Low-level climatological wind fields over the La Plata River region of South America synthesized with a mesoscale boundary-layer model

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Summary

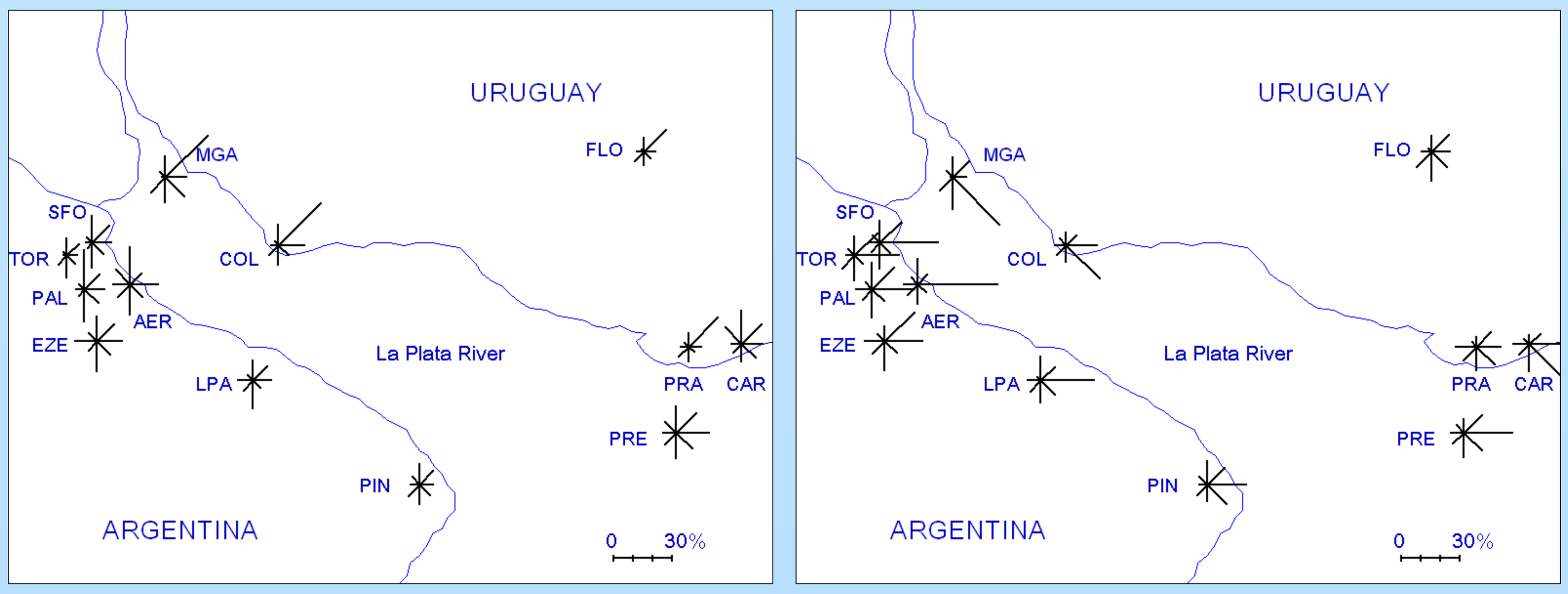
A primitive equation, dry and hydrostatic mesoscale boundary layer model (BLM) is used to simulate the high-resolution low-level wind field climatology over the La Plata River region in South America. The horizontal model domain (350 km x 316 km) has 79x58 points, with a horizontal resolution of 0.05 degrees; and the vertical domain (2 km) has 12 levels.

The model climatology is the ensemble result of a series of daily forecasts obtained by forcing the model with limited local observations. Each ensemble member produces a daily forecast that participates in the definition of the wind climatology with a probability calculated with the local observations. The upper boundary condition is taken from the local radiosonde observation at Ezeiza airport, and the lower boundary condition consists of a surface heating function calculated with the temperature observations of the surface weather stations in the region.

The study conducted during the period 1960-1990 reveals an overall good agreement between the observed and the modeled surface wind climatology at five weather stations of the region. The BLM model represents very well the differences in the wind speed magnitudes and predominant wind direction sectors throughout a region that displays a strong sea-land breeze daily cycle. The average rms value of the model relative error is 31% for wind direction and 23% for wind speed. .

