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Fog water collection under sea breeze conditions in the western Mediterranean basin (Valencia region, Spain)

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Abstract

The aim of this study is to analyse the basic climatological features of fog water collection under sea breeze conditions in the eastern of the Iberian Peninsula (Valencia region, Spain). A network of five passive fog water collectors located at coastal mountain stations was used to sample water volumes during a 6-yr study period (2004-2009). The current study simultaneously applied manual and automated filters for identifying past orographic fog events associated with sea breezes. The preliminary results indicate that (a) sea breeze orographic fog episodes occur preferably in summer, but also in autumn and spring months; (b) fog water is collected during the late evening and night; and (c) collection occurs under well defined wind patterns. Orographic fog water input associated with sea breezes is particularly important for vegetation in the driest summer season.

1. Introduction

Sea breezes develop over the eastern coast of the Iberian Peninsula (IP) for almost two out of three days ([1], [9]), arriving to inland areas placed between 30 and 300 km from the nearest sea. [3] confirmed that the effect of sea breezes on cloud genera is to increase the frequency of low (*Stratus*, St) and convective (*Cumulus*, Cu) clouds. The primary impact of sea breeze flows corresponds to low stratiform clouds (St, and *Stratocumulus*, Sc) formed in the convective internal boundary layer (CIBL) due to the inflow of moist sea air at lower levels. The formation of Sc clouds is caused by the rising and cooling of turbulent moist sea air over the highest slopes of the mountains at the end of the day. In the most Sc formation, it is common to observe dense fog banks of *Stratus nebulosus* (St neb) and dew during the early next morning, covering the inland topographical depressions [7]. This multiyear study aims to verify for the first time the impact of sea breezes on fog water collection in the Mediterranean area.

2. Data source and methods

2.1 Study area and dataset

Figure 1 shows the topography features of the Valencia region, placed in the eastern fringe of the IP. The terrain is quite complex, with wide and flat coastal plains on the central coast; river valleys oriented approximately NW to SE which enhance the inland propagation of sea breezes; and the steep Iberian and Subbetic mountain ranges (Calderón is the highest mountain peak, at 1839 m.a.s.l.) located from 10-15 km inland, with coastal mountain ranges in the southern and the northern shoreline. The blocking of sea breeze flows by the mountain ranges has some impacts on the development of low stratiform clouds. This empirical study is mainly based upon a network of five passive fog water collectors maintained by the CEAM Foundation (http://www.ceam.es/ceamet/). The stations are distributed over five coastal-mountain areas (<7 km from the shore; altitudes vary between 428 and 845 m.a.s.l.) for the period 2004-2009. A cylindrical fog water instrument (i.e. omnidirectional collection efficiency) based on the ASRC (Atmospheric Science Research Centre, State University of New York) string collector is used to sample fog water volumes (FGW, in mm) on a 10-minute basis [5]. The fog water instrument is a cylinder, 26 cm in diameter and 46 cm in height (fog collection surface: 1196 cm^2), strung with five concentric rows of 0.8 mm thick nylon line. These stations also sampled 10-minute temperature (TEMP, in ºC), relative humidity

(RH, in %), wind speed (WS, in m s^{-1}), wind direction (WD, in º), and precipitation (PCPN, in mm) measurements. Furthermore, all data were subject to quality control in order to detect any unrealistic value check prior to analysis. Missing values are <0.5%, except for the Mt. Bernia (33.1%) and Mt. Helada (28.6%).

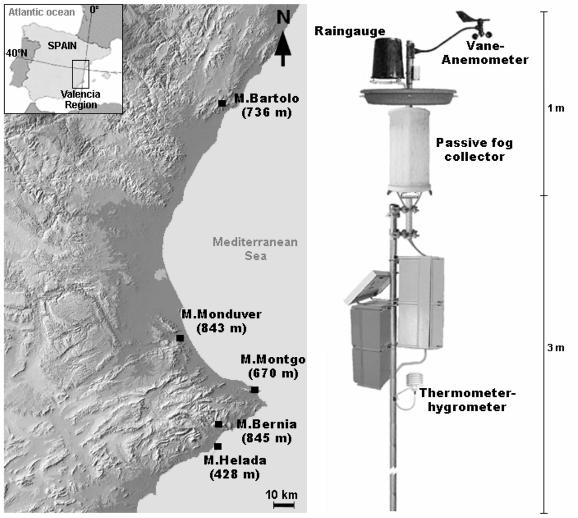

Figure 1: Map of the Valencia region showing locations of the stations (left), and the passive fog collector and meteorological equipment (right)

