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Interactive comment on "Estimation of effective porosity in large-scale groundwater models by combining particle tracking, auto-calibration and ^{14}C dating" *by* Rena Meyer et al.

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Meyer et al describe the estimation of the porosity parameter in a steady-state groundwater flow model of a coastal region in Denmark, using 14C dated groundwater samples as a calibration target. We find this a very interesting work and welcome the effort

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to calibrate groundwater models on targets other than groundwater heads. Such efforts are crucial to improve our understanding of groundwater flow in coastal environments. However, their paper did spark two comments we could not resist to raise.

1. The groundwater flow system cannot be assumed stationary over the timescales considered Meyer et al use a stationairy groundwater flow model to calculate the age of groundwater at measurement locations, and compare this with corrected 14C dates at these locations. Their model represents the present-day groundwater system, and is forced with present-day boundary conditions. However, the historical trajectory of the measured water droplets has likely been far more complex than assumed in the stationary flow model. Sea level changes, shifting of coastlines, marine transgressions and subsequent infiltration of sea water, drainage of arable land, land subsidence, development of well fields all significantly alter groundwater flow patterns over the timescales considered. See e.g. Delsman et al. (2014) in HESS (sorry to cite our own work), where we show – in a very similar hydrogeological setting – massive changes in groundwater flow patterns occurring over millennia, and even over the very last decades.

The authors do acknowledge the non-stationarity of groundwater flow patterns at larger timescales, by discarding all samples over 5 pMC of activity. But that still leaves samples with a corrected age of 1800 years in the data set, a timeframe in which a lot can happen. For example, as described by Meyer et al., “low-lying marsh areas (with elevations below mean sea level) in the west were reclaimed from the Wadden Sea.” With profound effects on groundwater flow patterns: “the large drainage network, established in the reclaimed terrain keeping the groundwater table constantly below the sea level, acts as a large sink for the entire area.” And while this dominant flow-defining feature has only been present for the last 200 years, the analysis presented by Meyer et al assumes the present-day groundwater flow pattern to have existed for at least 1800 years. Furthermore, the North sea level has risen about 2 m over the past 1800 years (Van de Plassche, 1982). Given the very shallow local bathymetry , the coastline

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of 1800 years ago may have been located as far as 25 km westward of its present-day position. Such significant changes should in our opinion be accounted for (for instance by paleo-hydrogeological modeling) before attempting to use age data as a calibration target.

2. Density effects may significantly affect groundwater flow patterns and should be addressed Our second point concerns the use of a constant-density groundwater flow model in the analysis. In this specific coastal groundwater system, saline groundwater has clearly been detected from an airborne electro-magnetic survey (Støvring Harbo, 2011; Jørgensen et al., 2012). This means density variations will significantly affect groundwater flow patterns and should have been addressed in the analysis, e.g. by using the computer code SEAWAT. Correcting the seaward boundary for density effects will unfortunately do little to improve modeled inland flow patterns (and hence calculated age distributions) affected by density variations. Simmons (2005) has a nice way of showing the importance of density variations, by equating a typical head gradient of 10-3 to the density effect caused by a density difference of only 1 kg/m3 (5% seawater). In addition, we wonder if the seaward boundary condition accurately represents the connection of the groundwater flow system to the groundwater flow system underlying the North Sea. The boundary condition is located directly next to the system of interest, and seems to be applied without taking into account the likely seaward extension of the clay layers that are depicted in Figure 2.

Therefore, given the issues outlined above, we wonder if the conceptualization of the groundwater flow model used by Meyer et al is indeed sufficient to accurately model groundwater age, and if the obtained results are not merely a case of “The right result, for the wrong reasons” (Beven, 1993).

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