Spatial interpolation of potential evapotranspiration for precision irrigation purposes

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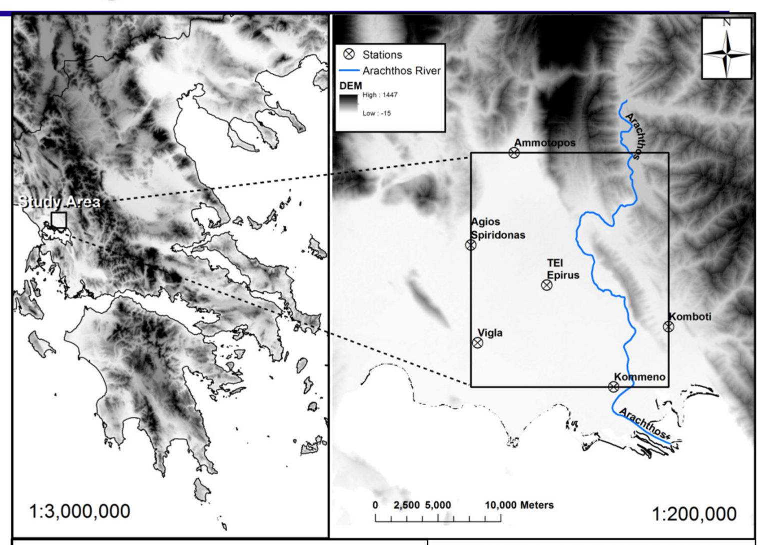
Abstract

Precision irrigation constitutes a breakthrough for agricultural water management since it provides means to optimal water use. In recent years several applications of precision irrigation are implemented based on spatial data from different origins, i.e. meteorological stations networks, remote sensing data and in situ measurements. One of the factors affecting optimal irrigation system design and management is the daily potential evapotranspiration (PET). A commonly used approach is to estimate the daily PET for the representative day of each month during the irrigation period. In the present study, the implementation of the recently introduced non-parametric bilinear surface smoothing (BSS) methodology for spatial interpolation of daily PET is presented. The study area was the plain of Arta which is located at the Region of Epirus at the North West Greece. Daily PET was estimated according to the FAO Penman-Monteith methodology with data collected from a network of six agrometeorological stations, installed in early 2015 in selected locations throughout the study area. For exploration purposes, we produced PET maps for the Julian dates: 105, 135, 162, 199, 229 and 259, thus covering the entire irrigation period of 2015. Also, comparison and cross validation against the calculated FAO Penman-Monteith PET for each station, were performed between BSS and a commonly used interpolation method, i.e. inverse distance weighted (IDW). During the leave-one-out cross validation procedure, BSS yielded very good results, outperforming IDW. Given the simplicity of the BSS, its overall performance is satisfactory, providing maps that represent the spatial and temporal variation of daily PET.

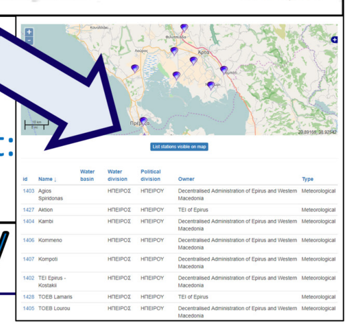
Study area and meteorological stations network

- The study area was located at the plain of Arta (453.29 km^2), at the Region of Epirus at the north west coast of Greece.
- Irrigation in the area is performed by means of surface irrigation, sprinkler irrigation and drip systems in proportions of about 40%, 40% and 20% respectively, (Tsirogiannis and Triantos, 2009).
- Six agrometeorological stations were installed in early 2015 to monitor evapotranspiration related parameters for the IRMA_SYS online decision support system (Malamos *et al.* 2016):

http://arta.irrigation-management.eu/



The data from the six meteorological stations are free and available at: http://openmeteo.org/



Potential evapotranspiration by Penman-Monteith

- The Penman-Monteith (PM) equation for estimating potential evapotranspiration from a vegetated surface, as formalized by Allen *et al.* (1998), is:

$$\mathrm{PET} = \frac{1}{\lambda}\,\frac{\Delta(R_n - G) + \rho_a c_a (v_a^{*} - v_a)/r_a}{\Delta + \gamma(1 + r_s/r_a)}$$

where PET is the daily potential evapotranspiration.

