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Earth System Dynamics
Discussions

Interactive comment on "Recent changes of relative humidity: regional connection with land and ocean processes" *by* Sergio M. Vicente-Serrano et al.

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Anonymous Referee #1 Received and published: 11 July 2017 The paper analyses changes in surface relative humidity (RH) in the last 35 years. It is mostly based on ERA-Interim reanalysis data, but observations (HadISDH) are also considered. The main technique used is a Lagrangian analysis of the moisture source regions. I think the topic is very important, and in scope for Earth System Dynamics. The paper will be a valuable contribution to the field, but in my opinion it requires some revisions.

We really appreciate the careful reading, the comments raised by the reviewer#1 and the positive assessment of the manuscript. Please find below the answers to each

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Discussion paper

comment and if you have any further concerns, please feel free to raise these new comments.

Major Issues 1. My main criticism is that the paper lacks clear conclusions. Section "Discussion and Conclusions" is dominated by a discussion of other relevant studies, with too little effort to distill out what is new. My suggestion is to separate out "Conclusions" to a separate section. There, clearly state what is new, what are the specific conclusions of this study.

We have included a separate section of Conclusions in the revised manuscript:

“The main conclusions of this study are: âĂć There are dominant negative trends of RH and this decrease is mostly linked to the temporal evolution of RH during the boreal warm season. Negative trends do not show homogeneous spatial patterns, and some regions also show positive trends. âĂć There is a high agreement between RH and specific humidity trends at the global scale, suggesting a moisture deficit in large areas to explain RH trends in opposition to atmospheric warming. âĂć In general we found significant correlations between the interannual variability of land evapotranspiration and RH. âĂć There are not correlation between the ratio of the air temperature over the target regions and SST in the source regions and the RH variability. âĂć There is not a significant relationship between the interannual variability of the oceanic evaporation in the oceanic humidity source regions and RH in the target areas.

Given strong relevance of understanding current RH trends at the global scale, further research is still needed to consider other dynamic and radiative factors that may affect the temporal variability and trends of RH over continental regions.”

2. l139-l151: Text and formulas for RH computation:

In this study we followed the formulation used by Willett et al. (2014) for the HadISDH RH dataset. The reason for this is to make better comparable the RH obtained from observations in the HadISDH and the RH obtained from the ERA-Interim dataset. This

has been stated in the revised manuscript.

a. Why is the decision, whether the ice or liquid equilibrium pressure is used, based on the wet bulb temperature (and not, for example, the physical temperature)? Please justify or change.

We took this decision following Willett et al. (2014):

“Where the calculated Tw values are below 0 âÛęC, values of e are recalculated with respect to ice. This assumes that the wet bulb was in fact an ice bulb at that time and that the measurement was taken with a wet bulb thermometer. This potentially introduces a dry bias in q and e when T is near 0 âÛęC. For RH, dry biases could be up to 4 % RH, increasing as Tw rises towards 0 âÛęC.”

In any case, we do not think this may have a key role in the interannual variability and trends of RH. The relationship found among HadISDH and ERA-Interim RH at the annual and seasonal scales is very strong and consistent spatially.

b. There are two different equilibrium pressures to consider, one for liquid water and one for ice. Authors chose to use the ice one for temperatures below 0âÛęC. There is no direct physical reason for this, since there will be large open water areas even at sub-zero air temperature and vice versa. But I guess it is a reasonable first choice if information on the surface itself is not available. However, the authors should be clear about that it is a choice they are making, and not dictated from physics. c. Generally, I find text and forumlas here confusing and outdated. From Eq. 1 it follows simply that RH = 100*e/es(T) = 100*es(Td)/es(T) where RH = relative humidity in percent, e = water vapor partial pressure, T = physical temperature, Td = dewpoint temperature, es() = equilibrium water vapor pressure. So, to calculate RH from Td, all that is needed is a valid parameterisation of es(T). An accepted modern one is given in Murphy, D. M. and T. Koop (2005), Review of the vapour pressures of ice and supercooled water for atmospheric applications, Q. J. R. Meteorol. Soc., 131(608), doi:10.1256/qj.04.94. (They give two different es(T) parameterisations, one for liquid, and one for ice.)

