Moisture Recycling in the Andes of Colombia

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Abstract

Evapotranspiration from land surface and vegetation plays an important role as a source of precipitation at continental scale in South America, and more so over the Andes cordillera. We evaluate the local recycling of moisture in a complex orography region located in the Central Andes of Colombia (CAC; 4.5N to 7.5N, 78.6W to 71.4W), comprising the East, Central and West Andean ranges and the two inter-Andean valleys of the Magdalena and Cauca Rivers. To this end, we apply the offline atmospheric moisture tracking model, WAM-2layers (Water Accounting Model-2layers). The model input data comes from the ERA-Interim Reanalysis spanning the period 1980-2016 and at 0.125 x 0.125 degrees resolution. We estimate the spatial distribution of the evaporation recycling ratio εc (source moisture zones) and the precipitation recycling ratio ρc (sink moisture zones) at annual and seasonal timescales. According with our results, up to 63% of the average annual evapotranspiration returns as local precipitation in the CAC. Some specific zones of the Western Cordillera and the eastern hillside of the Central Cordillera are "hot spots" for local moisture recycling given the high values of both εc and ρc. At seasonal timescales, there is more activity of the identified source moisture zones during March-April-May (MAM) and June-July-August (JJA). The higher moisture recycling activity in those seasons interconnects two source regions of moisture: the eastern piedmont of the Eastern Cordillera with the eastern piedmont of the Central Cordillera. Both piedmonts also show high intensity rainfall rates. Finally, our work confirms the fundamental role of local recycled moisture to enhance the midnight and early morning peak of the diurnal cycle of precipitation in the CAC during JJA.

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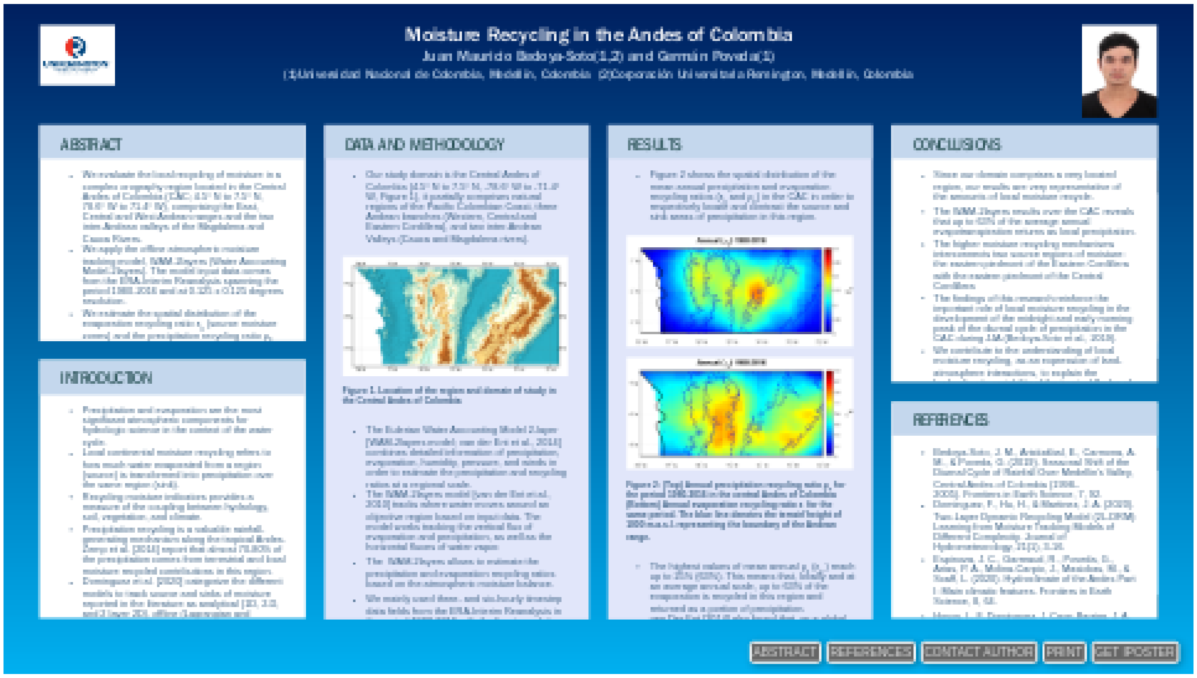

