Atmos. Chem. Phys. Discuss., 14, C6779–C6789, 2014
www.atmos-chem-phys-discuss.net/14/C6779/2014/

Atmospheric Chemistry and Physics
Open Access
Discussions

Interactive comment on "On the importance of cascading moisture recycling in South America" *by* D. C. Zemp et al.

D. C. Zemp et al.

delphine.zemp@pik-potsdam.de

Received and published: 9 September 2014

Below you find a point-by-point response to the comments of the referee #2. Excerpts from the referee's report have been marked in bold.

This paper discusses the recycling ration in the Amazon using a complex network approach. The problem is clearly important and the approach interesting. However, it is not clear to me what new results are really obtained (besides a fancy display of complex network terminology) nor whether these results are robust. I urge the authors to rewrite the papers using a description which is easier to read and follow for the readers of ACP, as well as address the following points:

We thank the referee for this comment. We agree with the referee that the description might be a little confused for readers who are not familiar with the concepts. In the revised manuscript, we will put effort to systematically use a terminology carefully defined in the introduction (e.g., cascading moisture recycling (CMR), direct moisture recycling (DMR) and re-evaporation cycles). We will also make sure that the description is intuitive and easy to follow with the help of simple schematic representations explaining the concepts and methods. We will also explicitly mention what results and metrics are new.

1. How do the results depend on the resolution (temporal and spatial) of the fields and on the various choices that are adopted in the proposed method?

We thank the referee for this interesting question. We will answer the three points separately.

- Spatial resolution:

The WAM-2layers is based on a 1.5° longitude/latitude spatial resolution in accordance with the grid of the ERA-Interim dataset used previously (van der Ent et al., 2010). We agree with the reviewer that the question of spatial resolution is an important one. In fact, the amount of locally recycled moisture within a grid cell is highly dependent on the spatial resolution of the fields (van der Ent and Savenije, 2011, Fig. 4). However, in our study, the re-evaporation cycles are occurring along the path. In all presented measures we are integrating over all paths contributing to the large-scale moisture transport, hence the resolution does not influence our results. Because the typical length scale of direct links in moisture recycling is larger than 1000 km (c.a. 9 geographical degrees) in the region (van der Ent and Savenije, 2011, Fig. 5), working on a finer resolution would not change significantly our findings. We will mention this explanation in the revised manuscript.

We remind that due to the projections of the data on a fixed latitude/longitude grid, the size of the grids decreases with increasing latitude which might lead to biases in the results. This has been taken into account by correcting the different metrics using a well-established framework (Zemp et al., 2014). This statement has been mentioned in the manuscript.

- Temporal resolution:

In WAM-2layers, the actual moisture tracking is performed on a 0.5-hour basis for numerical stability purposes. The temporal resolution of the input-data corresponds to the smallest one of the available products from ERA-Interim (3-hour time step for evapotranspiration and precipitation and 6-hour time step for the specific humidity, wind speeds and pressure). Because the smallest time step that we can get for the MODIS evapotranspiration data is 8 days, we down-scaled the MODIS dataset to 3-hours resolution using the temporal variability of the evapotranspiration product from ERA-Interim. The output of WAM-2layers is provided on a monthly basis. The time scale of moisture feedback is no longer than 30 days in the studied region (van der Ent and Savenije, 2011, Fig. 5), so the monthly resolution is reasonable to study this process. Our analysis is presented as the seasonal time scale in order to consider the large variability in moisture transport and rainfall in the South American monsoon system. Yearly temporal resolution might be an interesting choice to investigate the role of inter-annual variability (or extreme events) on moisture recycling, but is beyond the scope of this paper. We will make this clear in the revised manuscript.

- Choice adopted in the method:

The WAM-2layers model is an established tool and has been used in a variety of publications focusing on moisture tracking and moisture recycling (e.g. van der Ent et al. (2010); Keys et al. (2012); van der Ent et al. (2014)). The WAM-2layers model is to our knowledge the only model that provides the output needed to perform the analysis of cascading moisture recycling using network techniques as presented in this manuscript. However, as the question does not refer to the WAM-2layers model but to the new network analysis methods presented here, the main methodological choice adopted in our manuscript is about the calculation of the Betweenness Centrality (B) (Sect. 2.5.2) and the threshold used to define the intermediary regions (Sect. 2.4).

