

Interactive comment on “HadISDH: an updated land surface specific humidity product for climate monitoring” by K. M. Willett et al.

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Thank you for your very helpful review and support for this work. We have addressed all of your points and feel that the analysis is much improved thanks to your advice. We hope you are happy with the way these points have been dealt with – as described in line below. Changes to text are shown in red. We have changed a few of the figures in addition to comments made by reviewers (e.g., Fig. 5 now shows the ratio of raw to homogenised trends as opposed to difference because this clearly shows gridboxes where the trend is of the same direction vs where the homogenisation has changed the direction of the trend). All amended figures are shown at the end of this report. We have also taken the opportunity to update to the end of 2012 and rectify a problem with the sea level pressure algorithm that became apparent during our revisions (see

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response to reviewer 2 comment #7). This means that all of the figures have been updated and some of the numbers in the text have changed slightly reflecting the extra year of data, the new SLP algorithm and also some retrospective changes to the ISD source database that we have no control over. The issue with retrospective changes is now noted in the text as it was not something we had thought to be an issue before – see text at the end of this response. It has not changed any of the main conclusions of this work.

We have submitted a pdf of responses (including responses to both reviewers, new figures and other changes made to the paper) so that you can see the changes to the text in colour and new figures (which have come out rather poor quality in the pdf conversion). The responses to your review are also pasted below but without colour coding:

Specific comments: (i) The ERA-Interim values plotted in Figure 10 appear to be incorrect. The agreement between ERA-Interim and HadCRUH/HadCRHext is not as good as published in Simmons et al. (2010). The first panel below is extracted from Fig.10 and shows ERA-Interim to lie below the other curves from 1998 onwards. The second panel is my own update of a figure in Simmons et al. (2010). There's finer-scale detail because I plot 12-month running means, not annual means. But the better agreement is clear. It is essential that this discrepancy be resolved. I am of course willing to assist in this.

Initially we plotted the complete coverage for ERA-Interim for all gridboxes that contained any land. As was done in the Simmons et al. paper, applying a spatial match to HadISDH and weighting ERA-Interim gridboxes by their percentage land cover to reduce the ocean influence gives much closer agreement. Both this time series and the full land average are now shown for the globe, Northern Hemisphere, Tropics and Southern Hemisphere. These show clearly the better agreement in the well-sampled Northern Hemisphere. The Southern Hemisphere shows better agreement than may be expected between the complete ERA-land and HadISDH although the small land

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coverage here will be a factor. We note that the complete ERA-land will still likely contain some moderating effect of the oceans and the likely low biased SSTs from 2001 onwards. The new text is as follows:

“For the globally averaged annual time series there is very good agreement between all data-products both in long-term changes and inter-annual behaviour. There are sporadic deviations between the HadCRUH family, HadISDH and Dai which may be due to differences in spatial sampling or the homogenisation applied (none has been applied to Dai). The spatially matched ERA-Interim gives closer agreement with HadISDH, as expected, and agreement deteriorates outside of the well-sampled Northern Hemisphere. As noted in Simmons et al. (2010), a change in SST source ingested into ERA-Interim in 2001 led to a cooler period of SSTs henceforth, which almost certainly will have led to slightly lower surface specific humidity over this period, even over the land. This is apparent in Figure 10a-d. While Dai, HadISDH and all varieties of HadCRUH use the same source data, the methods are independent and station selection differs. ERA-Interim does ingest surface humidity data indirectly through its use for soil moisture adjustment, but also has strong constraints from the 4Dvar atmospheric model and many other data products, so it can be considered independent (Simmons et al., 2010). However, it is not impossible that the ERA-Interim reanalysis and the in situ products may be jointly affected by a contiguous region of poor station quality.”

(ii) The discussion of results needs to be a little deeper. To be sure specific humidity has increased over land since the 1970s, and the El Niño peaks of 1998 and 2010 are noteworthy, and duly noted in the paper. But inspection of the first panel of Fig. 10, as reproduced on the preceding page, shows that apart from the two El Niño peaks, specific humidity over land has not increased since the late 1990s. This should be discussed, and flagged in the Abstract. Moreover, the discussion of warm years is not the correct one, in that the reference in the second sentence of section 5.4 to the warmest years on record refers to global means, not means over land, and specific humidity is presented here as means over land. The evolution of temperature averaged

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over land (12-month running means) is presented below, from CRUTEM4 and ERA-40/Interim. Here 2005 does not provide the highest values, and there is recent warming over land that is not accompanied by rising specific humidity. This is consistent with the fall in relative humidity reported by Simmons et al. (2010), which has continued since that paper was published. The discussion given in section 5.4 needs to be revised.