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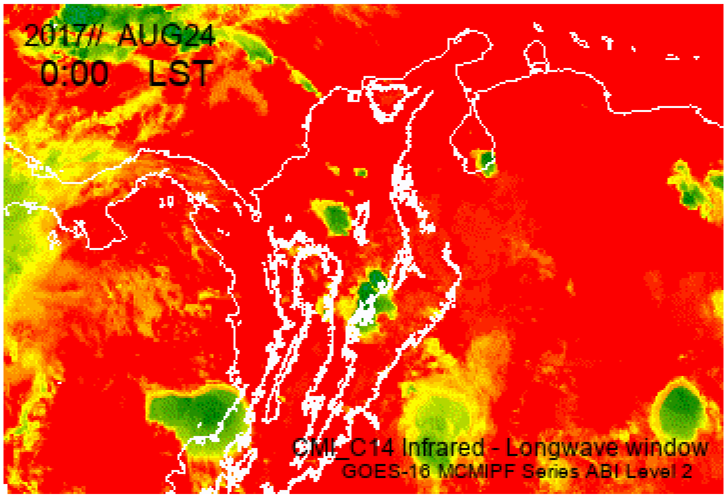
MOTIVATION



- Looking for pieces of evidence supporting the hypothesis proposed by Bedoya et al. [2019] on the influence of local moisture recycling in the night and early morning peak of the diurnal cycle of rainfall over the Aburrá Valley.
- They proposed that this local moisture recycling is originated from evaporation advected from the bottom of the Magdalena River Valley.
- Satellite imagery from GOES-R shows the influence of local evaporative sources coming from the bottom of the Magdalena Valley in the midnight and early-morning rainfall over to the Aburrá Valley during the J-J-A season.
- Evidence in form of animations of band 14 (IR-Longwave Window) for the hourly time spanning the period 24-26 of August 2017 identify the formation of clouds over the lowlands of the Magdalena Valley, which move later to the Central Andes.

INTRODUCTION

- Precipitation and evaporation are the most significant atmospheric components for hydrologic science in the context of the water cycle.
- Local continental moisture recycling refers to how much water evaporated from a region (source) is transformed into precipitation over the same region (sink).
- Recycling moisture indicators provides a measure of the coupling between hydrology, soil, vegetation, and climate.
- Precipitation recycling is a valuable rainfall-generating mechanism along the tropical Andes. Zemp et al. [2014] report that almost 70-80% of the precipitation comes from terrestrial and local moisture recycled contributions in this region.
- Dominguez et al. [2020] categorize the different models to track source and sinks of moisture reported in the literature as analytical (1D, 2-D, and 2 layer 2D), offline (Lagrangian and Eulerian), and online (Global and Regional).
- Moisture recycling also evidences that forests play a key role in preserving the current fluxes rates in the terrestrial water cycle. This fact indicates that the increasing rates of deforestation over the Andes of Colombia turn into an underlying factor influencing the spatiotemporal patterns of precipitation [Keys et al., 2016; Hoyos et al., 2017; Poveda, 2020].
- Keys and Wang-Erlandsson [2018] consider the connections between moisture recycling, deforestation, and social dynamics.
- On this basis, understanding the land-atmosphere interactions expressed as moisture recycling reveals the considerable socio-economical and environmental impacts of deforestation.

DATA AND METHODS

- Our study domain is the Central Andes of Colombia -**CAC**- (4.5° N to 7.5° N, -78.6° W to -71.4° W, Figure 1), it partially comprises natural regions of the Pacific Colombian Coast, three Andean branches (Western, Central and Eastern Cordillera), and two inter-Andean Valleys (Cauca and Magdalena rivers).