2.2 Selection of sea breeze fog events

Datasets of past orographic fog events associated with sea breezes were constructed applying two methodologies. Firstly, an initial manual selection consisted on the examination of the daily time series of 10-minute observations of WS, WD, TEMP, RH, PCPN and FGW for each coastal-mountain station. This manual task was considerably laborious. We selected as possible orographic fog episodes associated with sea breezes those days with FGW and PCPN below 5 mm [8]. Moreover, these fog episodes were selected if we observed distinctive features of sea breezes, i.e., a stabilization and slight downward inflection of TEMP curves, and a stabilization and upward inflection of RH curves; WS curves with a steady increase from after sunrise until noon; and a landward-moving WD shift. Those days which met the manual filters were screened using the Western Mediterranean Oscillation Index (WeMOi), as an objective filter for finding fog episodes under weak surface pressure gradients and local winds (i.e., sea breezes). The WeMOi values were computed as the daily normalized difference between the sea level pressure (NCEP/NCAR reanalysis project; [6]) at the point 35ºN, 5ºW and that at the point 45ºN, 10ºE. The [-1,1] threshold interval used here for selecting fog days associated with sea breezes was firstly proposed by [2].

3. Results

3.1 Occurrence of sea breeze Sc clouds

A subset of 192 (Mt. Montgo), 158 (Mt. Bartolo), 157 (Mt. Monduver), 72 (Mt. Bernia) and 64 (Mt. Helada) orographic fog episodes associated with sea breezes were found for the 6-yr study period (Table 1). Therefore, the probability of a day with a sea breeze orographic fog (P_1= [1]/N) is very low for the five passive fog water collectors, being greater in the Mt. Montgo (0.09), the Mt. Monduver (0.07) and the Mt. Bartolo (0.07). The lower probabilities were encountered in the Mt. Bernia (0.05) and the Mt. Helada (0.04), due in part to the missing values.

Table 1: Monthly number (ni), collected volumes (mm) and rates (r; in $l/m^2/day$) of sea breeze orographic fog events in the five passive fog water collectors for the 6-yr (2004-2009). Maximum values are shown in bold.

	Bartolo			Monduver			Montgo			Bernia			Helada			Σ		
Month	ni	mm	r	ni	mm	r	ni	mm	r	ni	mm	r	ni	mm	r	ni	mm	r
J	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
F	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
M	0	0.0	0.0	3	7.2	2.4	2	2.7	1.4	0	0.0	0.0	2	2.4	1.2	7	12.3	1.8
A	5	21.8	**4.4**	7	16.2	2.3	7	27.3	3.9	5	10.9	2.2	3	0.7	0.2	27	76.9	2.8
M	10	26.1	2.6	13	41.2	**3.2**	16	82.7	5.2	3	4.3	1.4	9	**11.5**	**1.3**	51	165.9	3.3
J	28	66.0	2.4	18	21.6	1.2	34	256.9	**7.6**	5	5.5	1.1	11	5.5	0.5	96	355.5	**3.7**
J	**53**	**82.2**	1.6	29	53.4	1.8	47	**325.0**	6.9	16	34.7	2.2	**14**	5.4	0.4	159	**500.6**	3.1
A	43	52.0	1.2	**47**	**110.5**	2.4	**54**	215.0	4.0	**21**	**48.3**	2.3	13	7.5	0.6	**178**	433.3	2.4
S	17	26.5	1.6	23	22.4	1.0	25	70.7	2.8	15	29.9	2.0	7	4.2	0.6	87	153.8	1.8
O	2	4.2	2.1	8	14.9	1.9	7	20.4	2.9	3	1.4	0.5	4	4.2	1.1	24	45.1	1.9
N	0	0.0	0.0	9	6.6	0.7	0	0.0	0.0	4	10.6	**2.7**	1	0.1	0.1	14	17.3	1.2
D	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Σ	158	278.9	1.8	157	294.0	1.9	192	1000.8	5.2	72	145.5	2.0	64	41.5	0.6	643	1760.7	2.7