We have revised this section completely and recognise that we should have compared HadISDH with land temperatures in the first place. We now show the good agreement between HadISDH annual anomalies and those from CRUTEM4 land for the globe, hemispheres and tropics in a new figure (see new figures at end of response). We also show HadSST3 for comparison with the thinking that much of the humidity over land originates from evaporation over the oceans. We also note here that the uncertainty for HadISDH is greatest in the tropics, which is not the case for temperature. We suggest that this is due to greater year-to-year variability here in the specific humidity and due to poorer coverage which dominates the uncertainty estimates. We include a comparison of the two moistest years of 1998 and 2010 with the annual averages from HadCRUT4 but for comparison we also show 2007 which stands out as a warm year in the land record from CRUTEM4 but not an especially moist year for HadISDH and make the point that to have a strong moist signal it depends strongly on when and where the warming occurs. The new text is as follows:

Abstract: “HadISDH is in good agreement with existing land surface humidity products in periods of overlap, and with both land air and sea surface temperature estimates. Widespread moistening is shown over the 1973-2012 period. The largest moistening signals are over the tropics with drying over the subtropics, supporting other evidence of an intensified hydrological cycle over recent years. Moistening is detectable with high (95%) confidence over large-scale averages for the globe, Northern Hemisphere and tropics with trends of 0.089 (0.080 to 0.098) g kg⁻¹ per decade, 0.086 (0.075 to 0.097) g kg⁻¹ per decade and 0.133 (0.119 to 0.148) g kg⁻¹ per decade respectively. These changes are outside the range of uncertainty for the large-scale average which

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is dominated by the spatial coverage component; station and gridbox sampling uncertainty is essentially negligible on large-scales. A very small moistening (0.013 [-0.005 to 0.031] g kg⁻¹ per decade) is found in the Southern Hemisphere but it is not significantly different from zero and uncertainty is large. When globally averaged, 1998 is the moistest year since records began in 1973, closely followed by 2010, two strong El Niño years. The period in between is relatively flat, concurring with previous findings of decreasing relative humidity over land.”

“5.4 Analysis of interannual variability in land surface specific humidity with surface temperature

The strong El Niño events of 1998 and 2010 are clear in the year-to-year variability of the data, these two years being the moistest since the record began in 1973. These were also two of the three warmest years for the globe (combined land air and sea surface temperature) since 1850, the third being 2005 (Sanchez-Lugo et al., 2012). However, the land air temperature, as shown by CRUTEM4 in Figure 13 shows a number of very warm years in the mid-2000s that were not especially moist years. In fact specific humidity over the 2000s, although mostly above the long-term average demonstrates a period of plateauing more akin to global SSTs. For comparison the global SST record from the median of the HadSST3 ensemble is also shown in Figure 13, with the rationale that specific humidity over land is likely to be related to SSTs given that the majority of evaporation occurs over the ocean. Correlations of the detrended annual time series show relatively strong r values (~ 0.8) for both land air and sea surface temperatures with the land specific humidity for all regions except the Southern Hemisphere where the land air/specific humidity lowers to $r=0.54$. The stronger correlation with SSTs is perhaps to be expected here given that the Southern Hemisphere is mostly ocean. The annual average uncertainty estimates are also shown in Figure 13. It is interesting to note that uncertainty is largest in the tropics for specific humidity whereas for land air temperature it is by far the largest in the Southern Hemisphere. This is likely due to the poorer station coverage in the tropics, where year-to-year vari-

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ability in specific humidity is highest.

CRUTEM4, although presenting a different atmospheric component to HadISDH uses a number of the same stations so is not truly independent. However, HadSST3 uses ship and buoy data and so is an independent record. Overall, these relatively high correlations between HadISDH and both temperature records provides further evidence that HadISDH is a reasonable estimate of large-scale land surface specific humidity. The relatively strong relationship with SST may go some way to explaining the recent plateauing in the land specific humidity record, which concurs with the decreasing RH over land found in Simmons et al. (2010). Assuming that the oceans are the major source of surface specific humidity, even over land, it follows that the slower rate of warming over the ocean cannot support evaporation at a rate sufficient to maintain increases in specific humidity in concert with land surface temperatures. This needs further investigation utilising marine surface specific humidity and marine and land RH (currently unavailable) in addition to assessing rates of change over time. This will be addressed further in future papers.

It is clear from Figure 13 that very warm years do not always lead to very moist years. While we may not expect land specific humidity to follow land air temperatures exactly given that SSTs are also an important factor, the 2000s saw warm years both in the land air and sea surface temperature records that did not constitute especially moist years. Annual anomaly maps of HadISDH and HadCRUT4 for the two warm and moist years of 1998 and 2010 are shown in Figure 14 in comparison to 2007, a very warm year over land but not exceptionally moist. It is clear that the main temperature signal in 2007 originates from the high latitudes whereas in the strong El Niño years it is in the lower latitudes. This matches the spatial distribution of high specific humidity anomalies. Following the Clausius-Clapeyron relation, the warmer lower latitudes can drive a much greater increase in moisture for a given rise in temperature, than the cooler higher latitudes. On further investigation (not shown here), the warmth of 2007 was strongest during the boreal winter and over land whereas during the 1998