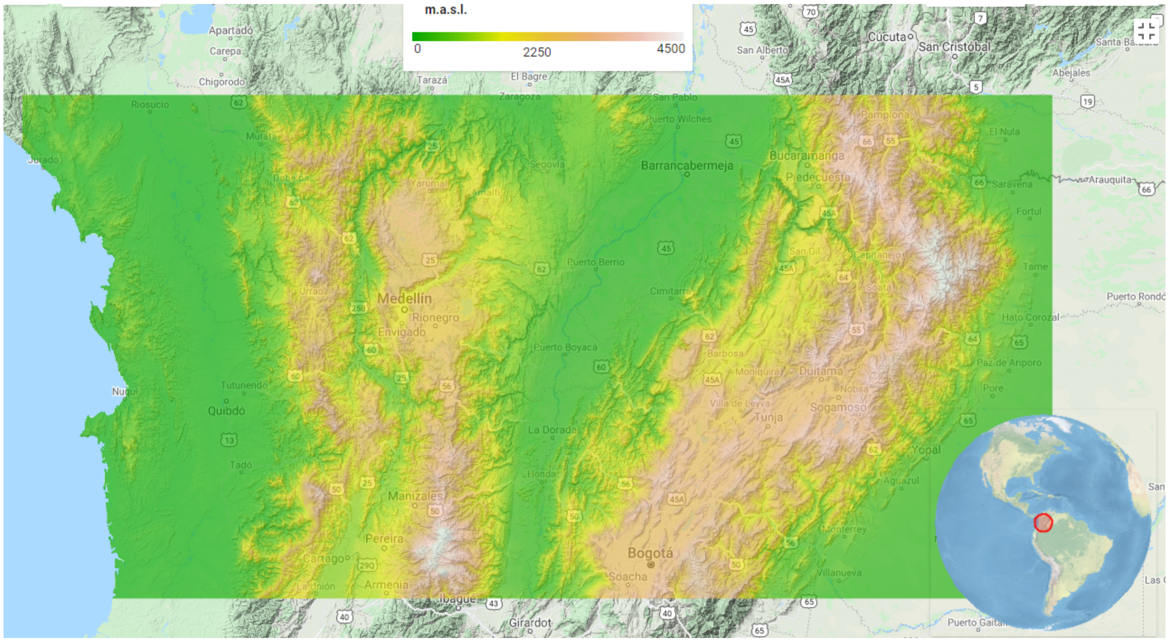


Figure 1. Location of the region and domain of study in the Central Andes of Colombia (CAC)

- The Eulerian Water Accounting Model 2-layer [WAM-2layers model; van der Ent et al., 2014] combines detailed information of precipitation, evaporation, humidity, pressure, and winds in order to estimate the precipitation and recycling ratios at a regional scale.
- The WAM-2layers model [van der Ent et al., 2010] tracks where water moves around an objective region based on input data. The model works tracking the vertical flux of evaporation and precipitation, as well as the horizontal fluxes of water vapor.
- The WAM-2layers allows to estimate the precipitation and evaporation recycling ratios based on the atmospheric moisture balance.
- We mainly used three- and six-hourly timestep data fields from the ERA-Interim Reanalysis in the period 1980-2016 with the finest resolution scale of 0.125° x 0.125°, that is, the interpolated version of the original 0.75 x 0.75 resolution [Dee et al., 2011].
- Table 1 shows the implemented data:

Surface variables			
Parameter name	**Acronym**	**Temporal resolution**	**Spatial Resolution**
Precipitation	P	3-hour time step	0.125° x 0.125°
Evaporation	E		
Total column water	TCW	6-hour time step	
Total column of water vapor	TCWV		
Vertical integral of eastward water vapor flux	EWVF		
Vertical integral of eastward cloud liquid water flux	ECLWF		
Vertical integral of northward cloud frozen water flux	ECFWF		
Vertical integral of northward water vapor flux	NWVF		
Vertical integral of northward cloud liquid water flux	NCLWF		
Vertical integral of northward cloud frozen water flux	NCFWF		
Surface pressure	p_s		
Pressure levels variables			
Specific Humidity	q	6-hour timestep	0.125° x 0.125°
Zonal wind	u		
Meridional wind	v		

- We used this finest resolution to overcome the issue that our spatial domain covers a highly heterogenous variety of heights and land-cover features.
- Over a delimited study region (control volume), ρ_c quantify the portion of the total precipitation that is recycled from evaporation sources in the same area (forward tracking moisture). High values of ρ_c represent the sink regions of moisture that comes from the evapotranspiration.
- ε_c is the proportion of evapotranspiration converted to precipitation on the defined region (backward tracking moisture). High values of ε_c indicate the source regions of moisture that contribute directly to the precipitation.

SPATIAL DISTRIBUTION OF THE MEAN ANNUAL RECYCLING RATIOS

- Figure 2 shows the spatial distribution of the mean annual precipitation and evaporation recycling ratios (ε_c and ρ_c) in the CAC in order to respectively locate and contrast the source and sink areas of precipitation in this region.