- Given that the typical time scale of the PM equation is daily, all associated fluxes are expressed in daily or mean daily units.
- The Penman-Monteith PET values acquired at the stations locations for the characteristic day of each month for the 2015 irrigation period are presented in Table 1:

Table 1. Penman-Monteith PET values at the locations of each of the six stations

Julian dates	PM PET (mm)					
	Agios Spiridonas	Vigla	Ammotopos	TEI of Epirus	Kommeno	Kompoti
105	3.4	3.2	3.4	3.2	3.2	3.1
135	4.1	4.4	4.5	4.4	4.5	4.1
162	4.8	4.4	5.2	4.9	5.5	5.4
199	6.2	5.2	6.7	6.4	6.1	6.3
229	4.6	4.7	5.0	4.7	4.9	4.8
259	3.8	3.4	3.8	3.7	3.6	3.6

Spatial interpolation methods

- Daily PET maps for the characteristic day of each month for the 2015 irrigation period were produced, using the recently introduced non-parametric bilinear surface smoothing (BSS) methodology (Malamos and Koutsoyiannis 2016a) against the well-known Inverse Distance Weighting (IDW).
- Comparison and cross validation against the calculated FAO Penman-Monteith PET for each station, were performed between the two methods, in order to evaluate the performance of BSS.
- The mathematical framework of Bilinear Surface Smoothing (Malamos and Koutsoyiannis 2016a), suggests that fit is meant in terms of minimizing the total square error among the set of original points $z_i(x_i, y_i)$ for $i = 1, \ldots, n$ and the fitted bilinear surface.
- The general estimation function for point u on the $(x\ y)$ plane, according to the Bilinear Smoothing Surface (BSS), method is:

BSS → $\hat{z}_u = d_u$ $\qquad$ $\hat{z}_u = d_u + t_u\, e_u$ ← This includes the use of explanatory variable, t, (BSSE)

- where, d_u, e_u are the values of the two bilinear surfaces at that point and t_u is the corresponding value of the explanatory variable.

BSS and IDW application

- The global minimum of Generalized Cross-Validation (GCV - Craven and Wahba, 1978) for each day was reached by implementing it for different numbers of segments mx and my (1 ≤ mx ≤ 15 and 1 ≤ my ≤ 15, while m + 1 ≥ 6) and minimizing GCV for each one, by altering the adjustable parameters.

BSS optimal parameter values and performance indices

Julian dates	mx	my	$\tau_{\lambda x}$	$\tau_{\lambda y}$	Mean square error	Global minimum GCV
105	2	3	0.902	0.154	1.75×10^{-5}	2.93×10^{-3}
135	4	5	0.003	0.765	1.42×10^{-5}	3.76×10^{-3}
162	5	4	0.99	0.001	1.13×10^{-5}	4.95×10^{-3}
199	6	12	0.76	0.019	7.42×10^{-5}	3.15×10^{-2}
229	14	6	0.201	0.001	3.77×10^{-6}	6.35×10^{-4}
259	2	6	0.784	0.067	2.47×10^{-5}	5.11×10^{-3}

