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A probabilistic approach in GNSS meteorology from ground stations

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The dynamic of water vapor (WV) concentration and its status changes in the atmosphere are well known key factors affecting the heat energy fluxes and, consequently, the atmospheric stability and the development of precipitating systems. Quantity and quality of WV measurements influence the weather forecasts, and particularly on now-casting and short term predictions. WV time series measurements have also a role in climatology studies, especially those related to climate change, being WV a main greenhouse gas.
The capability of providing information on the atmospheric state and specifically on WV quantities has imposed GNSS data as a fundamental source of information in meteorology, boosted by the increasing number of GNSS signals, their increasing precision, the low cost of ground receiving stations and their multidisciplinary applications.
The future promises tens of signals (from different platforms), detectable at any time from any (open) point on the earth, with an accuracy better than few ns in measuring the signal travel time. However the exploitation of all these upcoming benefits could be limited by the errors hidden in the number of assumptions made in the GNSS data processing for retrieving the tropospheric parameters of interest (mainly WV), whose validity depends on the varying atmospheric conditions. This aspect is reflected by the common absence of error evaluations for the retrieved atmospheric parameters, if not for average posterior estimations, resulting from validation analyses. All this can show up as a non-trivial issue, because the increasing relevance of meteo GNSS products is also (if not mainly) in the framework of the forecast model assimilation (at different scales), where a precise error estimation is generally mandatory, for any measurement to be assimilated.
Other, somehow related, open questions are on the amount of information that can be really gained by increasing the number of receiving stations in a given area, the number of received (and processed) signals or the signal precision.
In the present work, we want to primarily address the issue of the accuracy estimation in GNSS meteorology. This is achieved through a novel Bayesian algorithm that is designed to retrieve tropospheric parameters from ground measurements of temperature, pressure, humidity and GNSS signal delays. The algorithm produces posterior probability distributions (hence the uncertainty) for the retrieved parameters, extracting plausible profiles, consistently with the ground observations. Poor precisions and lack of some measurements do not prevent the feasibility of the retrieval, even if deteriorate the final accuracy. The method is tested on data from a measurement site in Cagliari (Italy) and results (namely of precipitable water and atmospheric profiles of water vapor and temperature) are compared versus atmospheric radiosoundings for the same site.
Finally we introduce how the method can also be straightforwardly applied for addressing the other questions that we have raised above, measuring the variation of entropy as a consequence of the ingestion of further information from different observations.
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