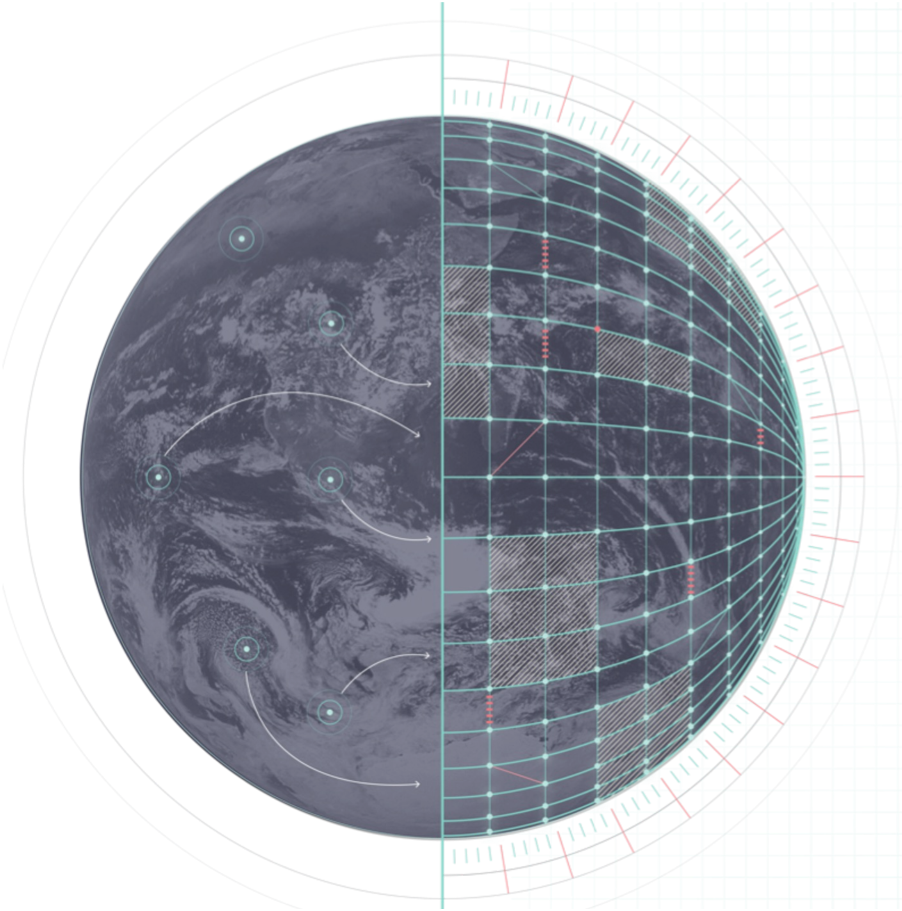


OPTIMISING OROGRAPHY FOR GLOBAL HIGH-RESOLUTION SIMULATIONS

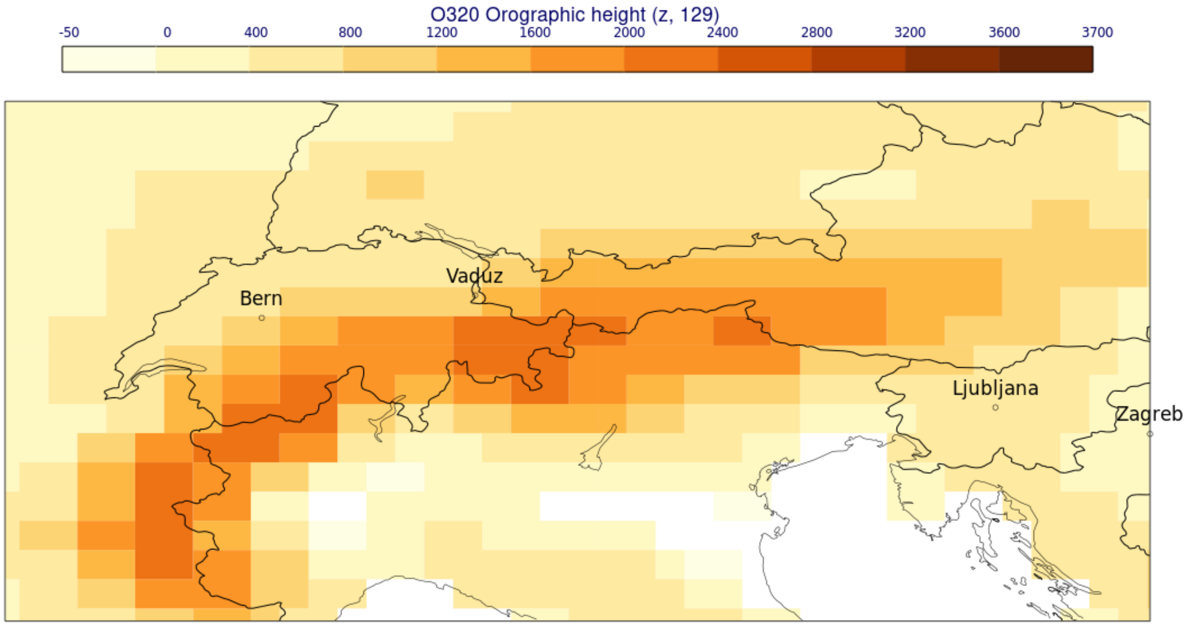
Birgit Sützl, Annelize van Niekerk, Pedro Maciel, Anton Beljaars, Margarita Choulga, Benoît Vannière, Matthew Chantry, Martin Janoušek, Gianpaolo Balsamo, Richard Forbes, Inna Polichtchouk, Irina Sandu, Peter Düben