For the calculation of the B, we had to remove from the network the long-range moisture transport, i.e., occurring over distances larger than a certain threshold, in order to reveal cascading moisture recycling pathways. In the manuscript, this threshold is set to 15 geographical degrees. The choice of the threshold does not influence the results qualitatively: regions with high B are still located in the south-western part of the Amazon region and east of the subtropical Andes (Supp.Fig.1).

The value of $\Delta Pm/P$ represents the fraction of total moisture inflow that comes from CMR in the intermediary region. It is of course dependent on the underlying definition of the intermediary regions. We choose to define the intermediary region as the regions which have a value of $\Delta Ec/E$ larger than the 80 percentile. For better transparency in the revised manuscript, we propose to highlight the corresponding region in Figs. 5b and 5d and to refer to these figures when the intermediary regions are mentioned.

2. Is the cascading recycling ratio robustly defined? Can the authors provide examples (synthetic examples) where the method can recover what was put in?

We thank the referee for this question and suggestion. In order to test the robustness of the (direct and indirect) precipitation recycling ratios, we have computed the steps explained in Sect. A1 and A2.1 with Ω being the ocean. Thus, ρ_o is the fraction of precipitation that comes from the ocean without any re-evaporation cycle on the way and $\rho_o^{(k)}$ is the fraction of precipitation that comes from the ocean with k re-evaporation cycle(s) on the way ($k = 1, ...n$) (see Suppl.Fig.2). We confirm that:

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

- The sum $\rho_o + \rho_o^{(1)} + \rho_o^{(2)} + ... + \rho_o^{(n)}$ is equal to 1. This is easy to interpret as all the precipitation in a location must always have been come from the ocean (either directly or after a certain number of re-evaporation cycles).
- The sum $\rho_o^{(1)} + \rho_o^{(2)} + ... + \rho_o^{(n)}$ represents the fraction of precipitation that comes from the ocean with at least 1 re-evaporation cycle. It is equal to the continental recycling ratio ρ_c (see Sect. 2.3.1 and van der Ent et al. (2010)).
- The sum $\rho_o^{(2)} + ... + \rho_o^{(n)}$ is the fraction of precipitation that comes from the ocean with at least 2 re-evaporation cycles (see Suppl. Fig. **??**). It is equal to $\Delta P/P$, introduced in the manuscript as the fraction precipitation that has been evaporated at least twice on the continent (see Sect. 2.4).

We obtained thus the same results using different metrics. We hope that this is a convincing argument to justify the robustness of the cascading recycling ratio and we will mention it in the revised manuscript.

We can not test the evaporation recycling ratio the same way because $\Delta E/E$ quantifies the fraction of evapotranspiration that is involved in cascading moisture recycling (i.e., that comes from the continent and precipitates further over the continent) while $\epsilon_o^{(2)} + ... + \epsilon_o^{(n)}$ would be the fraction of evapotranspiration that runs through at least 2 re-evaporation cycles before precipitating over the ocean. This is also the reason why the two methodologies are needed even if they lead to the same results for the previous mentioned case. We will make this clear in the revised manuscript.

3. What are the error bars on the estimates provided in the paper?

We thank the referee for this relevant question. Our estimates are of course subject to errors from different sources: (1) the input data, (2) the assumptions made in WAM-2layers van der Ent et al. (2010); van der Ent et al. (2014) and (3) the assumptions made in our analysis (see Sect. 2.2). We think the referees point is very important and we share his concerns. To this end, we reproduced our analysis based on a different dataset to test for the robustness of our results. In addition to previously used datasets (MODIS and TRMM), we will use a merged product based on forty different evapotranspiration data sets derived from observations, calculated via land-surface models and output from reanalysis (LandFlux-Eval (Mueller et al., 2013)), as well as an average of four different observation-based precipitation datasets (CRU (New et al., 2000), GPCC (Huffman et al., 1995; Adler et al., 2003), GPCP (Adler et al., 2003)and CPC (Chen et al., 2008)) for the period 1989-1995. In the revised manuscript, we will provide the results for the two sets of input data side by side and discuss the robustness of our findings in greater detail.

