Int J Appl Earth Obs Geoinformation 64 (2018) 96–103

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Land-atmosphere interaction patterns in southeastern South America using satellite products and climate models

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ARTICLE INFO

Keywords:
Land-atmosphere interaction
Southeastern South America
Satellite products
Soil moisture
Land surface temperature
Climate modelling

ABSTRACT

In regions of strong Land-Atmosphere (L-A) interaction, soil moisture (SM) conditions can impact the atmosphere through modulating the land surface fluxes. The importance of the identification of L-A interaction regions lies in the potential improvement of the weather/seasonal forecast and the better understanding of the physical mechanisms involved. This study aims to compare the terrestrial segment of the L-A interaction from satellite products and climate models, motivated by previous modeling studies pointing out southeastern South America (SESA) as a L-A hotspot during austral summer. In addition, the L-A interaction under dry or wet anomalous conditions over SESA is analyzed. To identify L-A hotspots the AMSRE-LPRM SM and MODIS land surface temperature products; coupled climate models and uncoupled land surface models were used. SESA highlights as a strong L-A interaction hotspot when employing different metrics, temporal scales and independent datasets, showing consistency between models and satellite estimations. Both AMSRE-LPRM bands (X and C) are consistent showing a strong L-A interaction hotspot over the Pampas ecoregion. Intensification and a larger spatial extent of the L-A interaction for dry summers was observed in both satellite products and models compared to wet summers. These results, which were derived from measured physical variables, are encouraging and promising for future studies analyzing L-A interactions.

L-A interaction analysis is proposed here as a meeting point between remote sensing and climate modelling communities of Argentina, within a region with the highest agricultural and livestock production of the continent, but with an important lack of in-situ SM observations.

1. Introduction

The identification of regions where the land surface condition has a significant impact on the atmosphere is crucial to improve our understanding of regional and local climate. In these regions −called hotspots-, soil moisture (SM) variability has the potential to modulate the atmospheric conditions through changes in the latent- and sensible-energy fluxes on time scales ranging from diurnal to seasonal (Seneviratne et al., 2010). SM influence on precipitation is predominant during the summer season, when energy fluxes are high enough to trigger convection. As SM anomalies persist longer than atmospheric ones, L-A interactions can also contribute to the intensification and persistence of extreme temperature events (Mo and Berbery, 2011); for example low soil moisture values reduce the evaporative cooling, increasing the atmospheric heating through sensible heat fluxes (Hirschi et al., 2014; Seneviratne et al., 2010). Therefore, an improved knowledge of L-A interactions and more realistic SM data for atmospheric models can improve weather and seasonal forecast skills over these hotspot regions. In transition zones between dry and wet climates, SM is in general characterized by medium range values and high variability, giving the potential conditions for strong L-A interactions (Koster et al., 2004).

Conceptually, L-A interaction can be divided in two segments; the terrestrial and the atmospheric. The terrestrial segment involves the direct influence of SM anomalies over surface variables such as temperature or evapotranspiration through their influences on the partitioning of latent and sensible heat fluxes (Dirmeyer, 2011). This mechanism has been confirmed over regions with water-limited regimes where the partitioning of available energy is sensitive to changes in SM conditions (Fig. 2a of Entekhabi et al., 2010). The atmospheric segment, i.e. SM influence (through evapotranspiration or temperature) on precipitation, is of high complexity since it involves thermodynamic and dynamic atmospheric processes on a wide range of temporal and spatial scales (e.g. Ruscica et al., 2015). Here, the "interaction" and "coupling" terms follow the definitions given in Seneviratne et al. (2010).

Land surface models (LSMs) represent processes ranging from basic

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http://dx.doi.org/10.1016/j.jag.2017.08.016
Received 7 February 2017; Received in revised form 14 August 2017; Accepted 31 August 2017

