**)		

***Table 1*. Statistical parameters describing the output of *wh*-estimation procedure**

RESULTS

We test the approach based on satellite derived TPW firstly by analyzing monthly large scale features possibly highlighted by the ratio TPW/SST. To this end, we check the consistency of our results by comparing them with independently derived data from AMSR-E. These data, although without diurnally and spatially detailed information, provide an independent reference, also due to the long period available. We build the map of frequency of occurrence (FRQ) of lowest 10% of the TPW/SST ratio over Mediterranean basin using AMSR-E data for summer (June-July-August) 2002-2009 and respectively, using SEVIRI data, for 1-31 August 2004 and 8-23 September 2006 (fig.1). The thresholds corresponding to 10% and 90% percentiles of the ratio TPW/SST for the AMSR-E dataset have similar values as found from SEVIRI data analyzed, namely 0.75 and respectively 1.13 mm/C. The spatial patterns of FRQ of low TPW/SST ratio obtained from the two datasets generally agree, like for example the area with higher FRQ in the Eastern Mediterranean, near the Israel coast. There can also be noticed a certain correspondence with known upwelling areas (Bakun and Agostini, 2001) (e.g. near Sicily channel, near coasts of Morocco).



a) **b)**

Figure 1. **a) Frequency of occurrence, in the range 0% (black) to 20% (dark red) of values lower than 0.7 mm/C of the ratio TPW/SST, for the period 1-31 August 2004, 8-23 September 2006, as derived from SEVIRI-based TPW and SST from OSI-SAF. b) Frequency of occurrence, in the range 0% (black) to 6% (dark red) of lowest 10% of ratio TPW/SST as derived from AMSR-E data for summer (June-July-August) 2002-2009.**

The analysis of near-surface moisture anomalies characteristics performed by using the monthly averaged fields of indices *pc50* and *pc80* for August 2004 gives information about the non-equilibrium states between atmosphere and sea-surface. The two indices, that are not exactly complementary (fig. 2), refer to instantaneous instances and their monthly average may be interpreted as a frequency of occurrence of the state characterized by each index – dryer atmosphere (for *pc50* larger than *pc80* at the same location) or wetter atmosphere. The monthly field of the difference *pc80-pc50* (fig.3) show coherent structures in correspondence to some upwelling regions, e.g. dryer atmosphere corresponding to Western Mediterranean or on a larger area on the direction of strong Etesian winds

(fig. 4a). Generally, these dry-atmosphere regions seem to be associated with stronger wind at surface, which prevents the accumulation of near-surface moisture. However, in all other regions the positive values of this difference suggest a moister atmosphere, characterizing the local non-equilibrium between atmosphere and sea-surface, even in areas where the ratio TPW/SST is low. One example is the area in the Eastern Mediterranean, near the Israel coast where the high FRQ (about 5 % in AMSR-E data) of low TPW/SST ratio, although no significant upwelling or strong surface winds are characteristic for this period. For this region, the AMSR-E average of TPW for August 2004 show a lower TPW (fig. 4b), reflected in the TPW/SST ratio. On the other hand, the typical synoptic conditions affecting this region in summer (from June to mid- September) are characterized by a semi-permanent subtropical ridge at upper levels and the Persian Trough at the surface (Goldreich, 2003), which favors the presence of a permanent, low marine inversion at about 300 to 700 meters, between the coastal areas and central mountains. Thus, even if on average the atmospheric column presents a low TPW, as shown by the TPW/SST ratio, at the surface the humidity is high in the coastal area, as suggested by the *pc80* index.
Aiming to use the analysis tools to highlight details of moisture anomalies at smaller temporal and spatial scales, we further try to relate the diurnal variations of these parameters to atmospheric observables that are usually available. To this end, we use radiosounding data from IGRA archive from 4 coastal stations in the Mediterranean basin (Pratica di Mare (WMO#16245), Trapani (WMO#16429), Cagliari (WMO#16560), Heraklion (WMO#16754)), as well as surface wind field derived from QuikScat data.
The comparison of the daily variation of TPW/SST ratio with surface measurements of pressure, wind speed and water vapour mixing ratio, as well as with the synoptic wind defined here as the average wind speed in the layer 850-500 hPa, showed that the most coherent relationship is found between TPW/SST ratio and wind speed at the surface (fig. 5). The variations of ratio TPW/SST present a small time lag compared with the surface wind speed, the ratio increasing soon after a decrease in the wind speed, which may be explained by the accumulation of moisture in the layers closer to the surface when the surface wind is low, and vice-versa. This dependency is probably due the sensitivity of TPW to moisture in the lower layers, while the influence of upper vertical distribution of water vapour may be responsible for the difference in the amplitude of variation for the two parameters – TPW/SST ratio and wind speed at surface.
In the analysis of results based on satellite retrieved TPW, it should be taken into account that the ratio TPW/SST represents an average over 3x3 pixel around station location, and the number of cases included in the average refers only on clear-sky pixel, thus may vary from one instance of the comparison to the other. Other factors, possible sources of uncertainties/errors are given by the lacks of cloud mask adopted – a probable consequence of extrapolating the original SST field into SEVIRI grid; inherent errors associated the TPW retrieval algorithm; choice of threshold values – representative for the entire Mediterranean basin, not taking into account regional climatological characteristics.
The expected relationship between variations of near-surface mixing ratio and those of wind speed are found also for the average *wh* of the distribution of solution estimated with the LUT method. An example is presented in figure 6, where the Hovmoller diagram for the period 2-10 June 2007 of *wh* shows an increase/decrease (days 2 and respectively 7 June 2007) of this parameter corresponding to opposite variations in surface wind speed as derived from QuickScat. A similar connection is found between *pc50*, *pc80* and wind surface variations analyzing daily behavior of these parameters at Pratica di Mare station (fig. 7)

