Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1029-1035.

THE IMPACT OF LAND USE CHANGES OVER THE LOW LEVEL CIRCULATION RELATED TO THE NORTHWESTERN ARGENTINEAN LOW.

Ferreira Lorena Judith[1], Saulo Celeste[1,2], Juan Ruiz[2] and Seluchi Marcelo[3]

[1]Universidad de Buenos Aires, DCAO, Buenos Aires, Argentina
[2]Centro de Investigaciones del Mar y la Atmósfera, CONICET, Buenos Aires, Argentina
[3]Centro de Previsao de Tempo e Estudos Climáticos, Cachoeira Paulista, Brasil

ABSTRACT

The Northwestern Argentinean Low (NAL) is a low pressure system with its center located approximately at 66ºW- 30ºS, close to the eastern Andean slopes. Previous studies show that NAL life cycle and position is strongly conditioned by the heat budget at the surface (particularly during the warm season). This leads to the hypothesis that NAL could be very sensitive to changes of surface parameters which ultimately modulate the surface heat balance.

In order to investigate land/ atmosphere interactions over the NAL and surrounding areas, several sensitivity studies employing different land use and soil moisture patterns are proposed. They have been done using WRF (Weather Research and Forecasting) model, for a particular NAL episode observed during SALLJEX (South America Low level jet experiment).

Results reveals a strong sensitivity to an augmentation of soil dryness that causes a deepening of the NAL and an acceleration of the northerly flow to the east of the NAL. This kind of response also leads to a change in the position of the related precipitation area.

1. INTRODUCTION

Previous studies (Schwerdtfeger (1954), Lichtenstein (1980)) evaluated some aspects of the Northwestern Argentinean Low (NAL) that led to the classification of this system as a thermal-orographic low, which is positioned immediately to the east of the Andes. Seluchi et al. (2003) (from now on SO3) analyzed the mechanisms associated to the life cycle of two NAL cases. In that study, they identified surface warming and warming by orographic subsidence as the main mechanisms controlling the evolution of this system in summer and winter respectively. The fact that the NAL in summer is highly controlled by the heat balance at the surface, suggests that its position is in correspondence with the regions where this parameter is larger. Clearly, the warming strongly depends on the surface characteristics: soil moisture, soil type and land use. Accordingly, it is expected that a change in these conditions would lead to a modification of the associated circulation system.

Combining these evidences with other process-studies like those by Fast and Mc Corcle (1990), Zhong et al (1996), Paegle et al (1996) and Wu and Raman (1997), showing that the Great Plains low-level jet exhibits a strong sensitivity to changes in soil moisture and land surface contrasts, it is proposed here to analyze how changes in surface conditions alter not only the NAL structure but also the circulation patterns associated with these events (i.e. the low level jet). It should be stressed that, besides Collini and Berbery (2005) who analyze the role of soil moisture over La Plata Basin in a very different way as is proposed here, there are no studies like this focusing over Southeastern South America.

Identifying land/atmosphere linkages over this particular region, may also have a strong implication on the regional climate, because it has been demonstrated that the NAL has an important role in the southward penetration of the South American Low Level Jet (SALLJ) (Salio et al., (2002), Marengo et al., (2004), among others) which in turn drives much of the warm season precipitation over Northeastern Argentina and Uruguay (Ferreira et al. (2005), Liebmann et al. (2004)).

The other motivation arises from the fact that there is a westward expansion of the Argentinean agriculture/farm frontier that is certainly modifying the surface characteristics, so it is important to

---

[1] Corresponding autor address: Ferreira Lorena Judith. Universidad de Buenos Aires. Depto Cs. de la Atmósfera, FCEyN. Ciudad Universitaria Buenos Aires Argentina; e-mail: ferreira@at.fcen.uba.ar

understand how changes in surface characteristics may drive changes in the low level circulation.

In order to address these issues, this paper shows several sensitivity studies employing different land use and soil moisture patterns using the Weather Research and Forecasting (WRF) model, which has been run over a domain encompassing South America for a particular NAL episode observed during SALLJEX (South America Low level jet experiment). This particular event started by January 30, 2003 and ended by February 6, 2003 and its evolution has been described by Saulo et al.,(2004) using all available SALLJEX data, including those from the NOAA P3 flight mission.

