Early Warning System for Meteorological Risk in Lisbon Municipality: Description and Quality Evaluation

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ABSTRACT

The current work describes and evaluates an early warning system for meteorological risk in Lisbon that has been functioning in SMPC since February 2008. The system aims to integrate multiple sources of information and facilitate cross checking observations, forecasts and warnings, allowing for an efficient and timely evaluation of the alert level to issue. Currently, it comprises hourly weather and tide level forecasts and automated warnings for Lisbon city, given by MM5 and WRF models running at IST. Results show MM5 performing better than WRF except for warm weather. The overall skill of the warning system is 40% with some false alarm ratios, mainly for forecasts with more than 3 days in advance. This is a reasonable characteristic for early warning since a potentially problematic situation can be anticipated and checked avoiding unnecessary economic expenditures if the warnings do not persist.

Keywords

Early warning, Lisbon, weather, forecasts, integration.

INTRODUCTION

Weather and climate play an important role in people's well being and long exposure to adverse conditions has negative impacts in daily activities. To cope with unusual and intense meteorological events in an increasing world population, early warning systems are being developed at different scales, allowing the use of the best available technologies (Grasso and Singh 2008; WMO, 2010). The urban environment presents unique challenges due to increased vulnerability (higher population density, impervious surfaces, construction in flood plains, poor isolation in households, etc..., see SOER, 2010) and meteorological events that are influenced by local effects, such as the irregular distribution of building heights, heating footprints, and also by tide level and sea breeze in coastal cities. Being so, an early warning system at the city scale requires tools that can describe this heterogeneity and finer scale (Pullen *et al*., 2008; Trusilova *et al.*, 2008). Urban early warning systems are being developed for many cities all over the world (e.g. Koskinen *et al*., 2010; Sharif *et al*., 2006; and chapter 4 of WMO, 2010) with successful state of the art examples given by the Olympic Games (Mailhot *et al.*, 2010; Wilson *et al.*, 2010; and the recent implementation of a "Smart City" system in Rio de Janeiro for the 2016 Olympics, as reported by The Economist magazine in 2011-01-03).

According to the Civil Protection Department of Lisbon Municipality (Serviço Municipal de Protecção Civil, hereafter SMPC), meteorological situations with greater impact in Lisbon are: (i) intense precipitation, (ii) strong wind speed and gusts, (iii) temperature extremes, and (iv) strong fluvial and maritime agitation and storm

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surges. Although some of these situations may not be too intense they can cause great damage due to urban specificities. For instance, intense precipitation or persistence of rainy days can cause urban flood events by the abnormal flux of pluvial waters, but this will be more dangerous in the lower parts of the city, near the Tagus Estuary. The vulnerability of these lower areas is very dependent on the tide level at the time of precipitation. Extreme wind speed and gusts affect the functioning of the city mainly in what concerns air transport in Lisbon International Airport, fluvial, due to the proximity of the Tagus Estuary, and road and rail traffic in the bridges across the estuary. Other frequent damages are in urban furniture (awnings, antennas, lamps, scaffolds, etc...) and fall of trees. Also, despite Lisbon's mild climate, there are episodes of cold and heat waves that endanger several layers of the population. Cold waves affect mainly the homeless while heat waves affect mainly the elderly (24% of Lisbon's resident population is over 65, according to 2001 information from the National Statistical Institute), children in their early years, and people with chronic diseases, obesity or bedridden, or simply with deficient air conditioning at home. If coincident with the dry period, heat waves are also precursors of man induced forest fires.

The SMPC is responsible for the management of the city during crisis and exceptional conditions and works in articulation with the National and District Authorities for Civil Protection (respectively, Autoridade National de Protecção Civil, hereafter ANPC, and Comandos Distritais de Operações de Socorro, hereafter CNOS). Due to urban specificities and detailed knowledge of the city circumstances at all times, the SMPC can give a faster and more efficient response in emergency management. To deal with emergencies at all levels - prevention/mitigation and preparedness/awareness (before), rescue/emergency (during) and normality reposition (after) - the SMPC has an operational structure and daily routines that allow constant monitoring of the current and expected meteorological risk:

