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RESEARCH NOTE

Verification of a Synthesized Method for the Calculation of Low-Level Climatological Wind Fields Using a Mesoscale Boundary-Layer Model

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Abstract Low-level climatological wind fields over the La Plata River region of South America are synthesized with a dry, hydrostatic mesoscale boundary-layer numerical model. The model is forced at the upper boundary with the 1200 UTC local radiosonde observations and at the lower boundary with a land-river differential heating function defined from the daily meteorological observations of the region. The climatological wind field is defined as the mean value of a series of individual daily forecasts, employing two methods. The simplified method considers a 192-member ensemble (16 wind directions and 12 wind-speed classes at the upper boundary). Each member has a probability of occurrence that is determined from the 1959–1984 observations; the daily method uses a total of 3,248 days with available data during the same period. In both methods each realization is a daily forecast from which the mean wind distributions at 0300, 0900, 1500 and 2100 local standard time are calculated and compared to the observations of five meteorological stations in the region. The validation of the climatological wind fields for both methods is evaluated by means of the root-mean-square error of the wind-direction frequency distribution and mean wind speed by wind sector. The results obtained with the two methods are similar, and the errors in wind speed are always smaller than those in wind direction. The combined errors of wind direction and wind speed show that the ensemble method is outperformed by the daily method, on average by meteorological station in only one out of five of them, and on average by the time of the day in only one out of 4 h. The conclusion of the study is that the ensemble method is an appropriate methodology for determining high resolution, low-level climatological wind fields, with the boundary-layer model applied to a region with a strong diurnal cycle of surface thermal contrast. The proposed methodology is of particular utility for synthesizing wind fields over

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regions with limited meteorological observations, since the 192-member matrix can be easily defined with few observing points, as well as in the case of relatively incomplete records.

Keywords Coastal regions · Low-level wind · Synthetic climatological fields

1 Introduction

The La Plata River of South America is an extended water surface 300 km long and between 40 and 200 km wide that creates a considerable surface temperature contrast with the adjacent land surface that establishes a well-defined sea–land breeze circulation. The low-level wind patterns display significant changes of the predominant wind directions across the region throughout the day. For example Fig. 1 shows the observed 1959–1984 mean winds at five meteorological stations in the region, and at four different times of the day. In the afternoon (Fig. 1a) the meteorological stations over land show the north-east and east wind sectors as the dominant ones, while those over the river present as dominant sectors the east, south-east and south wind directions. The wind directions at the land stations at night (Fig. 1b) show predominant north and north-east winds, while the stations over the river show a significant change to north and north-east wind sectors.