Study region

Observed 1994-2008 mean wind direction frequency



0600 local time (early morning) | 1800 local time (late afternoon)

Model equations

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - \alpha_0\frac{\partial p}{\partial x} + fv + \frac{\partial}{\partial x}\left(K_{mh}\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{mh}\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{mz}\frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - \alpha_0\frac{\partial p}{\partial y} - fu + \frac{\partial}{\partial x}\left(K_{mh}\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{mh}\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{mz}\frac{\partial v}{\partial z}\right)$$

$$\frac{\partial \theta}{\partial t} = -u\frac{\partial \theta}{\partial x} - v\frac{\partial \theta}{\partial y} - w\frac{\partial \theta}{\partial z} + \frac{\partial}{\partial x}\left(K_{\theta h}\frac{\partial \theta}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{\theta h}\frac{\partial \theta}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{\theta z}\frac{\partial \theta}{\partial z}\right)$$

$$\frac{\partial w}{\partial z} = -\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}$$

$$\frac{\partial p_0}{\partial z} = -\frac{g}{\alpha_0} \qquad \frac{\partial p'}{\partial z} = \frac{g}{\alpha_0}\frac{\theta'}{\theta_0}$$

$$p = p_0 + p' \qquad \theta' = \theta - \theta_0$$

General characteristics of the model

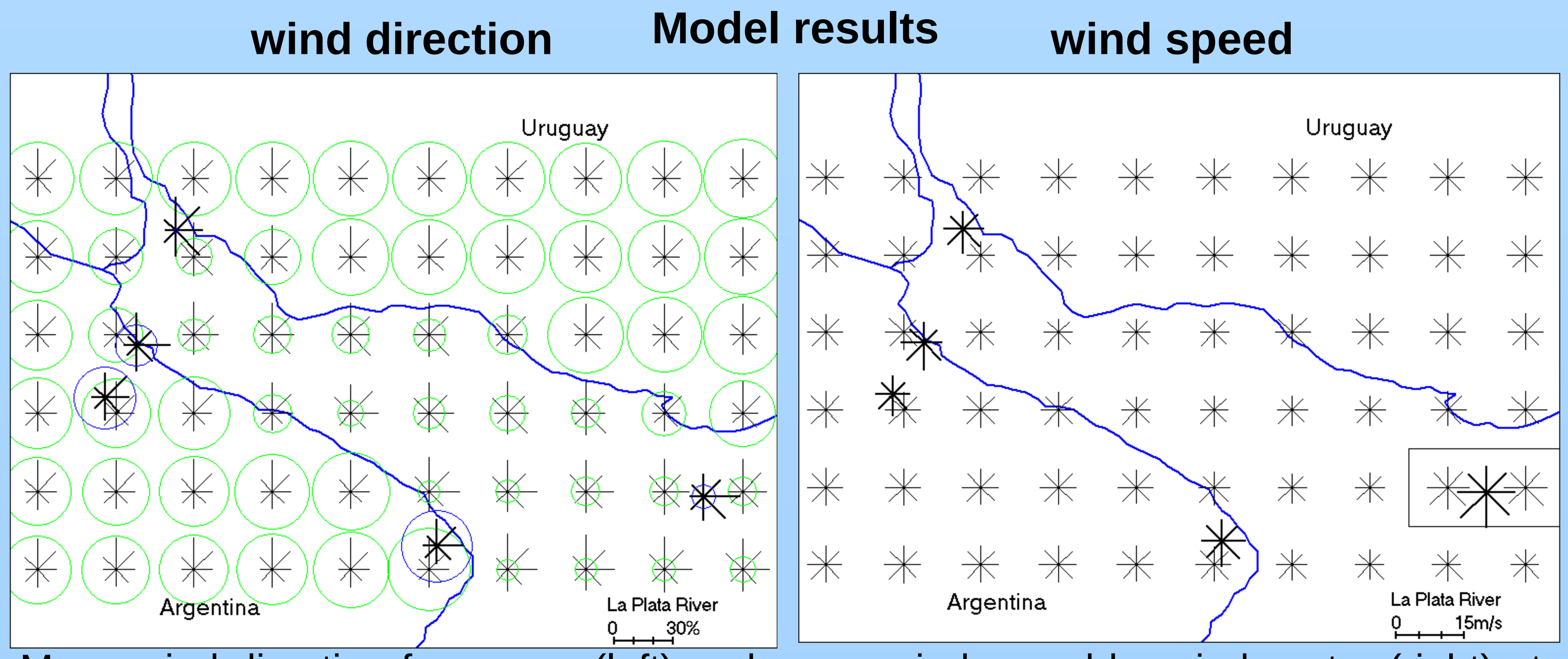
- hydrostatic, incompressible, dry
- horizontal resolution 5 km (79 longitude points, 58 latitude points)
- 12 vertical levels (m): 0.01, 10, 40, 80, 140, 220, 350, 550, 800, 1100, 1500, 2000
- first-order turbulence closure
- numerical method: semi-implicit Crank-Nicholson, dt = 20 sec