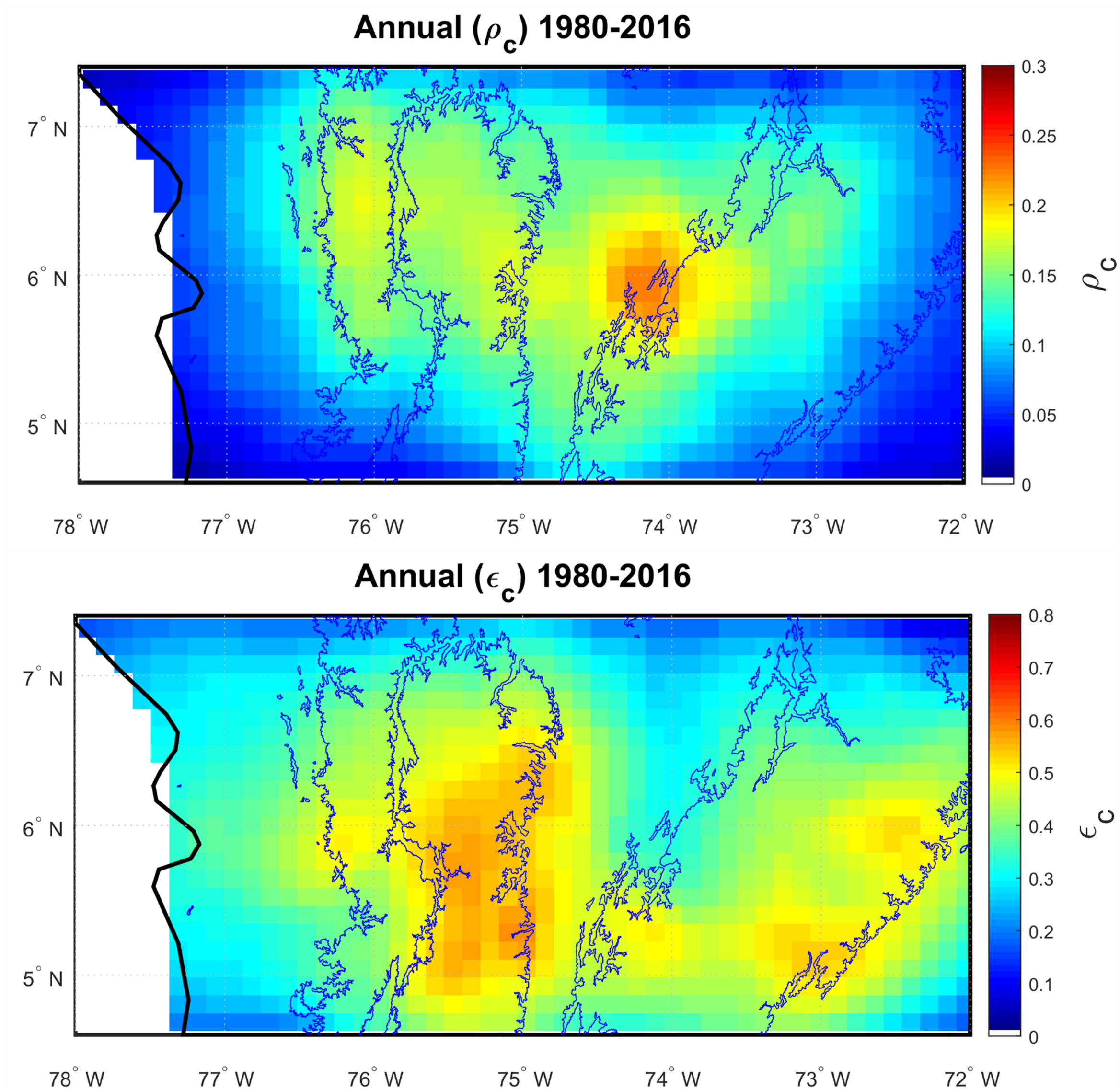


Figure 2: (Top) Annual precipitation recycling ratio ρ_c for the period 1980-2016 in the Central Andes of Colombia (Bottom) Annual evaporation recycling ratio ε_c for the same period. The blue line denotes the terrain height of 1000 m.a.s.l. representing the boundary of the Andean range.

