Revising orographic fields and sub-grid orography parameterisations

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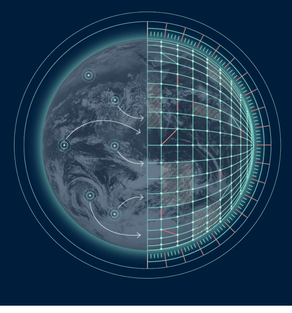
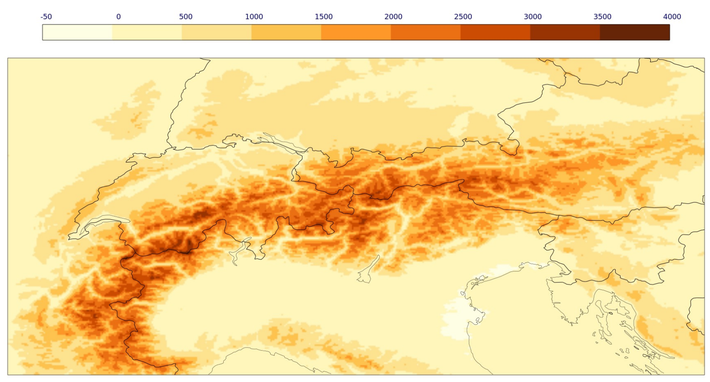


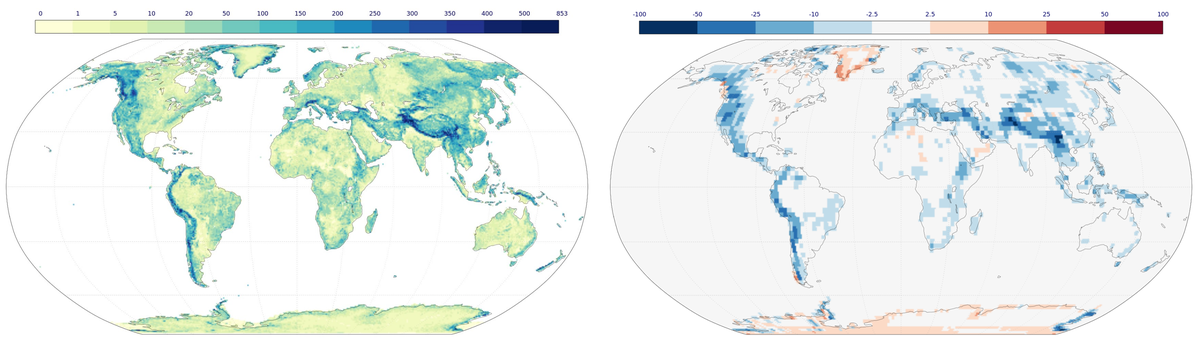
Global orography at kilometre scale

ECMWF runs simulations at a wide range of horizontal resolutions. While fine scales of orography become better resolved at km-scale resolutions, some still require parameterisation. To ensure consistency across resolutions and suitability for km-scales, we revise the current processing of orography ancillary fields.



Orographic height (in metres) at 2.8 km resolution.

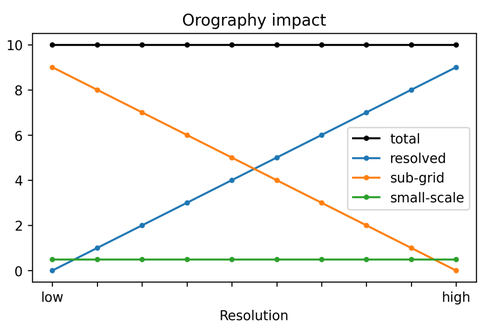
Small-scale orography (< 5 km horizontal scale)



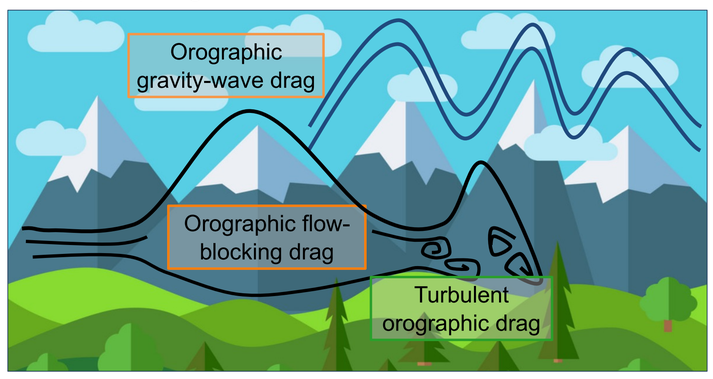
Left: New standard deviation of small-scale orography (in metres). Right: Difference field between new and current field, averaged to 2.5 degrees resolution. Variability in height decreases in most parts except for Antarctica and Greenland. This increase in standard deviation is both due to change in the method and more detailed source data.

Orographic drag across resolutions

The mean orography acts as the boundary condition for the model dynamics and leads to resolved drag on the atmosphere. Unresolved orography is represented through drag parameterisations, separated into different processes. These are: turbulent orographic form drag (TOFD, Beljaars et al., 2004), from orography with scales < 5 km; low-level flow blocking drag and vertically propagating orographic gravity-wave drag (SSO, Lott and Miller 1997), from scales > 5km and up to the grid-scale.

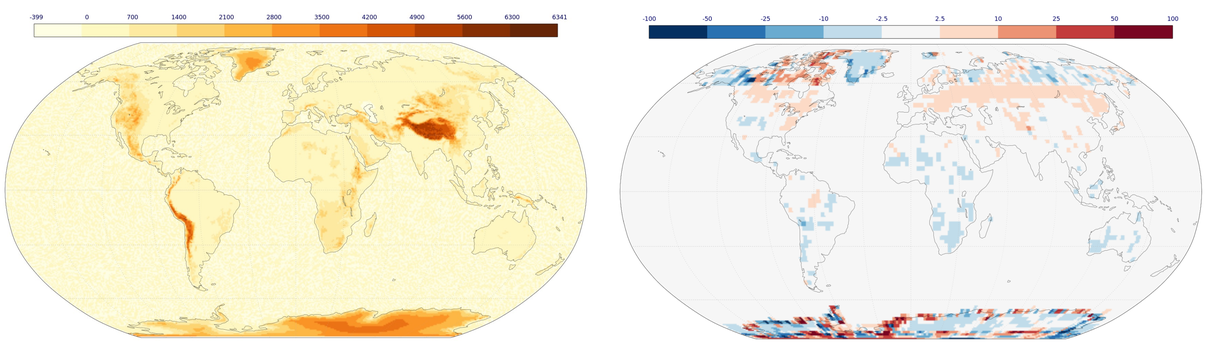


Orographic processes across resolutions.



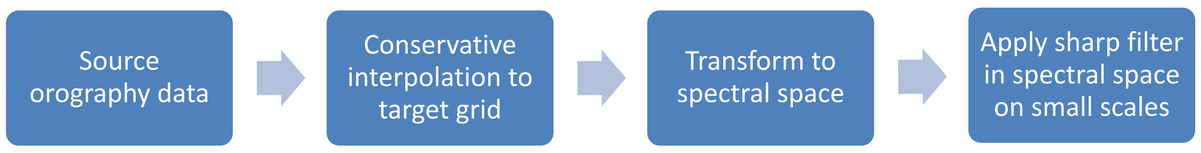
Types of parameterised atmospheric drag from orography.

Mean orography



Left: New mean orography (in metres). Right: Difference field between new and current mean orography, averaged to 2.5 degrees resolution. Visible improvement through new data source with corrected elevations in mid latitudes and additional data north and south of 60° latitude.

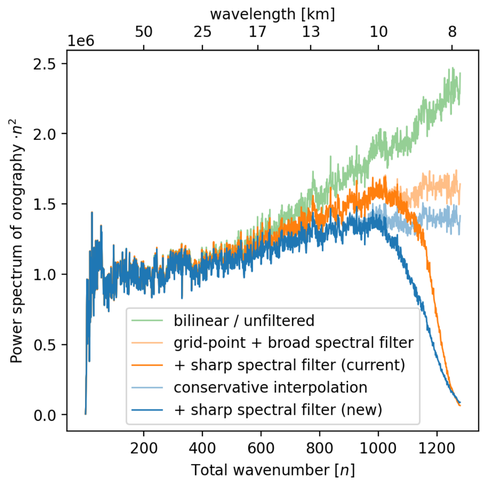
The model mean orography is generated through interpolation of the observed source orography to the target grid. Since the IFS has a spectral dynamical core, it is converted to spherical harmonics using spectral transforms. A sharp spectral filter then dampens some of the smallest scales, which are too close to the grid scale to be accurately represented by the model timestep and/or numerics. The subjective choices made in processing the mean orography have a significant impact on model performance.