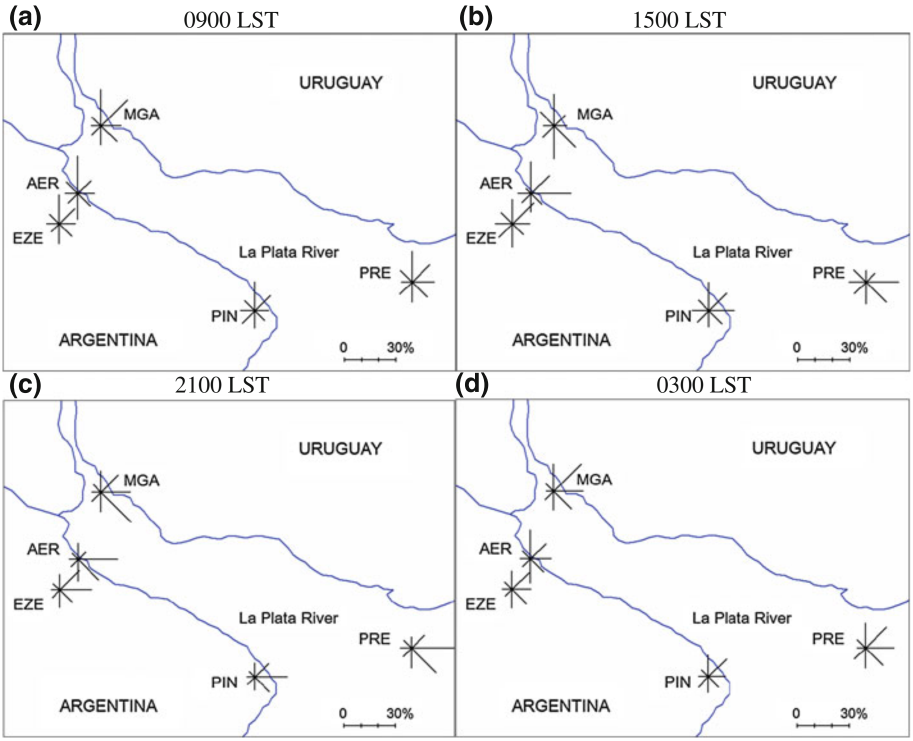

Fig. 1 Mean wind direction frequencies, as a percentage, observed during the period 1959–1984 at four local standard times: **a** 0900, **b** 1500, **c** 2100, and **d** 0300 LST; at weather stations Ezeiza (EZE), Aeroparque (AER), Martín García (MGA), Punta Indio (PIN), and Pontón Recalada (PRE)

Numerical mesoscale models have been traditionally employed in studying sea–land breeze circulation; for example Case et al. (2004) used the Regional Atmospheric Modeling System (RAMS) coupled to the Eta model, Colby (2004) used the MM5 model, and Zhang et al. (2005) used the NCEP mesoscale spectral model, among others. Berri et al. (2010) propose a method for representing the low-level climatological wind fields over coastal regions, which calculates the wind field as the mean value of a reduced number of daily forecasts using a mesoscale boundary-layer model (BLM). Each forecast, or ensemble member, represents a subset of atmospheric conditions with an associated probability of occurrence that is calculated from the observations of the historical database. The above-mentioned study conducted during the period of 1959–1984 revealed an overall good agreement between the observed and the modelled surface wind climatological fields over the La Plata River region.

Normally, the climatological mean value of any meteorological variable is calculated by averaging all available observations. In the case of a model climatology the same concept applies, so that the climatological mean value should be the result of averaging a long series of individual realizations. The question that motivates the present study is: how good is the "ensemble method" for calculating the low-level climatological wind field in comparison with a conventional method based on individual daily forecasts? In order to answer this question, the climatological wind field is calculated in two different ways and the results are compared with the observations. For this purpose, the same model version and dataset period are employed. In one case, namely the "ensemble method", the climatological wind field is calculated as proposed by Berri et al. (2010), as the average of 192 members and their associated probabilities. In the other case, namely the "daily method", the climatological wind field is calculated as the average of 3,248 days with available data during the same period 1959–1984. The resulting wind frequency distributions, as well as the observed distributions, are calculated in a similar manner.

The objective of our study is to evaluate the veracity of the ensemble method to synthesizing low-level climatological wind fields, based on a reduced number of realizations, in comparison with the conventional method that employs a long series of individual realizations. Section 2 briefly describes the BLM formulation and boundary conditions, Sect. 3 presents the methodology for the calculation of the climatological wind fields, and the validation methods are described in Sect. 4. Finally, Sect. 5 discusses the results and presents conclusions.

2 Model Formulation and Boundary Conditions

The BLM has been specifically developed for simulating the low-level circulation over coastal regions. The model is based on a dry, hydrostatic boundary layer and includes the basic conservation equations of momentum, mass and heat, with a first-order turbulence closure scheme (see Berri et al. (2010) for the details). The model domain for the experiments is the region depicted in Fig. 1, which consists of 30 points in the x direction (390 km) and 20 points in the y direction (315 km). The horizontal resolution is 0.15°, which corresponds to an average of 15 km. The vertical domain has 12 levels between the surface and the material top at 2,000 m, distributed according to a log-linear spacing. The boundary conditions at the top of the model are taken from the 0900 LST (local standard time) Ezeiza radiosonde observations (EZE in Fig. 1), whereas the lower boundary condition is defined at every timestep, as described below. At the lateral boundaries, all variables are allowed to change in order to provide a zero gradient across the boundaries at each timestep, except the pressure, since its gradient provides the geostrophic wind.

