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Sensitivity of WRF short-term forecasts to different soil moisture initializations from the GLDAS database over South America in March 2009

María E. Dillon [a,b], Estela A. Collini [a,c], Lorena J. Ferreira [a]

[a] Servicio Meteorológico Nacional, Argentina
[b] Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina
[c] Servicio de Hidrografía Naval, Argentina

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ABSTRACT

In Numerical Weather Prediction models it is essential to properly describe both the atmosphere and the surface initial conditions. With respect to the last, a major issue is the difficulty to attain a correct representation of soil moisture due to the lack of a measurement network established. This fact is crucial in South America. One alternative is the information given by the Land Surface Models (LSM), for example those provided by the Global Land Data Assimilation System (GLDAS).

Our main concern is to investigate the sensitivity of short-term numerical weather prediction to soil moisture initializations. The analysis is focused in precipitation mainly to the second forecast day, and other variables related to the atmospheric water balance. To accomplish this, we perform five experiments including some of the GLDAS databases (NOAH, VIC and MOSAIC) in the initialization of the Weather Research and Forecasting (WRF) model, during a test period of one month (March 2009). An initial field normalization procedure using one of the soil models as reference is also evaluated.

We show that the ambiguity of the soil models, given by their spatial and temporal variability as well as the forcing atmospheric fields, is transferred to the weather prediction model coupling, all over the month considered. Particularly, we show that the normalized percentage bias (NBIAS) of daily precipitation calculated for the second forecast day does not present well-defined patterns of over or underestimations: all the experiments show a wide range of variation. With respect to the normalized root mean square error (NRMSE) calculated for the same variable, we find that the values are generally low. In addition, the mean values of each statistic measure (NBIAS, BIAS, NRMSE and RMSE) do not show significant differences among the experiments (at 99% of significance). Nonetheless, it was shown that using the MOSAIC LSM for the initial conditions leads to minor NRMSE and RMSE maximums. Finally, while analyzing both moisture fluxes and precipitable water at different periods of the month, we find sensitive areas where the impact is mostly important, as Southeastern South America, central Argentina and Northeastern Brazil.

1. Introduction

It is well known that in order to achieve better results in short-term numerical weather predictions, the initial conditions must be improved. Not only an appropriate description of the atmosphere is essential, but also an adequate representation of the soil state. Many authors have shown the existence of land – atmosphere interactions over different parts of the world (de Goncalves et al., 2006; Betts, 2009; Sörensson et al., 2010; Seneviratne et al., 2010; Dirmeyer et al., 2012; Ferguson et al., 2012; Santanello et al., 2013; Zaitchik et al., 2013; Pathirana et al., 2014; Hirsch et al., 2014; among others). Both Eltahir (1998) and Pal and Eltahir (2003) proposed a positive feedback between wet soil moisture conditions and precipitation, through the enhancement of boundary layer moist static energy. Koster et al. (2004) analyzed the land atmosphere coupling strength during the boreal summer using the results of the Global Land – Atmosphere Coupling Experiment (GLACE), which yielded a multimodel average global distribution of the land-atmosphere coupling strength, with the aim of eliminating much of the undesired individual model dependence. This study showed hot spots of the land-atmosphere coupling in different regions of the world, addressing the local impact of soil moisture in precipitation, mainly in the transition zones between dry and wet climates.

Collini et al. (2008) studied the feedbacks between soil moisture and precipitation during the early stages of the South American monsoon, using the regional Eta model, and found a decrease of precipitation as an outcome of the initial soil moisture reduction. In the analysis carried out by Dirmeyer et al. (2009) from datasets containing both observations and numerical model results, the authors showed that the soil

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moisture memory lasts less than 15 days over some regions of South America during the austral summer. This article motivated Saulo et al. (2010), who selected a particular case study to analyze the impact of the coupling between land and atmosphere in short to medium – range predictability over Southeastern South America (SESA). In fact, they found that more soil wetness enhances the convective available potential energy (CAPE) and in consequence it increases precipitation, and vice versa.

More recently, interactions between soil moisture and precipitation were evaluated by Ruscica et al. (2014) analyzing the coupling of soil moisture with surface and boundary layer variables, selecting subregions at SESA based on the soil moisture and evapotranspiration coupling and the mean intensity of precipitation.

Taking into account this evidence, an appropriate initialization of soil conditions, particularly of soil moisture, in a Numerical Weather Prediction (NWP) model would have a positive impact in the short-term forecasts quality.

The main issue is the difficulty to attain a correct representation of the soil moisture, particularly over SESA, which is our region of interest. Generally, soil moisture data is collected at few locations and for a short period of time: there is not an institutional gauging network established (Spennemann, 2010). Most of the data is obtained during field campaigns which are regional and sporadic, so it can not be used to initialize NWP models on regular basis. An alternative would be to use satellite estimations in order to have a wide coverage, both spatial and temporal, but those estimations generally correspond to the superficial soil moisture from a layer of a few centimeters depth. For example, this is the case of the data derived from the passive radiometer AMSR-E on board of EOS-Aqua satellite, which has 2 algorithms to obtain the soil moisture retrieval: the one developed by NSIDC – NASA (National Snow and Ice Data Center and NASA) (Njoku, 1999) and the other generated by VUA – NASA (Vrije Universiteit Ámsterdam and NASA) (Owe et al., 2008). However, it has been demonstrated in various regions that the soil dynamics explained by each of the algorithms are different (Rudiger et al., 2009; Draper et al., 2009; Dillon et al., 2012), leading to uncertainties about which is the best estimation.

