J1.13 SHORT TERM FORECASTING OF REFERENCE EVAPOTRANSPIRATION USING LIMITED AREA MODELS AND TIME SERIES TECHNIQUES

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1. INTRODUCTION

Reference evapotranspiration (ETo) forecasts can be obtained using analytical models (Penman-Monteith, Penman, etc.) and meteorological data from numerical weather forecasts. The use of both ETo equations and weather forecasts makes possible to obtain ETo forecast on hourly base, usually for up to 72 hours, and with different spatial resolution. Data spatial resolution is a key factor for many applications in regions with high variable landscape characteristics, in particular in case of complex terrain.

Evapotranspiration forecast can be also based on time series analysis of ETo and meteorological variables related to evapotranspiration process. For example, regional ETo maps for budgeting irrigation water needs have been developed using past information on ETo rates (Pruitt, 1984) and then time series analysis has been extensively used to predict weekly, monthly or seasonal ETo rates (Mariño et al., 1993; Mohan and Arumugam, 1995). In earlier research, the discrepancy between calculated ETo and predicted ETo using weather forecasts resulted from inaccuracy of the forecast weather variables such as wind speed, water vapor pressure or solar irradiance (Meyer et al., 1988). Time series analysis is a major statistical prediction tool and it is based on the collection and analysis of past observations of a variable to develop a model for future trends. Time series models do not assume knowledge of the structural relationships between variables involved in the studied process, for example the relations between evapotranspiration rates and weather variables. Since an observed time series is an actual realization of a stochastic process, time series models are simply stochastic models.

The most common time series models are the autoregressive integrated moving average (ARIMA) models (Box et al., 1994) where the forecast of a variable is described as a linear (additive) combination of the previous states of the variable (pure autoregressive component) and the previous forecast errors (pure moving average component). The term "integrated" refers to the adjustment of the time series removing seasonal or periodic components (detrending or differencing). The major limitation of ARIMA models is the linear correlation structure that is assumed among the time series values (Zhang, 2003), while the linearity is only an approximation of the real world. Therefore, ARIMA models are not able to capture non linear patterns, which can coexist with linear patterns in real-world time series. ARIMA models have generally been used to provide weekly or monthly forecasted ETo values. Mariño et al. (1993) developed seasonal ARIMA models to forecast ETo on a monthly basis. ARIMA models performed better than other statistical methods in two distinct climatic areas of California. Mohan and Arumugam (1995) used both Winter's exponential smoothing and ARIMA models to forecast ETo on a weekly basis, and concluded that their use could improve irrigation scheduling and management of irrigation systems.

The aim of this study is to analyze and compare the performances of the above-mentioned techniques in short-term prediction of hourly and daily ETo.

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2. MATERIALS AND METHODS

The forecast weather data came from the Limited Area Model BOLAM, developed by the Institute of Atmospheric Sciences and Climate of the National Research Council of Italy and then used routinely by the Agrometeorological Service of Sardinia, SAR, Italy. The first run of the BOLAM model uses as inputs the initial and boundary conditions from a run of the general circulation model (GCM) of the European Centre for Medium-Range Weather Forecast in Reading (ECMWF), United Kingdom. The BOLAM model predicts weather variables hourly for up to 72 hours for any location in Sardinia using a 20 km grid resolution (BOLAM20).

A new release of the BOLAM model is operationally in use at SAR from 2004. This second release of the model (BOLAM5) was obtained nesting the model into the +12h BOLAM20 forecast, and then using its initial and boundary conditions. BOLAM5 can predict weather variables hourly for up to 36 hours using a 5 km grid resolution.

Forecasts obtained using the two releases of the BOLAM model were compared with ETo and weather data from three stations of the SAR automated weather network. These sites cover a wide range of climatic conditions typical of the agricultural areas of Sardinia.