4. What is new which could not be obtained with more standard methods? And what is new, can be tested and believed?

We thank the referee for his questions which helps us to point our the uniqueness of our approach. In most of the previous studies using moisture tagging experiments, moisture from a group of grid cells covering a domain of interest (typically the continent) is tracked simultaneously until it precipitates or leaves the domain. Here, we track moisture evaporating from each grid cell covering the domain (i.e., the South American continent) individually. By doing so, we are able to diagnose for each grid cell the amount of evaporating moisture that precipitates in any other cell, i.e, to build a moisture recycling network. This approach enables us to focus on cascading moisture recycling. We will mention this explicitly in the revised manuscript.

We know only two previous studies dealing with the importance of cascading moisture recycling using a different methodology (Numaguti, 1999; Goessling and Reick, 2013). Dividing the world in source and origin regions and adding different tracers in a tagging experiment within an atmospheric general circulation model, the authors

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

counted the number of re-evaporation cycles that moisture experience on the way from the ocean until a specific location. The author also provided results on moisture recycling between some source - destination pairs (Numaguti, 1999, Fig.4). Nevertheless, we argue that the notion of intermediary regions in moisture recycling has never been introduced and the share of the CMR to the total moisture inflow (precipitation) and outflow (evapotranspiration) has never been quantified. Furthermore, the approach followed by (Numaguti, 1999; Goessling and Reick, 2013) is based on the full diagnostics provided by a general circulation model and can not be applied to observed-based data as it is done here. This explanation will be mentioned in the revised manuscript.

In addition, we further develop the well-known concept of recycling ratios (van der Ent et al., 2010; Keys et al., 2012; Eltahir and Bras, 1994; Trenberth, 1999; Bosilovich and Chern, 2006; Dirmeyer et al., 2009; Bagley et al., 2014) (called DMR ratios in our manuscript) defined as the fraction of precipitation coming from a specific location (or the fraction of evapotranspiration precipitating over a specific location) without any re-evaporation cycle on the way. We extend this definition to take into account the transport of moisture with re-evaporation cycles (called CMR ratios in our manuscript). This enables to highlight further backward (or forward) the origin (or destination) of moisture. Finally, we apply for the first time common complex network measures (betweenness centrality and clustering coefficient) to a moisture recycling network. We will take a special care to explicit what is new in our revised manuscript.

References

Adler, R. F., Huffman, G. J., Chang, A., Ferraro, R., Xie, P. P., Janowiak, J., Rudolf, B., Schneider, U., Curtis, S., Bolvin, D., Gruber, A., Susskind, J., Arkin, P., and Nelkin, E.: The version- 2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979–present), J. Hydrometeorol., 4, 1147– 1167, 2003.

Bagley, J. E., Desai, A. R., Harding, K. J., Snyder, P. K., and Foley, J. A.: Drought and defor-

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

estation: has land cover change influenced recent precipitation extremes in the Amazon?, J. Climate, 27, 345–361, 2014.

Biemans, H., Hutjes, R. W. A., Kabat, P., Strengers, B. J., Gerten, D., and Rost, S.: Effects of Precipitation Uncertainty on Discharge Calculations for Main River Basins, J. Hydrometeorol., 10, 1011–1025, 2009.

Bosilovich, M. G. and Chern, J.-D.: Simulation of water sources and precipitation recycling for the MacKenzie, Mississippi, and Amazon River basins, J. Hydrometeorol., 7, 312–329, 2006.

Chen, M. Y., Shi,W., Xie, P. P., Silva, V. B. S., Kousky, V. E., Higgins, R.W., and Janowiak, J. E.: Assessing objective techniques for gauge-based analyses of global daily precipitation, J. Geo- phys. Res.-Atmos., 113, D04110, 2008.

Dirmeyer, P. A., Brubaker, K. L., and DelSole, T.: Import and export of atmospheric water vapor between nations, J. Hydrol., 365, 11–22, 2009.

Eltahir, E. A. B. and Bras, R. L.: Precipitation recycling in the Amazon basin, Q. J. Roy. Meteor. Soc., 120, 861–880, 1994.