The work is structured as follows: the section 2 shows a descriptions of the numerical experiments. The simulations results are exposed in section 3, while the conclusion and references are shown in section 4 and 5 respectively.

2. NUMERICAL EXPERIMENTS

With the purpose to evaluate how dryness conditions and bare soil acts in the NAL development strength, position and its associated circulation and precipitation, different experiments over the NAL domain have been performed.

The Weather Research and Forecasting model (WRF) version 2.0 has been used (Skamarock et. al. 2005) to perform all the experiments. The domain is centered on the La Plata Basin. Figure 1 shows a reduced portion of the simulation domain. The grid follows a Mercator projection with a horizontal resolution of approximately 50 km and 31 vertical sigma levels. The model is run in the non-hydrostatic mode. The microphysics scheme utilized is the Eta Grid-scale Cloud and Precipitation (http://www.emc.ncep.noaa.gov/mmb/mmbpll/eta12tpb/). Convection is parameterized using Grell scheme (Grell (1993)), RRTM scheme (Mlawer et. al. (1997)) and Dudhia (1989) scheme are used to represent radiative fluxes. Mellor and Yamada, (1982) scheme is used in the boundary layer processes parameterization and a NOAH Land Surface Model, is used to represent surface processes (Chen and Dudhia,(2000)).

The surface characteristics for each of the simulations are summarized in Table 1.

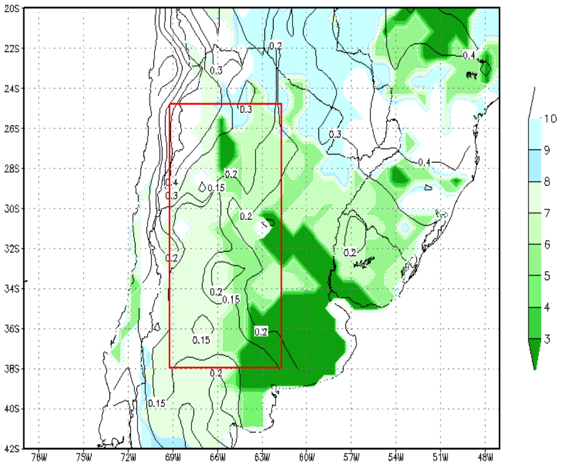
The simulations done using the WRF model were initialized on 29 January at 12UTC with the GDAS (Global Data Assimilation System) analyses provided by the National Centers of Environmental Predictions (NCEP) and were integrated for a 10-day period. The land use categories employed by the WRF came from the USGS (US Geological Survey Land Use/Land Cover System, Anderson et al,(1976)).

	Soil moisture Initial condition	**Land use**
E1	Reduction 50% from analysis GDAS/NCEP	USGS
E2	Constant value of 0.04	USGS
E3	Analysis GDAS/NCEP	Bare Soil
E4	Constant value of 0.04	Bare Soil
Ctrl	Analysis GDAS/NCEP	USGS

Table1: Summary of the numerical simulations based on various surface parameters. USGS = U.S.Geological Survey.

All the proposed experiments modify the conditions over the NAL domain (see red Box in figure 1).This sub-domain shows driest conditions and is mostly dominated by grassland / shrubland land use.

The Experiments 1 and 2 are designed to evaluate the impact of soil moisture initial condition. In the first one, soil moisture spatial distribution is kept, but in the second, an homogeneous field is determined by a constant value close to the wilting point. This implies a stronger impact on soil moisture field than E1. The E3 is proposed for to see how an abrupt change in land use, e.g. Bare soil, can affect the NAL and its associated patterns. Finally, experiment 4 combines both effects in order to evaluate how they mutually interact.



