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ANGELA (ALGORITMO DI NOWCASTING PER LE GELATE): A TOOL OF FROST FORECASTS

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Abstract

Friuli-Venezia Giulia is a region in North-East Italy in which apples, pears, peaches and actinides crops cannot be considered a negligible part of farming activities, especially over the plane. Frost doesn't damage these crops very often, anyway this problem isn't marginal. Frost damages usually take place in spring (March – May) and in fall (November), in the last case they are limited to the Actinidia. To reduce damages, it's possible to modify the orchard microclimate by irrigation techniques. Short-term forecast of minimum night temperatures is a useful tool for farmers to organize their irrigation actions. At CSA, we have set up a program that forecasts and issues night temperatures with a time resolution of one hour, called ANGELA (Algoritmo di Nowcasting per le GELate) i.e. frost nowcasting algorithm. To forecast temperatures, ANGELA uses the Reuter's radiative model and data from 14 meteorological stations which are spread all over the plane. Stations' data give the starting conditions to the forecast algorithm and they are updated each hour since all stations are connected to the operative centre at CSA by modem. The radiative model we use needs robust initial conditions to give realistic forecasts, so ANGELA makes comparisons among all measured temperatures to avoid instrumental spikes or very local temperature features. Forecasts are available to the users in real time by a teletext system of a local television broadcasting station and ANGELA automatically updates them every hour during the night. To test the forecast algorithm we used the CSA meteorological database that stores hourly temperature records throughout the period 1990 – 1999. At present ANGELA works routinely during those periods of the year in which we consider crops potentially exposed to the frost risk.

Introduction

The Friuli-Venezia Giulia region is placed in the north-east of Italy and, thanks to its fair climate, fruit growing has a rather relevant weight on the local farming. Orchards extend mainly over the Friuli plane with apple-trees covering about 1400 ha, peaches-tree 300 ha, actinidias and pears about 400 ha for each (Boschian et al. 1990 – Filaferrero et al. 1996). Usually frost is very frequent during winter over Friuli plane, but during spring and fall its occurrence isn't very high (Cicogna et al. 1999); anyway frost is a not negligible risk for fruit growing. For this reason, several orchards are provided with irrigation devices that are used against spring frost and, in some situation, against fall frost. In frost conditions it's possible to stop it in a limited region by means of irrigation; of course it's very important to know when the frost will take place since the action of the water on the air has to be started in advance. In order to enable this, the CSA (Centro Servizi Agrometeorologici), that is an organism voted to Meteorology and Agrometeorology and promoted by ERSAs, the institute for the regional agriculture development, has been studying the problem of night temperature drop to improve the daily minimum temperature forecasts. The main aim of these studies is to give to the farmers a tool for the optimisation of their actions on the frost, that is saving money. The provided tool is called ANGELA (Algoritmo di Nowcasting per le GELate) and it gives the forecasted temperature evolution from the sunset to the sunrise in

14 points on the plane where meteorological automatic stations exist (Fig. 1). At CSA are available many information useful for frost prevention, numerical models outputs, satellite images, ground station data, forecasters' and agronomists' expertise, just to say some of them, and ANGELA try to summarise them in an useful and easy tool to get temperature trend forecast.

The algorithm

ANGELA is fed by information from the sunset to the end of the night. Inputs can be classified as follow:

1. **Minimum temperature subjective forecast.** This is the forecast of the minimum temperature for the incoming night issued by the forecaster. It's the synthesis of numerical model outputs, all meteorological data present up to that time at the CSA and the forecaster's skill.
2. **Hourly temperature measurements during the night.** These data are gathered from the meteorological stations spread over the plane. They are refreshed every hour so they give an up to date snapshot of the ground temperature field.