Low-level climatological wind fields with the BLM model

- the low-level wind climatology is the result of a 192-member ensemble (16 wind directions and 12 wind speeds at the upper boundary)
- each member has a probability of occurrence *Pij* (16 -*i*- wind direction sectors, 12 -*j*- wind speed classes), which is determined from the 1960-1990 observations
- the upper boundary condition (2 km above the surface), is taken from the 1200 UTC (0900 local time) radiosonde observations
- the lower boundary condition (surface) is a land-river differential heating function defined from the meteorological observations of the region, interpolating 4 daily observations
- each member is a 24-hour forecast, initialized at 0900 local time
- at each grid point, the mean wind direction frequency distribution and mean wind speed by wind sector are calculated by applying the probability matrix *Pij*

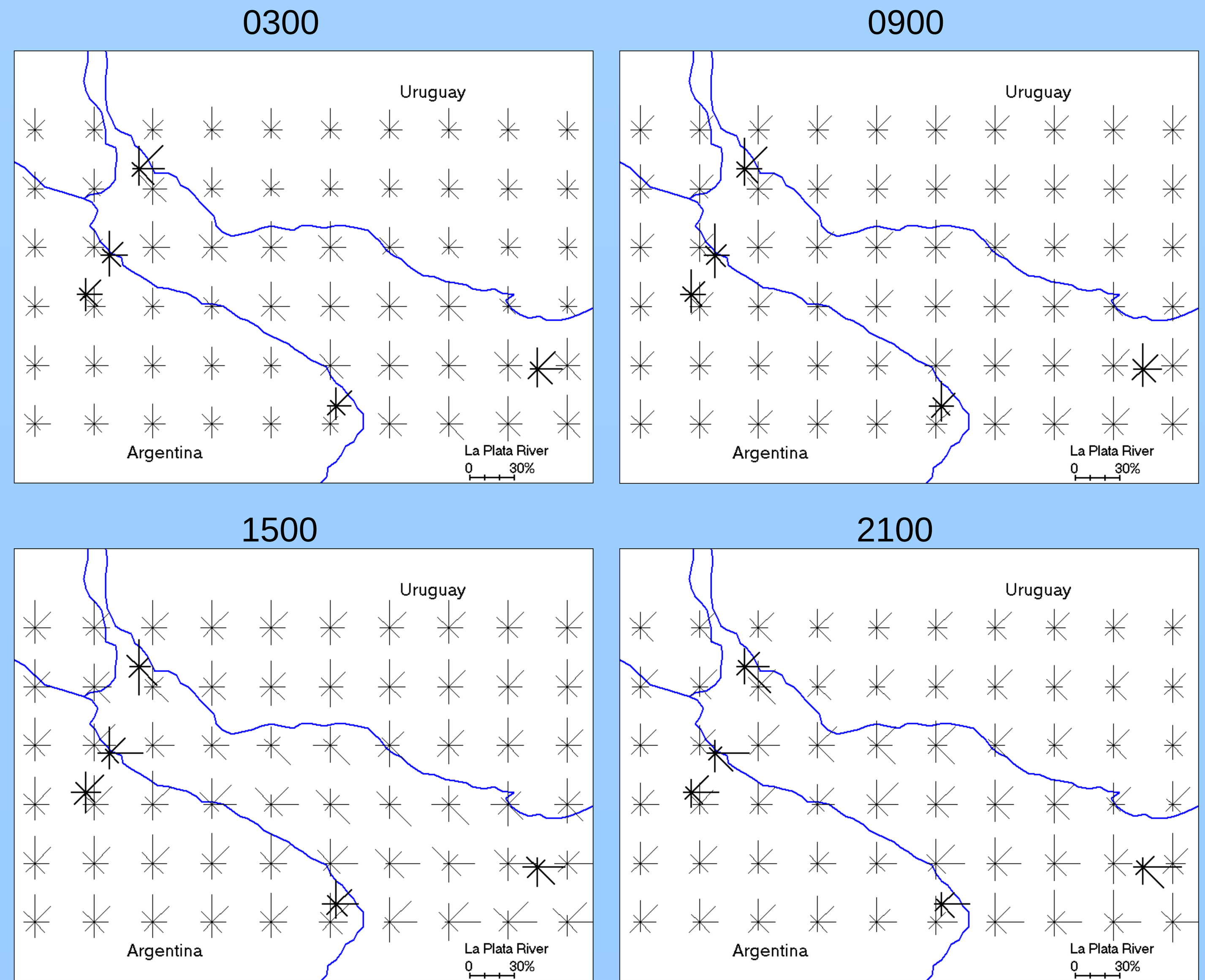
Model results

wind direction | wind speed



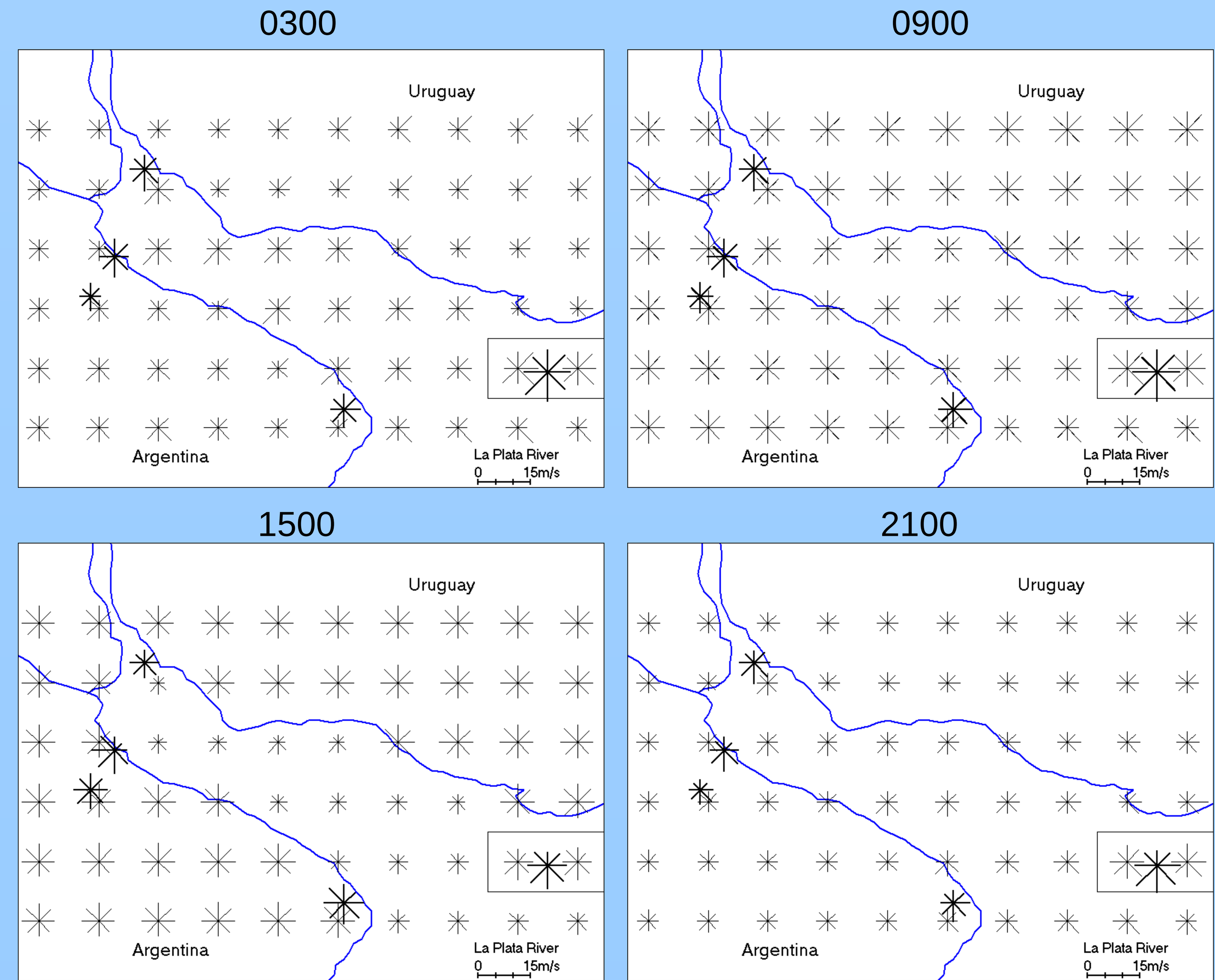
Mean wind direction frequency (left) and mean wind speed by wind sector (right) at 10 m (21 m in the small rectangle coincident with observation) obtained with BLM (thin lines), and observed at five weather stations (thick lines), period 1960-1990. The green circles represent the frequency of calms

Mean wind direction frequency



Mean wind direction frequency at 10 m. obtained with BLM (thin lines), and observed at five weather stations (thick lines), at four local times of the day (period 1960-1990)

