Differences in modelled and observed near-surface relative humidity (RH)

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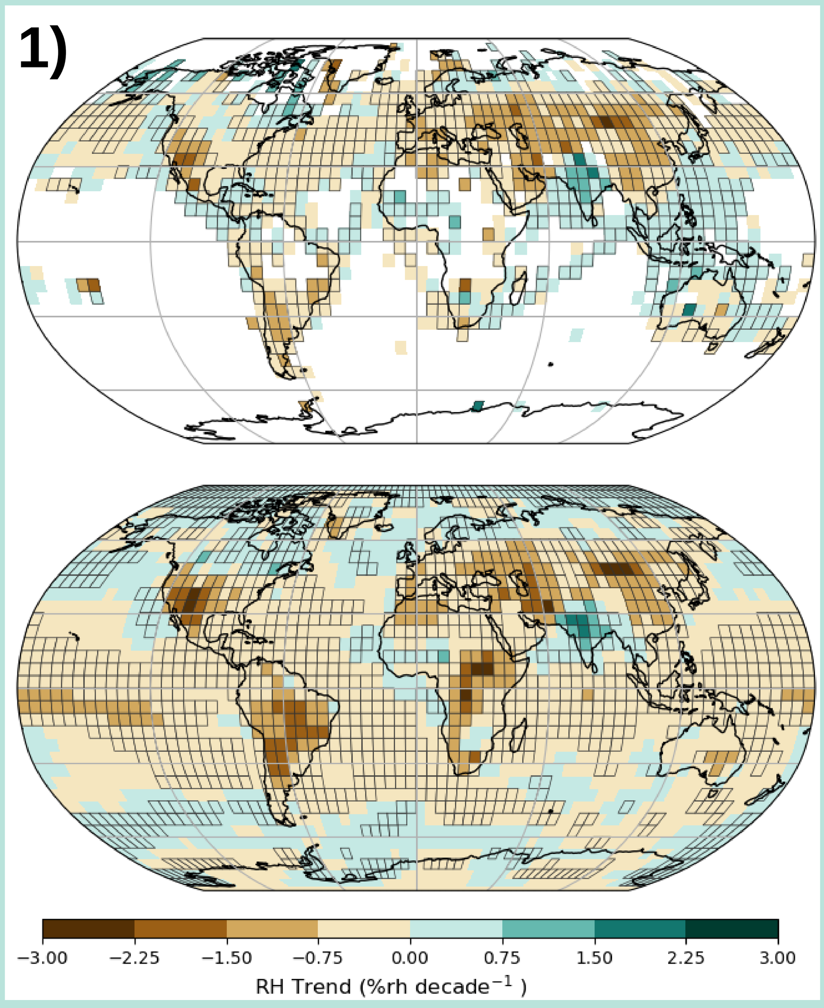
Observed near-surface RH is generally decreasing. Over land this is reasonably well understood, but over ocean such a decrease is surprising. ERA5, which does not assimilate in-situ near-surface ocean humidity or temperature, also shows a decrease over oceans.

Figure 1. Decadal trends in RH from 1982 to 2023 from (top) HadISDH (Willett et al., 2020; www.metoffice.gov.uk/hadobs/hadisdh/ version blend.1.6.0.2023f which combines land.4.6.0.2023f and marine.1.6.0.2023f used hereafter) and (bottom) ERA5 (Hersbach et al., 2020). Gridboxes with black boundaries identify significant trends.