BOLAM20 forecasts and SAR estimates of ETo were calculated using the hourly Penman-Monteith equation (PM-ETo) (Allen et al., 1999; Walter et al., 2002) for a 3-year period (2002-2004). In addition, ETo values using BOLAM5 forecasts were calculated from July to September 2004 using the same equation.

Hourly and daily ETo estimates were also obtained for the same period from the autoregressive integrated moving average (ARIMA) model. The ARIMA model was developed using the approach proposed by Box et al. (1994), which includes three iterative steps of model identification, parameter estimation and diagnostic checking.

In the identification step, differencing transformations of the data were applied to remove the seasonal and non seasonal trends. In addition, the autocorrelation function and the partial autocorrelation functions of the hourly ETo time series (1996-1999) from the three SAR stations were analyzed to identify the components of the ARIMA model.

Once the tentative models were identified, model parameters were estimated using a nonlinear optimization procedure such that the overall measure of error was minimized. Diagnostic check of the model adequacy was performed by analyzing PM-ETo data of the period 2000-2001 from SAR using a multi-lag prediction technique.

The results from the ARIMA models were tested using PM-ETo data of the period 2002-2003. Analysis of the data included the comparison of results from BOLAM (20 km and 5 km resolution) and ARIMA models with PM-ETo estimates to determine the accuracy of ETo forecasts. Statistics of the linear regression between computed and predicted PM-ETo forced through the origin were calculated.

The root mean squared difference (RMSD) statistics was used to compare the hourly forecasts with the calculated PM-ETo. Since RMSD is an indication of both bias and variance from the 1:1 line, it provides a good measure of how closely the two independent data sets match. A normalized RMSD (NRMSD) was also calculated dividing the RMSD by the mean value.

3. RESULTS AND DISCUSSION

Regression statistics for calculated versus forecast ETo at noon on one, two, and three days following input of weather data are shown in Table 1. The forecast overestimates PM-ETo by 4 to 6%. The root mean squared difference values indicate that the error is less than 0.15 mm (about 100 W m^{-2}), which represents a good accuracy for an hourly forecast. The values of the coefficient of determination, R^2, decrease from the 12-hour to 60-hour prediction exhibiting more scatter of the data with time. However, the forecast was nearly as good after three days as after one day. Similar results were obtained for each forecast hour.

Table 2 is similar to the previous but the regression statistics are calculated for daily values of calculated versus forecast PM-ETo on one, two, and three days following input of weather data. The slope of the regression was close to 1 for all three days, the scatter was smaller than for hourly forecast with R^2 values ranging from 0.80 to 0.88. The RMSD values indicate that the error on a daily basis was equal to about 1 mm.

In Table 3 results provided by the two releases of the weather forecast model (BOLAM20 and BOLAM5) are reported. The two versions of the model were comparable only at the second day from the emission of the forecasts, because of the differences in temporal horizon (72 hours versus 36 hours, for BOLAM20 and BOLAM 5 respectively) and initial conditions (+12UTC of the ECMWF GCM and +12h from the firs run of the BOLAM20).

At noon of the second day (+12th BOLAM5 forecast, +24th BOLAM20 forecast) the two methods showed similar results at all locations. Only small differences in R^2 values were observed, with a great scatter of BOLAM20 estimates. On daily basis BOLAM5 estimates provided the best results at all locations, with values of RMSD ranging from 0.69 to 0.77 mm d^{-1} and a low scatter of the data. The two

Table 1 - Regression statistics for calculated versus predicted hourly ETo values at 1200 h Greenwich Mean Time (GMT) for three locations in Sardinia, Italy.

Forecasting (hour)	b	R^2	RMSD (mm)	NRMSD	n
12	0.96	0.60	0.11	0.22	551
36	0.96	0.45	0.14	0.27	544
60	0.94	0.45	0.14	0.26	531

b, regression coefficient for regression through the origin; R^2, coefficient of determination for regression through the origin; RMSD, root mean squared difference; NRMSD, normalized RMSD.