The physical model implemented in ANGELA for the night time temperature drop is that of Reuter (Pelosi 1986). In this model the ground temperature is function of sunset temperature and the time passed since the sunset.

$$T_n = T_s - K \cdot n^{1/2} \quad (1)$$

In equation (1) T_n is the temperature at n hours from the sunset in °C, T_s is the temperature recorded at the sunset in °C, K is the temperature drop coefficient, a constant, and n is the number of hours since the sunset. In spite of its simplicity, the model represents the reality very likely if the coefficient K is updated every hour during the night. The initialisation of the model is done with the forecaster's minimum temperature, the sunset temperature and the length of the night in hours, assuming that the lower temperature is reached at the end of the night. In this step two values for K are computed: one concerning the pure minimum temperature issued by the forecaster and the other concerning the forecaster's minimum temperature minus 2 °C. This is done to give two extreme values for K : K_{max} and K_{min} which define the range for the K values computed in the further steps. The starting K is the simple average of the two extremes. Every hour after the sunset, for each of the 14 points in the plane, the observed temperature is used to compute the new constants K . To give more robustness to the forecasts, that is to issue temperature forecasts without too much fluctuation during the whole night, the applied K is constrained in the defined range by means of linear combination of K , K_{max} and K_{min} . Furthermore a check on observed temperatures is performed to avoid the use of local spikes. Indeed it's common that temperature decrease has abrupt changes from one hour to the next because of very local meteorological forcing, that is cloud coverage, local winds, moisture and so on. It's also possible to get spikes because of instrumental problems. The check is based on the average temperature deviation, \overline{SC} , defined as follow:

$$\overline{SC}_n = \frac{1}{N} \sum_{i=1}^N (T_n^{(f)}(i) - T_n^{(o)}(i)) \quad (2)$$

Where N is the number of stations (14 for ANGELA) $T_n^{(f)}(i)$ is the forecasted temperature at i^{th} station, n hours after the sunset and $T_n^{(o)}(i)$ is the observed temperature at i^{th} station, n hours after the sunset. \overline{SC}_n is a variable showing the general trend of the forecasted temperatures with respect of the observed ones. If $\overline{SC}_n \geq 0$, on average the model is underestimating the temperature drop, if this happens, to compute the new K values, observed temperatures $T_n^{(o)}(i)$

are used if $T_n^{(o)}(i) < T_n^{(f)}(i)$, otherwise if $T_n^{(o)}(i) \geq T_n^{(f)}(i)$, then $T_n^{(f)}(i)$ is used. When $\overline{SC}_n < 0$, the algorithm is forecasting temperatures on average lower than the observed ones, in this case it's necessary to keep in mind that a general reduction on the night temperature drop all over the plane doesn't mean that temperature trend is permanently modified. Several times a strong temperature drop reduction take place for a small part of the night and after temperatures fall down. An example of the above reported situation is the occurrence of the end of a cold front event during the night. In the evening when the sky is still cloudy the temperature decrease at the ground is weak, but during the night the sky becomes clear and the air dryer, so the radiative loss of energy at ground is high and temperatures fall down. Of course the opposite can occur, that is strong temperature drops are stopped or strongly reduced during the night, but first ANGELA's goal is to reduce at minimum the probability of missing frost events, so the computation of K constants is biased towards low temperature forecasts. For these reasons, if $\overline{SC}_n < 0$, the observed temperature at the i^{th} station is considered as inputs for ANGELA if $|\overline{SC}_n| > |T_n^{(f)}(i) - T_n^{(o)}(i)|$ otherwise the input temperature is $T_n^{(input)}(i) = T_n^{(f)}(i) + |\overline{SC}_n|$. The above described procedure smoothes out the fluctuations of K and so gives more robustness to the forecasts; in fact the thermal field of our plane is generally enough smooth to justify this procedure. Since $T_n^{(f)}$ shall meet the observed temperature at hour n , when K is computed it's necessary to set a new virtual T_s to cope with the constrain. Once the observed temperatures are available at CSA and the ANGELA temperature forecasts are computed, an automatic connection with a local television broadcasting station updates the forecast, making them available to everybody by means of a teletext system in real time. An example of the teletext page for some of the 14 stations is shown in figure 2. Teletext system is very easy to use, practically free and it can reach the whole interested audience. For these reasons it was chosen for dissemination of ANGELA results (Gani et al. 1999, Cicogna et al. 2000). At present ANGELA works routinely during those periods of the year in which we consider crops potentially exposed to the frost risk.