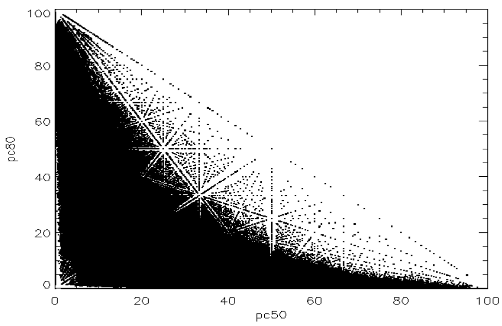


Figure 2. **Scatter plot of *pc50* versus *pc80* indices for period 1-10 August 2004, for the entire Mediterranean basin.**

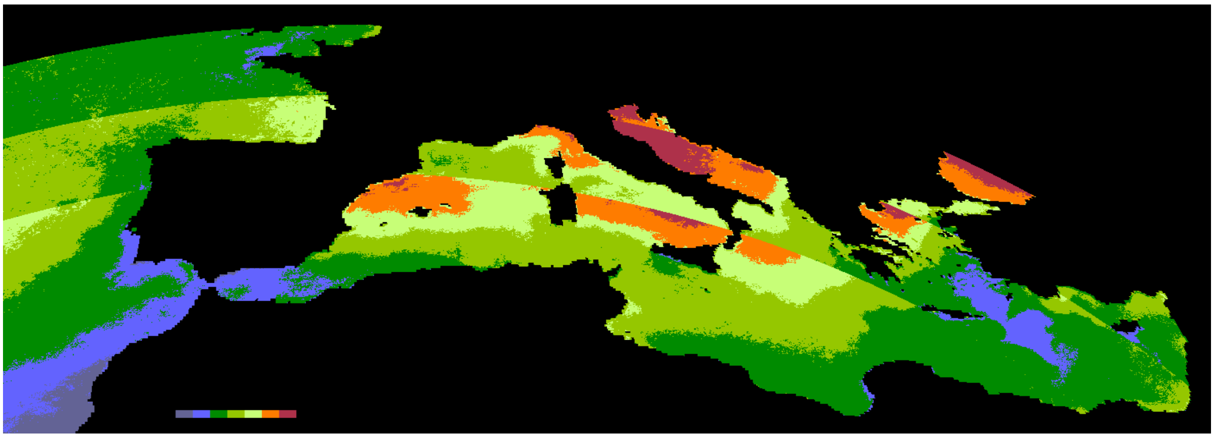
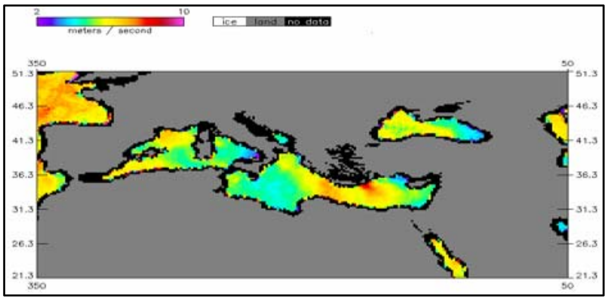
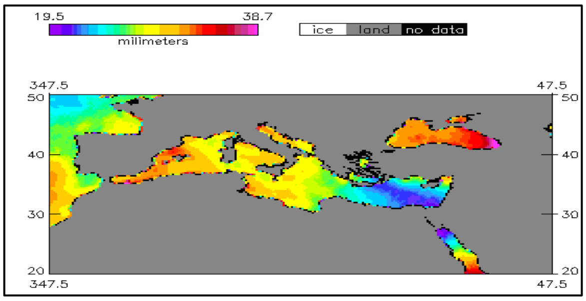