Table 2 - Regression statistics for calculated versus predicted daily ETo values for three locations in Sardinia, Italy.

Forecasting (day)	b	R^2	RMSD (mm)	NRMSD	n
1	0.99	0.88	0.85	0.20	517
2	0.98	0.82	1.01	0.24	513
3	0.96	0.80	1.08	0.25	504

Table 3 - Regression statistics for calculated versus predicted ETo values from BOLAM20 and BOLAM5.

			BOLAM20			BOLAM5		
Time step	Site	n	b	R^2	RMSD (mm)	b	R^2	RMSD (mm)
12th hour	Bonnanaro	88	1.04	0.51	0.11	0.99	0.43	0.11
“	Sorso	88	0.94	0.43	0.10	0.94	0.32	0.11
“	Dolianova	88	0.98	0.44	0.12	0.97	0.40	0.12
	All locations	263	0.99	0.43	0.11	0.97	0.41	0.12
2nd day	Bonnanaro	88	1.04	0.62	0.82	0.98	0.66	0.77
“	Sorso	88	0.93	0.51	0.74	0.98	0.52	0.73
	Dolianova	88	0.94	0.66	0.76	0.92	0.72	0.69
“	All locations	264	0.97	0.58	0.80	0.96	0.64	0.74

methods underestimate the PM-ETo by 2 to 8%, with the exception of Bonnanaro, where BOLAM20 gave an overestimation (4%) of PM-ETo. To understand the reason for scatter in the calculated versus forecasted hourly PM-ETo values, each individual weather variables was analyzed for accuracy. In Figure 1 the plots of the observed versus forecast air temperature, water vapor pressure, wind speed and solar irradiance at noon two days following weather data input are shown. BOLAM model gave the best forecast for temperature with a slope of the regression equal to 1.0 and a scatter relatively small (R^2 = 0.84). The performances of the forecast for vapor pressure and solar irradiance were similar showing R^2 values ranging from 0.41 to 0.49 and a slope of the linear regression forced through the origin greater than 0.90. The relationship between observed versus predicted wind speed shows poor result with a slope equal to 0.87 and R^2 = 0.20 illustrating the wind speed is difficult to forecast. The comparison of the performances obtained using numerical weather forecast and time series models are shown in Table 4 where regression statistics for calculated versus forecasted hourly PM-ETo values are reported. The slope of the linear regression forced through the origin was slightly greater than 1.0 for ARIMA model indicating a little underestimation. The best results in terms of scatter and RMSD values were obtained from BOLAM. Table 5 shows the results obtained when the regression statistics were calculated for daily values. The forecast was good for all three days (in particular from BOLAM), the scatter was generally smaller in comparison with hourly forecast and the RMSD values indicate that the error on a daily basis ranged from about 1 mm for BOLAM to 1.3 mm for ARIMA model.

4. CONCLUSIONS

In this paper the performances of different methods to forecast the reference evapotraspiration on hourly and daily basis in a Mediterranean area are evaluated. The method based on the use of weather forecasts provided by a Limited Area Model gave RMSD values of the forecasted ETo smaller than 0.15 mm on a hourly basis and equal to about 1.0 mm on a daily basis. However, the analysis showed a large scatter of observed versus predicted ETo values, in particular for hourly values (0.45-0.60). The evaluation of the effect of weather forecast variables on forecast ETo accuracy showed that solar irradiance is the main parameter affecting ETo forecast. Time series models performed less well; then the method based on weather forecasts showing more scatter between calculated and predicted ETo and R^2 values ranging from 0.42 to 0.48 on hourly basis and from 0.71 to 0.78 on daily basis. The use of weather forecast provided by the model BOLAM5 (5 km spatial resolution) did not affect significantly the accuracy of PM-ETo forecasts.

Future research will be addressed to improve the parameterization of cloud cover and solar radiation, and to apply new methods to produce high resolution near surface weather forecast.

