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THE COMBINED FOG MONITORING SYSTEM OF ARPAV OVER THE VENETO REGION, PO VALLEY – ITALY

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1. INTRODUCTION

The presence of fog is a frequent problem in the Po Valley. The consequent reduction in visibility has a strong impact on the road, air, ship and railway traffic.
Both, fog monitoring and forecasting, constitute significant challenges, not least due to the high spatial and temporal variability of the phenomenon. In the last 10 years new opportunities were given by the *Meteosat Second Generation* satellite (*www.eumetsat.int*) and by the availability of different methods for the monitoring of visibility (visibility sensors, webcam).
The monitoring systems, from the ground as from the sky, present different values and problems; a system that can take advantage from the values of different methods, merging the information, would provide a more complete estimation on visibility reduction.
The many issues of the COST 722 'Short-range forecasting methods of fog, visibility and low clouds', has given some important starting ideas for the realization of the work presented in this paper (*COST 722 Reports: 2005 and Final Reports*).
The impact of fog conditions is important in general, and for Italy represents about a 0.5-1.5% of the total road accidents. In the Veneto Region only, the economic loss (total social cost) due to road accidents in low visibility conditions is close to 35 millions of euro per year (*Italian Central Institute of Statistics, Automobile Club Italia*). ARPAV, the Regional Agency for Environmental Prevention and Protection of Veneto, is the regional meteorological service of the north-eastern Italian region Veneto and, as such, is responsible for meteorological support to institutional and private users. Since real-time visibility information over an extended area would represent an interesting product for road and transport safety, ARPAV, in the framework of the FP7 project ROADIDEA*, on road safety and traffic control, proposed and developed the system described in the present paper, as a pilot system for the fog monitoring.
(*ROADIDEA Project involves 14 partners from 8 countries, it started on December 2007, and will finish on August 2010).
The main idea of this fog monitoring methodology is to merge information derived from different observation platforms, i.e. satellite low stratus cloud classification, direct visibility monitoring, statistical estimation of low visibility from meteorological parameters at the ground. Each information is translated into probability maps of fog occurrence, with a weight attributed to the estimation itself, on a common grid (4x4 km) covering the flat portion of the region Veneto. These three different information are combined, taking into account the weight of single information, into the final fog probability map.
A probabilistic verification applied to the resulting product yields encouraging results, and is systematically more skillfull than the fog probabilities derived from the individual data sources. First real-time products are now available on the ARPAV Fog Pilot website for a group of specific users (motorway head office, road police, national railways and others) and are under testing.
Address of the test site:
http://85.42.129.76/ROADIDEA

2. DATA

2.1. Screen–level visibility network

The in situ fog monitoring requests instruments for direct observation of the visibility at screen level (height of 2 or 10 meters). For this aim ARPAV has purchased 10 visibilimeters, and installed them in their surface station network, in the plain part of Veneto, in an average resolution of 30 km. The instruments are included in the real time calling procedure (every hour).

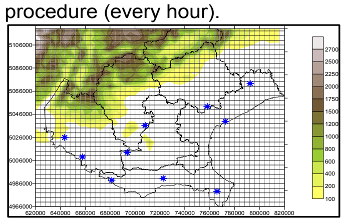

Figure 1: Map of the actual visibilimetry network, working since Jan 2009.

2.2. SAFNWC Cloud Classification

For the area of northern Italy the second generation geostationary satellite of EUMETSAT, Meteosat 8-9, is an essential source of information. The SAFNWC system is a software developed over the last years by a consortium involving many different organizations (*http://www.nwcsaf.org – SAFNWC documentation*). Of the set of 12 products available by the SAFNWC, we use the "Cloud Classification Type" (CT) product; this product provide an estimation on the type of

cloudiness covering a point on the satellite optical range, including low and very low clouds.
At the Meteorological Centre of Teolo the SAFNWC software was installed in order to obtain from Satellite a good estimation on cloud coverage, derived from combination of satellite imagery and meteorological models. The CT product takes part of the operational chain, contributing with the satellite-derived information.

2.3. CALMET and PBL parameters

CALMET (*Scire et al., 2000*) is a meteorological diagnostic model, normally used as a pre-processor for CALPUFF, pollution dispersion model. The starting data are coming from ground stations, Synop data, description of the cloud coverage.
In the framework of the ROADIDEA FOG PILOT the CALMET model output is used to estimate the meteorological conditions at the lower levels of atmosphere, including relative humidity, temperature and mixing height.
The relation between our surface station meteorological data and the visibility is established by a statistical non parametric analysis method, more precisely the "Classification And Regression Tree" ('*Classification and Regression Trees', Breiman et al. 1984*).

2.4. Grid of the Probabilistic Fog diagnostic system

Each information about visibility have to be related to the same geographical grid. We have opted for the geographical grid UTM32, used by the CALMET model in our operational settings. The UTM32 is a metric reference system, that allows to calculate directly the real distance between two points (important for the weight calculation). The grid spacing is 4x4 km; this size well matches with the dimension of the basic cell of the SAFNWC output at the lat-lon of northern Italy.

