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Estimation of uncertainties in geological 3D raster layer models as integral part of modelling procedures

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The Geological Survey of the Netherlands (GSN) develops and maintains subsurface models with regional to national coverage. These models are paramount for petroleum exploration in conventional reservoirs, for understanding the distribution of unconventional reservoirs, for mapping geothermal aquifers, for the potential to store carbon, or for groundwater- or aggregate resources. Depending on the application domain these models differ in depth range, scale, data used, modelling software and modelling technique.

Depth uncertainty information is available for the Geological Survey's 3D raster layer models DGM Deep and DGM Shallow. These models cover different depth intervals and are constructed using different data types and different modelling software.

Quantifying the uncertainty of geological models that are constructed using multiple data types as well as geological expert-knowledge is not straightforward. Examples of geological expert-knowledge are trend surfaces displaying the regional thickness trends of basin fills or steering points that are used to guide the pinching out of geological formations or the modelling of the complex stratal geometries associated with saltdomes and saltridges. This added a-priori knowledge, combined with the assumptions underlying kriging (normality and second-order stationarity), makes the kriging standard error an incorrect measure of uncertainty for our geological models. Therefore the methods described below were developed.

For the DGM Deep model a workflow has been developed to assess uncertainty by combining precision (giving information on the reproducibility of the model results) and accuracy (reflecting the proximity of estimates to the true value). This was achieved by centering the resulting standard deviations around well-tied depths surfaces. The standard deviations are subsequently modified by three other possible error sources: data error, structural complexity and velocity model error. The uncertainty workflow applied for DGM Deep proves to be an effective way to (graphically) represent the reliability of the DGM Deep model, although the relative contribution of the various error sources needs further attention.

For the DGM Shallow model a cross-validation procedure in a moving window environment has been used to calculate mean deviations and standard errors on a sub-regional scale. Subsequently, these cross validation standard errors have been rescaled to account for local data configuration and clustering. This resulted in standard deviations expressing both regional and local uncertainties.

Both workflows are state-of-the-art, form an integral part of the geological modelling and result in reproducible uncertainty values. They can be considered a good starting point for incorporating other errors that contribute to uncertainties of geological 3D raster layer models. For example, the mis-positioning of data used or the error underlying mis-ties at well locations. An additional, perhaps more easy-to-read, parameter that can be calculated to visualize these uncertainties would be the information entropy, as proposed by Wellmann & Regenauer-Lieb (2012). Where a value of 0 means there is no uncertainty, and a value of 1 means there is a high uncertainty.

At the moment depth uncertainty information is disseminated through our webportals (www.dinoloket.nl and www.nlog.nl) in an on-line map viewer and as downloadable GIS products.