- Assembly of daily weather information, by email, fax or online consultation of the National Meteorological Service (Instituto de Meteorologia or IM) web site. The available data are: (i) Hourly observed precipitation, wind speed and gusts, and temperature in two IM's meteorological stations in Lisbon (Gago Coutinho and Instituto Geofísico), (ii) Descriptive weather forecasts for Lisbon district, up to 3 days ahead, (iii) 10 day's weather forecasts for Lisbon district with daily values of temperature and precipitation probability, (iv) Daily briefing issued by the ANPC and CDOS, with weather forecasts for Lisbon district, for the current and next 2 days.
- Consultation of daily tide level and peak time in downtown Lisbon, from Hydrographical Institute (HI) web site and from FCUL (Antunes, 2007).
- Conversion of all data to the same tabular format for comparability.
- Evaluation of the risk level, together with the warnings issued by ANPC and CDOS (sent by email).
- Determination of the alert level to issue and activate the necessary plans and services.

Notice that IM issues meteorological *warnings*, which shouldn´t be confused with the *alerts* that can only be issued by civil protection authorities. Alerts are based on meteorological warnings but take into account specific vulnerabilities that may exist.

Although the SMPC has a prompt response to emergency it has some limitations, namely the existence of multiple sources of information and communication channels (email, fax, website consultation) arriving to the SMPC in different formats, incompatible with each other and sometimes not allowing an immediate statistical treatment of data. This diversification of formats doesn't allow cross checking observations, forecasts and corresponding warnings. For instance, the daily forecasts issued by IM (to the current and 2 days ahead) to the ANPC are received in the SMPC by email but in WORD format, which doesn't allow direct treatment of the data. In addition, IM forecasts are only sent by the ANPC in work days, the forecasts available at their web site are descriptive, and thus not quantifiable, and their update frequency is unknown as well as the spatial resolution of Lisbon district. Also, the observed data provided by IM via ftp doesn't cover the entire city (only two stations) and the format doesn't allow directly exporting to a database. Furthermore, IM meteorological warnings are issued at the district level, which is an area comprising a multitude of microclimatic zones.

Being so, the time it takes the SMPC to issue an alert is severely dependent on the time of the reception of the IM meteorological information, telephone clarifications directly with IM for detailed information in Lisbon city, and the manual cross checking of the different meteorological and maritime variables, warnings and briefings, in their multitude of formats. For these reasons, the SMPC in collaboration with Instituto Superior Técnico (IST) has been developing an Integrated Operational System for Meteorological Risk in Lisbon Municipality (OS) in a project funded by POVT-QREN (Operation POVT-03-0335-FCOES-000102). Figure 1 shows the architecture of the system, which aims to integrate the diverse sources of information arriving at the SMPC in a single platform, facilitating cross checking observations, forecasts and warnings. Also, the platform aims to be compatible with the municipality geographical information system (ArcGIS) and include satellite imagery provided to the SMPC by the European project ESA-UHI (2008). The system will also allow building a historical thematic database, with meteorological information as well as geo-referenced emergencies and responses, facilitating the evaluation of the city's current vulnerabilities, the quality of forecasts, the adequacy of meteorological warnings to emergency situations, and the efficiency of the municipal services involved.

Figure 1. Architecture of the Integrated Operational System for Meteorological Risk in Lisbon Municipality (OS).

Currently, the system is comprised of hourly weather and tide level forecasts provided by IST, for Lisbon city. Forecasted variables are precipitation, 2-meter air temperature and relative humidity, and 10-meter wind speed, direction and gust, sea level atmospheric pressure and tide level in Lisbon's downtown. Forecasts are for 3 days ahead, updated 4 times per day (at 00, 06, 12 and 18 h UTC) and for 7 days ahead, updated every 00 h UTC. This information is delivered to SMPC through a restricted web site, with forecasts in tabular format for direct exportation to other databases, and graphical format for a quicker visualization of unusual phenomena. In addition, at every forecast update, warnings are automatically computed with the thresholds provided by IM for Lisbon (described in the next section), posted in the web site and also sent by email. Precipitation warnings are complemented with the hour and level of the next high tide. The OS has been functioning since February 2008 with forecasts given by the MM5 meteorological model in its operational configuration for Portugal (Sousa, 2002). The system has proven to be reliable, particularly to complement the aggregated information provided by IM. Verification studies have been made for several locations, revealing approximately 10% root mean square error in wind power, 2 m/s in 10-meter wind speed, 2 ºC in hourly 2-meter temperatures and 10% in 2-meter relative humidity (Trancoso *et al.*, 2007). Since September 2009 a new set of forecasts were included, from WRF model with higher resolution in the city which is being verified against observations and satellite data.

