Application of a mesoscale atmospheric coupled fire model BRAMS-SFIRE to Alentejo wildland fire

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Introduction:

In the first phase of research was collected forestry fuels in montado in Évora district, trough Pardiela river basin and the samples was analyzed in laboratory of Pastures and Technologies of Fodder Plants and in Agricultural Chemistry of University of Évora (UE), and in the Centro de Investigacíon Agraria Finca La Orden-Valdesequera in Guadajira, Spain.

In the second phase was realized coupling between mesoescale Brazilian Developments on the Regional Atmospheric Modelling System (BRAMS 5.0) and the module of spread fire SFIRE coupling to Weather Research and Forescasting (WRF-SFIRE) give in by Jan Mandel of University of Colorado Denver.

The coupling of BRAMS-SFIRE was made with Modeling Atmospheric and Interfaces (GMAI) group of the Center of Prediction Weather and Climate Studies (CPTEC) of the National Institute for Space Research (INPE), group who develop BRAMS model.

Collect data from forestry fuel together with information of data from Portuguese National Forestry Inventory of 2006, was used for parameterize a name list of parameters of SFIRE simulation. This data was introduced in BRAMS-SFIRE and in WRF-SFIRE for simulations on regions of interest (3 grid in south of Portugal (Alentejo)) and for simulations of comparison in a forestry fire of both models.

The results of the coupling with BRAMS to spread Fire Model (SFIRE) show a great proximity to values of researcher in the area of study.

Methodology:

The research was developed in two phases:

1) Was collected in plots of 10 square meters in well-defined communities of shrubs inside and near Pardiela Basin in district of Évora, five sets of seven species of shrubs, namely, Cistus ladanifer, Cistus crispus, Cistus Salvifolius, Calicotome villosa, Retama sphaerocarpa, Rubus ulmifolius, Tamarix Africana, Quercus coccifera, and of grasses, Juncus acutus, Stipa gigantean and other grass, and Carlina corymbosa, in the agro-silvopastoral system 'montado' dominates the landscape of the south-western Iberian Peninsula, which occupies proximally 3.1 million ha of woodland in Spain (Díaz et al, 1997, by Pinheiro and Ribeiro,2013) and 1.2 million ha in Portugal (DGF-IFN, 2001, by Pinheiro and Ribeiro, 2013) The forest system 'montado' is mostly dominated by Mediterranean evergreen oaks such as cork oak (Quercus suber L.) and holm oak (Quercus rotundifolia). This experiment was conducted in August and autumn of 2011. Inside of sample areas, measured of percentage of cover and height of the shrubs and grass species was inventoried. The set of species inside the sample areas was clipped; each species keeps in a bag and weight with a common digital kitchen scale and with dynamometer model STA 1000 with a range of 1000kg and precision of 500g, and brought to laboratory of Pastures and Technologies of Fodder Plants of University of Évora.

Follow Burgan and Rothermel 1984, shrubs species was separated in thickness classes, dead (dry branches) and alive, see table 1, and the class less than 0,64 cm, comprised by a mix of components (branchlets, stalks and leaves).

Oven-dries weights were determined. Samples of live leaves thickness of the species collect in the communities were measured.

Part of the samples of thin classes (0.64 cm) of the set of all studied species, was wash, oven-dry at 75 ºC, crushed and riddled with a 0.5 mm cribble for measure its calorific value and percentage of mineral content. The grass collected was considered be 0.64 cm class and processes follow same methodology (Menezes et al, 2013). This fuel mineral component free of silica was determined with a PERKIN ELMER 2380 spectrophotometer of atomic absorption, calibrated with standards followed the equipment manual instructions.

Measures of calorific power of fuel were taken with a bomb calorimeter, (IKA C-200) according to CEN/TS 14918 method. Was placed in a melting pot approximately 0.2 grams of dry biomass weighed with a precision balance (sensitivity ±0.0001 g), then was introduced the ignition wire and placed into the vessel in the combustion bomb, then close calorimeter cover making certain the latch is engaged and measures of heat was taken. Fellow the methodology of Telmo and Lousada, 2011, the low heat value of species was determined. Fuel density was obtained from the biomass volume determined from water displacement method using small pieces of branches of shrubs and herbaceous dried in an oven.