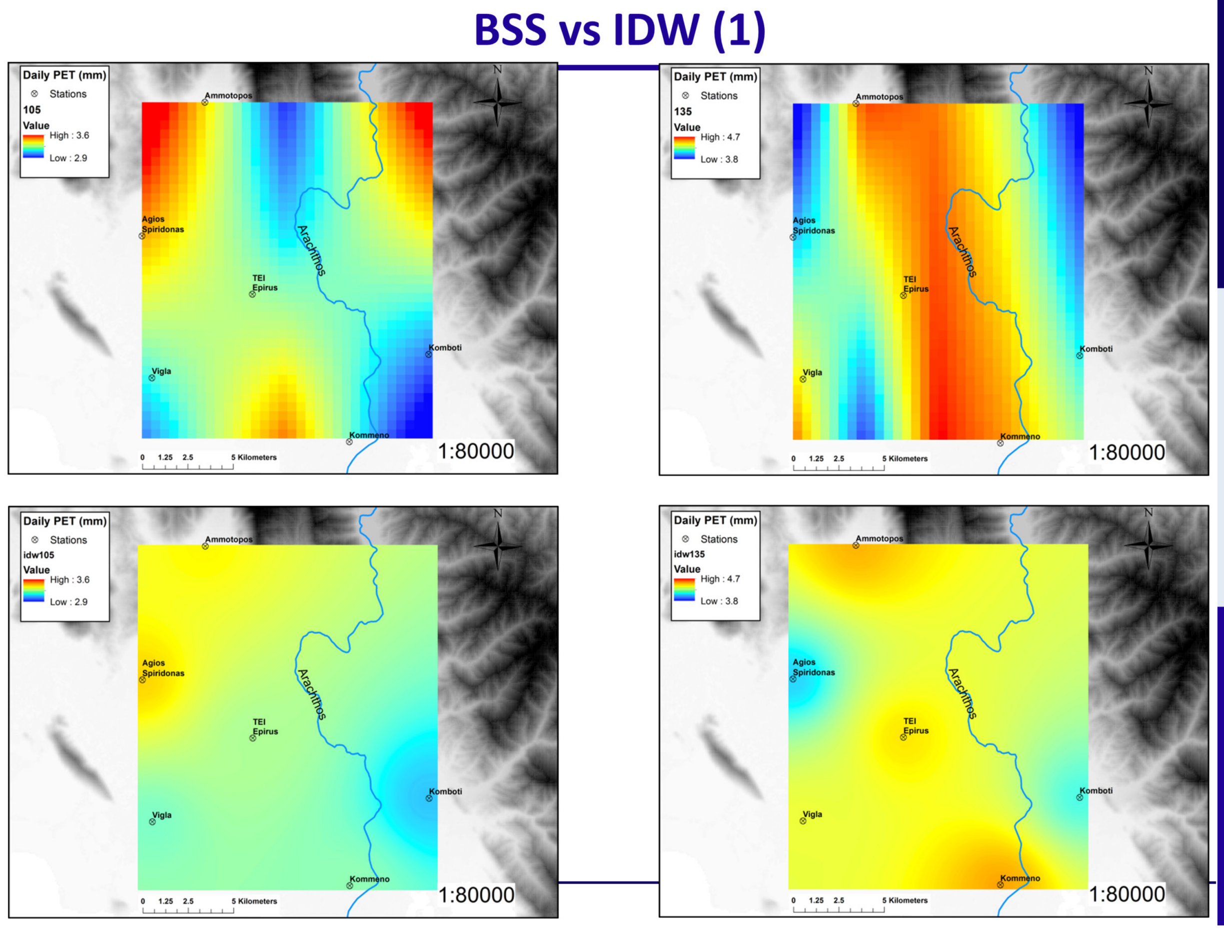
Very small values => respecting the estimated PM PET values at the stations locations

- The IDW implementation for producing the PET maps of the study area was performed by means of ESRI's ArcGIS environment.