Forecasts verification

ANGELA's forecasts have been compared with observations; in order to do that the whole database of Centro Servizi Agrometeorologici has been considered. Verification of minimum temperature forecasts considers the periods 10th March -30th April and 1st October - 10th November from 1991 to 1999. In this data set we found 122 nights with 2 meters minimum temperature below zero. Considering all the meteorological stations involved in the forecast, the verification is based on 1328 forecasts. Figure 3 gives a quick look at ANGELA performance; there are presented the differences between minimum temperature ANGELA's forecasts and observed minimum temperatures. Differences are grouped in classes, each class represents a range for the computed difference as follow:

1. Forecasted minimum temperature – Observed minimum temperature $< -2^{\circ}\text{C}$
2. $-2^{\circ}\text{C} \leq$ Forecasted minimum temperature – Observed minimum temperature $< -1^{\circ}\text{C}$
3. $-1^{\circ}\text{C} \leq$ Forecasted minimum temperature – Observed minimum temperature $< +1^{\circ}\text{C}$
4. $+1^{\circ}\text{C} \leq$ Forecasted minimum temperature – Observed minimum temperature $< +2^{\circ}\text{C}$
5. $+2^{\circ}\text{C} \leq$ Forecasted minimum temperature – Observed minimum temperature

The percentage of events belonging to each class versus the number of hours separating the forecast to the minimum temperature observation is shown in figure 3. As stated above, ANGELA updates its forecasts every hour according to the input of station measurements, so the

abscissa in the plot reports the hours ahead for the minimum temperature to happen. The first information from the right is that of the forecaster, then ANGELA forecasts follow up to the 1 hour ahead forecast in the left side. Class 3 is that of best forecasts and it's broadening when hours are reduced; of course this is because ANGELA relaxes over the observed minimum, learning how to adjust the temperature drop from the data gathered every hour. Classes 1 and 2 are more populated than classes 4 and 5 since ANGELA issues forecasts biased towards low temperature, according to the principle of minimizing the missing forecast of frost events. Even if classes 1 and 2 have a considerable weight on the totality of forecast issued at 11 hours ahead of the minimum temperature, their weight clearly decrease approaching the hour of minimum and 3 hours before the lowest night temperature only about 25% of events have a forecast temperature lower than the observed one.

Very interesting is the comparison between ANGELA's and forecaster's performances. The advantage of ANGELA is that it learns the status of the actual thermal field from the stations data hour by hour and it corrects the temperature drop to meet the reality. The forecaster issues his judgement on the minimum temperature at least 15 hours before it takes place, on the basis of information he got up to the time of the issue and his ability to forecast the future weather conditions. Since ANGELA starts with the forecaster's minimum temperature and it uses more information than the forecaster does, it's natural to expect ANGELA to be more skilled than the forecaster. In figure 4 we present the empirical distributions (Ledermeann 1984) of differences between forecasted and observed minimum temperatures. Each plot refers to a fixed hour before the time the minimum is observed; the bold black line is the empirical distribution of forecaster's differences, the light blue line refers to the ANGELA's differences. Starting from the 14 hours ahead plot going throughout the entire sequence and ending with the 1 hour ahead forecasts, ANGELA's distribution becomes sharper with a mean closer to zero, that is forecasts are closer to the observations with small deviations. On the other hand, forecaster's distribution is always the same since his forecast doesn't change during the night. Kolmogorov-Smirnov statistical test (Ledermeann 1984) puts in evidence that ANGELA's distribution cannot be considered the same of the forecaster's one at 99.9% confidence level starting from 13 hours ahead the observed minimum. The 14 hours plot distributions are similar since in this case ANGELA's forecast are mainly the zero step values that is they are the forecaster's issued minimum temperatures. To go further in the comparison, we computed the (MSE) mean squared errors (Wilks 1995) as follow:

$$MSE = \frac{1}{M} \sum_{j=1}^M (T_j^{(f)} - T_j^{(o)})^2 \quad (3)$$

where $T_j^{(f)}$ is the forecasted minimum temperature of day j , $T_j^{(o)}$ is the observed minimum temperature of day j and M is the number of days in the data set. The MSE has been computed for the forecaster (MSE_f) and for each subset of ANGELA's forecasts belonging to the ahead hour class (MSE_h $h = 1,2,3,\dots,14$). We defined the ANGELA's skill score (SS_A) of hour h as follow:

$$SS_A(h) = \frac{MSE_h - MSE_f}{0 - MSE_f} \quad (4)$$

where $SS_A(h)$ represents how much ANGELA's forecast at h hours before the observed minimum temperature are skilled with respect to the forecaster's when its compared with the perfect forecast ($MSE=0$); for more details on skill scores refer to Wilks (1995). If $SS_A(h)$ is greater than zero ANGELA has more skill than the forecaster, otherwise its skill is lower. Figure 5 is the plot of $SS_A(h)$ versus h . ANGELA skill is increases during the night, at 10 hours before

the minimum temperature observation ANGELA has already gained about 50% of skill separating forecaster's performance from perfect forecast. Since 6 hour ahead to the hour of minimum the skill is very close to that of perfect forecasts $SS_A(h) \geq 0.75$.

Conclusions

The Algoritmo di Nowcasting per le GELAtè is a tool to help the farmers in the frost prevention. Its inputs are the subjective minimum temperature forecast issued by a forecaster and the hourly temperature measurements gathered from the local network of meteorological stations. The forecaster's temperature summarizes all the information available at the CSA before the sunset, that is station data, numerical models outputs, radar and satellite images, and forecaster's expertise. ANGELA forecasts are based on the Reuter model. After sunset, ANGELA adjusts its forecasts according to the evolution of the thermal field hour by hour. Possible spikes in station data are smoothed out by a rather simple technique, in order to avoid not realistic fluctuations of the forecasts. The performance of ANGELA is good; the comparison between ANGELA and the forecaster skills shows that ANGELA performance in forecasting minimum temperature is always higher than forecaster's one and its skill is increasing during the night.

References

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Fig.1 The regional network of Friuli-Venezia Giulia meteorological stations.



Fig 2. Example of Angela's forecast on a teletext page. Blue figures are the in situ measured temperatures, the yellow ones are the Angela's forecasts

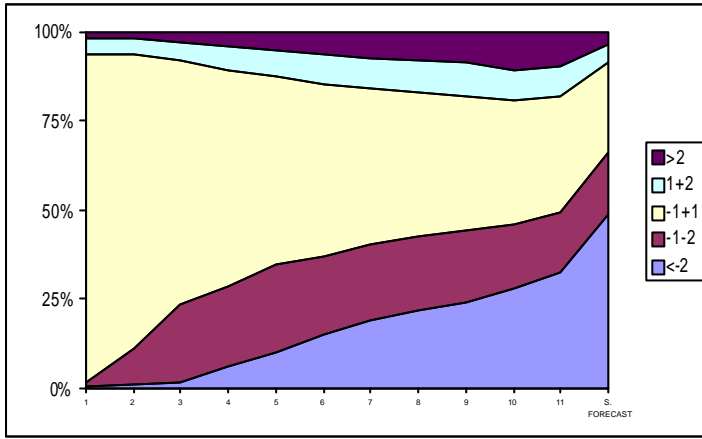


Fig. 3 Distribution of temperature difference classes. Each class represents the difference between forecasted and observed minimum temperature

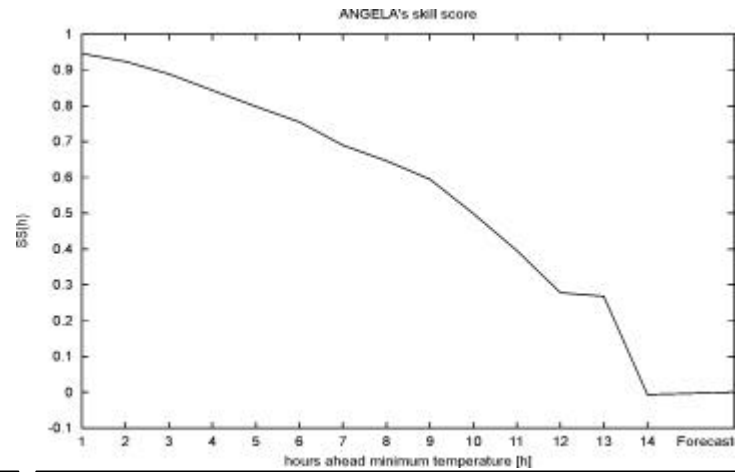


Fig. 5 Angela's skill score. Note the net increase from the forecaster input to the last Angela's forecast, their skill is close to the perfect one.