We really appreciate this suggestion. We will consider suggested parametrization for future studies. In this study, as stated above, we decided to follow the exact methodology followed by Willett et al. (2014) to facilitate the comparability between HadISDH (i.e. observed) and ERA-Interim RH (i.e. reanalyzed) datasets.

3. I would like to see an overview figure of the RH mean state and the E-P mean state, before the trends are discussed. Perhaps in the same style as Figure 1, for cold season, warm season, and anual mean. And also a short discussion, along with the figure. This is important to put the changes into perspective. Also, in my understanding the "null hypothesis", based on simple thermodynamic arguments and the simplistic assumption that the circulation does not change, is that the existing E-P pattern is enhanced under global warming. (The "dry gets drier, wet gets wetter paradigm (Held, Isaac M. and Brian J. Soden (2006), Robust Responses of the Hydrological Cycle to Global Warming, J. Climate, 19(21), 5686-5699, doi:10.1175/JCLI3990.1.).)

In the revised manuscript we have included a new figure with the mean RH and the Vertically Integrated Moisture Flux divergence and a short discussion. We have added the maps of the divergence of the Vertically Integrated Moisture Flux (VIMF) using data from Era-Interim instead E-P because, in general terms, VIMF divergence may be used to estimate regions where the precipitation dominates (negative values) over the evaporation (positive values).

“Supplementary Figure 1 shows the average seasonal and annual RH and the Vertically Integrated Moisture Flux (VIMF), which can be used to estimate regions where the precipitation dominates (negative values) over the evaporation (positive values), from the ERA-Interim dataset. RH shows higher average values over equatorial regions, Southeast Asia and the North Eurasia region. The lower values are recorded over tropical regions, mainly in the North Hemisphere. Spatial differences between the cold and warm regions are very low. The annual pattern of the VIFM over continents shows that precipitation exceeds evaporation over the Intertropical Convergence Zone, Southeast Asia and the islands between Pacific and Indian Oceans (Maritime

continent), a great part of South America, Central America, Central Africa, and northward to 40°N in the Northern Hemisphere. Evaporation is higher than precipitation over the main area of Australia, the Pacific coast of North America, Northeast Brazil, areas around Mediterranean Sea, Eastern coast of Africa and southwest Asia. Seasonally, it is evident the poleward movement of the ITCZ during the hemispheric summer, and the change of the pattern over North America and Eurasian continent."

Minor Issues The paper contains some English errors and idiosyncrasies. Example: "On the contrary", used in several places, where I think the authors mean "on the other hand". I recommend a careful proof-reading, preferably by a native speaker.

A careful proof-reading was conducted by a native speaker to avoid English errors.

l47 "water holding capacity": Please replace by "equilibrium amount of water vapor". (Holding capacity is physically wrong, since the air does not "hold" the water vapor in any way. The CC equation describes the equilibrium pressure of water vapor with liquid water.)

Replaced

l49 "could increase": Please replace by "is expected to increase".

Replaced

l83 "there are unavailable studies": Rearrange: "studies...are unavailable"

Replaced

l103 "challengeable" –> "challenging"

Replaced

l239 "moisture support": Perhaps replace by "moisture supply"? (Meaning of support is not clear here.)

Replaced

l277: "positive (E-P) field": I'm confused. Isn't Figure 1 showing just the RH trends? How does the E-P field enter the figure?

This is a mistake that has been solved in the revised manuscript.

l364 "controlled by": I would say "correlated to". How do you know what controls what?

Replaced

l378 [RH has increased] "as a consequence of changes in the continental humidity sources": Why have they increased?

This is detailed in the revised manuscript:

". . .given the positive trend in annual precipitation".

l407 "air temperature and SST ratio" –> "and air temperature to SST ratio"

Replaced

l492 "Thus, although some regions showed positive changes in the oceanic evaporation, the amount of increase was much lower than that found for SST, suggesting a general positive trend in most of the world's oceans (Supplementary Figure 48, Supplementary Table 1)." Confusing. Did you mean: "Thus, although some regions showed positive changes in the oceanic evaporation, the amount of increase was much lower than that found for SST, which suggests that SST changes do not drive evaporation changes (Supplementary Figure 48, Supplementary Table 1)."