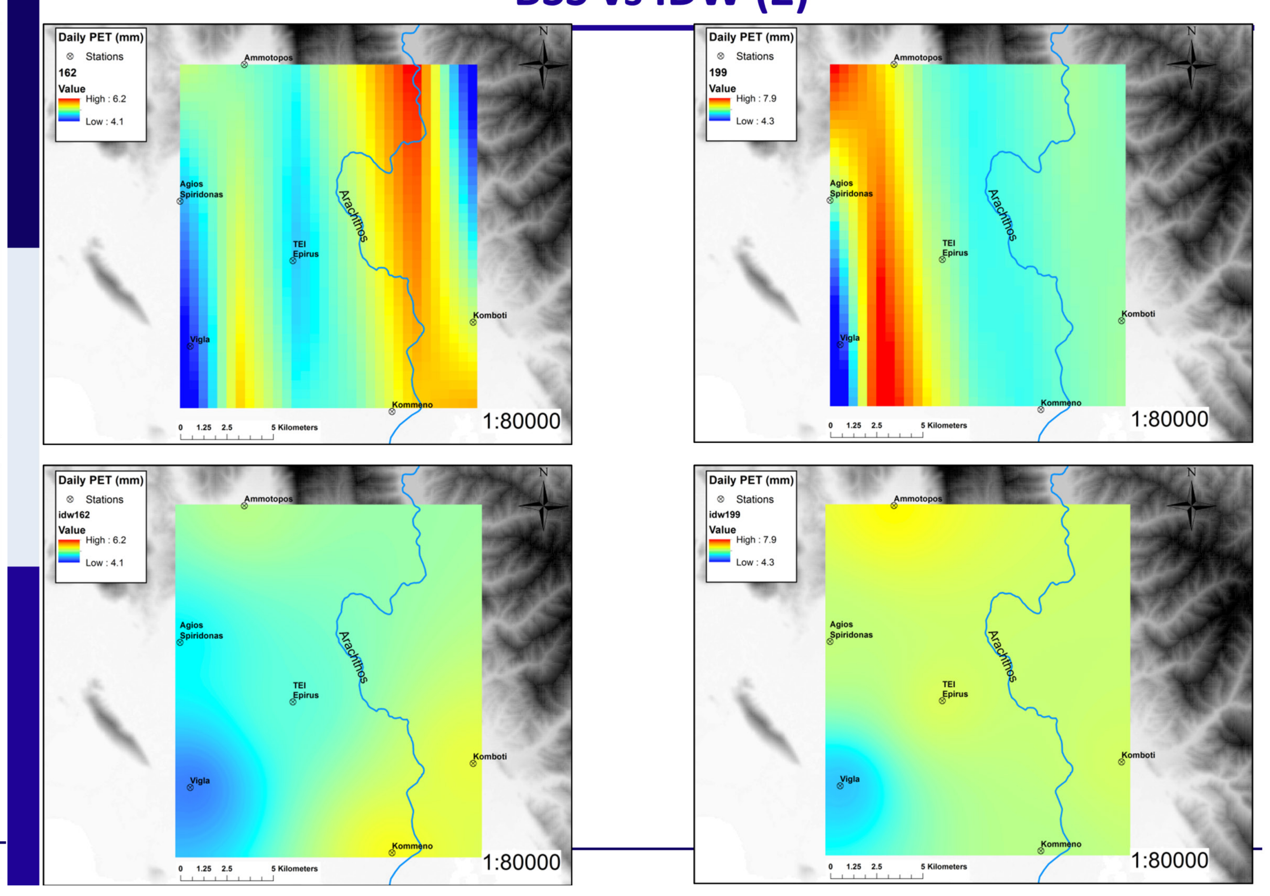
Leave-one-out cross validation

- The procedure was implemented in MS-Excel© and included a loop in which the PET values at the location of each station were estimated using the remaining five as the input dataset to each one of the two interpolation methods.
- In this way, we acquired a total of six, one for every day, PET estimates at the stations locations which were compared against the already acquired daily PM PET values.
- The performance of each method was evaluated by using statistical criteria such as: mean bias error (MBE), mean absolute error (MAE), root mean square error (RMSE), mean square error (MSE) and modelling efficiency (EF) which is calculated on the basis of the relationship between the observed and predicted mean deviations (Malamos and Koutsoyiannis 2016b).

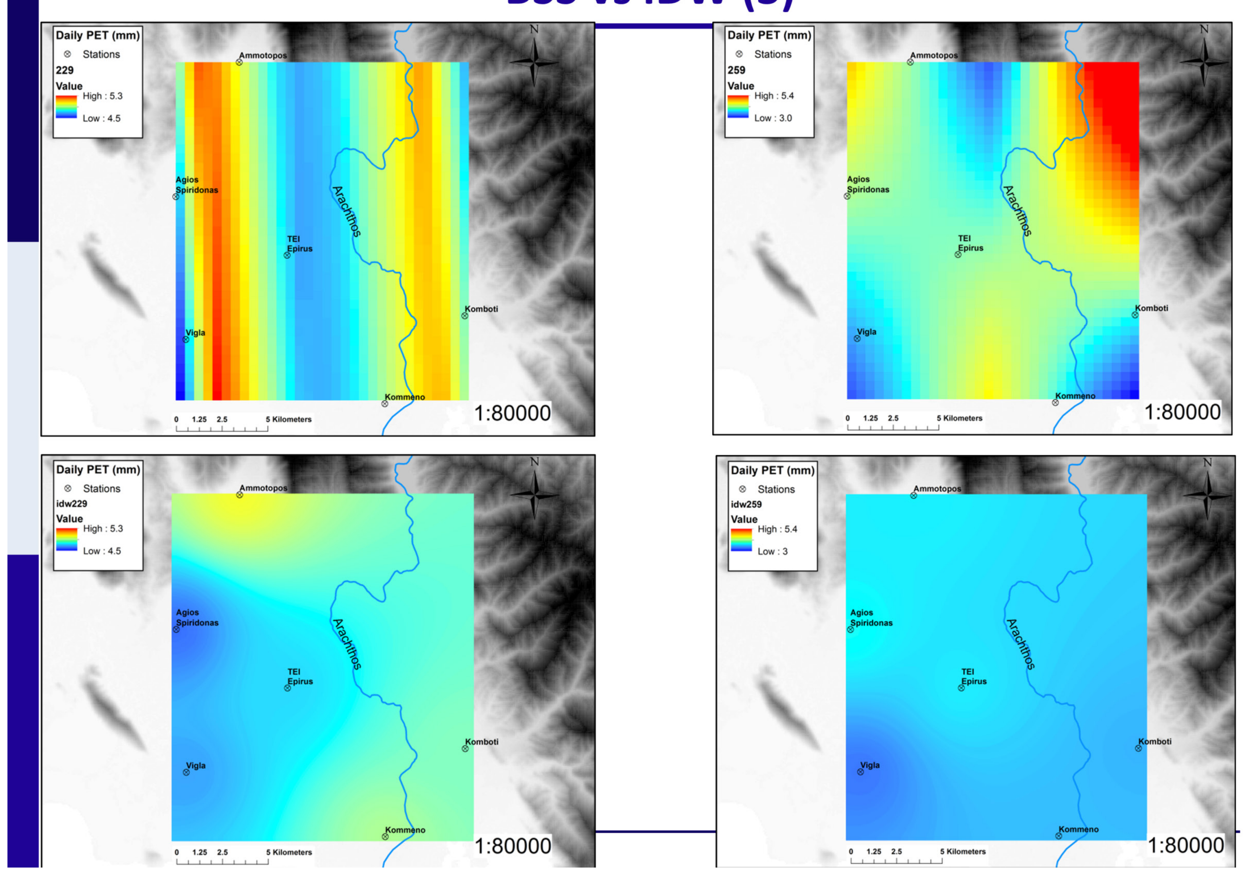
BSS vs IDW (1)