<u>Categories</u>: **1**-Urban,**2**-Dryland Cropland and Pasture, **3**-Irrigated Cropland and Pasture, **4**-Mixed Dryland/irrigated Cropland and Pasture,**5**-Cropland/Grassland mosaic, **6**-Cropland/Woodland mosaic,**7**-Grassland,**8**-Shrubland,**9**-Mixed Grassland/Shrubland,**10**-Savanna,**11**-others

<u>Figure 1</u>: A portion of the region under study, showing land use categories (shaded) and soil moisture initial condition on 29 January 2003 (contours).The NAL sub-domain(red Box) is also shown.

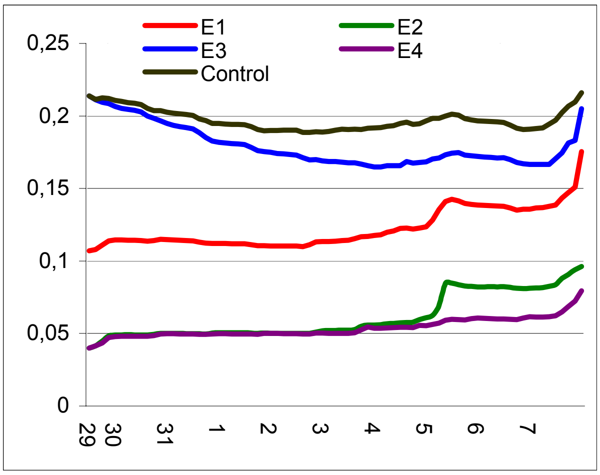
Each simulation was forced by the same synoptic conditions. In this way any differences between dynamics and thermal structure of the boundary layer among the simulation could be attributed to the different surface forcing.

3. RESULTS

The NAL developed on 30 January 2003 associated with a warm wave, and reached its maximum intensity between January 31 and February 1. By February 2, the low weakened as a response to the incursion of a frontal system but on the subsequent days reached its strength again. This system lasted long until February 6 when another frontal passage, with its associated cold advection, finished with the event. More details can be seen in Saulo et al.,(2005). and (2004).

In the following figures, we focus the analysis over a smaller sub-domain 30-27S;67-63W that encompasses the northern portion of the NAL. This choice has been done to concentrate over the area where the NAL exhibits its climatological center position.

The evolution of the soil moisture content for all of the experiments inside this sub-domain of NAL box is shown in Figure 2. The low values for the constant field experiments E2 and E4 are evident. During the first days, values are close to the wilting point, not far away from the initial perturbed condition, meaning that prevailing surface conditions almost correspond to those associated with the inhibition of evaporation that in turn may have a great impact in latent heat flux, particularly for E4. The augmentation of soil moisture from February 4 is associated with precipitation occurrence over this particular area (not shown). Soil moisture for the Bare Soil experiment (E3), is lower than the control, as expected, and larger than the others.



Z

Figure 2: Area average soil moisture (m3 m-3) evolution (67-63°W,27-30°S)for: control-black, E1-red, E2-green, E3-blue, E4-purple.

Figure 3 shows the impact of the different experiments on the sensible heat fluxes within the sub-domain, where positives values indicate a gain of heat for the atmosphere.