On the other hand, there are many uncoupled soil models developed that are forced by atmospheric conditions, fixing the shortcoming of the soil variables data. One of the most important projects is the Global Land Data Assimilation System (GLDAS) composed of four models with different characteristics (Rodell et al., 2004). Monthly and three hourly fields are available from distinct depths from the CLM (Community Land Model), Mosaic, NOAH and VIC (Variable Infiltration Capacity) models. Particularly, the soil moisture obtained from these databases has been used by several authors for atmospheric and hydroclimatic studies (Zhang et al., 2008; Liu et al., 2009; Spennemann, 2010; Ferreira et al., 2011; Dillon et al., 2012; among others).

In the present work, our main concern is to investigate through a sensitivity study, how is the impact of the soil moisture initialization over the short-term numerical weather prediction in South America, using the Weather Research and Forecasting (WRF) model. To accomplish this, we perform five experiments including some of the GLDAS databases in the initialization of the WRF, where we analyze the impact of the different initializations on the precipitation forecasts and the vertically integrated moisture fluxes, among other variables. An initial field normalization procedure (Koster et al., 2009) using the NOAH/GLDAS soil model as a reference is also evaluated. The data and methodology are described in Section 2, while the results are presented in Section 3. Finally, the remarks are summarized in Section 4.

2. Methodology

Our study is concentrated on March 2009. The selection of this particular month is related to the beginning of the precipitation over SESA, after an intense drought that has been affecting this region for more than a year. La Niña event was established at the last quarter of 2007 and prevailed during 2008, favoring the reduction of precipitation over La Plata Basin (http://www.atmos.umd.edu/~berbery/lpb/). Anomalies up to minus 60 percent of the annual mean precipitation were registered in this region. It was qualified as the worst drought in the last 65 years (Peterson and Baringer, 2009; Arndt et al., 2010).

In order to assess the interaction between the atmosphere and the soil moisture during this period, we employed the Advanced Research Weather (ARW) core, from **WRF** model version 3.1.1, which runs experimentally at the National Meteorological Service of Argentina since 2010, in an automatic but non operational way (Collini et al., 2011). Its spatial resolution is 24 km in the horizontal and 38 levels in the vertical (50 hPa model top), in a domain including South America and the adjacent oceans. Some of the parameterizations chosen are: the Rapid Radiative Transfer Model (RRTM) for long wave radiation (Mlawer et al., 1997) and the Dudhia scheme for the short wave one (Dudhia, 1989); the Betts – Miller – Janjic scheme for cumulus parameterization (Betts and Miller, 1986; Janjic, 1994); the Eta microphysics scheme (Zhao and Carr, 1997); the similarity Eta parameterization for the surface layer (Monin and Obukhov, 1954; Zilitinkevich, 1995); the Mellor – Yamada – Janjic scheme for the boundary layer (Janjic, 1990, 1996, 2002; Mellor and Yamada, 1982). In addition, the NOAH model was chosen to be in accordance with the land surface model (LSM) coupled in the Global Forecasting System (**GFS**), at the National Centers for Environmental Prediction (NCEP), whose analysis and 3 hourly forecasts of 1° x 1° latitude-longitude resolution were used as initial and boundary conditions respectively for the WRF. The NOAH has 4 soil layers: 0 – 0.1 m, 0.1 – 0.4 m, 0.4 – 1 m and 1 – 2 m (Chen and Dudhia, 2001).

We designed five sets of forecasts to carry out sensitivity studies, using some of the GLDAS version 1 uncoupled soil models (http://disc.sci.gsfc.nasa.gov/services/grads-gds/gldas) as initial soil moisture conditions. These datasets are forced by a combination of the Global Data Assimilation System (GDAS) analysis and the Climate Prediction Center Merged Analysis of precipitation (CMAP), and therefore, they receive information from surface and satellite observations (Rodell et al., 2004). In the present article three of the models are used, with a spatial resolution of 1°x1°: **Mosaic** (Koster and Suarez, 1996), which is based on the Simple Biosphere (SiB) model and has 3 layers of depth: 0 – 0.02 m, 0.02 – 1.5 m and 1.5 – 3.5 m; the **NOAH** model (Chen et al., 1997; Koren et al., 1999), mentioned above; and the **VIC** (Liang et al., 1994; Liang et al., 1996) model, which divides the soil into 3 layers: 0 – 0.1 m, 0.1 – 1.6 m and 1.6 – 1.9 m.

Each set of forecasts consists of thirty-one 2-day forecasts initialized at 12 UTC on each day of March 2009, using a WRF non – hydrostatic

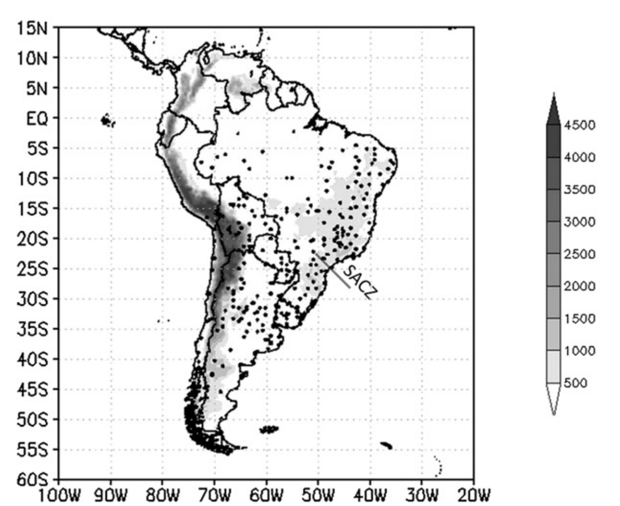

Fig. 1. Meteorological stations used in the precipitation forecast verification (dots), and the WRF topography [m] (shaded) in the full domain used in the simulations. The full line denotes the South American Convergence Zone (SACZ).