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Sampling biases and external source contamination in virtual magnetic observatories

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Virtual observatories (VOs) use satellite measurements to provide estimates of the mean magnetic field (MF) over a specified period at a fixed location in space, mimicking mean values obtained at ground-based observatories (GOs). These permit secular variation (SV) estimates anywhere on the globe, thereby mitigating the effects of uneven GO coverage, whose concentration in the northern hemisphere leaves much of Earth poorly constrained. Calculating VOs involves fitting a local potential to all track data within a volume of space surrounding the point of interest. We have investigated the statistical significance of estimated parameters using different parameterisations and bin sizes.

VO estimates of internally-generated MF suffer from two key contamination sources: local time sampling biases due to satellite orbital dynamics, and MFs generated in regions external to Earth such as the magnetosphere and ionosphere. Current VOs employ various methods to alleviate this contamination but each has drawbacks: first, averaging over several months, rather than one month as is typical for GOs, removes the local time sampling bias at the cost of reduced temporal resolution; second, stringent data selection criteria such as night-time, quiet-time only data greatly reduce, but do not entirely remove, external MF contamination but result in a small subset (<5%) of the available data being used; third, removing model predictions for external MFs from the measurements also reduces noise, however such parameterisations cannot fully describe these physical systems and some of their signal remains in the data.

We propose an alternative approach to calculating VOs that retains the monthly resolution, uses all available vector satellite data and removes contamination from orbital effects and external MFs. It uses an eigensystem method previously applied to GOs to rotate data into various "noisy" eigendirections, i.e. those that contribute most to geomagnetic residuals (the difference between observed and modelled SV), under the assumption that residuals provide information about sampling errors and external MFs that are present in the VO estimates but not in the internal field model. A key challenge in using this method is identifying the underlying physical mechanisms of different eigendirections, so that the appropriate noisy directions are removed from the data whilst unmodelled signals that originate from the core are retained. To that end, we have produced synthetic VOs using modelled CHAMP-like track data for external (magnetosphere and ionosphere) MFs. Subsequent eigenanalyses of these synthetics, and Fourier analyses of the rotated residuals, have shown how simplified representations of external MFs and their biased time sampling with the VO method manifest in the noisy eigendirections. Informed by the synthetic tests, we have produced denoised VOs for satellite data, which we compare to VOs calculated using standard methods.