- The highest values of mean annual ρ_c (ε_c) reach up to 25% (63%). This means that, locally and at an average annual scale, up to 63% of the evaporation is recycled in this region and returned as a portion of precipitation.
- van Der Ent [2014] also found that, on a global scale, the evaporation recycling ratio is higher than the precipitation recycling ratio.
- Spatially, the Western Cordillera and a focus area around 6N, -75.8W in the western piedmont of the eastern cordillera constitute the main sink local area of precipitation in the CAC (Figure 2 Top).
- Also, the Central Cordillera plays an important role as the major source zone of local humidity in association with the west side of the Magdalena River Valley.
- Another significant moisture source zone is located in the eastern piedmont of the easternmost Andean branch of the Andes (Figure 2 Bottom).
- These piedmonts also show high total rain rates although most of this rain is due to advected moisture by the trade winds that are lifted up by the orography of the Andean Cordilleras [Espinoza et al., 2020].

- Is important to note that the evaluated portion of the Western Cordillera works as a ‘hot spot’ of moisture recycling because both ρ_c and ε_c are high.

YEAR TO YEAR AND SEASONAL VARIABILITY OF RECYCLING RATIOS

- Figure 3 depicts the year to year series of precipitation and evaporation recycling ratios averaged over the study region of the CAC separated by seasons.