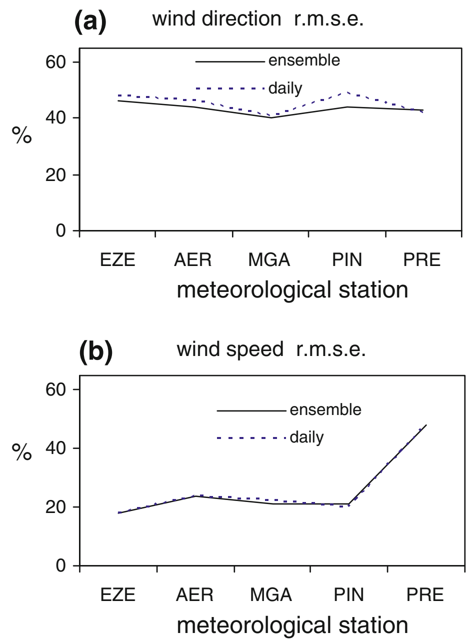

Fig. 2 Ensemble method and daily method r.m.s.e., as a percentage, at the meteorological stations of Ezeiza (EZE), Aeroparque (AER), Martín García (MGA), Punta Indio (PIN) and Pontón Recalada (PRE), averaged during the period 1959–1984. Panel **a** corresponds to wind direction and panel **b** corresponds to wind speed

The lower boundary condition consists of a surface heating function as follows: $T(x, y, t) = T_o + F_1(t)F_2(x, y)$, where T_o is the daily mean temperature, $F_1(t)$ defines the daily cycle of the river–land temperature difference, and $F_2(x, y)$ defines the river–land temperature difference as a function of the distance between every (x, y) point and the coast. Except near the coasts, the horizontal air temperature gradients over the land and over the river are much smaller than the river–land air temperature gradient (see Berri et al. (2010) for the details). Thus, the main forcing that drives the model at the surface is the daily variation of the horizontal air-temperature difference across the coasts. Two meteorological stations are chosen for determining this forcing, one on land, Ezeiza (EZE), and the other in the river, Pontón Recalada (PRE in Fig. 2). The temperature difference $F_1(t) = T_{EZE}(t) - T_{PRE}(t)$ is interpolated by means of a harmonic analysis from the four daily observations at 0300, 0900, 1500 and 2100 LST; it is positive during most part of the day and negative at night. The land–river temperature difference is defined as follows: $F_2(x, y) = \{1+\tanh[s(x, y)/B]\}2$, where $s(x, y)$ is the minimum distance from every grid point to the coast (positive over the land and negative over the river). The hyperbolic tangent distributes the land–river temperature difference symmetrically with respect to the coasts. In the present study the parameter B (unit of length) is set equal to 1,000 m, which provides 75% (90%) of the temperature change over a distance of $2B(3B)$ across the coasts. Over the river and away from the coast, the surface temperature $T(x, y, t) = T_o$ remains constant, since $F_2(x, y) = 0$. Over land and away from the coast the surface temperature develops a full daily cycle given by $T(x, y, t) = T_o + F_1(t)$, since $F_2(x, y) = 1$.

3 Low-Level Climatological Wind Field

The low-level climatological wind field is defined as the mean value of a series of individual 18-h BLM forecasts by applying two different methods, i.e. the ensemble method and the daily method. The ensemble method considers a set of 192 members in which each one participates with a given probability of occurrence calculated from the observations. The daily method, instead, simply averages the whole set of daily forecasts. Both methods use the same set of observations during the study period, as well as the same upper and lower BLM boundary conditions, so that the difference is in the post-processing of the forecast output. The dataset corresponds to 1959–1984, the only extended period with complete observations available in a suitable manner for the study. The model results are validated at 0300, 0900, 1500 and 2100 LST, which are the times of the day when the observations are available in the historical database. Since the model is initialized at 0900 LST, each forecast runs for 18 h until 0300 LST of the following day, which is the last time of validation.