Goessling, H. F., and Reick, C. H. (2013). Continental moisture recycling as a Poisson process. Hydrol. Earth Syst. Sci., 17, 4133–4142, 2013.

Huffman, G. J., Adler, R. F., Rudolf, B., Schneider, U., and Keehn, P. R.: Global precipitation estimates based on a technique for combining satellite-based estimates, rain-gauge analysis and NWP model precipitation information, J. Climate, 8, 1284–1295, 1995.

Mueller, B., Hirschi, M., Jimenez, C., Ciais, P., Dirmeyer, P. A., Dolman, A. J.,Fisher, J. B., Jung, M., Ludwig, F., Maignan, F., Miralles, D. G., McCabe, M. F., Reichstein, M., Sheffield, J., Wang, K., Wood, E. F., Zhang, Y. and Seneviratne, S. I.: Benchmark products for land evapotranspiration: LandFlux-EVAL multi-data set synthesis., Hydrol. Earth Syst. Sc., 17, 3707 – 3720, 2013.

New, M., Hulme, M., and Jones, P.: Representing twentieth-century space-time climate variability. Part II: Development of 1901–96 monthly grids of terrestrial surface climate, J. Climate, 13, 2217–2238, 2000.

Numaguti, A.: Origin and recycling processes of precipitating water over the Eurasian continent: experiments using an atmospheric general circulation model, J. Geophys. Res.-Atmos., 104, 1957–1972, 1999.

Keys, P. W., van der Ent, R. J., Gordon, L. J., Hoff, H., Nikoli, R., and Savenije, H. H. G.: Analyzing precipitationsheds to understand the vulnerability of rainfall dependent regions, Biogeosciences, 9, 733–746, dopi:10.5194/bg-9-733-2012, 2012.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

Trenberth, K. E.: Atmospheric moisture recycling: role of advection and local evaporation, J. Climate, 12, 1368–1381, 1999.

van der Ent, R. J. and Savenije, H. H. G.: Length and time scales of atmospheric moisture recycling, Atmos. Chem. Phys., 11, 1853–1863, doi:10.5194/acp-11-1853-2011, 2011.

van der Ent, R. J., Savenije, H. H. G., Schaefli, B., and Steele-Dunne, S. C.: Origin and fate of atmospheric moisture over continents, Water Resour. Res., 46, W09525, doi:10.1029/2010WR009127, 2010.

van der Ent, R. J., Gordon, L. J., and Savenije, H. H. G.: Contrasting roles of interception and transpiration in the hydrological cycle – Part 1: Simple Terrestrial Evaporation to Atmosphere Model, Earth Syst. Dynam. Discuss., 5, 203–279,doi:10.5194/esdd-5-203-2014, 2014.

Zemp, D. C., Wiedermann, M., Kurths, J., Rammig, A., and Donges, J. F.: Node-weighted measures for complex networks with directed and weighted edges for studying continental moisture recycling, Europhys. Lett.,107, 58005, doi:10.1209/0295-5075/107/58005, 2014.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 17479, 2014.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

