Initializing a boundary layer model with radiosonde data to create climatological low-level wind fields

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Study region in South America

Summary

High-resolution low-level wind fields over the La Plata River region of South America are generated with a boundary layer model (BLM). The dry, hydrostatic and primitive equation model has been especially developed for simulating the atmospheric circulation over coastal regions. The horizontal model domain (354 km x 315 km) has 79x58 points, with a horizontal resolution of 5 km; 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 is 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 Buenos Aires airport (Ezeiza), 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 objective of the study is to evaluate different alternatives for initializing the model with radiosonde data, with the ultimate purpose of optimizing the ensemble mean method for the simulation of low-level climatological wind fields over regions with limited observations. The alternatives are:

i) standard levels
ii) first significant level
iii) level of the temperature inversion base
iv) interpolated levels at different fixed heights.

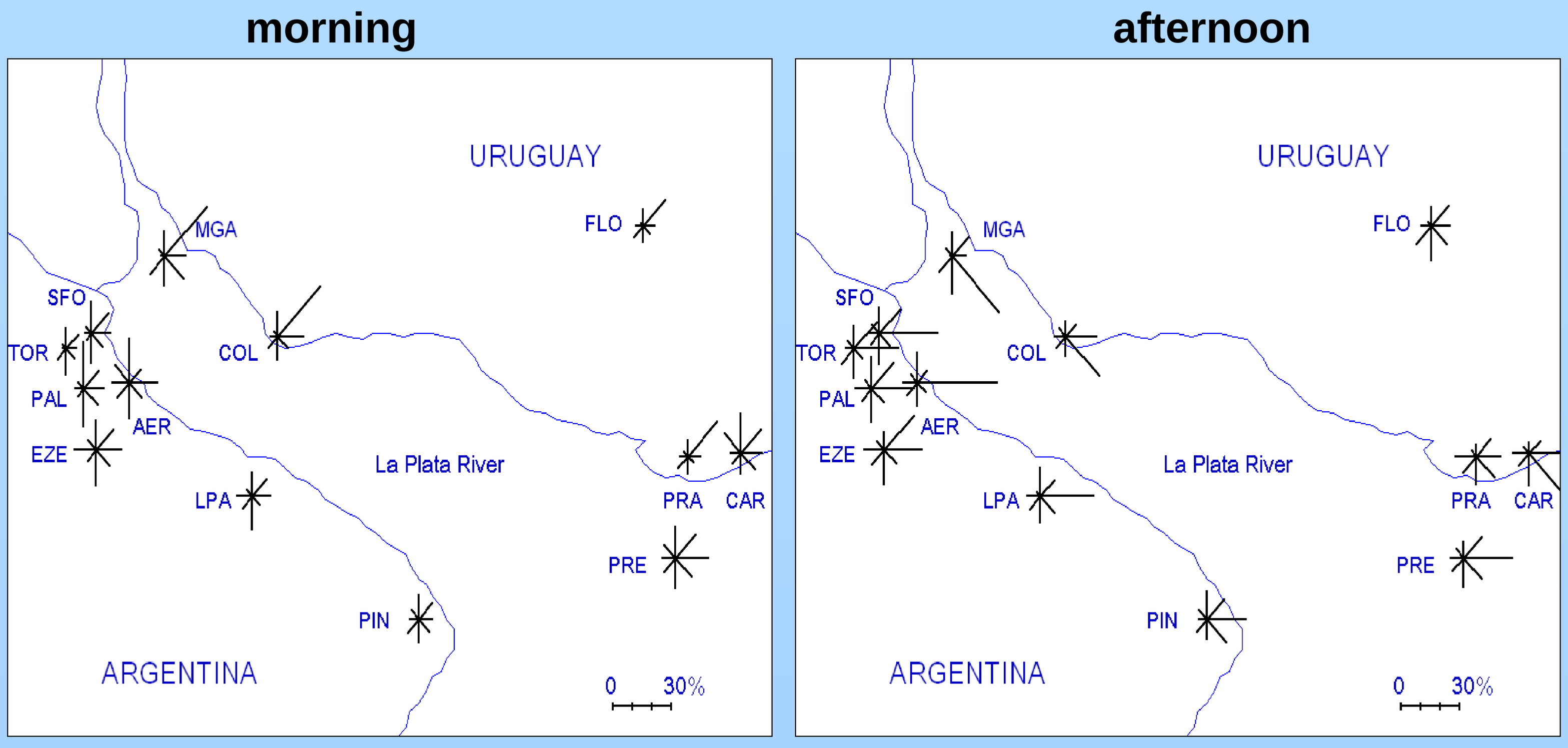
The preliminary conclusion of the study is that the overall best result, considering the different weather stations and times of the day, is obtained when using the 1000 hPa level data for initializing the BLM model