The ensemble method uses 192 members, each one characterized by a wind direction and a wind speed at the top of the model. The 192 members correspond to 16 wind direction classes (N, NNE, NE, … , NNW), and 12 wind speed classes with the following upper limits: 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14 $\mathrm{m\,s^{-1}}$, with the last class representing wind speeds greater than 14 $\mathrm{m\,s^{-1}}$. Each ensemble member has a probability of occurrence that is determined from the 0900 LST Ezeiza radiosonde data of the period 1959–1984. The $F_1(t)$ and T_o values of the surface heating forcing are calculated from the 0300, 0900, 1500 and 2100 LST averaged temperatures for all days in which the Ezeiza radiosonde observation corresponds to every combination of wind direction and wind speed classes at the top of the model.

The daily method, instead, considers every day with available data and runs a forecast for each of them. The upper and lower boundary conditions are defined from the 0900 LST Ezeiza radiosonde and the surface temperature observations of every day. The period of analysis is the same as the ensemble method, during which a total a 3,248 daily forecast were processed.

4 Validation of the Climatological Wind Field

The validation of the climatological wind field is performed by comparing the observed winds at five surface weather stations in the region (see Fig. 1) with those obtained with the BLM model at the nearest grid point. Each forecast gives the horizontal wind components u, v at 10 m, which are expressed as a wind direction d (degrees from the north), and a wind speed $V = (u^2 + v^2)^{1/2}$ in $\mathrm{m\,s^{-1}}$. The wind direction d defines the wind sector identified as one of the 8-sector wind rose. Calm conditions are defined as those cases when the wind speed is smaller than a given threshold, since the model is unable to predict a zero wind speed, and this value is adjusted for each observing time and meteorological station by running experiments with variable thresholds until the resulting percentage of calm conditions matches observations.

Once the set of model runs is completed, the modelled wind direction frequency distribution f_i (in percent), and mean wind speed per wind sector v_i (in $\mathrm{m\,s^{-1}}$) are calculated (i = 1–9, corresponds to eight wind sectors plus calm). They are compared to the observed wind direction frequency distribution and mean wind speed per wind sector f_{oi} and v_{oi}, respectively (see Berri et al. 2010) for the details). The model errors are calculated as the root-mean-square value of the relative error (r.m.s.e.) in wind direction frequency $\mathrm{Er}(D)$, and in mean wind speed per wind sector $\mathrm{Er}(V)$. Both are weighted by the mean observed wind direction frequency f_{oi}, as follows:

$$\mathrm{Er}(D) = \left[\sum_{i=1}^{9} f_{\mathrm{o}i}(ed_i)^2 \Big/ \sum_{i=1}^{9} f_{\mathrm{o}i}\right]^{1/2}, \tag{1}$$

$$\mathrm{Er}(V) = \left[\sum_{i=1}^{9} f_{\mathrm{o}i}(ev_i)^2 \Big/ \sum_{i=1}^{9} f_{\mathrm{o}i}\right]^{1/2}, \tag{2}$$

where $ed_i = (f_i - f_{\mathrm{o}i})/f_{\mathrm{o}i}$ and $ev_i = (v_i - v_{\mathrm{o}i})/v_{\mathrm{o}i}$ are the relative errors in wind direction and wind speed, respectively. For simplicity, the results of Eqs. 1 and 2 will be referred to as either wind direction or wind speed r.m.s.e. These errors are calculated for each one of the four daily observations at every meteorological station.

5 Discussion and Conclusions

Figure 2 compares the averaged daily r.m.s.e. of the low-level wind climatology obtained with both methods, at the five meteorological stations of the study. Except at station PRE, at the other stations the wind direction r.m.s.e. (panel a) of the daily method (dashed line) is a few percent greater than that of the ensemble method (solid line). In the case of wind speed, panel b shows almost no difference between the two methods. The r.m.s.e. of the two methods, averaged over the five meteorological stations and as a function of the local standard time, is compared in Fig. 3. In the case of wind direction (panel a), the ensemble method (solid line) has a smaller r.m.s.e. in all cases except at 1500 LST. The largest difference in r.m.s.e. between the two methods is at 0900 LST, being smaller that of the ensemble method (solid line). In the case of wind speed (panel b), the ensemble method has smaller r.m.s.e. than the daily method, except at 0900 LST, although the differences are always only a few percent.