The ratio of surface area to volume was estimated using measures of perimeter cross-sections and lengths of small pieces of twigs as well as scans (made with a HP Scanjet 4850) areas measurements from branchlets (<=6.4mm), and measurements of perimeter cross-sections of leaves. The images of scans were interpreted through the study of pixel area, made with the software ImageJ.

The determinations of coefficients of surface to volume of little ligneous stalks (herbaceous) and leaves, were done based on Fujioka e Fujii, 1980.

2) The mesoscale atmospheric model Weather Research and Forecasting (WRF) with module spread fire (SFIRE), give in By Jean Mandel of Center for Computational Mathematics da University of Colorado Denver, distributed as a part of WRF parallel computing infrastructure was install for real case in supercomputing Tupã of Center of Forecast and Climatic Studies of National Institute of Space Research (CPTEC/INPE). Libs and compilation flags, were configured, and required software's for make process was installed.

For analyzed the tree of process in model WRF-SFIRE was installed and use kprof and doxigen softwares.

SFIRE was decoupling from WRF.

For diagnosis of simulations with SFIRE model independent of WRF model, was use input data from a simulation of the WRF-SFIRE model get in steps of time, for determine the level of engagement that would have to handle with the Brazilian model on the Regional Developments atmospheric Modeling System (BRAMS) (Longo et al, 2013), and make the correct matching of the connection variables and check for errors of parallelism cleaning process generated on decoupling SFIRE from the WRF model.

The Coupling structure of SFIRE model to BRAMS was constructed through a main module with routines and calls to routines, similarly to the existent in the atmospheric model WRF and BRAMS, which connect SFIRE model, through atmospheric parameters (surface pressure, air moisture, air temperature, zonal wind, geopotential, rain, roughness height, air density) and reading surface data (topography, fuel models (NFFL (Anderson, 1982, Rothermel, 1972)) and geographic coordinates) of Continental Portugal, and reading two name lists of conditions parameters of simulation and physics parameters related with semi-empiric models of spread forestry fires and released of sensible and latent heat for atmosphere used by SFIRE model.

Was created the rules to make compilations for this project of software. These rules were defined in a file Makefile, used to do, link of files including the fire module when necessary.

Was used data from Portuguese National Forestry Inventory of 2006 and the ARCGIS system for select models of fuel NFFL of Portugal in a file GeoTiff (for WRF-SFIRE), and in txt (for BRAMS-SFIRE).

Were install external library libtiff e Geotiff in Tupã and the module WPS was compiled with then.

The tables and list of parameters of name lists was parametrized using the data from first phase of research for each type of fuel model NFFL existing in the Alentejo region.

The domain of simulation was defined based in forestry fires in the Alentejo region determinate based in product of temperature of surface of earth of Modis Sensor in August and Autumn of 2011, when they were collected fuel in the farms of Évora district. ERA-Interim global atmospheric reanalysis and Global Forecast System (GFS), and Weekly surface sea temperatures from CPTEC and NCEP were used in simulations of BRAMS-SFIRE and WRF_SFIRE, namely. Daily soil moisture data from CPTEC was used in simulations of BRAMS-SFIRE. A two-way nesting of four grids (64km resolution, 16km resolution, 4km resolution and 1km resolution) was carried out with WRF. A one-way downscaling of four grids (64km resolution, 16km resolution, 4km resolution, 1km resolution) was done with BRAMS, and a one-way gird downscaling (1km resolution, 200m resolution) was carried out with BRAMS-SFIRE. A one-way grid downscaling (1km, 200m) of WRF-SFIRE could not be completed on time this presentation. In the simulations by BRAMS-SFIRE, the fires were activated for start after 180 seconds, from Modis focus and from a fireline forced, in 3 different grids in mountain terrain and in plan terrain, and from a fire forced in terrain with homogeneous topography of 60 m.