The objective of this paper is to describe and make a pre-evaluation of the OS, namely the warnings issued with the IM's thresholds and assess the quality of each model in forecasting the different weather variables. The evaluation is a part of the OS as a tool that indicates forecasts strengths and limitations at the city level, allowing confidence in the forecasts delivered and thus better decision making. The next section presents a more detailed description of IST forecasts and the warnings computed. The results section presents the main statistical results, followed by discussion and conclusion.

DATA & METHODS

Weather forecasts in OS are hourly precipitation, 2-meter temperature and relative humidity, 10-meter wind speed, direction and gust, and sea level atmospheric pressure for Lisbon municipality. These are complemented with hourly tide level forecasts for Terreiro do Paço (Lisbon central downtown, and outlet of one of the wider drainage basins in Lisbon).

Forecasts are provided by IST which has implemented two numerical weather prediction models for Portugal, operationally producing 3 days weather forecasts, updated four times a day (at 00, 06, 12 and 18 h UTC) and 7 days forecasts updated at 00 h UTC. The models are MM5 (Meteorological Model 5) and WRF (Weather Research and Forecast), both freely provided and supported by the United States National Center for Atmospheric Research (NCAR). MM5 is running operationally at IST since 2001 (http://meteo.ist.utl.pt), producing forecast for Portugal with a nested grid system that downscales atmospheric circulation from 0.5º

(~40 km) to 27 km to 9 km spatial resolution. Since September 2009, WRF was also implemented for Portugal with nested grids of 27 km and 9 km (Portugal) and 3 km in a square grid of approximately 200x200 km centered in Lisbon. Since WRF implementation, both models are forced by the Global Forecast System (GFS - http://www.emc.ncep.noaa.gov/modelinfo/), which has forecasts with 0.5º of spatial resolution (approximately 40 km at our latitudes). WRF model has been implemented with the new land surface scheme NOAH (Chen and Dudhia, 2001), while MM5 continued to use the Five-Layer Soil Model (Dudhia, 1996). Tide information is given by 2 different models: MOHID TidePrev model (Lyard *et al*., 2006) and Antunes (2007) model.

In this paper, forecasts will be assessed in terms of issued warnings, for hourly and 6 hour accumulated precipitation and hourly temperature and wind speed. Wind gusts will not be assessed as the diagnostic algorithm is still being tested. Thresholds for the different warning levels as given by the IM are shown in Table 1. The color represents the degree of warning, from not dangerous (**green**), potentially dangerous (**yellow**), to dangerous (**orange**) and very dangerous (**red**). In other words, yellow warnings are associated with strong but not unusual weather phenomena, orange to unusual, and red to exceptionally intense phenomena. More information can be found in MeteoAlarm (www.meteoalarm.eu) and in IM's web site (www.meteo.pt).

Variable	Yellow	Orange	Red
6-hour accumulated precipitation (mm)	> 30	> 40	> 60
Hourly precipitation (mm)	> 10	> 20	> 40
Warm weather* - Air temperature (ºC)	> 33	> 37	> 40
Cold weather * - Air temperature (ºC)	< 3	< 0	< -1
Wind speed (km/h)	> 50	> 70	> 90
Wing gust (km/h)	> 70	> 90	> 130

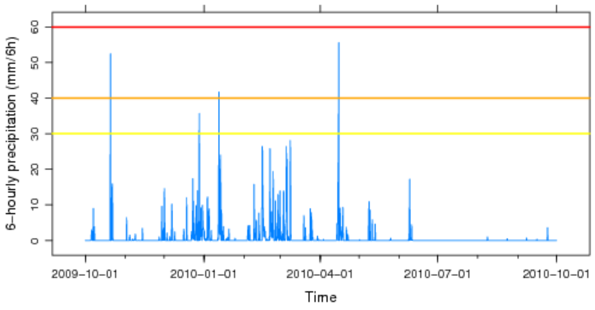
Table 1. Meteorological warning thresholds indicated by IM (*values in each class required to persist for at least 48h)

Forecasts are compared with observations from different meteorological stations, depending on the available data: (i) 6-hour accumulated precipitation was compared with a station located in the center of Lisbon (Instituto Geofísico – IGeo), which has data available at http://idl.ul.pt/bd_horaria.htm with 3 hour temporal resolution, (ii) hourly precipitation was compared with a certified udometric station from the National Water Institute – São Julião do Tojal (SJT), located in Sacavém, just outside Lisbon, which has hourly data available at http://snirh.pt, (iii) 2-meter temperature and 10-meter wind speed were compared with the Lisbon airport METAR which has hourly data but without precipitation information. Comparisons were performed for both models (MM5 and WRF) during the hydrological year 2009/2010, for all forecasts, and for lead times of 6 to 180 h (7.5 days) ahead, using categorical performance scores (Jolliffe and Stephenson, 2003).