Mean wind speed by wind sector



Mean wind speed by wind sector at 10 m (21 m in the small rectangle coincident with observation) obtained with BLM (thin lines), and observed at five weather stations (thick lines), at four local times of the day (period 1960-1990)

Model errors

The model errors are calculated as the root mean square value of the relative error in wind direction frequency *rmsDir*, and mean wind speed per wind sector *rmsVel*. Both are weighted by the mean observed wind direction frequency

$fo_i \quad vo_i$ observed wind direction frequency and mean wind speed by sector

$f_i \quad v_i$ calculated wind direction frequency and mean wind speed by sector

$ed_i = (f_i - fo_i)/fo_i$ relative error in wind direction

$ev_i = (v_i - vo_i)/vo_i$ relative error in wind speed

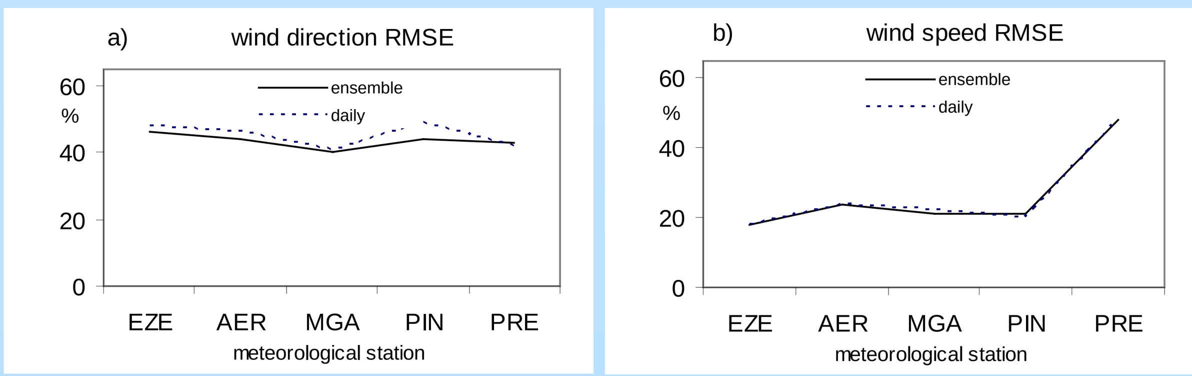
$$rmsDir = \left[\sum_{i=1}^{9} fo_i \, (ed_i)^2 \Big/ \sum_{i=1}^{9} fo_i \right]^{1/2}$$ rms wind direction

$$rmsVel = \left[\sum_{i=1}^{9} fo_i \, (ev_i)^2 \Big/ \sum_{i=1}^{9} fo_i \right]^{1/2}$$ rms wind speed

Comparison of model errors obtained with two different methods

the simplified method calculates the wind climatology as the mean value of the 192-member ensemble

the daily method calculates the wind climatology by simply averaging 3248 daily forecasts during the same 1960-1990 period



Climate variability study with the BLM model

The variability of the climatological low-level wind fields during the period 1960-1990 is studied, using the BLM model and the observations from five weather stations

The observations reveal:

- decrease of the daily amplitude of the land-river surface thermal contrast
- increase of the easterly wind component at the surface
- increase of the easterly wind component in the lower levels of the local radiosonde observations, accompanied by a decrease of the mean wind speeds.

The ensemble method is applied to two subperiods, i.e., 1967-1976 and 1982-1991, in order to calculate wind direction frequency distribution and mean wind speed by sector, with the BLM model

The difference between the climatological wind fields of the two periods is expressed in percentage, and compared to that observed at the five weather stations.

Conclusions

The ensemble method is an appropriate methodology for determining high-resolution, low-level climatological wind fields

This conclusion is based on the fact that the results obtained with the ensemble method are not outperformed by those of the daily method (traditional way of calculating climatology using *all* available information)

The BLM model is particularly useful for calculating wind fields over regions with strong diurnal cycle of surface thermal contrast

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

References

Berri G.J., L. Sraibman, R. Tanco and G. Bertossa, 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*, Journal of Applied Meteorology and Climatology, **49**, 6, 1293-1305.

Berri G.J., J. Galli Nuin, L. Sraibman and G. Bertossa, 2012, *Verification of a synthesized method for the calculation of low-level climatological wind fields using a mesoscale boundary-layer model*, Boundary Layer Meteorology, **142**, 2, 329-337.