Cistus salviifolius, Cistus ladanifer, Calicotome villosa, Retama sphaerocarpa, Cistus crispus, Quercus coccifera, Juncus acutus, Stipa gigantea and other herbaceous, Tamarix africana, Rubus ulmifolius, Soil of Montado, Carlina corymbosa

Results:

In the pictures of grid 2 can see the fires spread in elliptical pattern in heterogeneous landscape with flux of sensible heat in fire line about 500 Wm^{-2} to 50000 Wm^{-2}, with flux of latent heat of 250 Wm^{-2} to 1600 Wm^{-2}, and in the backing fire remains flux of sensible heat of 750 Wm^{-2} to 1200 Wm^{-2}, and in some zones strong absorption of latent heat of -50 Wm^{-2} and -25 Wm^{-2} in canopy of fuel model 2. Fuel model of region of grid 2 are type 2 and 5, and the fire are centered mostly in a region of fuel model 5. Spread fire does not change pattern due to slope or type of fuel model. The fire burned the immediately adjacent points and followed its elliptical path. The circulation of wind is local with wind from mountains to vale and around the vale with intensity maxim of 4.5 ms^{-1}, pattern changed inside fire for turbulent horizontal wind with intensification for values superiors of 5 ms^{-1}, with the strongest updraft velocities of values superior at 5 ms^{-1} measured from 700 m altitude constituted by strong streams Intermittent turbulent from 1200 m of altitude (vertical mixing coefficient with 350 m^2s^{-1} to 400 m^2s^{-1}) fellow, some seconds after, by Intermittent negative vertical downwind of -4 ms^{-1} at 1600 m, weakness to surface in weakness turbulent current (vertical mixing coefficient with less than 150 m^2s^{-1}). There was an increment of upwind of 1 ms^{-1} and increment of downwind of -2 ms^{-1} relative to a simulation for the area without a fire. The temperature of fire at 40 m of altitude as 38 ºC to 40 ºC, value 4 ºC more high then in simulation for region without fire.

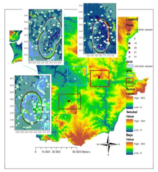
In the grid 1 the fire outbreaks are very far apart and is spread occurs with the intersection of three elliptical pattern fires to form an elliptical pattern fire. The flux of sensible heat and the flux of latent heat in fire line are similar to grid 2, changing in the backing fire where remains flux of latent heat of 500 Wm^{-2} and 750 Wm^{-2}. The horizontal wind, blow from the northwest and change for an irregular pattern (turbulent) in the region on fire. The intensity of horizontal wind intensifies for values fast then 5 ms^{-1} in the fire line (without fire values to 4.5 ms^{-1} in the region of interest). With updraft vertical velocities values superior at 5 ms^{-1}, start at 40 m and intensify in altitude superior at 1600 m in strong stream intermittent turbulent (vertical mixing coefficient with 450 m^2s^{-1}). In the latitudes in proximity, appear downstream with values superiors of -4 ms^{-1} from 600 m of Altitude, with weak vertical turbulence (vertical mixing coefficient with 100 m^2s^{-1}). The temperature of fire at 40 m of altitude as 34 ºC, value 4 ºC more high then in simulation for region without fire. Fuel model of region of grid 1 are 2 and 5, and the fire are centered mostly in a region of fuel model 2.

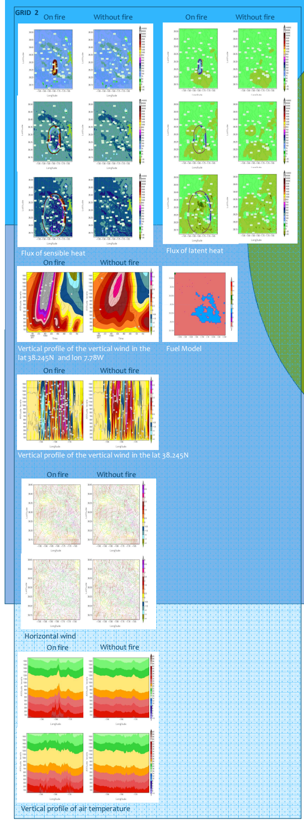
In the grid 3 the horizontal wind blows from the mountains to the plain and converges into the fire, with intensification for values to 4.5 ms^{-1} in the fire line (intensity of velocity values of 2 ms^{-1} and 2.5 ms^{-1} without fire). The flux of sensible heat are similar to grid 2, burn in fire line but do not burn in backing area closed by then and the flux of latent heat in fire line are smaller about 75 Wm^{-2} to 250 Wm^{-2}. Have strongest updraft velocities of values of 4 ms^{-1} (3.5 ms^{-1} higher than without fire) measured from 500 m altitude constituted by weak streams Intermittent turbulent (vertical mixing coefficient with 100 m^2s^{-1}), seconds after, appears downstream very weak of negative vertical velocities of -0.5ms^{-1}. Fuel model of region of grid 3 are 2 and 5, and the fire are centered mostly in a region of fuel model 2.