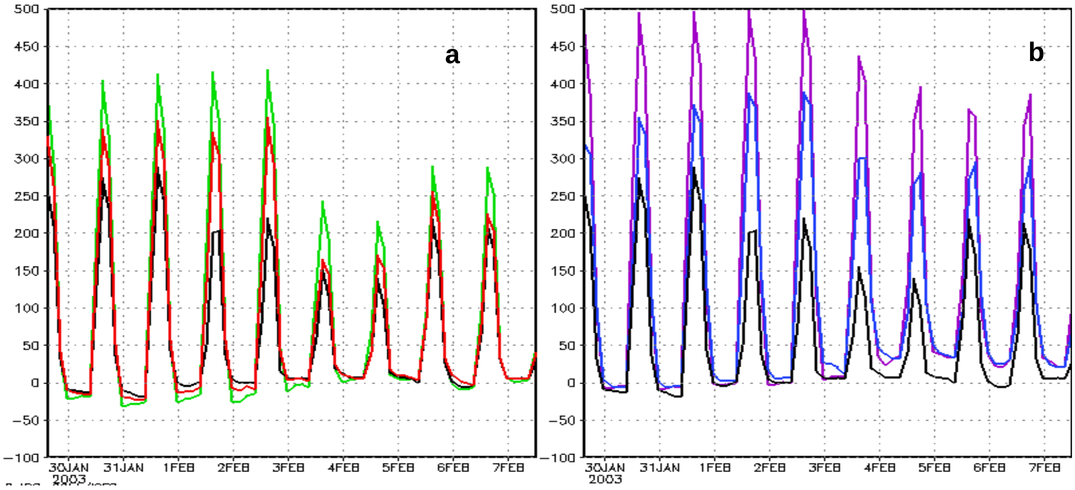
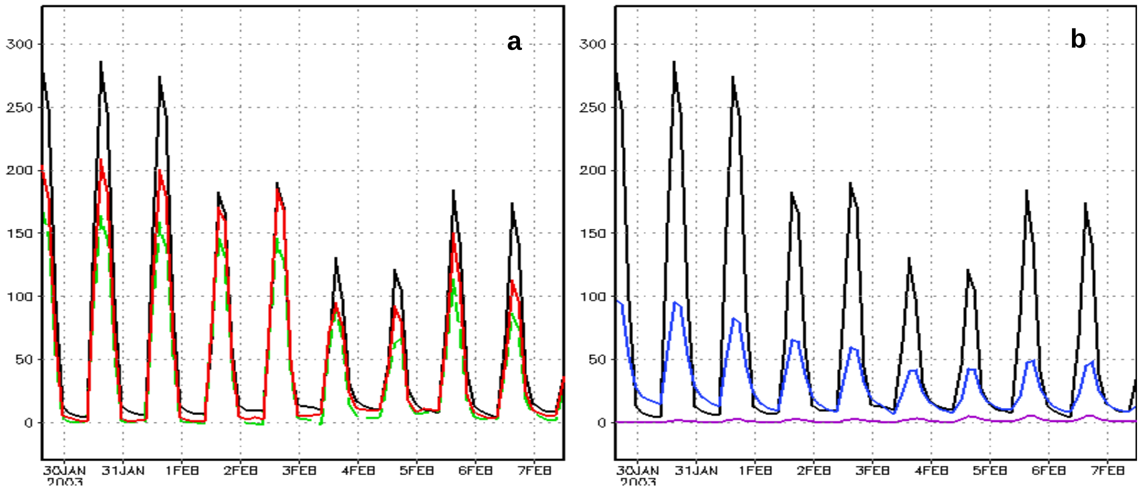


Figure 3: Area average over 67-63°W,27-30°S of the sensible heat flux evolution (Wm^{-2}) for: control-black, E1-red, E2-green, E3-blue, E4-purple. Tic marks correspond to 00 UTC

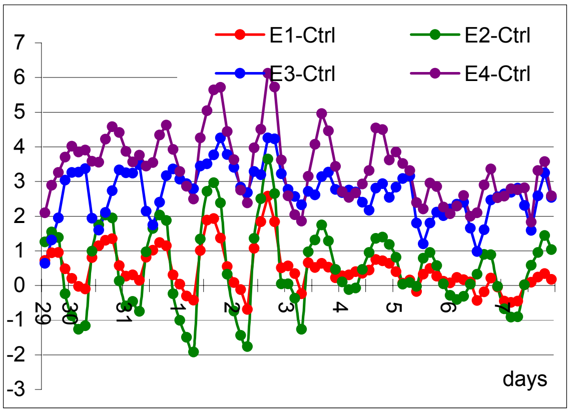


<u>Figure 4</u>: Area average Latent Heat Flux evolution (Wm^{-2}) (67-63°W,27-30°S)for: control-black, E1-red, E2-green, E3-blue, E4-violet

From this figure it can be seen the diurnal variability of the sensible heat flux and its evolution through the simulation, showing larger anomalies during the first part of the period. Down from February 3, E2 and E4 denote larger anomalies reaching values above 400 Wm^{-2}, while in the second part of the period, E3 values become more important than E1 and E2. This can be due to the fact that the change in land use affects all the integration period, so that all surface hydraulic properties, albedo and other characteristics associated with a bare soil, are maintained. On the other hand anomalies associated with a reduction of soil moisture initial condition, apparently have more effect on the first days but then decay. In some cases, as can be observed for E4 (Fig 3b, E4), the difference with the control is around 250Wm^{-2}, what can be due to a positive feedback between an extreme lack of soil moisture and no vegetation, what leads to a partition of energy that favors the sensible heat contribution. Similar results were founded by Chen and Dudhia (2001) for a dry point where a difference of 200Wm^{-2} between the control and the experiment was observed.