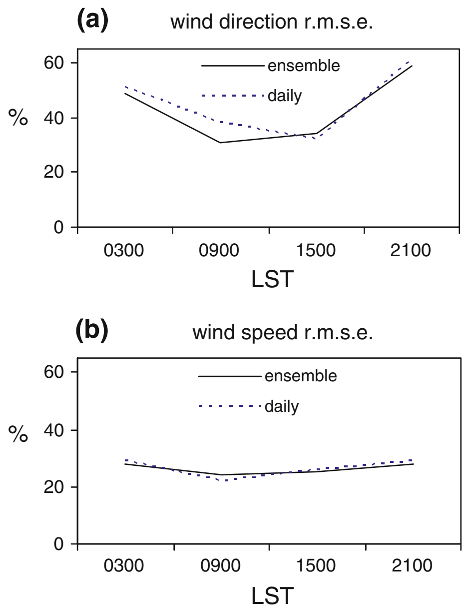

Fig. 3 Ensemble method and daily method r.m.s.e., as a percentage, as a function of the local standard time (LST), averaged over the five meteorological stations during the period 1959–1984. Panel **a** corresponds to wind direction and panel **b** corresponds to wind speed

Fig. 4 Ensemble method and daily method r.m.s.e., as a percentage, as a function of the local standard time (LST), at the five meteorological stations during the period 1959–1984. Wind direction (speed) r.m.s.e. is shown in *black* (*blue*)

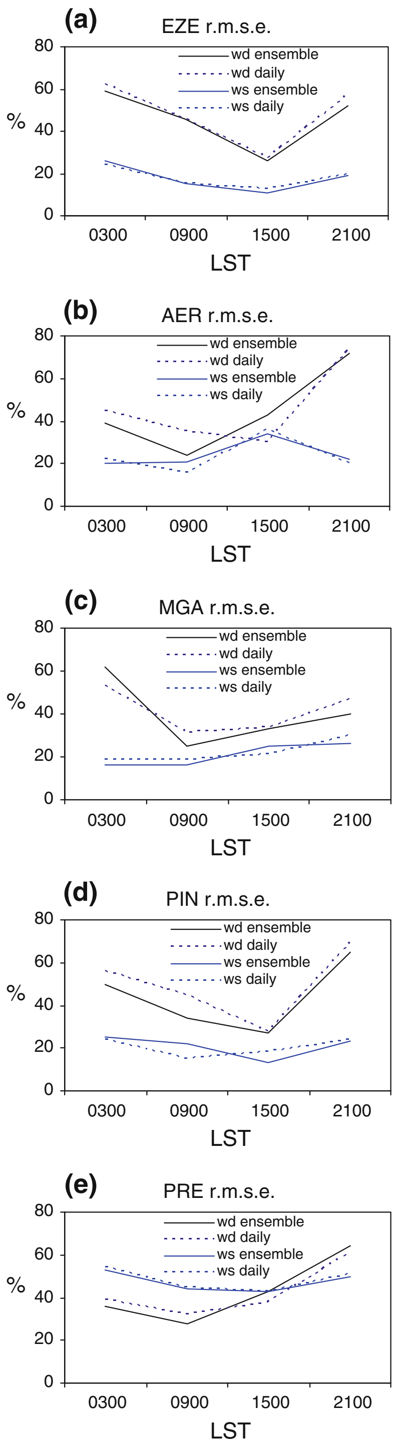

Table 1 Absolute difference daily method minus ensemble method r.m.s.e. (as a percentage) for wind direction (wd) and wind speed (ws), as a function of the local standard time (LST) at the meteorological stations of Ezeiza (EZE), Aeroparque (AER), Martín García (MGA), Punta Indio (PIN) and Pontón Recalada (PRE); averaged during the period 1959–1984