General characteristics of the BLM 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

observed wind direction 1994-2008

morning **afternoon**



strong daily cycle, sea-land breeze type

model equations

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

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

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

$$\frac{\partial w}{\partial z} = -\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \qquad \frac{\partial p_0}{\partial z} = -\frac{g}{\alpha_0} \qquad \frac{\partial p'}{\partial z} = \frac{g}{\alpha_0}\frac{\theta'}{\theta_0} \qquad \theta' = \theta - \theta_0 \qquad p = p_0 + p'$$

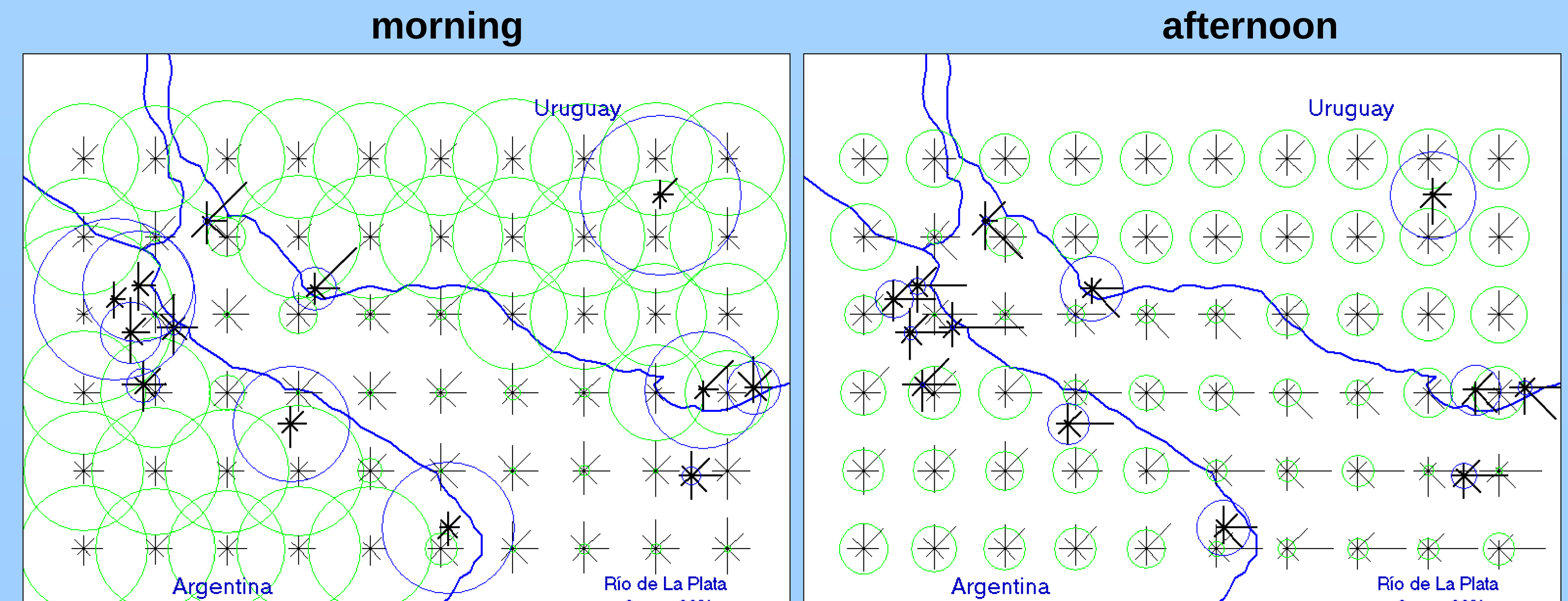
Low-level climatological wind fields with BLM model

Ensemble method

- 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 1994-2008 observations
- the upper boundary condition (2 km above the surface), is taken from the 1200 UTC (0900 local time) local radiosonde observation at Buenos Aires airport (Ezeiza)
- 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 validation 1994-2008

morning **afternoon**



10 m mean wind direction frequency (%), circles represent the frequency of calms, thick lines are observations and thin lines model outputs