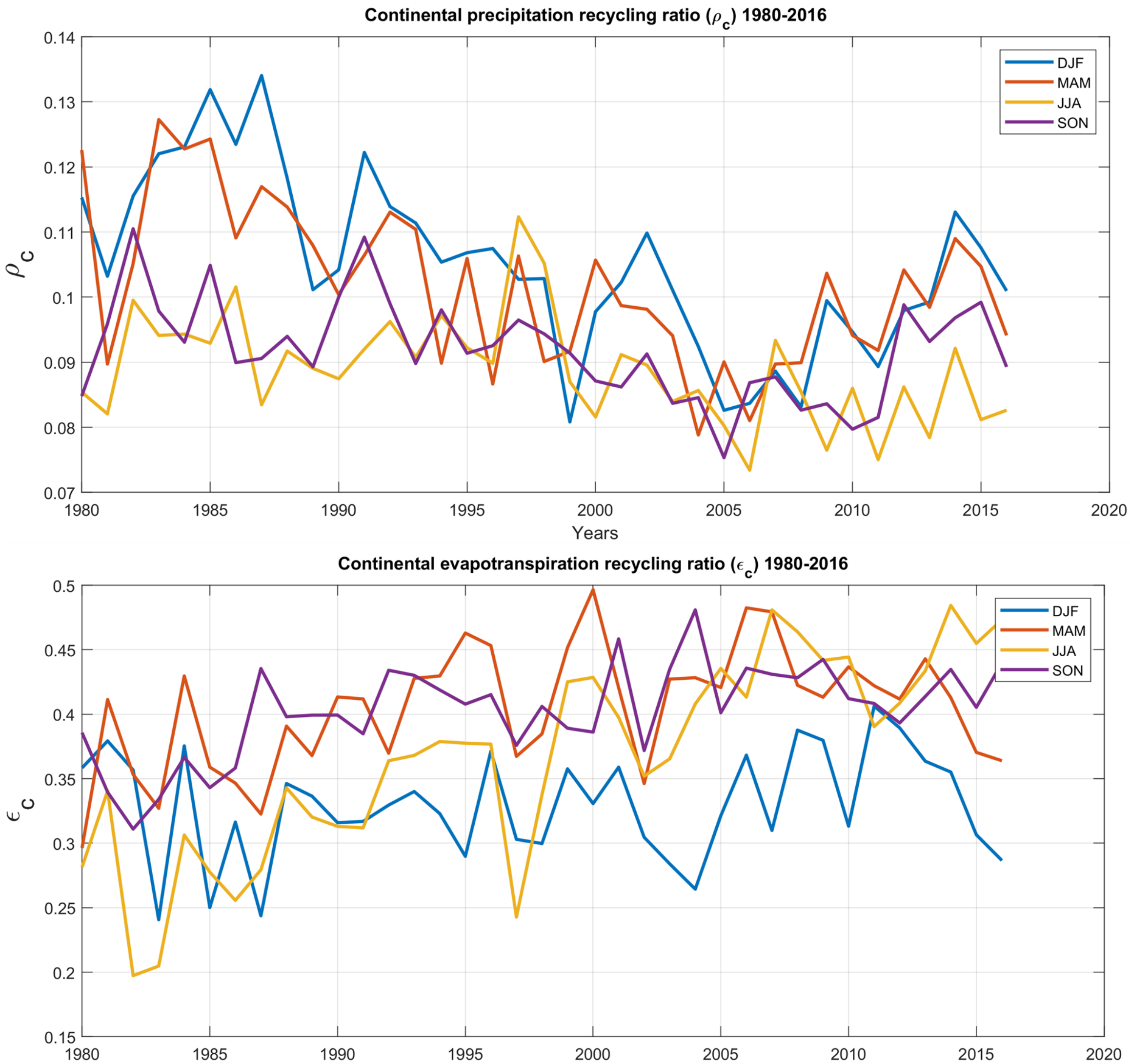


Figure 3: Year to year variability of the zonal-averaged evaporation, ε_c, (top) and precipitation, ρ_c, (bottom) recycling ratio over the CAC in the seasons DJF, MAM, JJA and SON

- Figure 3 reveals that the mean seasonal evaporation (precipitation) recycling ratio ranges between 20 % and 45 % (8 % and 13 %) over the region. Also, the highest values of ε_c in these years coincide with the wet seasons of the average annual cycle of rainfall in the region (MAM and SON).
- Hoyos et al. [2017] found a similar pattern but over the entire NOSA region. Likewise, the lowest activity of ε_c coincides with the dry seasons of the annual rainfall cycle (JJA and DJF).
- Our study provides evidence of two coherent long-term tendencies: as the evaporation recycling ratio is increasing over the region the precipitation ratio is decreasing (Figure 3).
- This means that although the amount of local moisture available for precipitation is rising, this moisture is really going out from the CAC.
- The dynamic of local moisture recycling is changing according to the shifting of land-cover and increasing rates of deforestation in the Andes of Colombia (Poveda, 2020).

CONCLUSIONS

- Since our domain comprises a very located region, our results are very representative of the amounts of local moisture recycle.

- The WAM-2layers results over the CAC reveals that up to 63% of the average annual evapotranspiration returns as local precipitation.
- The higher moisture recycling mechanisms interconnects two source regions of moisture: the eastern piedmont of the Eastern Cordillera with the eastern piedmont of the Central Cordillera
- The findings of this research reinforce the important role of local moisture recycling in the development of the midnight and early morning peak of the diurnal cycle of precipitation in the CAC during J-J-A (Bedoya-Soto et al., 2019).
- We contribute to the understanding of local moisture recycling, as an expression of land-atmosphere interactions, to explain the hydroclimatic variability of the tropical Andes of Colombia in space and time.

ABSTRACT

Evapotranspiration from land surface and vegetation plays an important role as a source of precipitation at continental scale in South America, and more so over the Andes cordillera. We evaluate the local recycling of moisture in a complex orography region located in the Central Andes of Colombia (CAC; 4.5° N to 7.5° N, 78.6° W to 71.4° W), comprising the East, Central and West Andean ranges and the two inter-Andean valleys of the Magdalena and Cauca Rivers. To this end, we apply the offline atmospheric moisture tracking model, WAM-2layers (Water Accounting Model-2layers). The model input data comes from the ERA-Interim Reanalysis spanning the period 1980-2016 and at 0.125 x 0.125 degrees resolution. We estimate the spatial distribution of the evaporation recycling ratio ε_c (source moisture zones) and the precipitation recycling ratio ρ_c (sink moisture zones) at annual and seasonal timescales. According with our results, up to 63% of the average annual evapotranspiration returns as local precipitation in the CAC. Some specific zones of the Western Cordillera and the eastern hillside of the Central Cordillera are “hot spots” for local moisture recycling given the high values of both ε_c and ρ_c. At seasonal timescales, there is more activity of the identified source moisture zones during March-April-May (MAM) and June-July-August (JJA). The higher moisture recycling activity in those seasons interconnects two source regions of moisture: the eastern piedmont of the Eastern Cordillera with the eastern piedmont of the Central Cordillera. Both piedmonts also show high intensity rainfall rates. Finally, our work confirms the fundamental role of local recycled moisture to enhance the midnight and early morning peak of the diurnal cycle of precipitation in the CAC during JJA.

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