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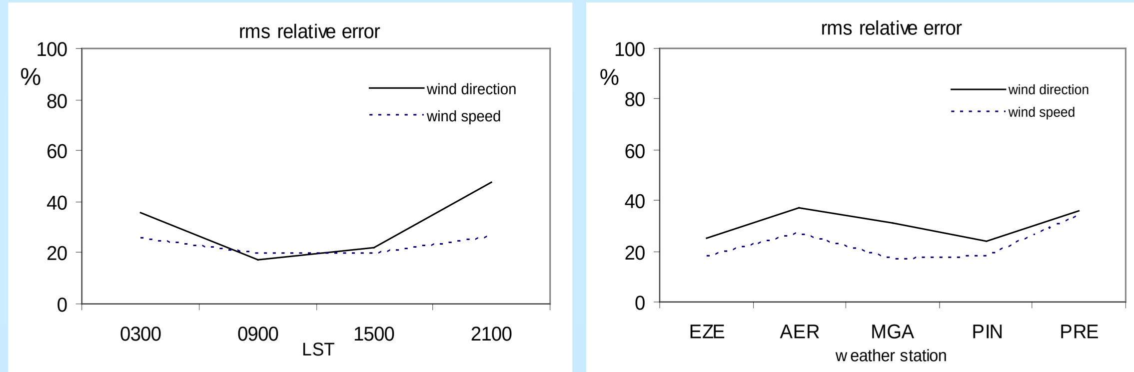
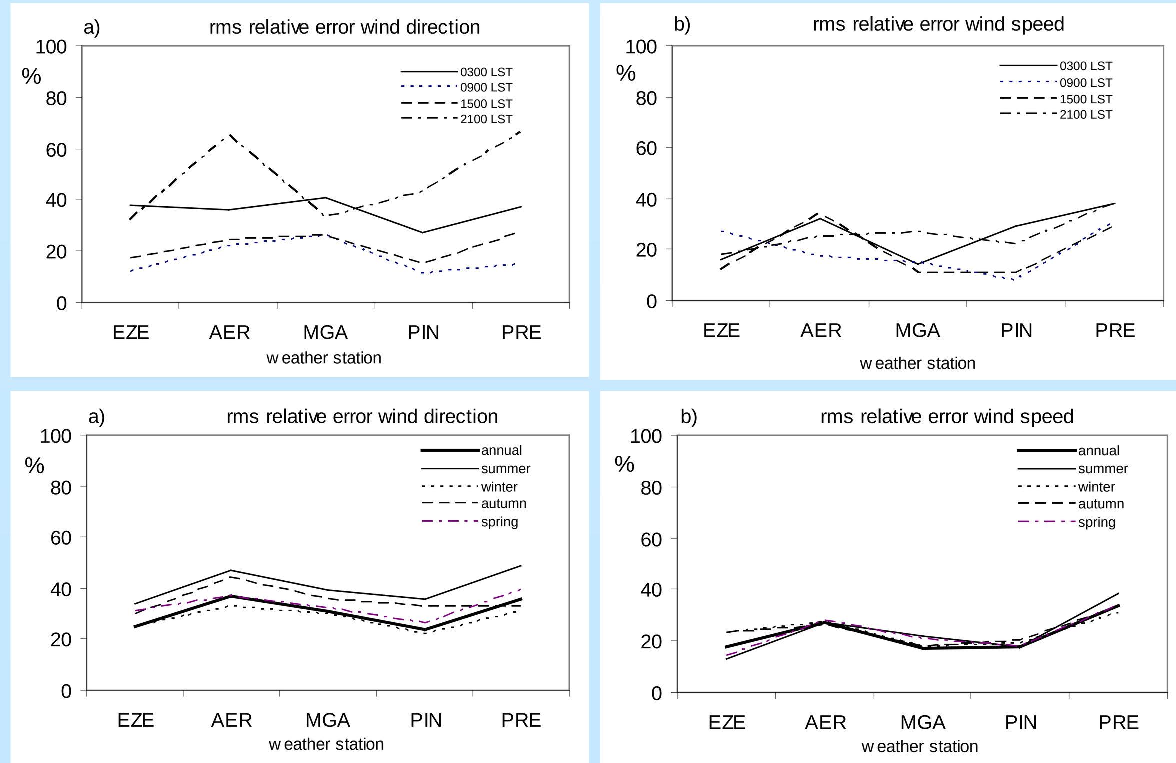
Mean model errors (1960-1990)