BSS vs IDW (2)

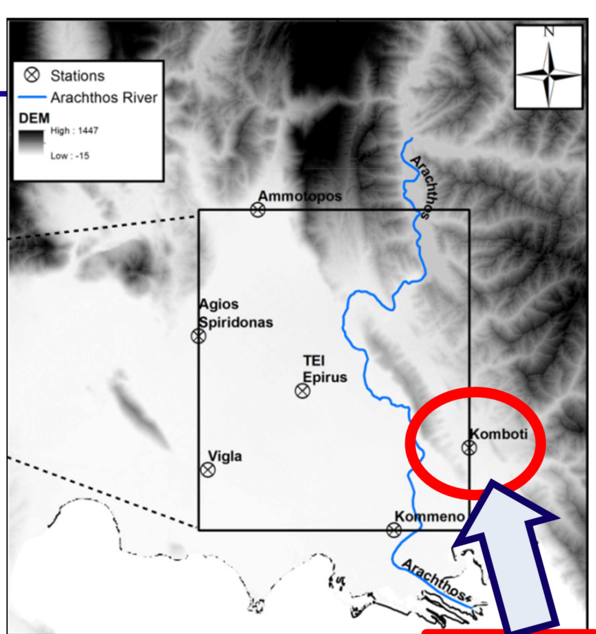


BSS vs IDW (3)



Leave-one-out cross validation

- BSS clearly outperforms IDW in all circumstances, apart from the EF and RMSE criteria at the Kompoti station.
- In this case, both methods failed to provide satisfactory estimates of PET values.
- An explanation to this behaviour is the fact that the Kompoti station is placed on the east side of the study area close to the mountains (see Figure) so when it is missing, the available information is inadequate to describe the orography effects, thus resulting in insufficient estimates.



	Agios Spiridonas		Vigla		Ammotopos		TEI of Epirus		Kommeno		Kompoti	
	BSS	IDW	BSS	IDW	BSS	IDW	BSS	IDW	BSS	IDW	BSS	IDW
MBE (mm)	0.0	0.8	0.0	0.4	0.0	0.4	0.0	0.1	-0.5	1.6	-1.7	1.7
MAE (mm)	0.1	0.8	0.1	0.4	0.0	0.4	0.1	0.1	0.5	1.6	1.7	1.7
RMSE (mm)	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.1	0.8	1.6	1.9	1.7
EF	0.99	0.18	0.95	0.47	1.00	0.85	0.99	0.98	0.44	-1.55	-2.02	-1.44

Conclusions

- Two different approaches for spatial interpolation of daily potential evapotranspiration were implemented using data from six meteorological stations located in the plain of Arta, at the Region of Epirus.
- Both approaches were implemented for the characteristic day of each month for the 2015 irrigation period, i.e. Julian dates: 105, 135, 162, 199, 229 and 259. The objective was to evaluate the performance of bilinear surface smoothing (BSS) method against the inverse distance weighting (IDW) method.
- The comparison against the estimated values of the FAO Penman-Monteith (PM) PET for each station showed that BSS yielded very good results with very small mean square error values, respecting the given PM PET values.
- A leave-one-out cross-validation procedure per station was used for validating the performance of both spatial interpolators. Thus we acquired a total of six, one for every day, PET estimates at the stations locations which were compared against the already acquired daily PM PET values. During this cross validation procedure BSS clearly outperformed IDW in almost every case, respecting the variation of the terrain and also avoiding the characteristic IDW's bull's eye shaped artefacts.
- Given the simplicity of the BSS methodology, its overall performance is satisfactory, providing maps that represent the spatial and temporal variation of daily PET, thus granting the necessary tools for implementing precision irrigation on daily or finer time scale.

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