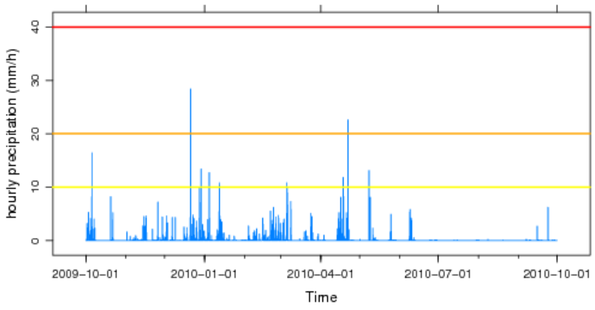
RESULTS

In this section, observed events are first analyzed to give an idea of their distribution and intensity, which is important to proper interpret the categorical performance scores that follow. The next subsections present contingency tables for each variable, with main categorical scores being described along the text but summarized at the end in Figure 4 and Table 7 for comparability.

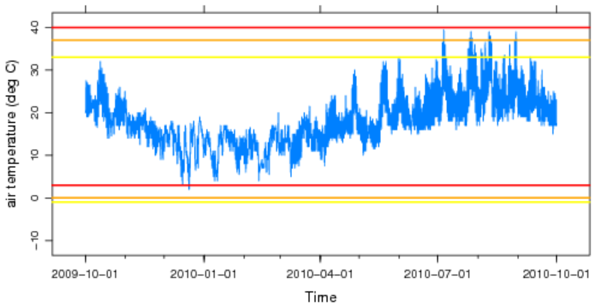
Figure 2 shows the temporal evolution of the analyzed variables with respective threshold levels. It can be seen that "Red" thresholds were not surpassed by any of the variables. "Orange" thresholds were not reached for cold weather and wind speed, but were hit 3 times by 6-hour accumulated precipitation at IGeo , in 2009-10-20 12:00 (52.5 mm), 2010-01-12 12:00 (41.7 mm), and 2010-04-15 06:00 (55.6 mm); twice by hourly precipitation at SJT, in 2009-10-21 05:00 (28.4 mm) and 2010-04-22 02:00 (22.6 mm); and twice by warm weather at LPPT, in 2010-07-05 15:00 (37.0 ºC) and 2010-07-26 15:00 (37.4 ºC). "Yellow" thresholds were surpassed once by 6-hour acc. precipitation at 2009-12-28 06:00 (35.7 mm); 8 times by hourly precipitation; 25 times by warm weather, 3 times by cold weather, in 2009-12-20 06:00 (2.9 ºC) and at 09:00 (2.4º C), and 2010-03-12 00:00 (1.1 ºC), and 3 times by wind speed, in 2009-10-22 12:00 (14.9 m/s), 2010-02-27 15:00 (14.39 m/s) and 2010-05-03 09:00 (15.42 m/s).



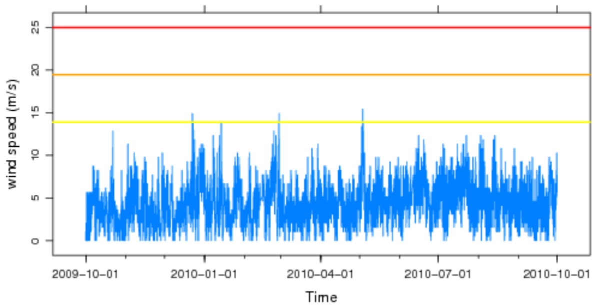
(a) 6-hour accumulated precipitation at IGeo.



(b) hourly precipitation at SJT.



(c) air temperature at LPPT (warm and cold weather)



(d) wind speed at LPPT.

Figure 2: Temporal evolution of the air temperature and wind speed at LPPT.

