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Advanced localization of small seismic events in Europe, case studies in Denmark, Netherlands and Iceland from the GeoERA HIKE project

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Earthquakes carry important information about the current state of stress in the subsurface as well as information on the location of weaknesses. Energy exploitation activities and energy storage are inherently connected to changes in pressure in the subsurface and varying pressure rates are applied depending on the level of activity. Especially rapid changes in pressure are known to lead to induced and triggered earthquakes, and in some cases lead to reactivation of otherwise stable and unknown faults. In some cases, increased small magnitude induced seismicity is an indication of possible larger events to follow.

Small earthquakes can be elusive and hard to locate precisely due to low signal-to-noise levels, an insufficient number of seismograph stations as well as over simplified methods and subsurface models. These challenges need to be overcome to be able to more accurately relate microseismicity to anthropogenic activities, and to be able to relate earthquakes to individual faults – both known faults and faults previously unknown. We explore ways to improve the hypocenter locations of earthquakes in exploited areas, principally by studying the effects of improving velocity models from standard 1D models to 3D models. When the geology is relatively uniform over the study area and the number of seismographs is abundant, using a 1D velocity model and a relatively simple method allows for fast and efficient processing yielding useful results. However, a 1D layered velocity model is not the best approximation where anisotropy is high, in areas with localized velocity anomalies, and where substantial velocity jumps in a layered medium control the differential arrival between P- and S-waves resulting in significant depth estimation uncertainties.

We present results using the NonLinLoc software for locating small earthquakes in Denmark, Netherlands and Iceland using 3D velocity models. The location method provides good uncertainty estimates on the hypocenters. To test the quality of the hypocenters calculated with 3D velocity models, results from NonLinLoc is compared to existing hypocenter solutions for the same earthquakes. The results are evaluated with respect to deviations in hypocenters, uncertainty estimates provided by the different methods, efficiency and applicability for different geological

settings. The focus of the Danish case study is the oil and gas fields in the North Sea, however due to sparse data and low seismicity the entire Danish region is included in the study. For The Netherlands the focus of the case study is the two decommissioned gas fields, Roswinkel and Castricum, where seismicity occurred after the end of production. The Icelandic case study focusses on the Reykjanes geothermal field located at the southwest point of the Reykjanes Peninsula. Most activity is natural but induced activity has been recorded near the production area of the Reykjanes power plant.

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