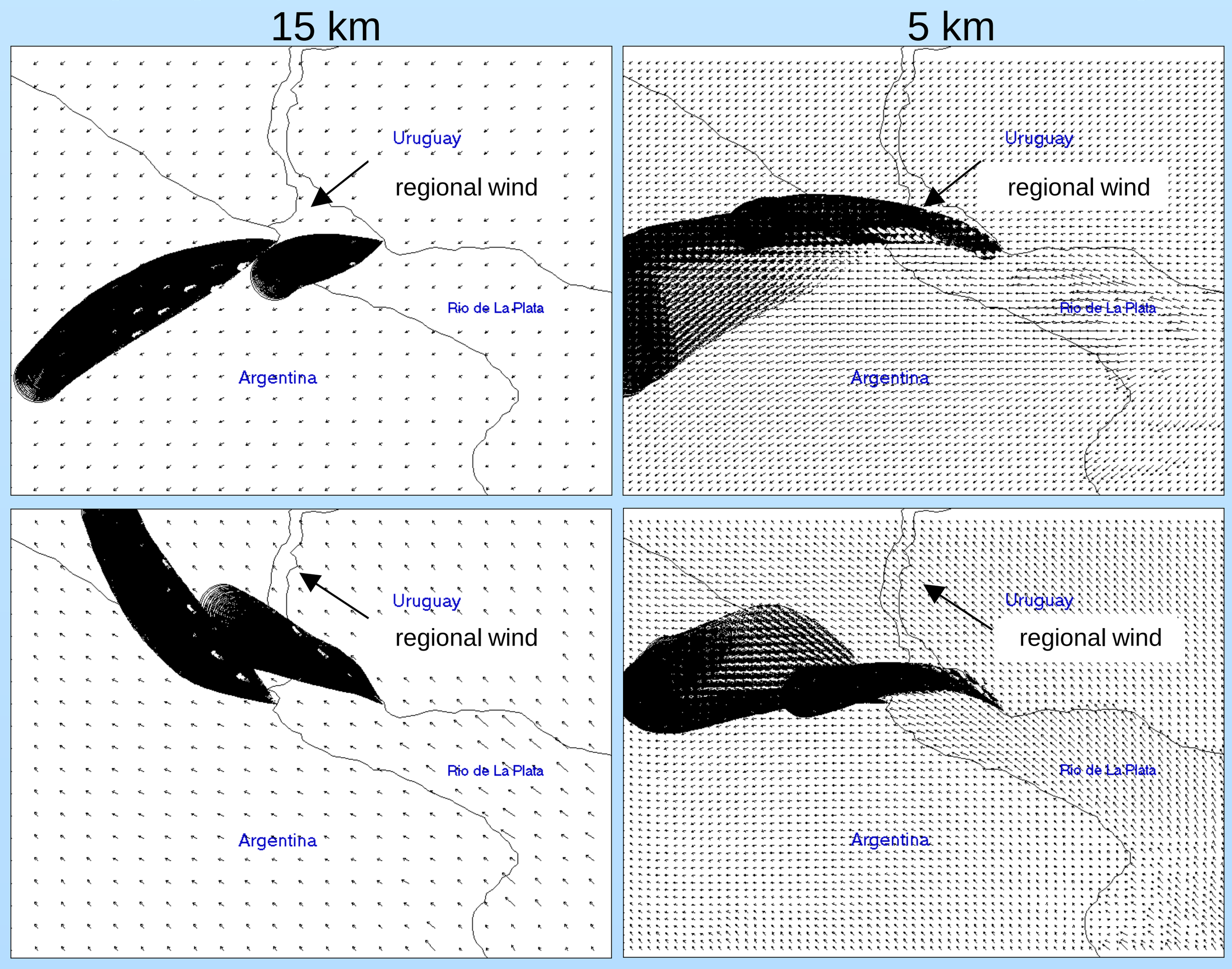
Model errors by season of year and time of the day (1960-1990)