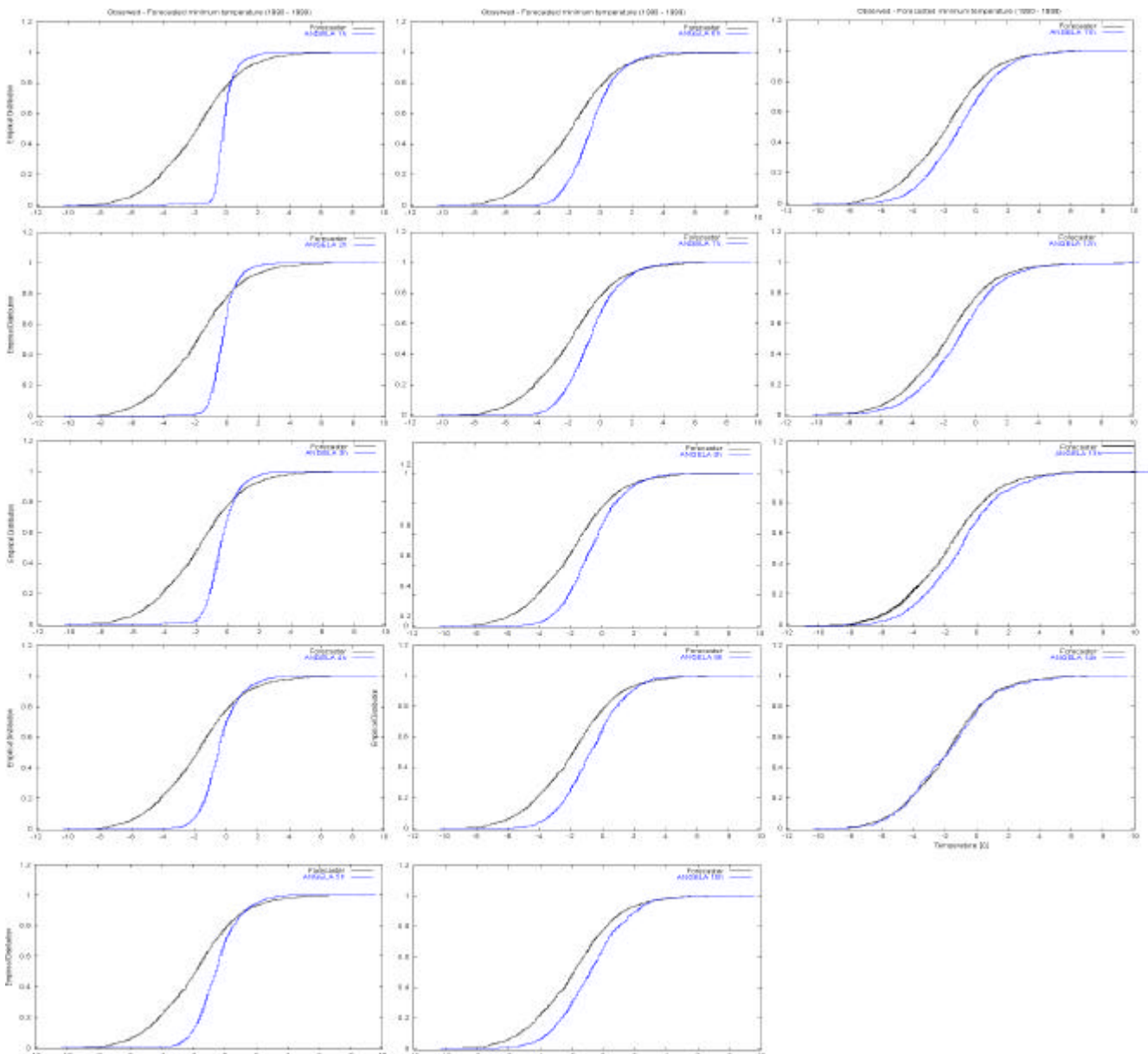


Fig. 4. Empirical distributions of the differences between minimum temperature forecasts and observations. Solid black line refers to forecaster's performance while light blue line is that of ANGELA's forecasts. Each plot concerns one of the hours ahead the observation of minimum temperature. See the progressive sharpening of ANGELA's distributions from 14 hours to 1 hour ahead.