Figure 3. **Monthly average of the difference *pc80-pc50* indices, for August 2004; colors correspond to class values of: [-15, -7] (dark blue),[-7,0] (light blue), [0,10] (dark green), [10,20] (light green), [20,30](yellow), [30,40](orange),[40,70] (red).**





a) **b)**

Figure 4. **a) Average wind speed at surface and b) average TPW for August 2004, derived from AMSR-E data.**

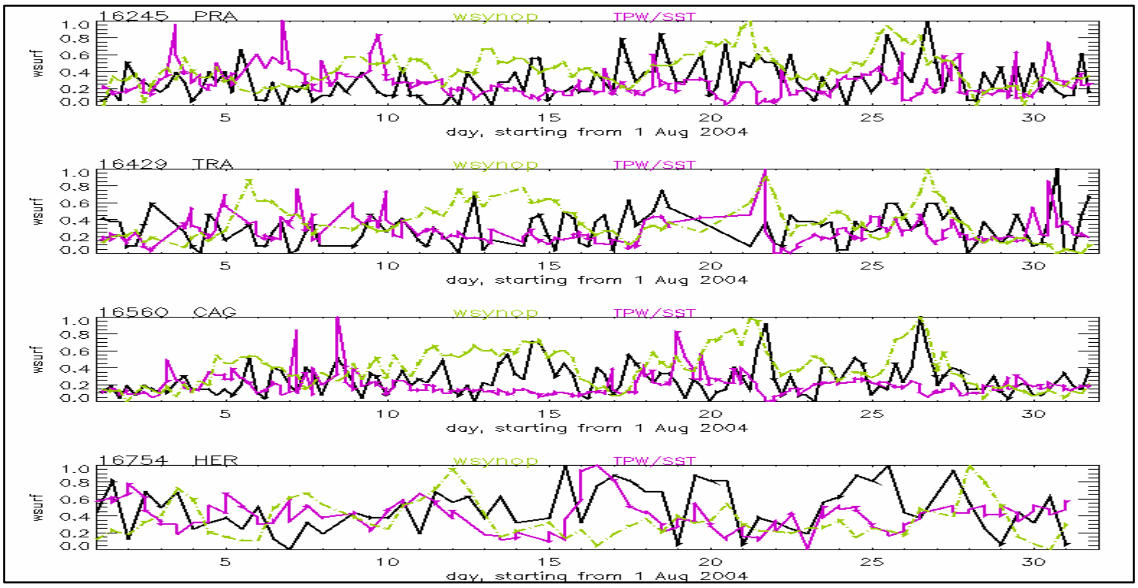
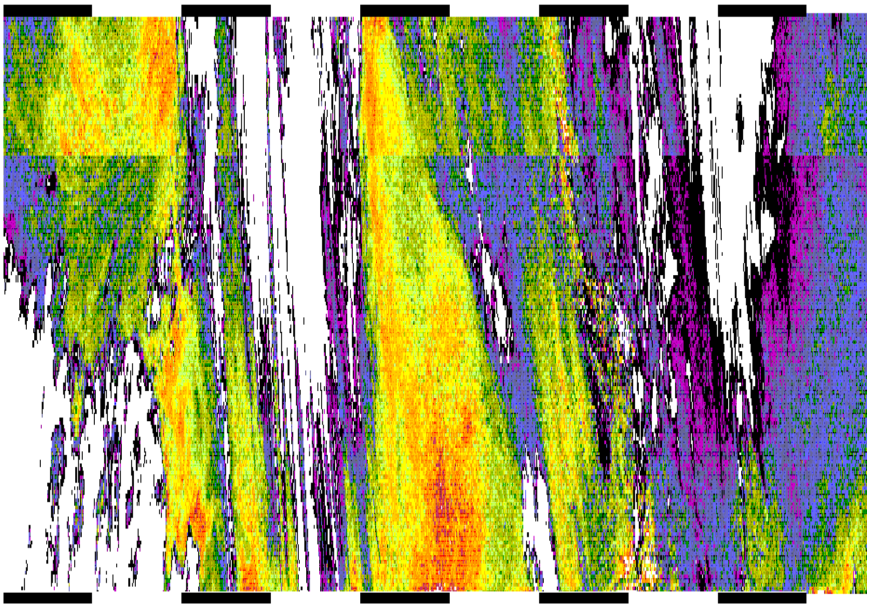
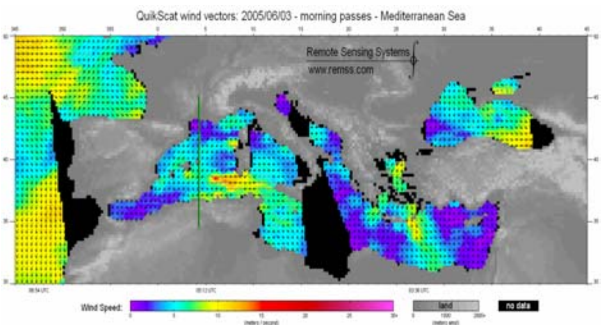
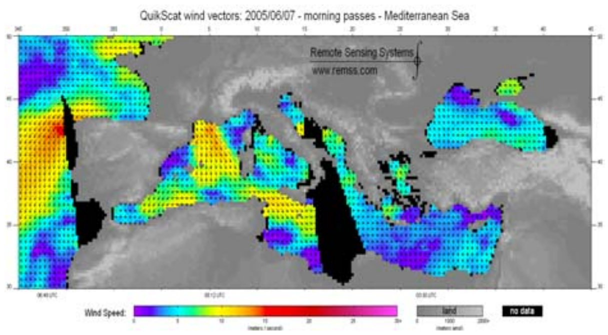


Figure 5. **Time series of normalized values of ratio TPW/SST(pink line), wind at the surface pressure (black line), and synoptic wind (average wind speed in the layer 850-500 hPa) (green line) for August 2004 using radisounding data from 4 coastal stations (up-down panels): Pratica di Mare (WMO#16245), Trapani (WMO#16429), Cagliari (WMO#16560), and Heraklion (WMO#16754).**



a)





b) c)

Figure 6. **a) Average value of estimated *wh* for the period 2-10 June 2005; values are in the range 8g/kg (violet) and 14g/kg (dark red); black and white bars in the lower part of the image indicate calendar days; white areas are pixels for which no solution was found; QuikScat estimated sea surface wind field for morning passes of b) 3 June 2005 ; c) 7 June 2005. Vertical green line in (b) shows the location where Hovmoller diagram was performed.**