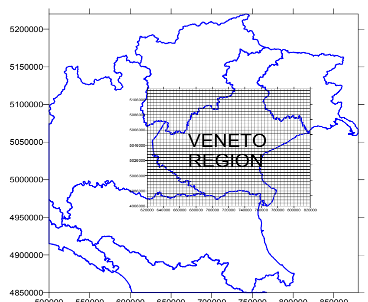

Figure 2: the metric grid UTM32 with cell size of 4x4 km, used in the probabilistic fog diagnostic system.

3. METHOD

3.1. Model elements, measures and its representativity

Using data sources presented in the previous chapters, we have three different sources of information/estimation available:

- Visibility sensors network information (10 points);
- Satellite derived cloud classification;
- Meteorological surface observations preprocessed by CALMET.

These pieces of information are different in essence; the visibilimeters network reports a set of local deterministic measurements; the Satellite CT reports an estimation of a condition that presents a relationship with the visibility reduction; the estimation derived by statistical method from meteorological ground stations returns a probability based on the analysis of a large set of observations.
In order to combine the available information, which are inherently uncertain, we opted for a probabilistic approach.
The merging method of the Fog Pilot will take into account the following conditions as essential:

- Each observation/estimation takes the form of a probability of an event occurrence (e.g. visibility less than 500 meters);
- Each observation/estimation has the form of a 2D field of probability, on the same geographical grid;
- Each observation/estimation must be linked to its level of uncertainty, expressed by a weight;
- The resulting product, obtained by merging the single information fields, will be more or less reliable depending on the specific reliability of the different information sources.

3.2. Probability derivation and weight of information

The information deriving from each monitoring system is translated into the "probability of visibility under 500 meters, within the cell".
The information given by CALMET or ground stations will be translated into probability with a decision three obtained by a CART analysis on meteorological data and visibility reports. The result of the three is an histogram counting the number of historical fog cases. This allows to derive a probability, and the dispersion of the histogram gives a measure of the weight of the probability estimation.
From the visibility sensors network a value of probability is derived from each instrument (probability=1 with visibility less than 500 meters, decreasing to probability=0 if visibility is upper 1 km). Then this values are interpolated on the entire grid of the system.
The Cloud Classification obtained by SAFNWC provide and information that can be divided into 3

classes: clear sky, overcast (medium-high coverage), low or very low clouds. To each class a value of probability of reduced visibility (under 500 m) was empirically assigned. The empirical values are checked only by a posteriori verification; in particular we assigned a probability of 70%, even if with the last analysis this value were found to be overestimated. Once recorded a year of complete data (August 2010) the values of probability will be reassigned more opportunely, with a specific statistical analysis.

3.3. Weighted average

The combination of available data is then performed with a simple weighted average. Once found the correct weight for every point in each field, a further weighting constant will be applied to each field, in the final merging procedure ('sigma').

To summarize, the single point probability of event is:

$$P(x,y)=\frac{\sigma_{sat}\cdot w_{sat}(x,y)\cdot P_{sat}(x,y)+\sigma_{vis}\cdot w_{vis}(x,y)\cdot P_{vis}(x,y)+\sigma_{cart}\cdot w_{cart}(x,y)\cdot P_{cart}(x,y)}{\sigma_{sat}\cdot w_{sat}(x,y)+\sigma_{vis}\cdot w_{vis}(x,y)+\sigma_{cart}\cdot w_{cart}(x,y)}$$

the 'sigma' parameters have been introduced to have an overall relative weight for the three data sources. These can be chosen plausibly or determined as the result of an optimization of the model.

It's well known how all the mentioned information sources about fog presence shows pros and cons.

Data source	Preprocessing	Pros	Cons
VISIBILIMETERS	Spatialization on the model grid	Good reliability	Very local information
Ouput by CALMET (or from STATIONS)	Statistical treatment	Instruments already available	Reliability very variable, local information
SATELLITE	Cloud Typing with SAFNWC	Coverage of the territory	Reliability very variable

Table 1: characteristics of data sources.

This merging process aims at reducing the individual limitation of the single data sources for fog estimation. In particular it is expected that:

- the surface information helps the distinction between low clouds and fog in the satellite information;
- satellite maps help the interpolation of the information even in areas not covered by instruments at the ground.

3.4. Performance measures

Verification is of principal importance for establishing the "goodness" of the fog probability maps and warnings that are output from the Fog Pilot. The verification process was chosen to act on the products derived from the individual data sources, as well as on the final merged product. The verification was performed for different periods during the winter 2009-2010, for a total of around 30 days (per 10 instruments, make available more than 7000 hourly samples). The following statistical indices and methods were applied:

- Reliability diagram, which compares the probability estimates with the effectively observed fog frequency given the probability estimate from the fog model;
- Probability of Detection (POD), Probability of False Detection (POFD, i.e. false alarms) and ROC curve diagram (ROC area);
- "TOTAL COST" (lower is better), or the directly derived "Economic Value" (higher is better), here calculated for a c/L ratio of 0.2.