Table 4 - Regression statistics for calculated versus predicted hourly ETo values from BOLAM20 and ARIMA.

	BOLAM			ARIMA		
For. (hour)	b	R^2	RMSD (mm)	b	R^2	RMSD (mm)
12	0.96	0.60	0.11	1.07	0.48	0.13
36	0.96	0.45	0.14	1.07	0.46	0.14
60	0.94	0.45	0.14	1.07	0.42	0.14

Table 5 - Regression statistics for calculated versus predicted daily ETo values from BOLAM20 and ARIMA.

	BOLAM			ARIMA		
For. (day)	b	R^2	RMSD (mm)	b	R^2	RMSD (mm)
1	0.99	0.88	0.85	0.99	0.78	1.13
2	0.98	0.82	1.01	0.97	0.74	1.23
3	0.96	0.80	1.08	0.97	0.71	1.30

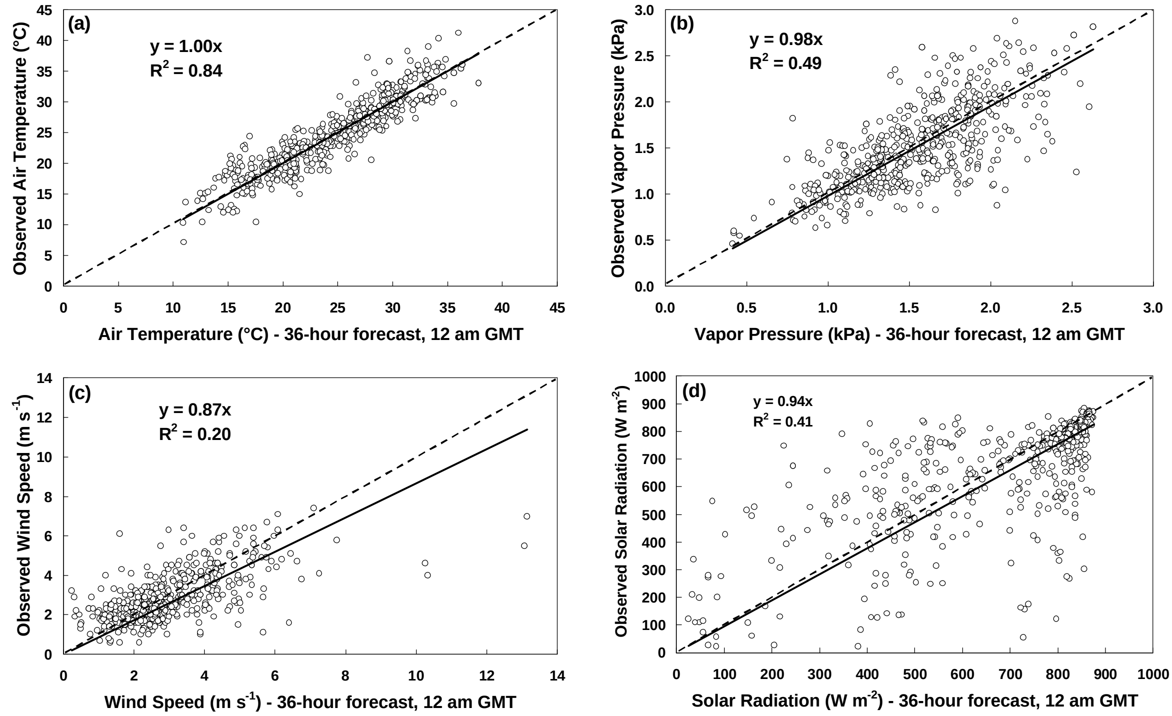

Figure 1 - Hourly observed air temperature (a), water vapor pressure (b), wind speed (c), and solar radiation (d) from SAR weather stations versus forecasts from the BOLAM model. Data were for noon on two days following input of weather data.

5. REFERENCES

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