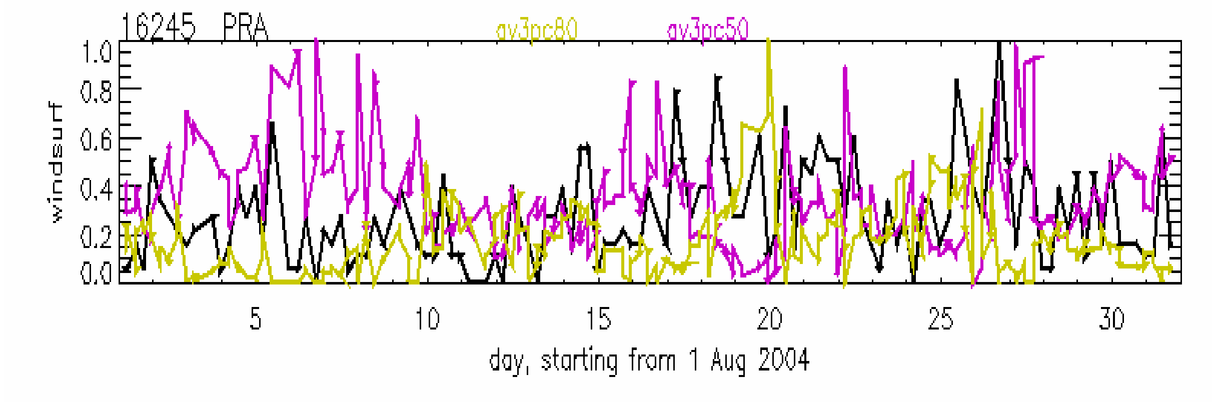


***Figure 7*. Comparison, in terms of normalized values, of *pc50* (pink line) and *pc80 (*yellow line*)* indices against wind surface (black line) at station Pratica di Mare (WMO# 16425) for August 2004. The retrieved parameters represent averages over 3x3 pixels around station location.**

CONCLUSIONS

We explored the MSG SEVIRI data with regard to the possibility to derive information about moisture anomalies at the air-sea interface at spatial and temporal scales of interest for the MBL. To this end two approaches were tested: firstly using the ratio between satellite derived TPW and SST to highlight regions with strong decoupling between atmosphere and sea surface, and secondly using a statistical estimation of near-surface mixing ratio to investigate near-surface moisture anomalies.

The results show that tools used in both methods evidentiate monthly large scale features. In particular, the TPW-based analysis show a fair agreement with results derived from AMSR-E data for summers 2002-2009. Also, there can be noticed a certain correspondence between spatial patterns of moisture anomalies, as found with both methods, and some regions of known upwelling. The TPW-based indicator shows a dryer atmosphere corresponding to those regions. The parameters *pc50* and *pc80* regarding the comparison of estimated near-surface mixing ratio with saturation values corresponding to actual SST and RH of 50% and respectively 80%, are more sensitive to instantaneous, local non-equilibrium between atmosphere and sea surface. Maps of the difference of these parameters also show patterns associated with the upwelling regions. Further studies are needed in order to investigate if this is a real feature or it is an effect of the algorithms used to derive TPW or *wh*, especially taking into account the literature (e.g. Prabhakara et al, 1979), which suggest an opposite sign of the moisture anomaly in the presence of upwelling (i.e. moist anomaly).

At smaller scales, the comparison with radiosounding data from 4 coastal stations in the Mediterranean Basin shows a coherent relationship between variations of TPW/SST ratio and those of wind surface, also found for the average estimated near-surface mixing ratio, as well as for the associated indices *pc50* and *pc80*.

These findings suggest that ratio TPW/SST is not an appropriate tool in this context, especially for fine-scale analysis, due, among other, to the correlation of TPW and SST derived from same satellite data and uncertainties on the accuracy of the TPW retrieval algorithm adopted. Furthermore, in order to use an analysis based on threshold values, these should be representative for smaller areas, more homogeneous with regard to climatic conditions. The alternative of defining threshold values for each pixel would not be able to identify regions of systematic un-equilibrium.

The results are overall encouraging, suggesting also some important possible directions of improvements. The TPW-based analysis may certainly benefit from the use of the standard TWP product, which provides a better estimate of this observable (e.g. by checking temporal and spatial coherency). The LUT method used to estimate the near-surface mixing ratio also needs improvements, like for example building the simulated database such that to be representative for the area of interest - e.g. using open-sea radiosoundings, a more appropriate definition of SST based on the probability distribution of RH over the area of interest- as well as with regard to the selection criterion of the possible *wh* values (e.g. use different weights for the channels in the selection condition) and a finer step in the satellite zenith angle used in the simulations;

ACKNOWLEDGEMENTS

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