The latent heat fluxes (Figure 4) in the experiments are all lower than in the control and decrease with time; particularly for E4 the contribution of the latent heat is null because of the lack of soil moisture available to evaporate. As was shown in figure 2, the evolution of the soil moisture for E2 and E4, was close to the wilting point, which is a critical value where is difficult to extract additional water to evaporate. In the case of E2, this effect appeared not to be relevant because some latent heat flux is observed.

The vegetation plays an important role in the evapotranspiration, and in this way in the contribution of the latent heat flux to the atmosphere. In the case of the NAL region, where soil moisture is low (see Fig.1) the inclusion of a bare soil, which can only produce direct evaporation, produces the greatest reduction in the latent heat flux. So this region seems to be sensible to changes in both, vegetation and soil types.



<u>Figure 5</u>: Area average temperature at 2 meters anomaly evolution(°C) (67-63°W,27-30°S) for: E1-red, E2-green, E3-blue, E4-violet

In order to quantify the impact of the modified heat balance at low levels, Figure 5 shows temperature anomalies at 2 meters. All the experiments tend to amplify the diurnal cycle and exhibit mean anomalies between +0,5°C for E1 and +3°C for E4, showing a clear impact of the changes in surface conditions. Also, following SO3 results, this behavior would contribute to increase the NAL diurnal cycle as can be confirmed by Figure 6 (see below). Also it can be seen that the diurnal change for E1 and E2, is negative during night. This could be due to the enhanced heat loss that characterizes soils with low moisture. This is not observed in E3 and E4, where the impact on temperature always results in surface warming. As expected, the experiment related to bare soil maintains a similar influence throughout the simulation period, while all the others tend to decay with time.

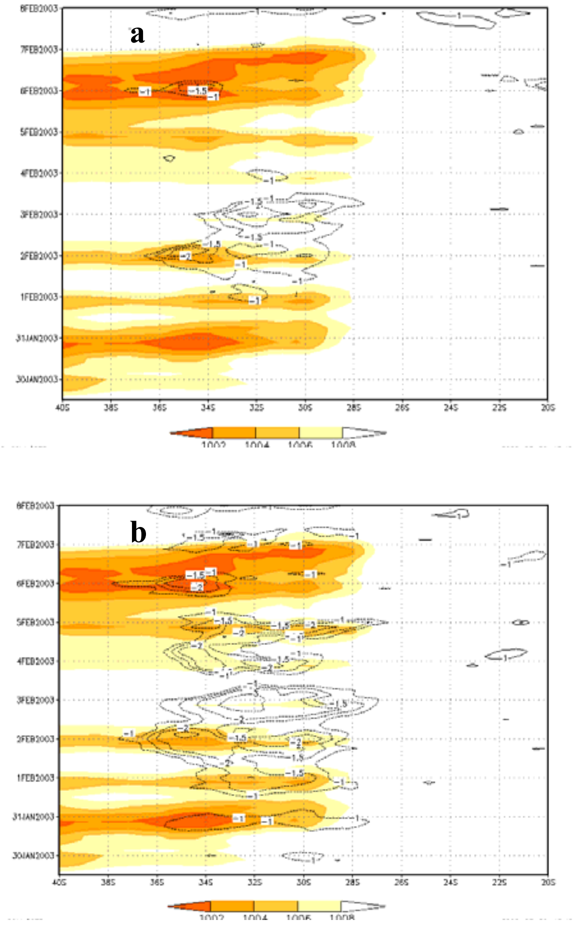


Figure 6: Howmoller of Sea Level pressure (hPa) for 67-63W, from WRF control simulation in shaded, E2-control(a) in contour, and E4-control (b) in contour.