At monthly scale and for the five collectors, the absolute number of sea breeze orographic fog episodes fluctuates from a maximum of 433 episodes for the summer months (Aug. 178; Jul. 159; Jun. 96) to a minimum of 0 for the winter months (Dec., Jan. and Feb.). The remaining number of episodes is of 125 in the autumn months (Sep. 87; Oct. 24; Nov. 14) and 85 in the spring months (Mar. 7; Apr. 27; May 51), showing a marked annual cycle. Fog water volumes fluctuated from a maximum of 1000.8 mm in the Mt. Montgo and a minimum of 41.5 mm in the Mt. Helada. Maximum volumes occurred in July (500.6 mm) and August (433.3 mm) over the five collectors.

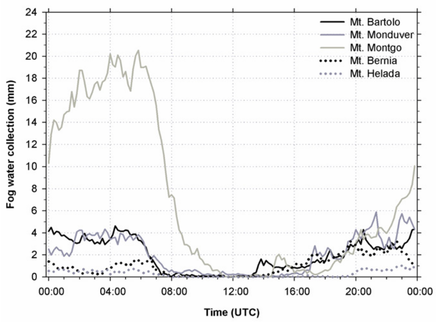

Figure 2: Daily accumulated fog water collection (in mm) under sea breeze conditions for the 6-yr study period (2004-2009)

3.2 Daily sea breeze fog water collection

Fog water collected under sea breeze episodes occurs after midday, preferably during the late evening and until the early next morning, showing a marked daily cycle. The maximum accumulated fog water volumes were found in the Mt. Montgo with 20.5 mm at 0550 h UTC. At all four sites, maximum volumes oscillated between 1 and 6 mm: Mt. Monduver 5.9 mm at 2120 h UTC; Mt. Bartolo 4.6 mm at 0420 h UTC; Mt. Bernia 3.3 mm at 2240 h UTC; and Mt. Helada 1.0 mm at 2300 h UTC (Figure 2). In contrast, the minimum amount of fog water (0 mm) was measured at about noon: Mt. Bartolo between 1140 and 1300 h UTC; Mt. Monduver at 1420 h UTC; Mt. Montgo between 1140 and 1430 h UTC; Mt. Bernia between 1020 and 1250 h UTC; and Mt. Helada between 0800 and 1850 h UTC. This fluctuation is associated with the daily cycle of sea breezes in the CIBL, which develop Sc layer clouds by the rising and cooling of turbulent moist sea air over the highest slopes during the late evening and night (nocturnal radiative cooling). Sc clouds are inhibited at noon because there may not be enough cooling in the ascending air for the water vapour to condense [4].

3.3 Prevailing wind regimes

Wind charts in the Figure 3 show a clear dominance of onshore (i.e. sea breezes) and mountain/valley winds. At Mt. Bartolo, light to moderate (>2.5-5 m s^{-1}) SSE sea breezes dominate with a frequency around 15%, whereas >16% of the fog occur under NNE and SSW winds with higher frequencies for the WS ranges from >5-7.5 m s^{-1} and >7.5 m s^{-1}. No clear dominance in WD was found at the Mt. Monduver, with light to moderate (<5 m s^{-1}) sea breezes coming from a wide range of directions: i.e., spread from NNE to SE (maximum frequency of 10%). However, at the summit of Mt. Monduver for water is collected with light to moderate winds (>2.5 m s^{-1}) coming from the NNW to NE (frequencies ~18% for the NNE direction). The wind pattern for the sea breeze events at the Mt. Montgo shows a clear SSW (~17%) and SSE (~12%) directions, with a dominant component from the NW (~20%) and moderate winds (>2.5 m s^{-1}) when fog is present. In the case of Mt. Bernia, there is a narrow SSE pattern (30-45%) for both wind roses, showing a dominance of winds greater than 5 m s^{-1} when fog is collected. Finally, the Mt. Helada is the only pilot site which displays two main sea breeze components, with light to moderate winds (<7.5 m s^{-1}) from the ESE and WSW, being most frequent (20-25%) for the fog occurrence wind rose. Despite wind roses show that WS is greater when fog is collected (i.e., wind is needed for a passive string collector, [4]), there was no statistically correlation between fog water collected and WS [8].