LST	EZE		AER		MGA		PIN		PRE	
	wd	ws	wd	ws	wd	ws	wd	ws	wd	ws
0300	3	−2	6	2	−9	3	6	−1	3	1
0900	0	0	11	−5	6	3	11	−7	4	1
1500	1	2	−13	2	1	−4	1	5	−5	0
2100	5	1	2	−2	7	4	4	1	−3	1

Positive numbers indicate a smaller r.m.s.e. for the ensemble method

The comparison between the r.m.s.e. of both methods is shown in more detail in Fig. 4, by time of day and meteorological station. In the case of wind direction (black line), stations EZE (Fig. 4a) and PIN (Fig. 4b) are the sites where at all times the ensemble method (solid line) has a smaller r.m.s.e. The largest differences in favour of the daily method (dashed line) are obtained for station AER (Fig. 4b) at 1500 LST and station MGA (Fig. 4c) at 0300 LST, i.e. 13 and 9%, respectively. In the case of station PRE (Fig. 4e), the daily method (dashed line) gives a smaller r.m.s.e. at 1500 and 2100 LST.

In the case of wind speed (blue line), station PRE (Fig. 4e) is the only site where at all times the ensemble method (solid line) has a smaller r.m.s.e., although by 1% only. Stations PIN (Fig. 4d) and AER (Fig. 4b) show two times of the day with a smaller r.m.s.e. for the daily method (dashed line), reaching 7% in the case of station PIN at 0900 LST. Finally, stations MGA (Fig. 4c) and EZE (Fig. 4a) presents only one time of the day with a smaller r.m.s.e. for the daily method (dashed line).

A qualitative summary of results is shown in Table 1 that presents the r.m.s.e. difference, daily minus ensemble method. Considering individual boxes, 75% of them have greater or equal than zero values, meaning equal or better results with the ensemble method. When the wind direction and wind speed are considered together, the ensemble method shows a smaller r.m.s.e. in 50% of the cases, while the daily method shows no such cases. Despite the fact that the ensemble method has, in general, a smaller error, in some cases the wind direction r.m.s.e. of the daily method is small enough to overcome a larger r.m.s.e. in wind speed. In these situations the daily method has a smaller combined error, outperforming the ensemble method. The most notable cases are station MGA at 0300 LST and station AER at 1500 LST.

The combined wind direction and wind speed error is largest in the evening (2100 LST). Berri et al. (2010) argued that the maximum error of the ensemble method at 2100 LST could be due to the fact that the transition from unstable daytime conditions to stable night-time conditions takes place around that time of the day. In summer, that time is just after sunset, while in winter it is about 3 h after sunset. Since the ensemble method averages the surface conditions of different days with the same upper boundary condition, there could be an inherent limitation for appropriately resolving the transition from unstable to stable conditions. Therefore, the daily method would offer the possibility of overcoming such a limitation by considering the individuality of each day of the data base. However, the present study indicates that this is not the case since the results of the daily method are not better than those of the ensemble method at 2100 LST.

Therefore, the conclusion of the study is that the ensemble method is an appropriate methodology for determining high resolution, low-level climatological wind fields, with the BLM applied to a region with a strong diurnal cycle of surface thermal contrast. The conclusion is based on the fact that the results provided by the ensemble method are not outperformed by those of the daily method. The proposed methodology is of particular utility for synthesizing wind fields over regions with limited meteorological observations, since the 192-member matrix can be reasonably defined with few observing points, and even in the case of incomplete records.

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References

Berri GJ, Sraibman L, Tanco RA, Bertossa G (2010) Low-level wind field climatology over the La Plata River region obtained with a mesoscale atmospheric boundary layer model forced with local weather observations. J Appl Meteorol 49:1293–1305

Case JL, Manobianco J, Lane JE, Immer CD, Merceret FJ (2004) An objective technique for verifying sea breezes in high-resolution numerical weather prediction models. Weather Forecast 19:690–705

Colby FPJr (2004) Simulation of the New England sea breeze: the effect of grid spacing. Weather Forecast 19:277–285

Zhang Y, Chen Y-L, Schroeder TA, Kodama K (2005) Numerical simulations of sea-breeze circulations over North-west Hawaii. Weather Forecast 20:827–846