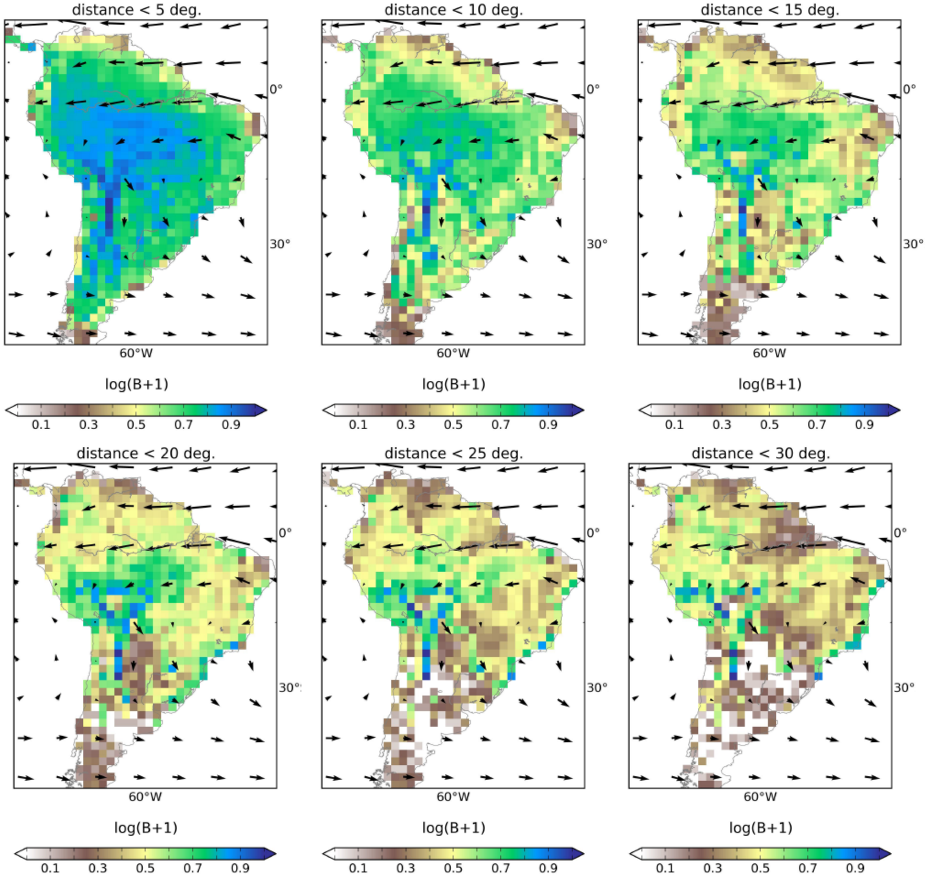
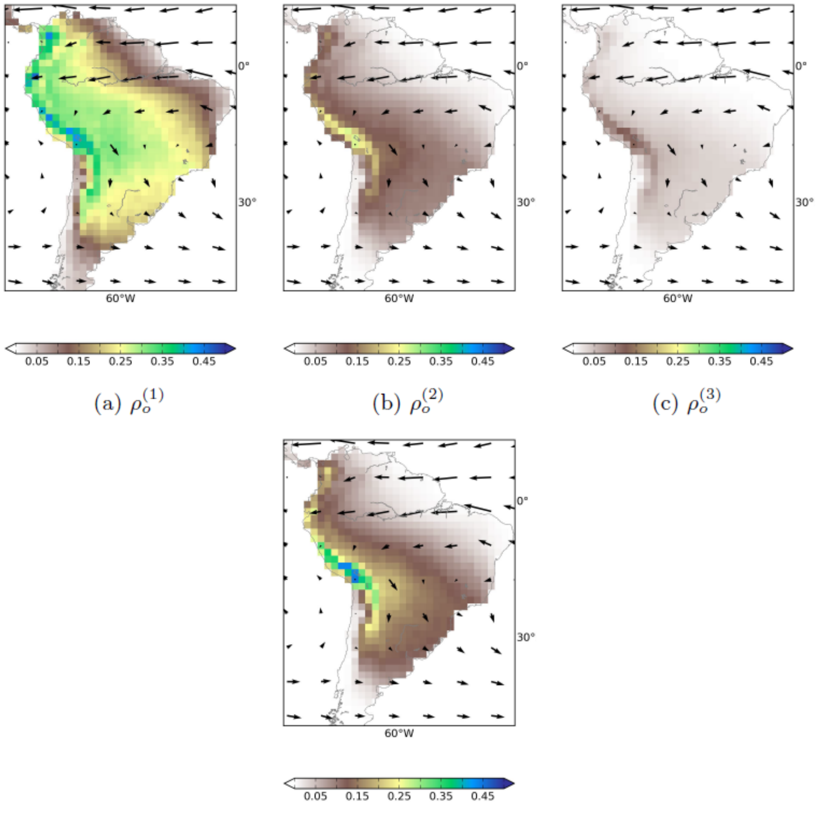


Fig. 1. Betweenness Centrality (B) obtained for different thresholds (yearly average).



(a) $\rho_o^{(1)}$

(b) $\rho_o^{(2)}$

(c) $\rho_o^{(3)}$

(d) $\rho_o^{(2)} + \ldots + \rho_o^{(n)}$

Fig. 2. Steps in the calculation of the cascading recycling ratio computed with the region of interest being the ocean (yearly average).

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper