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A novel constrained spectral approximation method

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The representation of subgrid-scale orography is a challenge in the physical parameterisation of orographic gravity-wave sources in weather forecasting. A significant hurdle is encoding maximum physical information with a simple spectral representation on unstructured geodesic grids with non-quadrilateral cells, such as those used in the German Weather Service's Icosahedral Nonhydrostatic Model. Additionally, the orographic representation must adapt to the grid cell size (scale awareness). This work introduces a novel spectral analysis method to approximate a scale-aware spectrum of subgrid-scale orography on unstructured geodesic grids. Our method reduces the dimension of physical orographic data by over two orders of magnitude in its spectral representation while maintaining the power of the approximated spectrum close to the physical value. Based on well-known least-squares spectral analyses, our approach is robust in the choice of free parameters, generally eliminating the need for tuning. Numerical experiments with an idealised setup show that this novel spectral analysis significantly outperforms straightforward least-squares spectral analysis in representing the physical energy of a spectrum, given the compression of spectral data and the irregular grid. Real-world topographic data studies show competitive error scores within 10% relative to the maximum physical quantity of interest across different grid sizes and background wind speeds. The deterministic behaviour of the method is investigated along with its principal capabilities and potential biases, showing that error scores can be iteratively improved if an optimisation target is known. This robust, physically sound method has broader potential applications in generic spectral analyses.

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