Ref. *'Statistical Methods in the Atmospheric Sciences' (Wilks 2006)*.

3.5. Model parameters to be tuned

The system contains a certain number of parameters that can be varied to find the best performance with the present processing; in particular:

- The range of influence of visibilimeters; an exponential decreasing factor that determines the loss of weight of the information from a visibilimeter;
- Parameters for the correction of SAFNWC-derived probability field; 2 parameters that depending on visibility sensors records increase or decrease the weight of the satellite derived field;
- Relative weights for the calculation of final product; the 3 sigma parameters, ranging from 0 to 1, that determine the overall weight of the three fields we are merging with the weighted mean.

The optimization of these parameters allows a consistent increase of the model performances.

The mentioned parameters were tuned by a verification of outputs, performed varying the parameters value; the behaviour of the indeces we used for the tuning were reported on a 1-dimensional graph (for single parameters, such as distance factor) or 2-dimensional graph (for coupled parameters, such as relative weights of fields or correction factors).

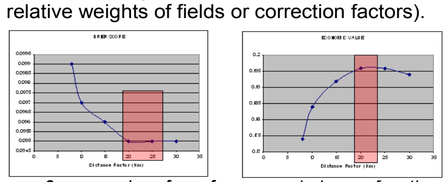

Figure 3: example of performance indeces for the fog probability field obtained with the Visibilimeters network, varying the Distance Factor; the optimal results are obtained for a factor close to 20 km.

4. Tuning And Performance Evaluation, added value of the merging procedure

Table 2 summarizes the performances, including the economic value, of various warning system setups, i.e. never warn, always warn, individual components as well as the merged version of the Fog Pilot. It can be observed that all the individual components of the Fog Pilot have a value, and that the merged product yields the best performance, also in terms of cost minimization and relative economic value.

	never	always	CART	SAF	VIS	MERGED
BEST POD	0	1	0.52	0.43	0.76	0.73
BEST POFD	0	1	0.23	0.008	0.22	0.18
COST (L)	1	1.2	0.8254	0.74	0.6229	0.6049
Economic value	0	-20%	17%	26%	38%	40%

Table 2: comparison of the performance indices between the individual components and the merged Fog Pilot products for a cost/Loss ratio of 0.2; the reference values are the absence of action (never protect) and the maximum of the security (always protect).

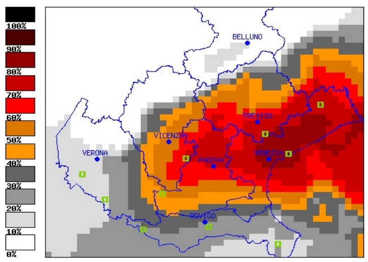

Figure 4: an example of the merged product; map of fog probability on 25 february 2010.

5. CONCLUSIONS

5.1. Overview of present Fog Pilot monitoring system

The Fog Pilot system in its current version, processes in real-time the data retrieved from a dedicated visibilimeter network of 10 stations, from the cloud classification scheme of the Meteosat Nowcasting Satellite Application Facility (SAFNWC), and from meteorological observations preprocessed by CALMET software.

The data of each source are transformed into a probability of fog occurrence based on a visibility threshold (500 m in our case, but in principle it's possible to implement other thresholds), and a weight representing the data quality is assigned. Then the three fields are merged taking the relative quality into account. The issues are hourly real-time maps of probability of reduced visibility under 500 meters at the ground level. The final product shows a POD up to 76% and a POFD lower than 10% (best performance verified by webcam records in Venice).

The results are encouraging for an operational employment of the Fog Pilot as a base for a warning system.

5.2. Operational applications, warnings and forecast

The present and potential applications of such a system are:

- To support the operational activities of the forecasters;
- To provide a base for warning about low visibility along road stretches;
- To provide an information, with known quality, to support the implementation and the improving of automatic forecasts of visibility reduction.

The information provided by the system can be directed to a large set of "private" users (drivers) and "great" users (police and public emergency services, heavy goods transport companies, motorway managements). A good exploitation of such information can have an impact on the huge amount of social costs caused by fog related accidents.

5.3. Futures perspectives

The potential, or already planned, developments are:

- Use of PBL parameters: parameters describing the boundary layer (Mixing height, vertical gradient of temperature), require a further statistical treatment to be related with the ground visibility; [PLANNED]
- Statistics on Cloud Type: a statistical analysis shall be performed on the Cloud Classification Type, in order to assess numerically the probability attributed to the visibility reduction from the Cloud Type field (this step requires at least 1 year of data, august 2010). [PLANNED]
- Extension of the system: more visibility sensors can be installed on the Veneto plain; [PLANNED]
- Involvement of neighbouring regions (Po plain area), in order to complete the monitoring over a climatologically coherent basin; [POTENTIAL]
- Integration of extra observations into the system: automatic or human reports, information from webcams, others. [POTENTIAL]

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