Daisuke Seto,2014, said, convective heat fluxes are not only main mechanisms for heat transfer that controls fire spread but are a direct indication of the fire's intensity, and Frankman et al (2012) measured the convective and radiant heat fluxes from 13 wildfires including surface fires over pine needle fuel and their results showed the peak convective heat flux values ranged from 13 kWm^{-2} and 140 kWm^{-2}.

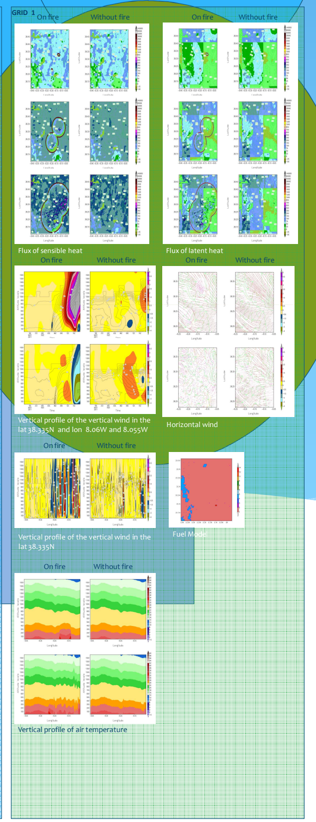
Measurements in situ collected at the fire line during the FireFlux experiment (Clements et al 2007, by Kochanski and al, 2012). The FireFlux experiment is the most intensively instrumented grass fire to date. The experiment was designed to study fire atmosphere interactions during a fast-moving head fire in grass fuels by measuring the wind, turbulence, and thermodynamic fields of the near-surface environment and of the plume. The wind was northerly at 3 ms^{-1} for the first 2 m above de ground level, and increasing in magnitude with height to approximately 7 ms^{-1} at 50 m of altitude. In the experiment the updraft velocities at 40 m altitude in the tower of control had values of 2 ms^{-1} to 10 ms^{-1}, at 46 m had values of downstream of -2ms^{-1} to upstream of 8 ms^{-1} of intensity, at 28 m had values of downwind -3 ms^{-1} to upwind with 6.5 ms^{-1} intensity, at 10m updraft velocities about -4 ms^{-1} to 4 ms^{-1} and at 2 m had vertical velocities between -2.5 ms^{-1} to 2.5 ms^{-1}, and the temperature of flames at 40 m altitude measured by thermocouple its about 40ºC (Kochanski and al, 2012).

This results show a great concordance with results of BRAMS_SFIRE, if we thinking that the model start from rest until 40 m altitude, here start the true dynamic environment of atmosphere simulation.

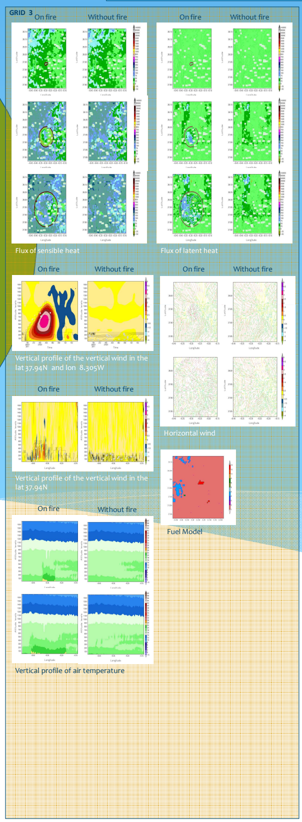




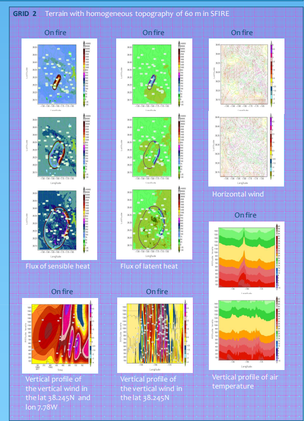
GRID 2 — On fire / Without fire: Flux of sensible heat; Flux of latent heat; Vertical profile of the vertical wind in the lat 38.245N and lon 7.78W; Fuel Model; Vertical profile of the vertical wind in the lat 38.245N; Horizontal wind; Vertical profile of air temperature



GRID 1 — On fire / Without fire: Flux of sensible heat; Flux of latent heat; Vertical profile of the vertical wind in the lat 38.335N and lon 8.06W and 8.055W; Horizontal wind; Vertical profile of the vertical wind in the lat 38.335N; Fuel Model; Vertical profile of air temperature



GRID 3 — On fire / Without fire: Flux of sensible heat; Flux of latent heat; Vertical profile of the vertical wind in the lat 37.94N and lon 8.305W; Horizontal wind; Vertical profile of the vertical wind in the lat 37.94N; Fuel Model; Vertical profile of air temperature



GRID 2 Terrain with homogeneous topography of 60 m in SFIRE — On fire: Flux of sensible heat; Flux of latent heat; Horizontal wind; Vertical profile of the vertical wind in the lat 38.245N and lon 7.78W; Vertical profile of the vertical wind in the lat 38.245N; Vertical profile of air temperature

Parametrizations of BRAMS

BRAMS grids	64 km 16 km and 4 km Resolution	1 km Resolution
Topography scheme	Silhouette Orography	Silhouette Orography
Lateral boundary condition	Klemp/Wilhelmson	Klemp/Wilhelmson
Shortwave radiation	4	4
Longwave radiation	4	4
Freq. of radiation tendency update	900 s	900 s
Convective parameters	3	no
Closure type	900 s	no
Shallow Cumulus Parameters	2	no
Frequency of convection parameters	1200 s	no
Microphysics (Moisture complexity level)	3	3
Surface layer/soil/veg model	JULES	LEAF
Eddy diffusion coefficient parameters	Horizontal deformation/Vertical Mellor-Yamada	Horizontal deformation/Vertical Mellor-Yamada

BRAMS grids	200 m Resolution
Topography scheme	Silhouette Orography
Lateral boundary condition	Klemp/Wilhelmson
Shortwave radiation	4
Longwave radiation	4
Freq. of radiation tendency update	900 s
Convective parameters	no
Closure type	no
Shallow Cumulus Parameters	no
Frequency of convection parameters	no
Microphysics (Moisture complexity level)	3
Surface layer/soil/veg model	LEAF
Eddy diffusion coefficient parameters	Isotropic deformation

Class	Thickness (cm)
Live herbáceous	< 0.64
Class 1 – branchlects, stalks and leaves	0 a 0.64
Class 2 – wood	0.64 a 2.54
Class 3 – wood	2.54 a 7.62
Class 4 – wood	7.62 a 20.32

	% of Total composition				Volatil metals(ppm)					
shrubs	P	Ca	Mg	K	Na	Mn	Fe	Cu	Zn	B
Calicotome villosa	0.14	0.43	0.08	0.66	446.80	34.97	15.54	9.71	nd	22.40
Tamarix Africana	0.11	0.59	0.28	0.59	4329.3	29.52	nd	nd	nd	30.40
Retama sphaerocarpa	0.12	1.06	0.25	0.51	509.65	39.20	nd	31.36	nd	24.60
Cistus ladanifer	0.12	1.14	0.06	0.65	509.91	125.52	nd	39.22	5.88	21.50
Quercus coccifera	0.13	2.17	0.08	0.41	332.33	43.01	nd	nd	nd	40.80
Cistus Salvifolius	0.15	0.82	0.11	0.57	429.51	113.29	3.90	1.95	nd	26.80
Cistus crispus	0.11	1.15	0.08	0.35	390.64	113.29	nd	19.53	nd	20.00
Rubus ulmifolius	0.15	1.09	0.24	0.90	682.22	62.37	nd	21.44	nd	36.30

	% of Total composition				Volatil metals(ppm)					
herbáceas	P	Ca	Mg	K	Na	Mn	Fe	Cu	Zn	B
Stipa gigantean and other herbaceous	0.10	0.39	0.02	0.13	414.39	7.89	nd	nd	nd	15.4
Juncus acutus	0.10	0.47	0.05	0.25	312.75	7.82	7.82	58.64	nd	25.1
Carlina corymbosa	0.11	1.96	0.18	1.03	994.70	74.12	nd	3.90	nd	36.9

Fuel moiture (%)