Figure 6 shows a Howmoller diagram of the sea level pressure for longitudinally averaged between 67-63W, E2 (fig.6a) and for E4 (fig6b). The reduction in soil moisture (E2), impacts NAL sea level pressure, producing an intensification mainly at the southern portion of the NAL up to 1 February. The anomalies have reached values of 2hPa.

For E4, the combined effects of low soil moisture and bare soil, produced anomalies that reach up 3hPa. In this case the intensification is more generalized. From this figures, a change on the NAL center position is not clearly. Other experiments have shown similar results.

To highlight the effect upon the circulation pattern, Figure 7 shows a height-time cross section of the control meridional wind component and its anomaly (related to E2) at 30°S, 64°W. The simulated wind speed clearly shows a large variability from day to day and a regular nocturnal peak at low level ranging between 9 and 15 ms^{-1}. The low level jet is strongest between 06 and 12 UTC what is in agreement with previous studies (Salio et al., (2002), Saulo et al.,(2004) and Inzunza and Berri,(1990) among others).The experiment generally shows an intensification of the northerly jet intensity reaching above 4 ms^{-1}. The stronger impact, however, is between February 5 and 6, at low levels, due to a short wave with its associated southerly flow that is not represented by the experiment E2. The others experiments show similar results (not shown).

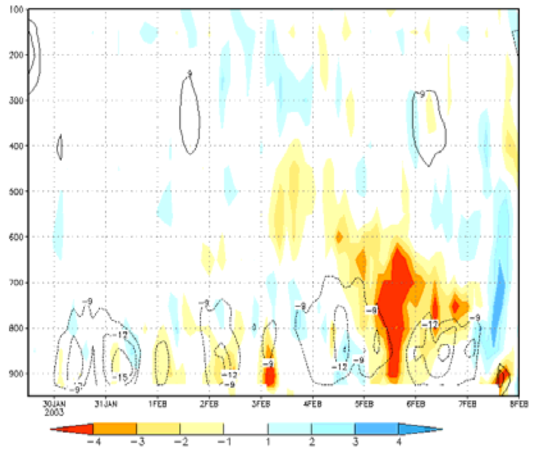


Figure 7: Vertical profile of meridional wind speed (ms^{-1}) for the control run (dashed line) and its anomaly (shaded) (E2-control) at 30°S,64°W.

Figure 8 shows for a particular day (February 3, at 6UTC) how the reduction in soil moisture and a bare soil (E4) impacts not only the intensification of the NAL sea level pressure, but the acceleration of the low levels northerly flow east of the NAL region, (over La Plata Basin) as well.

Finally, it is of interest to see how a change in surface characteristics can impact the precipitation intensity and/or position. Figure 9 shows, for all the experiments and the control, the mean areal accumulated precipitation during the simulation. This has been calculated over the NAL region (green bars), and over two other regions where the stronger precipitation occurred; the southern portion of La Plata Basin(blue bars) and the central portion of La Plata Basin (orange bars). These domains are indicated in figure 8.

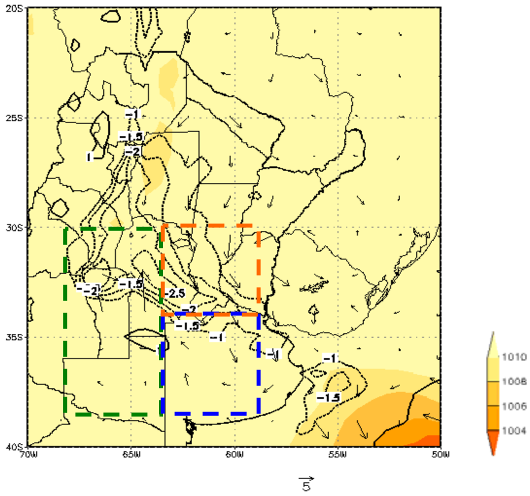


Figure 8: Sea level pressure (hPa) from WRF control simulation (shaded), its anomaly with respect to E4 (contour) and wind anomalies with respect to E4 at 900 hPa (in vectors -ms^{-1}) on February 3 2003 at 6UTC.The rectangles are used to calculate the areal precipitation shown in Figure 9.