6-hour accumulated precipitation

Table 2 shows the distribution of events according to the warning thresholds of Table 1, for MM5 and WRF models (MM5/WRF). As expected, the most frequent categories are "No Rain" and "Green" and both were correctly forecasted (high values in the diagonal of the matrix) although a significant number of the "Green" forecasts were "No Rain" events. This is reflected in the frequency BIAS for these 2 categories (see triangles in the BIAS panel in Figure 4) where the "Green" category is clearly over forecasted (BIAS > 1), particularly by WRF model. The "No Rain" has high hit rates (H), over 80%, and low false alarm ratios (FAR), under 10%, for both models, with higher hits in MM5. In the "Green" category, H is slightly lower but still over 80%, while FAR increases to approximately 50%. Looking at the contingency table, it can be seen that this is mainly due to forecasted "Green" events that were "No Rain". On the other hand, the few "Yellow" warnings forecasted revealed to be "No Rain" or "Green" events, leading to very low H and high FAR for this category. Also, in the "Red" category each model issued 1 single warning in the entire year, which also revealed to be false alarms. It is important to stress that the false alarms in the "Orange" and "Red" forecasts, as well 1/3 of the "Yellow" forecasts, were over estimations with lead times higher than 100 hours (~ 4 days).

Table 7 shows the overall performance of the forecasts in terms of skill scores. For this variable, skill scores are relatively good (~50%) and very similar for both models, although MM5 has higher H and lower FAR in the most frequent categories.

	Observ.					
Forecast	**No Rain**	**Green]0.01,30]**	**Yellow]30,40]**	**Orange]40,60]**	**Red]60,Inf[**	**Total**
No Rain	16938/16048	1151/870	0/0	4/3	0/0	18093/16921
Green]0.01,30]	2484/3778	2613/2937	16/17	44/47	0/0	5157/6779
Yellow]30,40]	6/4	7/9	0/0	0/1	0/0	13/14
Orange]40,60]	0/2	0/1	0/0	0/0	0/0	0/3
Red]60,Inf[	0/1	1/0	0/0	0/0	0/0	1/1
Total	19428/19833	3772/3817	16/17	48/51	0/0	23264/23718

Table 2. Contingency table for 6-hour accumulated precipitation: IGeo and MM5/WRF forecasts

Hourly precipitation

The distribution of events is similar to the 6-hourly accumulated precipitation, with high H and low FAR for the most frequent “No Rain” and “Green” categories (Table 3 and Figure 4). Here, the “Green” category is not so over forecasted as in the 6-hour acc. precipitation, but H is of the same order of magnitude as FAR (~50%). This leads to a decrease from 50% to 36% in the skill scores, which can be explained by phase errors, more significant for high temporal discretized data. Nevertheless, they should be investigated. As in the previous section, “Yellow” and “Orange” categories also have low H and high FAR, and again the false alarms correspond to over forecast, typically for lead times higher than 72 h. For instance, MM5 issued one “Orange” warning, for 2010-01-10 06:00 (20.47 mm) with 174 hours advance that was observed as “Green”. However, a peak occurred two days after, between 9 and 10 (~20 mm in 2 hours).

	Observ.					
Forecast	**No Rain**	**Green]0.01,10]**	**Yellow]10,20]**	**Orange]20,40]**	**Red]40,Inf[**	**Total**
No Rain	113246/110891	9952/8807	41/38	12/12	0/0	123251/119748
Green]0.01,10]	10036/14546	7882/9245	88/96	19/18	0/0	18025/23905
Yellow]10,20]	28/33	36/25	1/1	0/0	0/0	65/59
Orange]20,40]	0/0	1/3	0/0	0/0	0/0	1/3
Red]40,Inf[	0/0	0/0	0/0	0/0	0/0	0/0
Total	123310/125470	17871/18080	130/135	31/30	0/0	141342/143715

Table 3. Contingency table for hourly precipitation: SJT and MM5/WRF forecasts.

Air temperature

With so few extreme temperatures for the considered thresholds, the 48h persistence for temperature warning was disregarded in the contingency tables.

As expected, in both warm and cold weather, the most frequent category (“Green”) has almost unitary BIAS, high H and low FAR. All other categories are under forecasted (BIAS < 1) with low H and high FAR (see Table 4 and Table 5 for contingency tables and Figure 4 for performance measures, where TMax corresponds to warm weather and TMin to cold weather).

In the “Yellow” and “Orange” categories of warm weather, there is a clear difference between MM5 and WRF forecasts, with the first performing much worse (lower H, higher FAR) than the latter. From Table 4 it can be seen that MM5 frequency of “Yellow” warnings is much lower than WRF, and that MM5 didn’t forecast a single “Orange” warning. This is evident in the skill scores (Table 7) that are about 4% for MM5 and 40% for WRF.