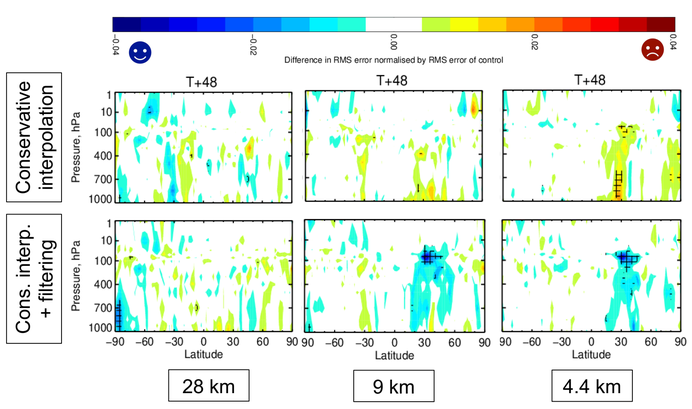
New processing steps for mean orography.

Detailed changes:

- Replace current method (grid-point filtering + broad spectral filtering + spectral truncation) with conservative interpolation (grid-box averaging)
- Spectral filter with more dampening removes poorly resolved small scales at high resolution and high-frequency gravity waves forced by these scales
- Updated source dataset: 30 m Copernicus Global Digital Elevation Model (GLO-30)

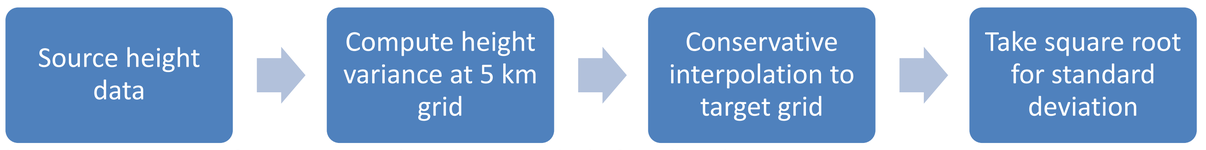


Scaled power spectrum of orography with different interpolation and filtering methods.



RMSE of vector wind compared to current method: using conservative interpolation without (top) and with (bottom) spectral filter across resolutions. Using a filter that dampens small scales more strongly leads to improved forecast performance at higher resolutions.

The small-scale orography captures orographic variance below horizontal scales of 5 km for boundary-layer drag over mountains (TOFD).

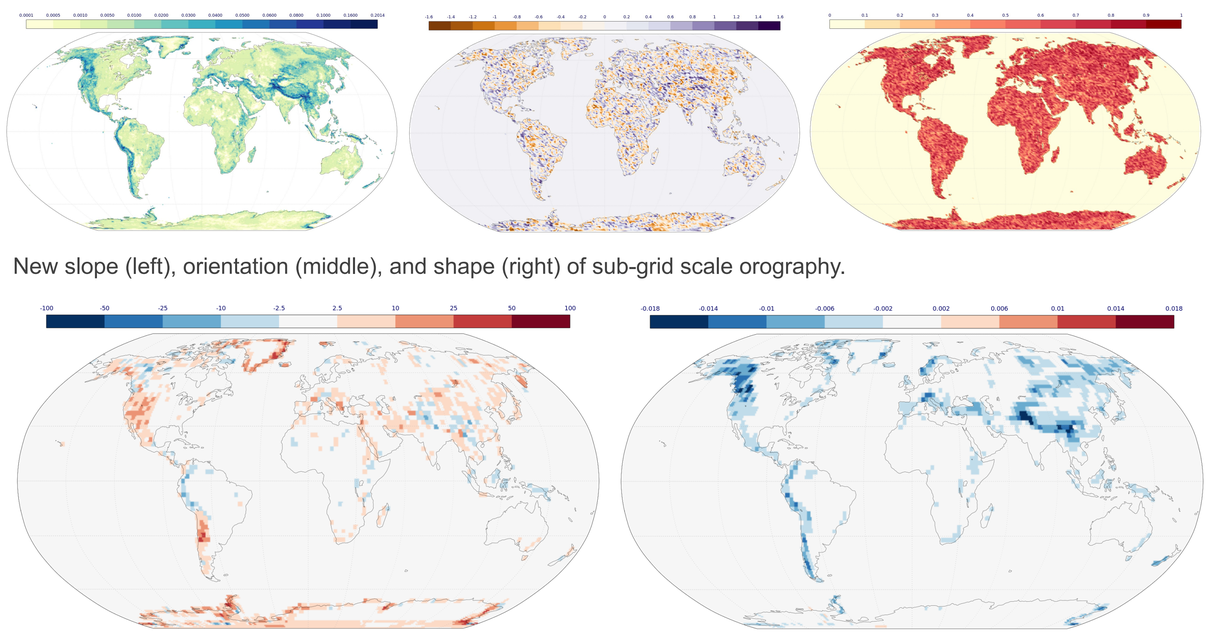


New processing steps for net variance (standard deviation) of small-scale orography.