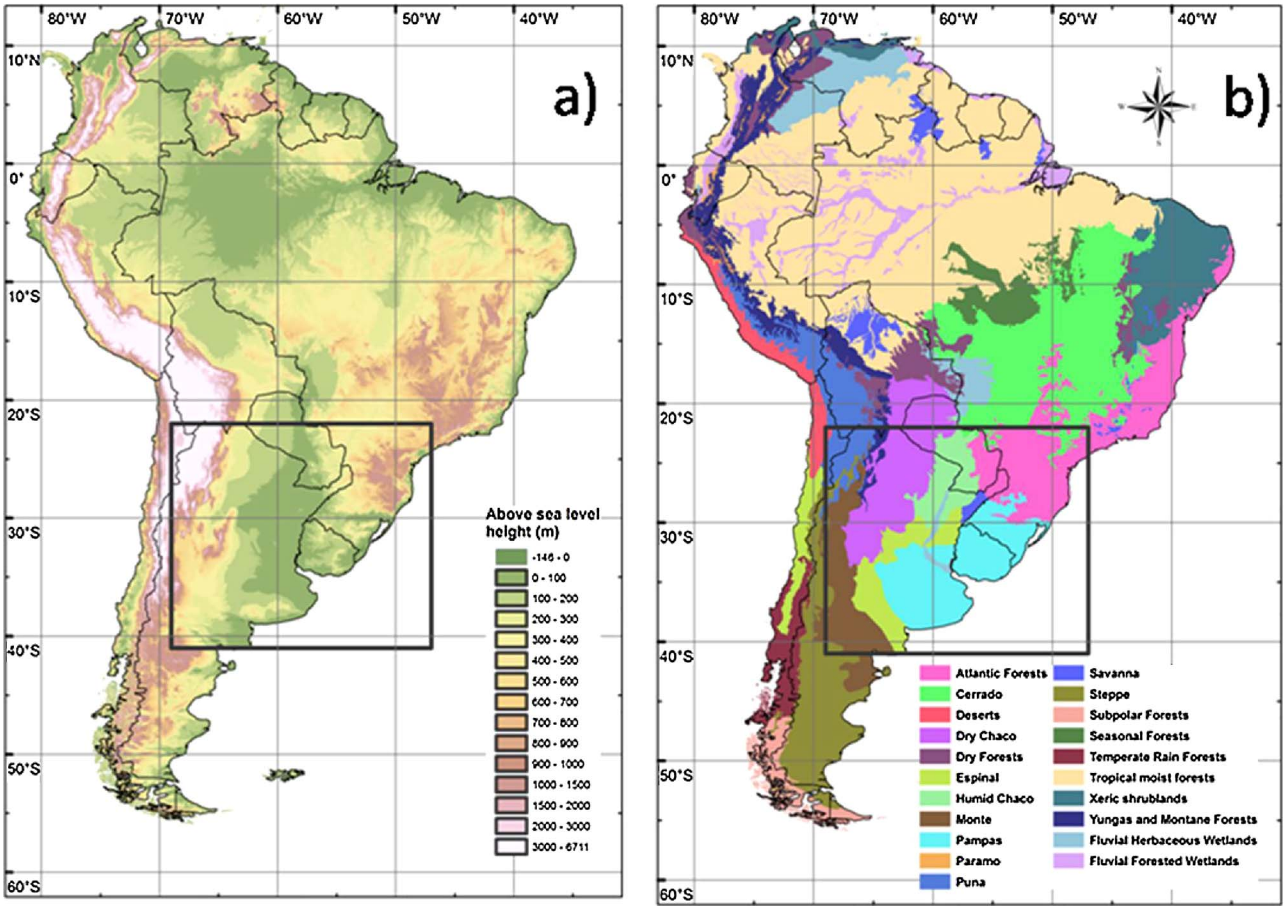

Fig. 1. a) Topography and b) Ecoregions over South America. Black box denotes SESA region. Topography data: 30 s conditioned DEM from HydroSHEDS (Lehner et al., 2006). Ecoregions have been modified from Terrestrial Ecosystems of the World (TEOW, Olson et al., 2001).

water and energy balances to complex biogeochemical interactions and dynamic vegetation (Sato et al., 2015). The atmospheric input to the LSM usually comes from an atmospheric model (coupled mode) or observations (uncoupled mode). Surface SM is among the most complex hydrologic variables to simulate as it interacts with the atmosphere, plant canopy and roots, and vadose zone (Du et al., 2016). In this sense, the main limitations of LSMs are related to uncertainties in the representation of the land surface information like vegetation (e.g. greenness fraction, leaf area index, stomatal resistance), land cover (e.g. surface roughness, albedo, emissivity) and soil-types (texture).

Climate and weather/seasonal forecasts are performed by numerical models that consist of physical equations that describe the components of the climate system and their interactions (Stensrud, 2007). In particular, in these numerical models the atmosphere is coupled to a LSM.

Global studies show that for summer, southeastern South America (SESA) is characterized as a water-limited region (Jung et al., 2010) and identified as a L-A interaction hotspot (e.g. Wang et al., 2007; Zeng et al., 2010). Hirschi et al. (2014) and Mueller and Seneviratne (2012) found a negative correlation between SM conditions and the number of hot days of the warmest month, thus highlighting the strong L-A interaction over the region of SESA.

Several continental-scale studies also found L-A hotspots over SESA, using different variables, models and statistical approaches. Among them, Sörensson and Menéndez (2011) found that the main summer hotspot of both evapotranspiration and precipitation is located within SESA using ad-hoc experiments to isolate the influence of SM on atmospheric variables. The same methodology was used in Ruscica et al. (2015), showing that coupling is stronger during anomalously dry summers. Studies using various statistical approaches applied to different datasets found strong L-A interaction in the same region (e.g. Spennemann and Saulo, 2015; Ruscica et al., 2016).

The scarcity of in-situ SM observation networks hinders a validation at regional scales, particularly in South America (https://ismn.geo.tuwien.ac.at/networks/). Alternatively, the recent availability of land surface variables −like SM- derived from multiple remote sensing products, allows the evaluation of L-A interaction based on simulations at global scale (Ferguson et al., 2012; Hirschi et al., 2014; Gallego-Elvira et al., 2016). The instruments operating in the microwave portion of the spectrum have received attention because this frequency range has the unique ability to return information on media (atmosphere, vegetation, soil) that are opaque to shorter visible/near-infrared and thermal wavelength and because microwave scattering and emission are directly related to the water content of the target. In particular, remote sensing from active and passive microwave sensors have demonstrated to be good and flexible tools for observing the SM content of the first centimeters of soil and for detecting its spatial and temporal variations from radar (e.g. Barret et al., 2009; Notarnicola et al., 2006) and radiometric microwave sensors (e.g. Jackson, 1993; Mladenova et al., 2014).

Satellite-derived SM products have benefited from ongoing improvements in the instrument and retrieval algorithm. Currently, several global SM products have become available (Sakai et al., 2016). The availability of in-situ SM observations to validate the products has also significantly increased, but mainly in the northern hemisphere (Dorigo et al., 2011).

Motivated by evidences of climate models that point out SESA as a L-A hotspot and by the availability of consistent time series of satellite products, this study aims at answering the following questions: 1) Do satellite estimations reproduce the terrestrial segment of the modelled summer L-A interaction over SESA? 2) Is this interaction enhanced or