The NAL region is a sensitive region (see fig1), where a reduction in surface moisture (E1 and E2) seems to be associated with an inhibition of precipitation, and a change in land use (E3) with more precipitation (green bars). These results show that the lack of evaporation by the in situ reduction in soil moisture seems to be more related with an inhibition of precipitation than with any other impact.

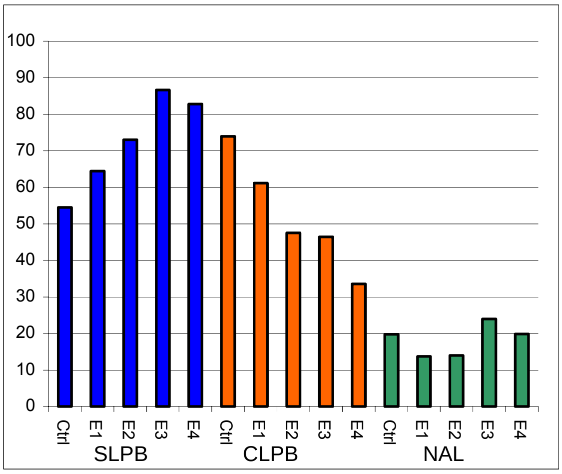


Figure 9: Area average accumulated precipitation during all the simulation for: the NAL 68-63°W,38-30°S (green), South La Plata Basin (SLPB) 63-58°W,38-34°S (blue) and the Central La Plata Basin(CLPB) 63-58°W,34-30°S(orange).

The Central portion of the La Plata Basin (Orange bars), where the control shows more accumulated precipitation during the simulation, observes an attenuation, in some cases of 35mm (see E4). An augmentation of precipitation over the Southern portion (Blue bars) in all the experiments is observed, showing a displacement to the south of the precipitation systems and an intensification of the rain.

4. Conclusions

In this paper, land/atmosphere interactions over the NAL region and its surroundings has been analyzed, motivated by plausible implications of these interactions on the regional climate.

Several sensitivity studies employing different land use and soil moisture patterns using the WRF model, have been run for a particular NAL episode observed during SALLJEX. They show that changes on surface parameters, and particularly those related with changes in soil moisture, significantly alter the surface heat balance, giving anomalous values around 200 Wm^{-2} and anomalous surface warming of 3°C. This modifies the NAL life cycle through an increased deepening of its Southern portion. Consequently, the low level circulation, which adjusts geostrophically to this low pressure system seems to be intensified and distorted. This kind of response also leads to a change in the position of the related precipitation area, given that the convergence region appears southward.

Less humidity has a negative effect on local evaporation, so the latent heat fluxes diminish, but a positive effect on surface warming rising sensible heat fluxes.

In general, changes in land use appeared to be more relevant during all the simulation while changes in soil moisture initial condition seemed to impact more during the first stages and weakened progressively.

This paper has showed that the Northwestern Argentinean Low can be very sensitive to changes in surface parameters and consequently in the associated circulation. This last has produced a clear impact in precipitation, mainly over La Plata Basin. This supports the importance of sensitivity studies like the one proposed here, in order to address how other configurations control alter the regional climate.

Acknowledgements: This research is sponsored by the Research Grants UBACyt X155- PIP 5417 and for PROSUR-CRN 055.

5. REFERENCES

Anderson J.R., Hardy E.E., Roach J.T. and Witmer R.E.,1976: A land use and land cover classification system for use with renote sensor data: U.S. Geological Survey Professional Paper 964, 28p.

Chen, S.-H., and J. Dudhia, 2000: Annual report: WRF physics, *Air Force Weather Agency*, 38pp.

Chen F. and Dudhia J, 2001:Coupling an Advenced land surface-hydrology model with the Penn state –NCAR MM5 modeling system. Part1:Model Implementation and sensitivity. *Mon. Wea. Rev*.,Vol N°129, 569-585

Collini E.A., Berbery E. H. and Barros V., 2005 : La Influencia del estado del suelo en la precipitación del monzón de sudamérica. Annals of IX Meteorological Argentina Congress. Buenos Aires, Argentina, 3-7 October 2005, 10pp.