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and 2010 El Niño years temperature anomalies remained high from the beginning of the year through to boreal summer and featured over both land and ocean. This also helps to explain the enhanced moisture increase in the El Niño years. So, in terms of changes in surface temperature, the 'where' and the 'when' are important factors governing changes in moisture content, and the surface specific humidity record shows a strong influence from the phase of ENSO. However, the correlation of the detrended monthly HadISDH from the tropics and an optimally lagged (at 4 months) Niño 3.4 index derived from HadSST2 (Rayner et al., 2006; provided by John Kennedy) is only approximately 0.54. This suggests the importance of other factors in explaining individual monthly variability. These could be land-sea temperature differences, changes in atmospheric circulation including subsidence of the dry air in descending regions, the vertical structure of temperature anomalies throughout the atmospheric column, and other modes of variability. "

(iii) HadCRUH is a dataset that contains values of both specific and relative humidity. HadISDH is not a complete replacement for it as HadISDH currently provides values of only specific humidity. It is of course pleasing to see it noted on page 5158 that HadISDH paves the way for a relative humidity product, but a bit more explanation could be given as to why one was not produced at the same time as the specific humidity product, as this would have enabled HadCRUH to be superseded. One can understand why this might be, as there are places in the discussion where issues for specific humidity can be put to one side as they are associated with cold regions and low absolute values, which may not be so for relative humidity.

Our initial thinking was to make this paper a 'proof of concept' that the Pairwise Homogenisation test could be used effectively with specific humidity data with a second motivation of trying to get the paper submitted in time for IPCC deadlines of (July 2012). Including RH involved more complex treatment of the measurement uncertainty and also requires some careful thinking in terms of homogenisation to make sure adjustments made to both the RH and specific humidity are physically consistent. We

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didn't want to rush this. As it turns out, it was more important to take the time to do things carefully than rush for the IPCC deadline so we didn't submit until September but including the RH is still another step which would have taken considerably more time. We have improved the discussion of this as follows:

End of Introduction: "HadCRUH also included relative humidity. We intend to include relative humidity and other related variables into HadISDH at a later date. This will involve the development of measurement uncertainty estimates specific to each variable and ensuring consistency across all variables after application of homogenisation procedures. Given that both of these are novel ventures it was felt that they could be dealt with more thoroughly in a separate paper. "

(iv) Page 5138, last line: There is a spurious "to" at the beginning of the line.

Now removed – thanks.

(v) Page 5140, line 15: "Instrumentation" could be changed to "measurement", as "instrumental" appears earlier in the line.

Good point – thanks.

(vi) Page 5156, line 5. ERA-Interim is largely independent, though if Td measurements were to be systematically and persistently biased over a significant region by a rather small amount, is there not a risk that this could creep into both ERA-Interim and HadISDH, notwithstanding the sophistication of the latter's various checks on the data?

There is a chance of a spatially consistent bias being present in both HadISDH and ERA-Interim. This paper focuses on the large scale features but we hope that later papers will explore the spatial detail of HadISDH and other products including other variables that are physically related to humidity (e.g., temperature, total column water vapour, etc.). We have amended the text to make this caveat clear as follows:

"For the globally averaged annual time series there is very good agreement between all data-products both in long-term changes and inter-annual behaviour. There are spo-

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radic deviations between the HadCRUH family, HadISDH and Dai which may be due to differences in spatial sampling or the homogenisation applied (none has been applied to Dai). The spatially matched ERA-Interim gives closer agreement with HadISDH, as expected, and agreement deteriorates outside of the well-sampled Northern Hemisphere. As noted in Simmons et al. (2010), a change in SST source ingested into ERA-Interim in 2001 led to a cooler period of SSTs henceforth, which almost certainly will have led to slightly lower surface specific humidity over this period, even over the land. This is apparent in Figure 10a-d. While Dai, HadISDH and all varieties of HadCRUH use the same source data, the methods are independent and station selection differs. ERA-Interim does ingest surface humidity data indirectly through its use for soil moisture adjustment, but also has strong constraints from the 4Dvar atmospheric model and many other data products, so it can be considered independent (Simmons et al., 2010). However, it is not impossible that the ERA-Interim reanalysis and the in situ products may be jointly affected by a contiguous region of poor station quality.”

(vii) Page 5159, line 2007. Perhaps some words such as “, and it provides an important [a much-needed][a vital] complement to the reanalysis data that have provided monitoring since then.” could be added after “2007”.

We agree that this is useful additional text and have added the following:

“and it provides a valuable complement to the reanalysis data that have provided monitoring since then.”

Please also note the supplement to this comment:

<http://www.clim-past-discuss.net/8/C3467/2013/cpd-8-C3467-2013-supplement.pdf>

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