Thanks for the suggestion; it matches much better with what is intended to show.

l591 "This finding indicates that while different model experiments fully supported the hypothesis that the different warming rates between oceanic and continental areas can explain the projected decrease in RH under climate change conditions, our results for 14 different regions in the world are contradictory, given that most of these regions exhibited a negative RH trend for 1979- 2014." What is the contradiction? The differential

land sea warming mechanism predicts a decrease of RH over land, and you find a negative RH trend. I'm not sure if this is a language issue, or if there is a fundamental point that I'm missing.

This has been replaced in the revised manuscript:

". . .the different warming rates between oceanic and continental areas can explain the projected decrease in RH under climate change conditions, our results for 14 different regions in the world show a non-clear influence of the air temperature to SST ratio to explain the observed RH trends."

l638 "Hadley Cell" –> "Hadley Cell (HC)"

Replaced

Figure 2: Please add a vertical zero line, so that one can judge whether trends are positive of negative.

The Figure already contains a vertical zero line. Probably it is an effect of the screen visualization.

Figures 6-8: Subplots are too small, titles almost impossible to read for me.

This is an issue for the large number of subplots included in the images but our intention is that these images appear in a full page so we will completely sure that titles are readable in the published manuscript.

Figures 10-11: "Signification" –> "Significance"

Replaced

Finally, we would like to thank the reviewer#1 for his/her effort on reviewing our manuscript and the good inputs suggested to improve it.

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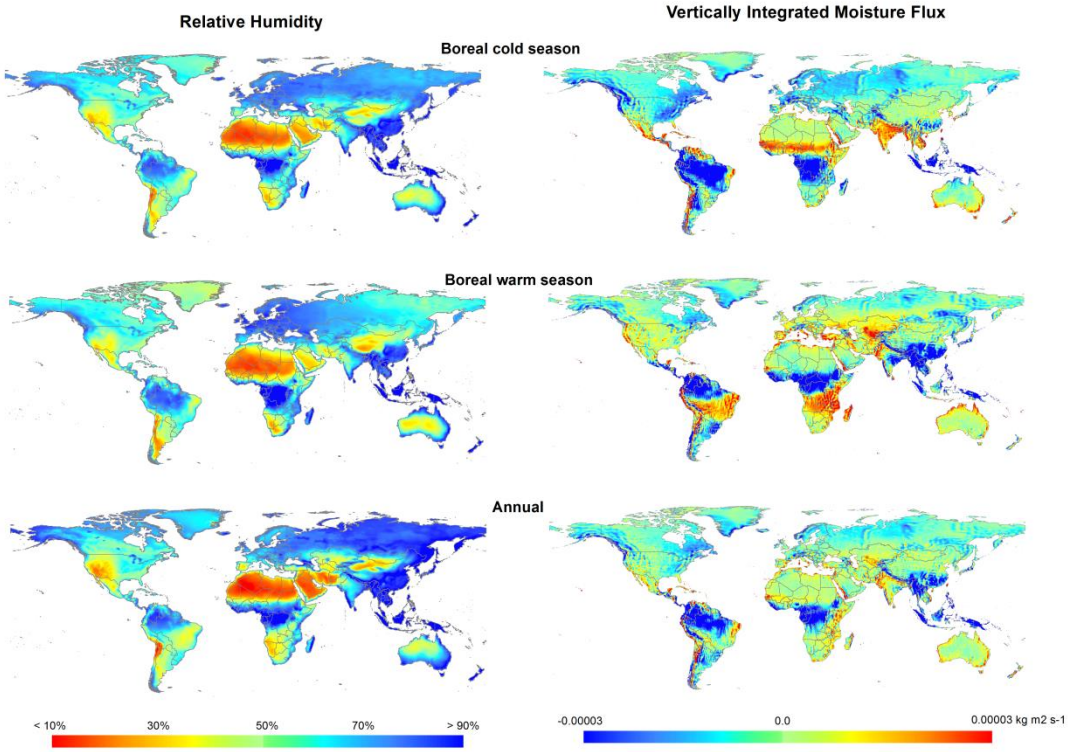

Suppl. Figure 1. Annual and seasonal average RH and Vertically Integrated Moisture Flux (VIMF) from ERA-Interim dataset