Dudhia J., 1989: Numerical Study of Convection Observed during the Winter Monsoon Experiment Using a Mesoscale Two-Dimensional Model. *J. Atmos Sci.* Vol. 46, 3077–3107

Fast J. and Mc Corcle M., 1990: A two dimensional numerical sensitivity study of the great plains low level jet. *Mon. Wea. Rev*.,Vol 118, 151-163

Ferreira L., A.C. Saulo, Seluchi M.and Gláucia Meira Carneiro, 2005: Estructura de los patrones termodinámicos asociados a eventos de baja del noroeste argentino. Annals of IX Meteorological Argentina Congress. Buenos Aires, Argentina, 3-7 October 2005, 10pp.

Grell G. 1993: Prognostic Evaluation of Assumptions Used by Cumulus Parameterizations. *Mon. Wea. Rev*.,Vol. 121, 764–787.

Inzunza, B. J. y G. J. Berri, 1990: Comportamiento del viento y transporte de vapor de agua en la baja troposfera en el norte de Argentina. *Meteorologica*, 17, 17-25.

Lichtenstein E.R., 1980: La Depresión del Noroeste Argentino (The Northwestern Argentina Low). PhD Thesis. 223 pp. *[Available at Departamento de Ciencias de la Atmósfera y los océanos, Buenos Aires, Argentina].*

Marengo, J., W. R. Soares, C. Saulo and M. Nicolini, 2004: Climatology of the Low-Level Jet East of the Andes as Derived from the NCEP–NCAR Reanalyses: Characteristics and Temporal Variability. Journal of Climate.Vol. 17, No. 12, 2261–2280.

Mellor G. and Yamada T., 1982: Development of a turbulence closure model for geophysical fluid problems. *Reviews of Geophysics and space Physics;* Vol. 20 N°4, 851-875.

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmosphere: RRTM, a validated correlated-k model for the long-wave. *J. Geophys. Res.:* 102(D14), 16663-16682.

Paegle J. ,Kingtse Mo, Nogues-Paegle J., 1996: Dependence of simulated Precipitation on Surface evaporation during the 1993 United State Floods. *Mon. Wea. Rev*.,Vol 124, 345-361

Salio, P., M. Nicolini, y A.C. Saulo, 2002: Chaco low-level jet events characterization during the austral summer-season. *J. Geophys. Res*., 107, D24, 4816-4832.

Saulo A.C, M. E. Seluchi and M. Nicolini., 2004. A Case Study of a Chaco Low-Level Jet Event: *Mon. Wea. Rev*. Vol. 132, No. 11, 2669–2683.

—— ., Ferreira L., Mejia J. and Seluchi M.,2004: Description of the Termal Low Characteristic using SALLJEX Special Observations. *Clivar Exchanges*, 9, 9-10 y 17

——, Ferreira L. And Seluchi M., 2005: La depresión del Noroeste Argentino durante el SALLJEX. Annals of IX Meteorological Argentina Congress. Buenos Aires, Argentina, 3-7 October 2005, 10pp.

Schwerdtfeger, W.C., 1954: Análisis sinóptico y aspecto climatológico de dos distintos tipos de depresiones báricas en el norte de la Argentina. *Meteoros,* 4, 301-323.

Seluchi, M., A.C. Saulo, M. Nicolini, y P. Satyamurty, 2003: The Northwestern Argentinean Low: A Study of Two Typical Events. *Mon. Wea. Rev*., Vol 131, 2361-2378.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2005: A description of the Advanced Research WRF Version 2. *NCAR Tech Notes-468+STR*

Wu Y. and Raman S.,1997:Effect of land use pattern on the development of low level jets. *J. Applied Met*, 36, 573-590.

Zhong S., Fast J.D and Bien X,1996:A case study of the Great Plains Low Levels Jet Using Wind Profiler Network Data and high resolution mesoscale model *Mon. Wea. Rev*.,Vol 124, 785-805.