Effect of model resolution

24-hour lagrangian plumes as a function of model resolution and regional wind

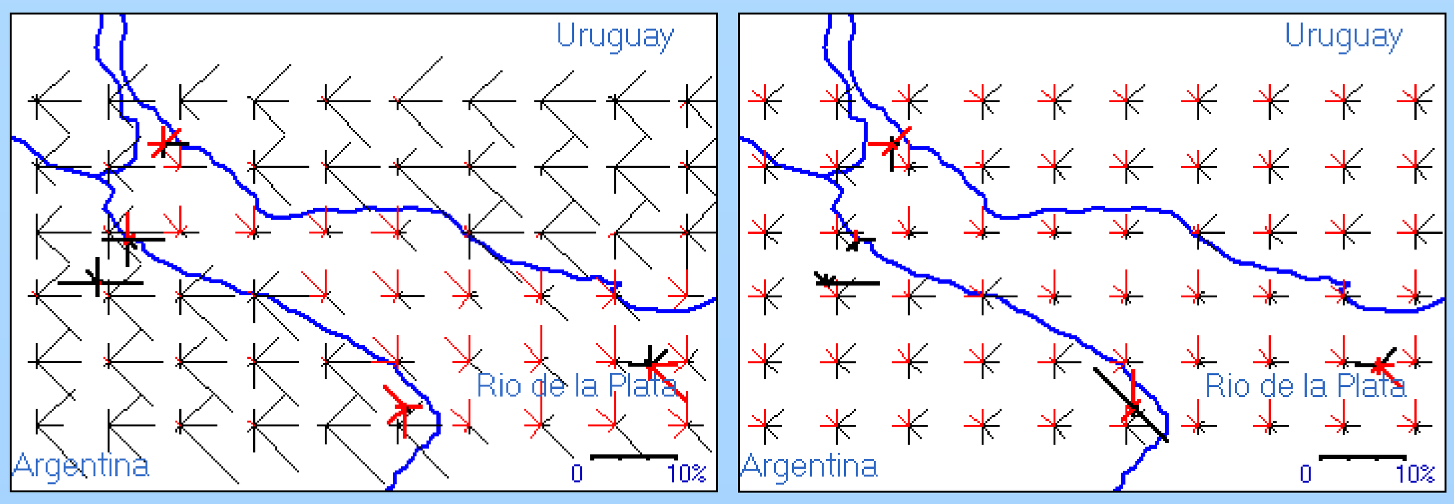
15 km 5 km



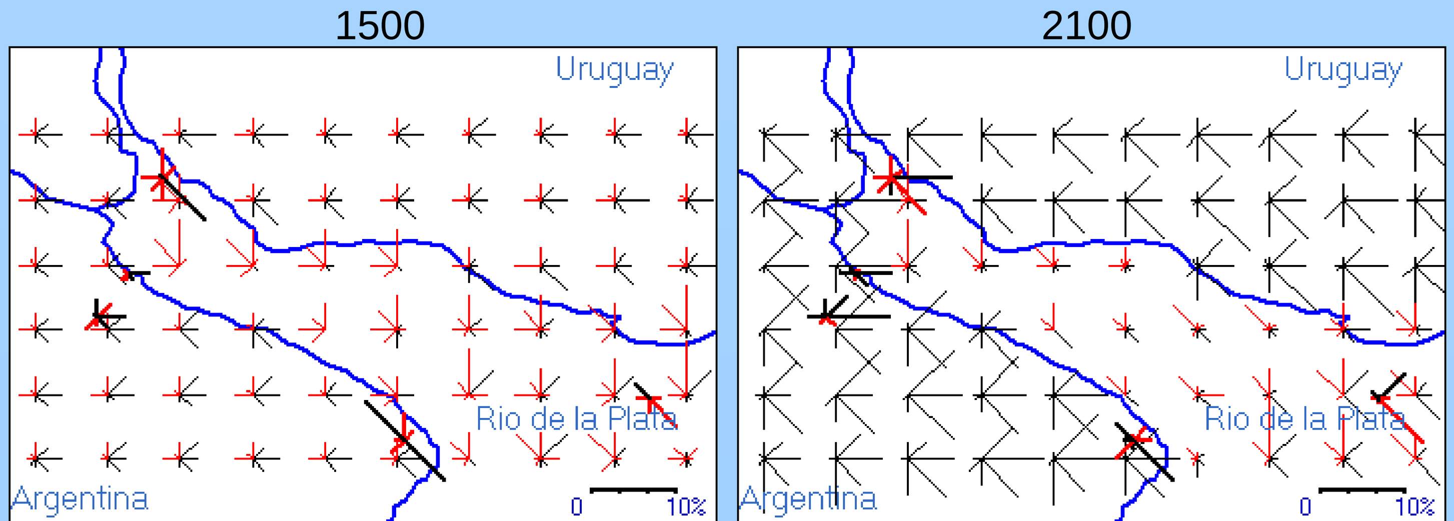
In *lower resolution* plumes travel basically downwind, while in *higher resolution* the area covered by the plumes is strongly conditioned by the sea-land breeze daily cycle

mean wind field changes between (1982-1991) and (1967-1976)

0300 0900



1500 2100



Relative difference (in percentage) between mean wind direction frequency distributions (1982-1991) *minus* (1967-1976), calculated with the BLM and the ensemble method, at four local times of the day. The red (black) lines indicate decrease (increase) in wind direction frequency between the two sub-periods

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