4. Conclusions and discussions

Sea breeze orographic fog occurrences determine water collection over the mountain ranges near the Iberian Mediterranean coast, particularly from May to September. The results have shown that sea breezes should play an important role for vegetation in the driest summer season. Future research will involve a removal of the rain component, with the aim of addressing the proportion of fog water exclusively associated with sea breezes. To conclude, other parameters should be researched in further detail, such as the influence of sea breezes and Sc development in the inland mountain ranges.

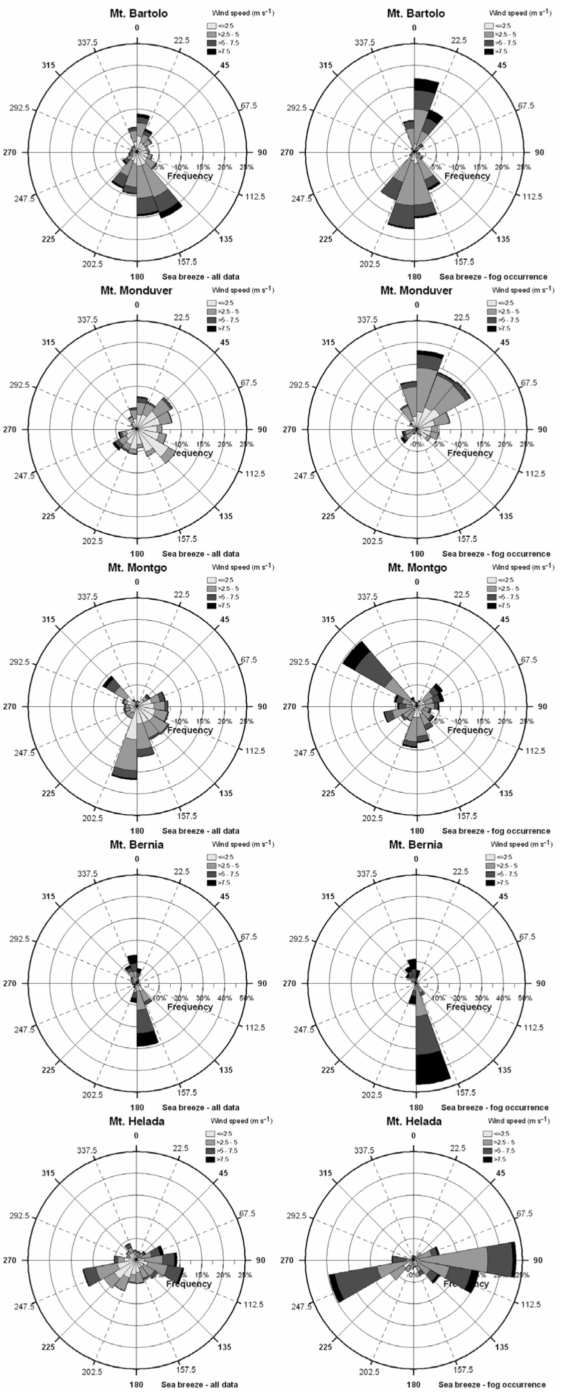

Figure 3: 6-yr wind charts from the five coastal mountain stations for (a, left) the entire dataset of sea breeze days, and (b, right) the 10-minute wind data that simultaneously collected fog water on those sea breeze episodes. Note that the frequency axis of the Mt. Bernia has been adjusted to 50%.

Acknowledgements

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