Levels used to define BLM upper boundary condition

i) standard levels
- 1000 hPa (STD_{1000})
- 925 hPa (STD_{925})
- 850 hPa (STD_{850})

ii) first significant level
- between 50-200m (SIG_{50-200})
- between 200-400m ($SIG_{200-400}$)

iii) level of the temperature inversion base
- between 50-300m (IVB_{50-300})
- between 300-600m ($IVB_{300-600}$)
- between 600-1000m ($IVB_{600-1000}$)
- between 1000-1500m ($IVB_{1000-1500}$)

iv) interpolated level at fixed heights
- 300m (INT_{300})
- 600m (INT_{600})
- 900m (INT_{900})
- 1200m (INT_{1200})
- 1500m (INT_{1500})

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

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

$f_i \;\; v_i$ 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

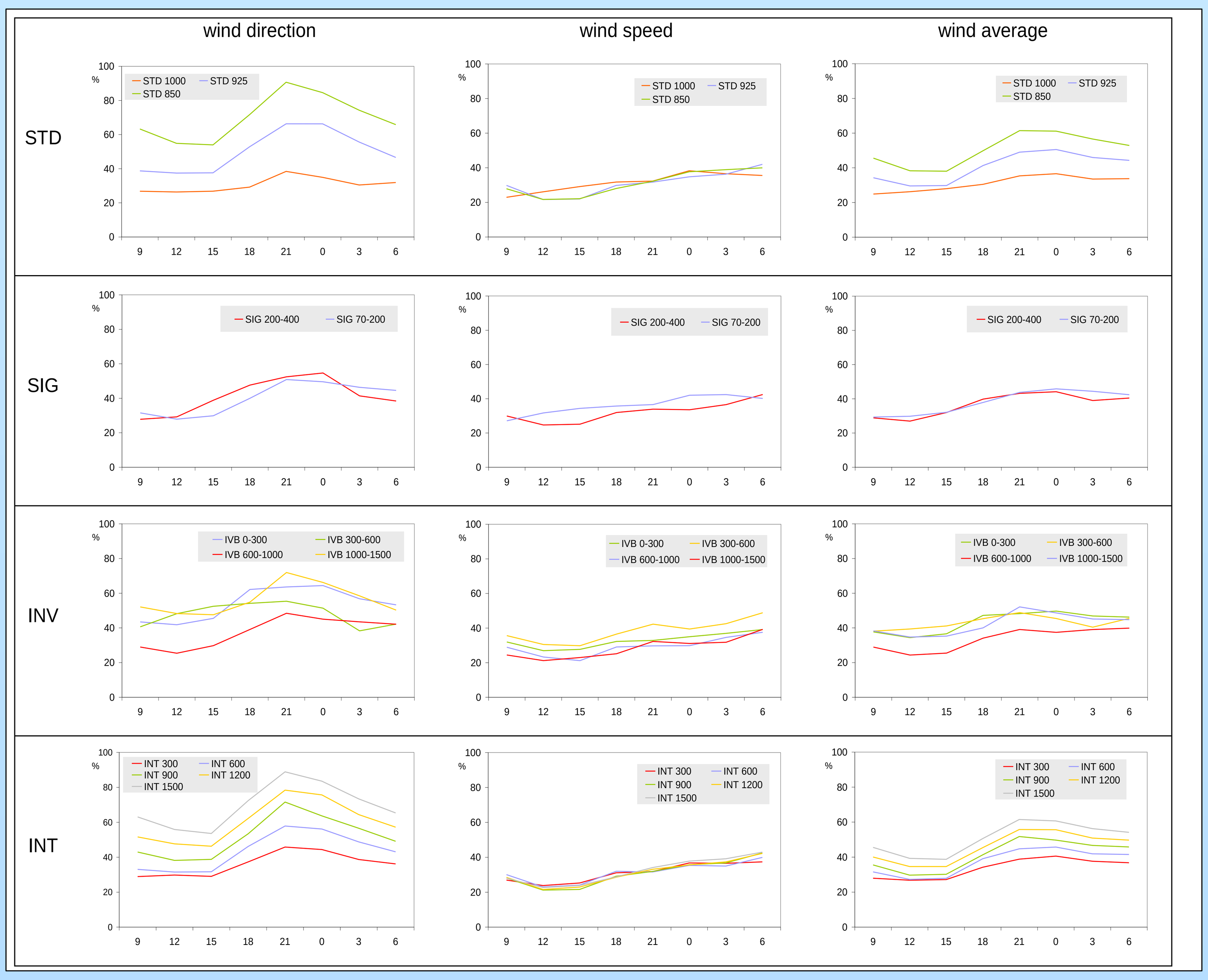
$$rmsDir = \left[\sum_{i=1}^{9} fo_i\,(ed_i)^2 \Big/ \sum_{i=1}^{9} fo_i \right]^{1/2}$$ rms wind direction

