Subject title: Detection of trends and climatic variability in atmospheric humidity estimated by GNSS observations and global and regional reanalyses over the last decades

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Presentation of the subject: (Maximum 2 pages)

Context:

Water vapor is a key component of the water cycle and plays a major role in many meteorological and climatic processes (e.g. energy balance, precipitation [1], weather extremes [2]). On a global scale, global warming is accompanied by an increase in atmospheric humidity which generates a strong positive feedback, water vapor being the 1st greenhouse gas of the atmosphere. On a regional scale, however, the scheme is more complex because it involves the nature and properties of surfaces (continental or oceanic), atmospheric composition and atmospheric circulation. Uncertainties in climate models, atmospheric reanalyses and observations, plus natural variability (eg; interannual and decadal), considerably limit our knowledge of the recent climate (20th century) and our ability to predict trends in the horizon of the end of the century [3].

The lack of uniformity in the observations, whether used directly or assimilated in the reanalysis, is particularly penalizing for the estimation of trends and decadal variability [4]. A multitude of statistical approaches have been developed for segmentation (detection of change points) and correction of climate series, but mainly for temperature and precipitation [5]. This is why we have recently developed a segmentation algorithm (GNSSseg) specifically for the GNSS integrated water vapor content (IWVC) [6] series, based on a differential (GNSS - reanalysis) and optimal approach (maximum likelihood is searched by dynamic programming).

Difficulties and obstacles: the detection methods are limited by the differences in representativeness between the target series and the reference series [7] and the intrinsic performance of the model and the segmentation algorithm [6]. The attribution of breaks to the target is limited by the presence of inconsistencies in the reference and the lack of metadata. Errors in the detection and attribution of target ruptures lead to errors in the estimation and interpretation of trends, but also of estimated means and climatic variability.

Objectives of the thesis:

i) develop a methodology to detect and assign breaks in the GNSS series in a more robust way, using optimal statistical approaches and the combination of multiple data sources.

ii) homogenize the global and regional GNSS IWVC series and analyze the homogeneity of the IWVC of the global and regional reanalyses as well as that of complementary data sources that we will use for the study of climate variability: in-situ observations (RH2m, T2m), satellites (IWVC, precipitation, cloud cover, flow) and reanalyses.

iii) analyze the trend and variability of the IWVC and of the global and regional water cycle in regions with contrasting climates (Europe, semi-arid to tropical humid regions of Africa, polar regions) using an extended set of variables (see above) from different homogenized data sets.

Work program (methodology, tools and data):

i) Detection of inhomogeneities: we envisage some targeted developments of our GNSSseg algorithm, the use of better correlated reference series (GNSS, high resolution regional reanalyses). In order to consolidate the allocation of breaks we also plan to seek more information / metadata on GNSS data (multi-path, cycle jumps, etc.) and on reanalysis (nature and quality of assimilated data). Partial reprocessing of the GNSS series is also planned to test the impact of various settings (cutoff elevation, antenna models, etc.) on the consistency of the series.

ii) Homogenization of the global and regional GNSS series: it will be based on the use of several global (ERA5, ERA20C, MERRA-2) and regional (UERRA, CERRA) reanalyses as well as on approaches using GNSS data as a reference when the network density allows it (eg Europe). To standardize the other data sources, we will use variants of GNSSseg as well as other existing algorithms (eg HOMER, RHtest) [3]. There are also global and regional datasets already homogenized (T2m, RH2m, precipitation, satellite IWVC) which should be evaluated with optimal methods.

iii) Analysis of variability (intra-seasonal to decadal) and trends: we will compare the estimates of the mean, the linear trend and the variability of the IWVC of several GNSS solutions from the repro3 of the IGS, reanalyses and satellites over the GNSS period (1995-2020) or even beyond. Simulations of climatic models could be added (eg CMIP6) and an extension over the entire 20th century could be envisaged (with certain reanalysis and observation datasets). For the regional study, the main focus will be on Europe, Africa, Antarctica and the Arctic. We will also analyze the homogeneity and variability of the other variables of the water cycle in the reanalyses in connection with the results of the IWV analysis to separate the sources of variability (climatic vs. inhomogeneities).

Expected results:

i) a methodology and tools for the homogenization of the GNSS IWVC series, with possible application to other geophysical variables; a better understanding of the sources of inconsistency in the GNSS series and recommendations for a more uniform treatment of GNSS data valid for both IWVC and the estimation of positions / speeds.

ii) homogenized GNSS IWVC datasets (global, regional, in particular the French network) and possibly other non-GNSS datasets (notably reanalyses).

iii) advances in the quantification of variability and recent trends in atmospheric humidity at global and regional scales, and new knowledge on the uncertainties of water cycle variables in reanalyses and possibly in models of climate.

References:

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