Shrubs and herbaceous	class 1	Class 2	class 3	class 4	1 h	10 h	100 h
Calicotome villosa	61.14	55.20	55.66		29.68	33.99	
Tamarix Africana	68.59	61.64	75.40	83.61	50.02	48.82	36.74
Retama sphaerocarpa	61.12	66.29	70.79		72.85	88.72	
Cistus ladanifer	71.84	76.60	55.16		29.45		
Rubus ulmifolius	111.48	134.67					
Quercus coccifera	60.86	76.01					
Cistus Salvifolius	71.69						
Cistus crispus	87.29						
Stipa gigantean and other herbaceous	9.59						
Carlina corymbosa	7.65						
Juncus acutus	51.29						

Fuel density (g/cm^3)

Arbustos e herbáceas	class 1	class 2	class 3	class 4	1 h	10 h	100 h
Calicotome villosa	0.75	0.85	0.85		0.76	0.85	
Tamarix Africana	0.92	0.91	0.87	0.80	0.77	0.74	
Retama sphaerocarpa	0.90	0.92	0.86		0.85	0.87	0.86
Cistus ladanifer	0.86	0.87	0.87		0.77	0.82	
Quercus coccifera	0.87	0.94					
Cistus Salvifolius	0.70						
Cistus crispus	0.60						
Rubus ulmifolius	0.83	0.88					
Stipa gigantean e outras herbáceas	0.43						
Juncus acutus	0.52						
Carlina corymbosa	0.22						

coefficient surface to volume (1/cm)

Shurbs	class 1	Class 2	Class 3	Class 4	1 h	10 h	100 h
Calicotome villosa	22.51	5.71	1.30		21.12	4.39	
Tamarix Africana	14.02	2.98	1.30	0.71	11.66	3.42	
Retama sphaerocarpa	10.11	2.79	1.68		10.64	3.45	1.68
Cistus ladanifer	13.78	4.23	1.73		11.71	2.94	
Rubus ulmifolius	10.44	8.49					
Quercus coccifera	13.18	4.68					
Cistus Salvifolius	24.30						
Cistus crispus	16.66						

coefficient surface to volume of little ligneous stalks (herbaceous) and leaves (1/cm)

shurbs	coef. S/V
Calicotome villosa	138.09
Tamarix Africana	50.13
Retama sphaerocarpa	21.53
Cistus ladanifer	43.66
Rubus ulmifolius	83.39
Quercus coccifera	77.52
Cistus Salvifolius	31.51
Cistus crispus	46.37

herbaceous	coef. S/V
Stipa gigantean e outras herbáceas	46.17
Juncus acutus	18.82
Carlina corymbosa	29.51

Weight of the living and dead fuel (kg)

Arbustos e herbáceas	class 1	class 2	class 3	class 4	1 h	10 h	100 h
Calicotome villosa	2.91	1.71	0.62		0.47	0.48	
Tamarix Africana	2.55	2.90	4.75	6.33	0.19	0.13	0.19
Retama sphaerocarpa	4.99	10.28	1.73		0.05	0.79	
Cistus ladanifer	4.88	3.05	1.52		0.59		
Rubus ulmifolius	0.71	0.09					
Quercus coccifera	1.19	0.49					
Cistus Salvifolius	2.58						
Cistus crispus	1.67						
Stipa gigantean and other herbaceous	0.64						
Carlina corymbosa	0.64						
Juncus acutus	6.05						

	Heat value (kJ/kg)	
	Baixo	Alto
shurbs	(Classe 1)	(Classe 1)
Calicotome villosa	19205	20577
Tamarix africana	17699	19071
Ratama sphaerocarpa	19319	20692
Cistus ladanifer	18024	19397
Quercus coccifera	18178	19551
Cistus salvifolius	17284	18657
Cistus crispus	17409	18781
Rubus ulmifolius	17700	19073
Herbaceous		
Stipa gigantea and other	17080	18453
Juncus acutus	16568	17940
Carlina corymbosa	16646	18018
trees		
Pinus pinaster	20284	21657
Pinus pinea	18868	20240
Eucalyptus globulus	19653	21025
Quercus ilex	18094	19467
Quercus suber	19145	20517

shurbs e herbaceous	Height (m)
Calicotome villosa	1.91
Tamarix Africana	3.48
Retama sphaerocarpa	2.61
Cistus ladanifer	1.66
Rubus ulmifolius	2.20
Quercus coccifera	1.72
Cistus Salvifolius	0.56
Cistus crispus	0.27
Stipa gigantean e outras herbáceas	0.57
Carlina corymbosa	1.16
Juncus acutus	1.23

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