Detailed changes:

- Conservative interpolation and variance formula ($Var(x) = E(x^2) + E(x)^2$) replace approximation from grid-point filtering at two different length scales.

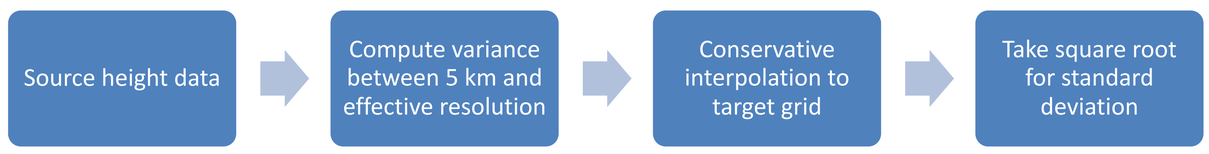
Sub-grid scale orography (> 5 km horizontal scale)



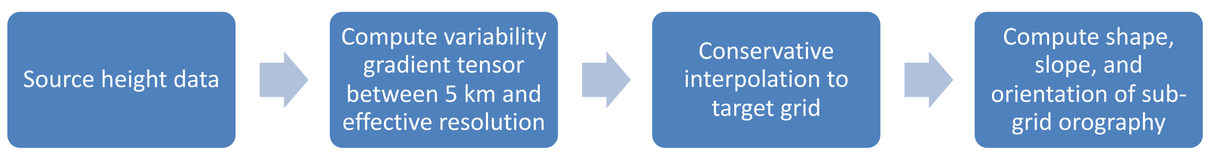
New slope (left), orientation (middle), and shape (right) of sub-grid scale orography.

Difference fields (in metres) between new and current fields for standard deviation (left) and slope (right) of sub-grid scale orography, averaged to 2.5 degrees resolution.

The sub-grid scale orography fields represent variability, principal orientation, slope and shape of orography between horizontal scales of 5 km and the effective grid scale for the parameterisation of low-level flow blocking and orographic gravity wave drag (SSO).



New processing steps for net variance (standard deviation) of sub-grid scale orography.



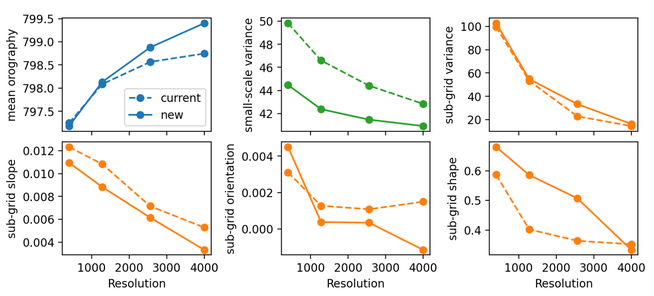
New processing steps for sub-grid scale orography slope, orientation (angle) and shape (anisotropy).

Detailed changes:

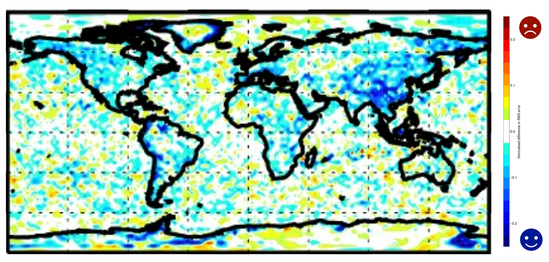
- Conservative interpolation replaces resolution-dependent grid-point pre-filtering
- Effective grid resolution changed from 4 x filter scale to 2 x grid-length scale
- Change order of interpolation to effective resolution and target grid to remove cross-correlations between target and effective grid

Impact of new ancillary fields

The processing is simplified and resulting fields are more consistent across resolution. Together with re-tuned parameters for the TOFD and SSO schemes, the new fields have a positive impact on large-scale and regional-scale circulation.



Global land-average of ancillary fields across resolutions.



RMSE of 10m wind at 28 km resolution with new ancillary fields and re-tuned parameters, compared to current method.

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