For cold weather, only “Yellow” warnings were issued and observed, but with lower H and higher FAR than for warm weather. In this case, MM5 forecasts were better than WRF, with skill scores of about 30% for MM5 and 10% for WRF.

	Observ.				
Forecast	**Green]-Inf,30]**	**Yellow]30,33]**	**Orange]33,37]**	**Red]37,Inf[**	**Total**
Green]-Inf,30]	137250/139745	1529/1011	269/99	0/0	139048/140855
Yellow]30,33]	9/189	26/541	51/170	0/0	86/900
Orange]33,37]	0/4	0/17	0/51	0/0	0/72
Red]37,Inf[	0/0	0/0	0/0	0/0	0/0
Total	137259/139938	1555/1569	320/320	0/0	139134/141827

Table 4. Contingency table for warm weather: LPPT and MM5/WRF forecasts.

	Observ.				
Forecast	**Green [3,+Inf[**	**Yellow [3,0[**	**Orange [-1,0[**	**Red]-Inf, -1[**	**Total**
Green [3,+Inf[	138936/141723	75/88	0/0	0/0	139011/141811
Yellow [3,0[	78/5	45/11	0/0	0/0	123/16
Orange [-1,0[	0/0	0/0	0/0	0/0	0/0
Red]-Inf, -1[	0/0	0/0	0/0	0/0	0/0
Total	139014/141728	120/99	0/0	0/0	139134/141827

Table 5. Contingency table for cold weather: LPPT and MM5/WRF forecasts.

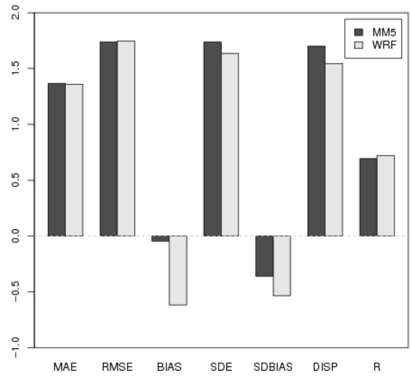
Wind Speed

Table 6 and Figure 4 show that the majority of the forecasts and observations are in the "Green" category, and that no "Orange" or "Red" warnings were forecasted or observed, which shows that the models are forecasting wind speed within the observed values. Nevertheless, the "Yellow" forecasts were almost all "Green" occurrences, and some of the "Green" forecasts were "Yellow" occurrences. A slight advantage can be given to MM5 but the higher H for the "Yellow" category is accompanied by higher FAR. This explains the higher skill scores of MM5 over WRF, but all skill scores for both models are very low (below 10%).

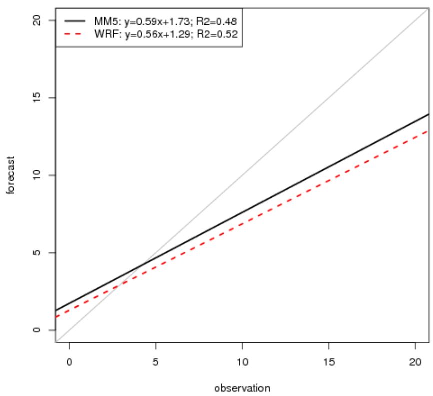
In the overall, MM5 and WRF 10-meter wind forecasts have low mean absolute error (MAE) and root mean squared error (RMSE) (~ 1 m/s) (Figure 3a), which is mainly due to phase errors as seen from the contribution of dispersion error (DISP) to RMSE (Lange, 2005). WRF also has a negative bias which explains the lower skill scores with respect to MM5. Figure 3b shows that, above 10 m/s, both models under forecast the wind speed by 40%.

	Observ.				
Forecast	**Green [0,14[**	**Yellow]14,19]**	**Orange]19,25]**	**Red]25,Inf[**	**Total**
Green]0,14]	135994/138650	45/48	0/0	0/0	136039/138698
Yellow]14,19]	43/7	4/1	0/0	0/0	47/8
Orange]19,25]	0/0	0/0	0/0	0/0	0/0
Red]25,Inf[	0/0	0/0	0/0	0/0	0/0
Total	136037/138657	49/49	0/0	0/0	136086/138706

Table 6. Contingency table for wind speed: LPPT and MM5/WRF forecasts.