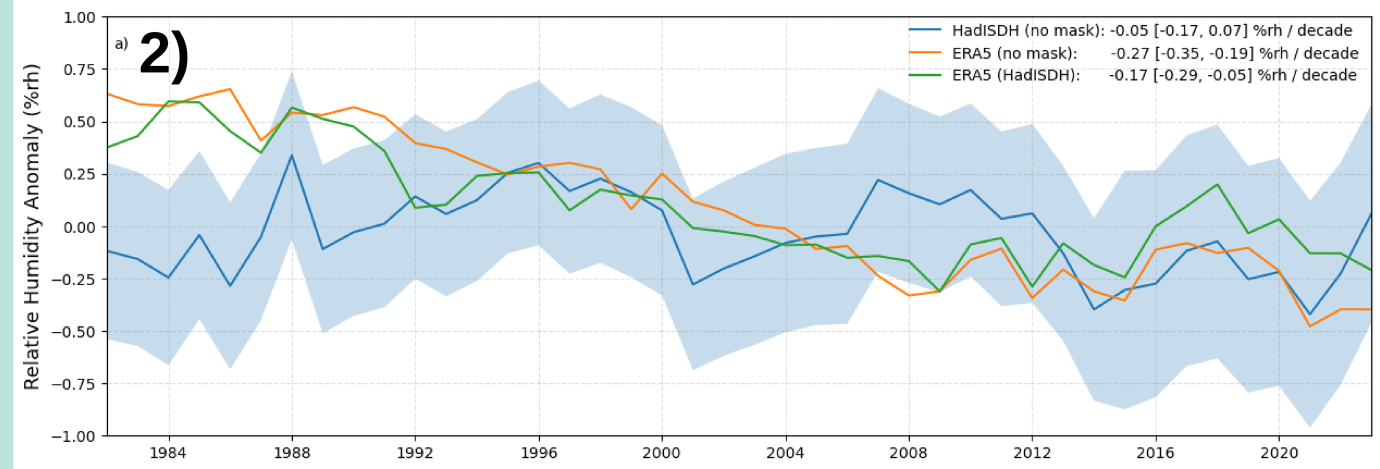


Figure 2. Global annual mean marine RH anomalies (1991-2020) from HadISDH (blue, 2 sigma uncertainty shading), ERA5 full coverage (orange) and ERA5 masked to HadISDH coverage (green) with decadal trends (and 90th percentile confidence intervals) from 1982 to 2023.

Analysis ignores the pre-1982 period where there is a suspected marine observation issue (Willett et al., 2020). Spatial agreement (Fig. 1) is mixed. Regions with decreasing RH common to HadISDH and ERA5 include the North Atlantic, off the southwest coast of Africa, the Great Australian Bight and small parts of the central Pacific and South American coastline. Trends are opposite in the North and West Pacific and Indian Ocean. Global marine RH (Fig. 2) in HadISDH is negative but weaker than ERA5 and not significant. Interannual variability differs considerably. Reducing ERA5 to the limited spatial coverage of HadISDH reduces the negative trend but makes little difference to variability.

Image: Nadii Ka, www.unsplash.com

Observed near-surface ocean RH contrasts to modelled *historical* trends and variability and theory suggests constant RH or a small increase.

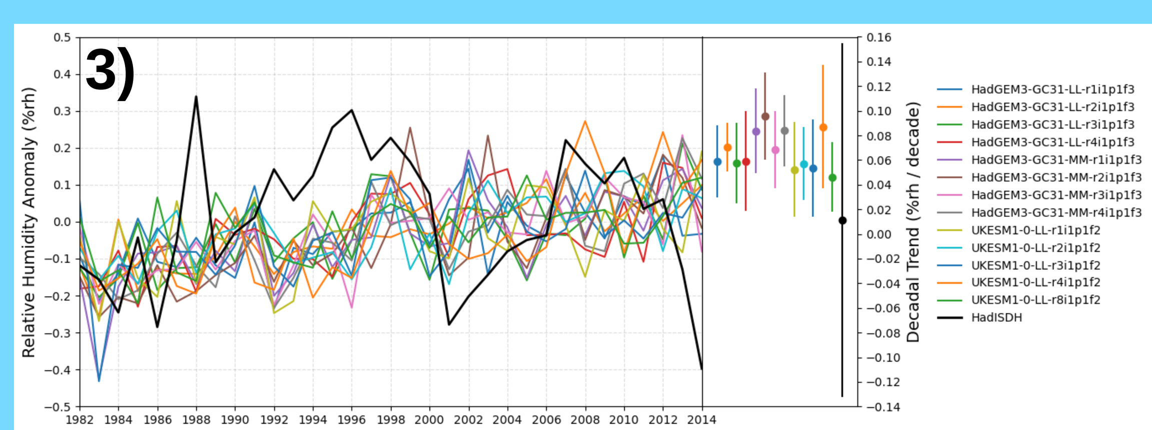


Figure 3. Global annual mean marine RH anomalies (1991-2014/2020) from HadISDH and Met Office CMIP6 model historical runs (spatially matched to HadISDH coverage) with decadal trends (and 90th percentile confidence intervals) from 1982 to 2014 also shown.

All 3 CMIP6 models in Fig. 3 show significantly increasing marine RH. HadISDH shows no significant trend and larger variability that is not explained by its limited spatial coverage because the models are masked to match. Increasing marine RH is consistent with Byrne and O'Gorman (2016), and smaller than 7% K^{-1} (CC-scaling) increases in evaporation. There is model uncertainty however – model RH frequently exceeds 100 %rh and model land RH (Dunn et al., 2017, Simpson et al., 2023) either decreases too little or increases – possibly due to excess water availability and dynamics.

Observational uncertainty in near-surface ocean RH is large. Limited spatial coverage, increasing ship height over time and changes to instruments and exposure over time play a role in HadISDH. ERA5 may contain artefacts from changes to satellites assimilated.