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

model errors by weather station

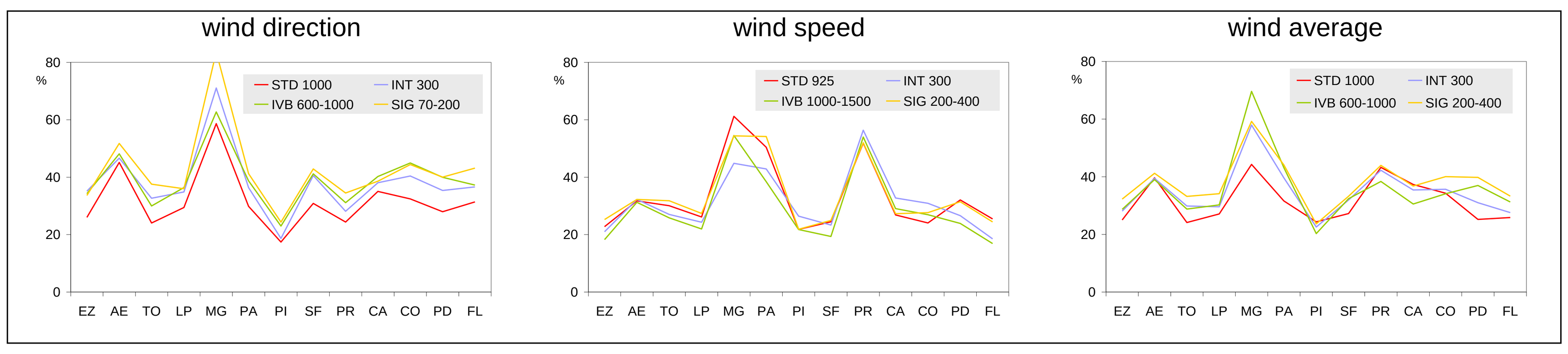
Percentage rms of relative errors in wind direction, wind speed, and simple average of both

model errors by time of day

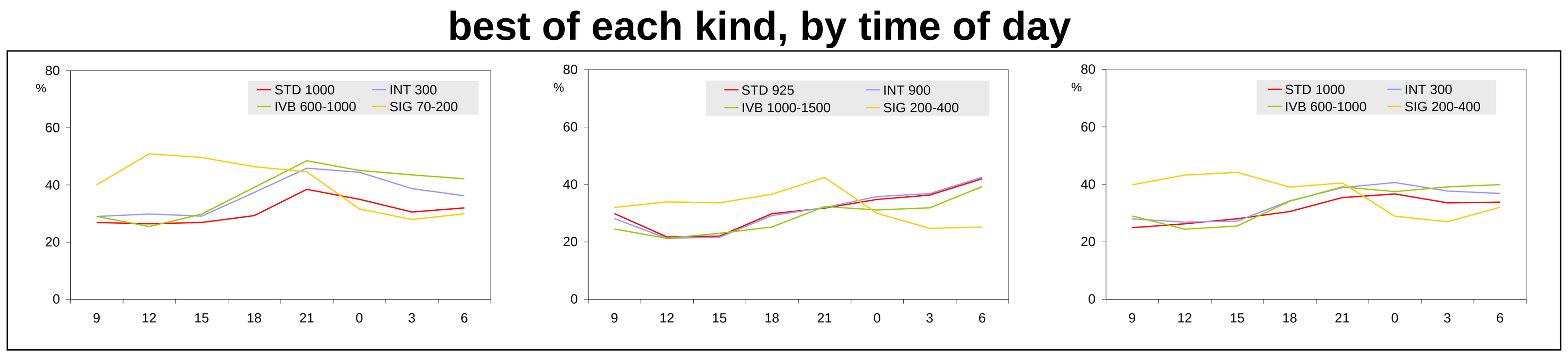


Percentage rms of relative errors in wind direction, wind speed, and simple average of both

best of each kind, by weather station



best of each kind, by time of day



Percentage rms of relative errors in wind direction, wind speed, and simple average of both

Conclusions

- the BLM model is particularly useful for simulating low-level wind fields over regions with strong diurnal cycle of surface thermal contrast (e.g. sea-land breeze)
- the ensemble method is an appropriate methodology for determining high-resolution climatological wind fields over regions with limited observations
- the proposed methodology is of particular utility for synthesizing wind fields over regions with limited meteorological observations
- errors in wind speed are in general smaller than errors in wind direction
- except for two weather stations, errors have similar magnitudes among them
- regarding time of day, errors are not monotonic, they initially grow and then decrease after sunset
- as a preliminary conclusion, considering the different weather stations and times of day, the overall best result is obtained when using the 1000 hPa level data for initializing the BLM model

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