(a) error decomposition (Lange, 2005)



(b) linear regression

Figure 3. Summary of wind speed observations and forecasts at LPPT.

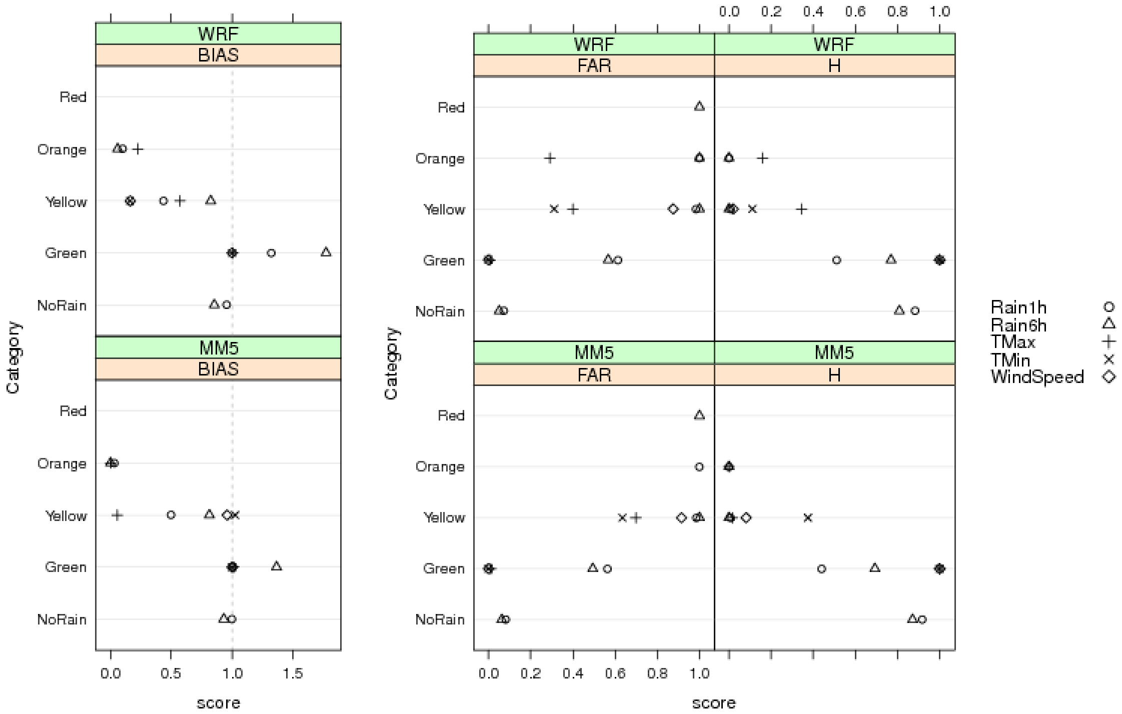


Figure 4. Categorical performance for warning variables: BIAS – Frequency bias (forecasted event over observed event); FAR – False Alarm Ratio (forecasted events that didn't occur); H – Hit Rate (probability of detection, or observed events that were correctly forecasted).

	MM5		WRF	
	HSS	**PSS**	**HSS**	**PSS**
Rain 6h	0.49	0.56	0.44	0.57
Rain 1h	0.36	0.36	0.35	0.39
Warm weather	0.05	0.03	0.47	0.36
Cold weather	0.36	0.37	0.19	0.11
Wind Speed	0.08	0.08	0.03	0.02

Table 7. Skill scores for warning variables: HSS – Heidke Skill Score (improvement of forecast accuracy, measured in proportion of corrects, over random forecasts statistically independent of observations); PSS – Peirce Skill Score (same as HSS but random forecasts are unbiased. Also, indicates how well the forecast discriminated different categories of events, being compromised by the large frequency of correct rejections). Skill scores are 0 for no skill and 1 for perfect forecasts (Jolliffe and Stephenson, 2003).

DISCUSSION

From the results it can be seen that, globally and with IM's thresholds, the OS can improve random warning forecasts by about 40% (skill scores). MM5 model has higher skill in forecasting precipitation, cold weather and wind speed, whereas WRF can significantly improve warm weather warnings. This is mainly due to the different parameterizations and resolutions of both models: WRF has a more detailed land use database than MM5, and uses a different physical parameterization (NOAH) that significantly improves the surface air temperature, but not the other variables.