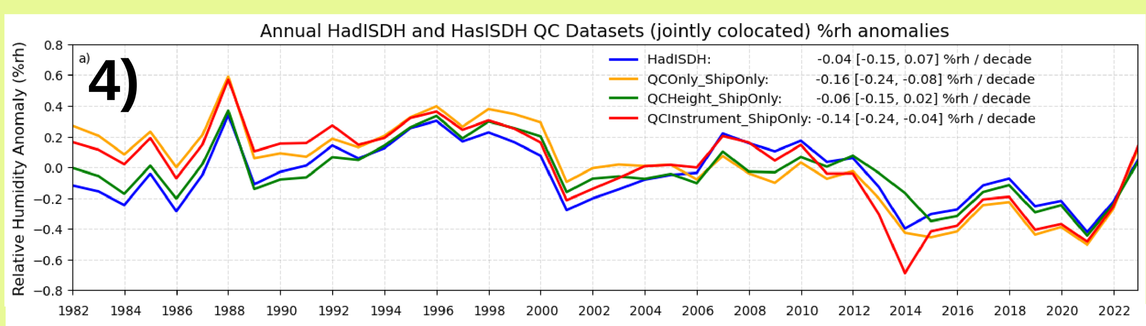


Figure 4. Global annual mean marine RH anomalies (1991-2020) from HadISDH quality controlled, bias adjusted, ship only (blue) compared to quality-controlled ship only (orange), quality-controlled and ship height bias adjusted ship only (green) and quality-controlled and instrument bias adjusted ship only (red). Decadal trends (and 90th percentile confidence intervals) from 1982 to 2023 are also shown. Difference series of HadISDH minus the other versions are also shown.

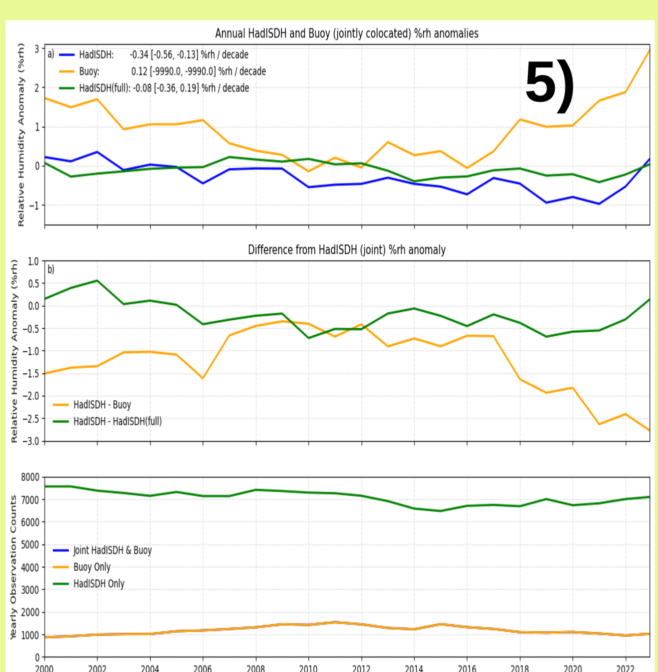


Figure 5. (top) Global annual mean marine RH anomalies (1991-2020) from HadISDH (green) compared to the quality-controlled buoy only (orange) and HadISDH spatially matched with the buoy only (blue). Decadal trends (and 90th percentile confidence intervals) from 1982 to 2023 are also shown. (middle) Difference series of HadISDH spatially matched to the buoy only minus the other versions. (bottom) Total number of gridboxes with observations per year for each version. Note that the blue line is identical to the orange line here.

Ship heights differ and have increased over time, possibly causing a spurious RH decrease as obs get further from the sea. Adjusted (10m) obs (blue, green, Fig. 4) show a weaker RH decrease than unadjusted (orange, red) but metadata (ability to adjust) is limited.

Non-aspirated instruments are biased moist compared to whirled and aspirated ones. Bias adjusted obs (red, Fig. 4) have a slightly weaker RH decrease than non-adjusted (orange). Other changes to instruments, exposure and reporting, and ship solar heating issues, may be present. Daytime only obs show a slightly weaker RH decrease (within 0.02 %rh, not shown) than nighttime only suggesting that this is not a major cause of error.

A buoy-only version is independent which does not show a decreasing trend. It has extremely limited spatial coverage (Fig. 5c.

ERA5 responds to various changes in assimilation data streams over time as different satellites and observing platforms become available. The advent of microwave imagers in the late 1980s lead to a warmer/drier lower troposphere (Hersbach et al., 2020).

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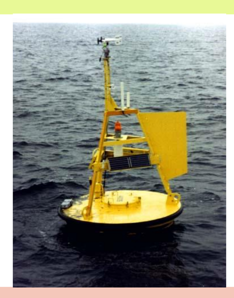

VOS
Voluntary Observing Ship Scheme

FINAL THOUGHTS…

Error in both HadISDH and ERA5 cannot be ruled out, but limited ship/buoy coverage and metadata availability makes this challenging.

Next steps could explore related variables (TCWV, evaporation, SST, MAT) from other reanalyses and platforms (satellites, GNSS-ground based obs). Processes that could lead to localised RH decreases (circulation, dry air advection, aerosols) could also be explored.

What is 'near-surface'? Do trends in humidity differ much within the lowest 40m of the atmosphere? If so, the precise analysis height is important – and the manner in which the modelled or reanalysed quantity is obtained. Near-surface is 2m in reanalyses and models (?) and 10m in HadISDH.

Changes in near-surface RH are not well constrained by models, contributing to large uncertainty in the hydrological cycle generally (Douville & Willett, 2023).

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