As expected, the most frequent categories ("No Rain" and "Green") have high H and low FAR for all variables. The "Yellow" category has low H and high FAR for both models, except for cold weather in MM5 and warm weather in WRF, which have higher H and lower FAR. The "Orange" and "Red" categories have practically no hit rates, all being false alarms, which is explained by their scarcity (just one year of data) and the model phase errors. With time, more data will be available to perform an inter-annual study and properly evaluate the most extreme phenomena.

Phase errors lower the skill of warnings forecast, as can be seen from the difference in scores of 6 hour accumulated and hourly precipitation (using SJT to forecast 6-hour acc. precipitation, the skill scores are about

2% lower than for IGeo but still higher than 1-hour precipitation). The accumulated precipitation aggregates phase errors into 6 hour periods. Phase errors are also significant in temperature and wind speed forecasts as can be seen from the great significance of the dispersion error (DISP) in RMSE (Figure 3). These findings are consistent with previous forecast verification studies (Trancoso *et al.*, 2007) .

Nevertheless, the system can be considered reasonable for early warning, since the false alarms are not severe (mainly in "Yellow" category) and correspond to forecasts with lead times above 3 days, allowing the SMPC to monitor a given weather situation with other tools (observations, satellite, radar, etc…) and be prepared with the necessary anticipation, while avoiding unnecessary economic expenditures if the warnings do not persist with forecast updates.

These aspects together with intrinsic phase errors of the models reinforce the importance of having access to the hourly forecasts, allowing the SMPC to be aware of events that are near the threshold limits and/or in the vicinity of the hour. For instance, severe incidents can occur in high intensity but low duration (under 30 min) precipitation, which would be "diluted" in the hourly and 6-hourly accumulated precipitation. One example of severe incidents in precipitation events below the "Yellow" threshold is the first rain event of the hydrological year, which, apart from the intensity or duration, cause more incidents than the following, due to road traffic sliding and floods by blocked gutters.

CONCLUSIONS

The current work describes and evaluates the skill of forecasts and warnings given by the OS, an early warning system for meteorological risk, which the SMPC is developing in collaboration with IST. This system arose from the need of the SMPC to integrate diverse sources of information arriving in multiple formats in a single platform, to facilitate cross checking observations, forecasts and warnings. Also, the platform aims to be compatible with the municipality geographical information system and include satellite imagery provided to the SMPC by the European project ESA-UHI (2008). This integration will allow the compilation of historical information, and also the evaluation of quality of forecasts, the adequacy of meteorological warnings to emergency situations, and the efficiency of the municipal services involved.

Regarding weather information, the OS allows the SMPC to have hourly forecasts, provided by IST, for the Lisbon municipality, as opposed to district level forecasts issued by IM, ANPC and CDOS, as well as automatically generated warnings for specific thresholds. Precipitation warnings are added with the hour and level of the next high tide. Forecasts are updated frequently during the day, and two models with different weakness and strengths are being used. All this information can be automatically accessed through a restricted web site where forecasts can be easily exported to any database.

In a pre-evaluation of the system, IST forecasts and warnings were compared with available observations. Results show MM5 performing better for precipitation, cold weather and wind forecasts, and WRF better for warm weather. This is mainly due to different parameterizations and resolutions of both models and a sensitivity study should be made for further improvements. The overall skill of the warning system is 40%, with the "Orange" and "Red" categories being rare. An inter-annual study should be made to properly evaluate the most unusual phenomena. In the "Yellow" category, the system has hit rates of the same order of false alarm ratios.

Nevertheless, the system can be considered reasonable for early warning, since the false alarms are not severe (mainly in "Yellow" category) and correspond to forecasts with lead times above 3 days, allowing the SMPC to monitor a given weather situation with other tools (observations, satellite, radar, etc…) and a potential problematic situation can be anticipated and checked, while avoiding unnecessary economic expenditures if the warnings do not persist with forecast updates.

This aspect, together with the intrinsic phase errors of the model, reinforces the importance of having access to the hourly forecasts, allowing the SMPC to be aware of events that are near the threshold limits and/or in the vicinity of the hour.

To further evaluate the warning system, forecasted warnings should be compared with the frequency of incidents in Lisbon municipality, assessing the adaptability of the thresholds to the forecasts. These data were not available at the time of writing, but they will be integrated into the OS allowing for an efficient evaluation of the emergency preparedness and response.

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