Funded by the European Union

Destination Earth implemented by ECMWF esa EUMETSAT

REPRESENTATION OF OROGRAPHY

- High-resolution (km-scale) global simulations with Destination Earth (DestinE) requires adequate representation of orography including orographic fine-scale features.
- Aim to improve the representation of orography in the IFS across scales.



35 km
(seasonal and extended range forecast)

REPRESENTATION OF OROGRAPHY

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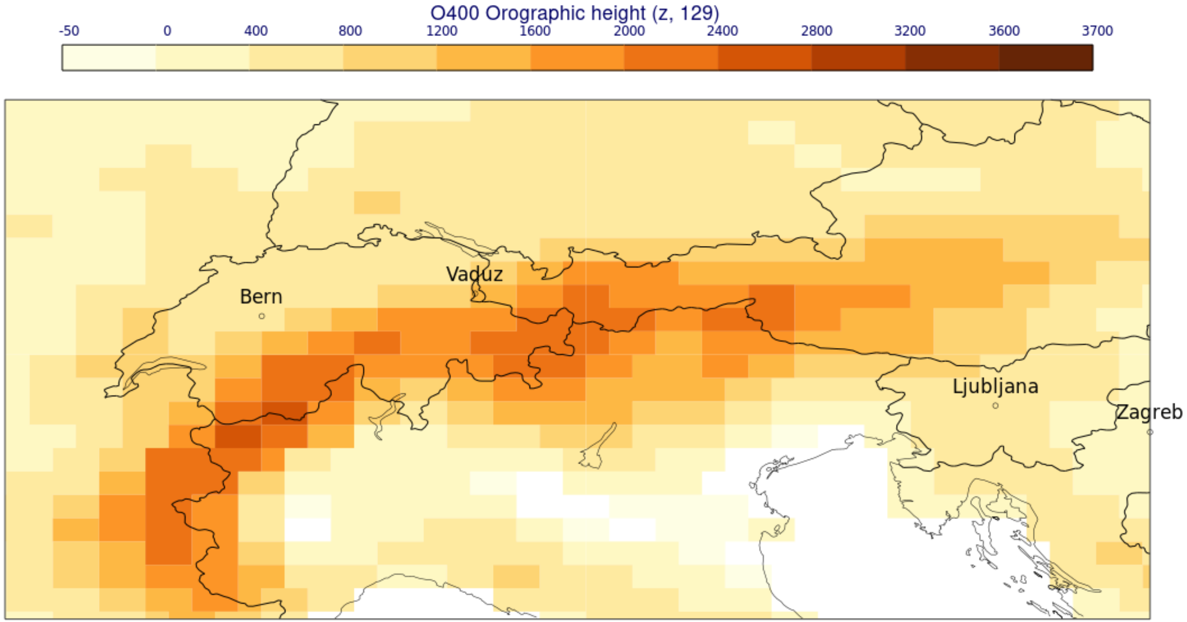

28 km
(testing)

REPRESENTATION OF OROGRAPHY

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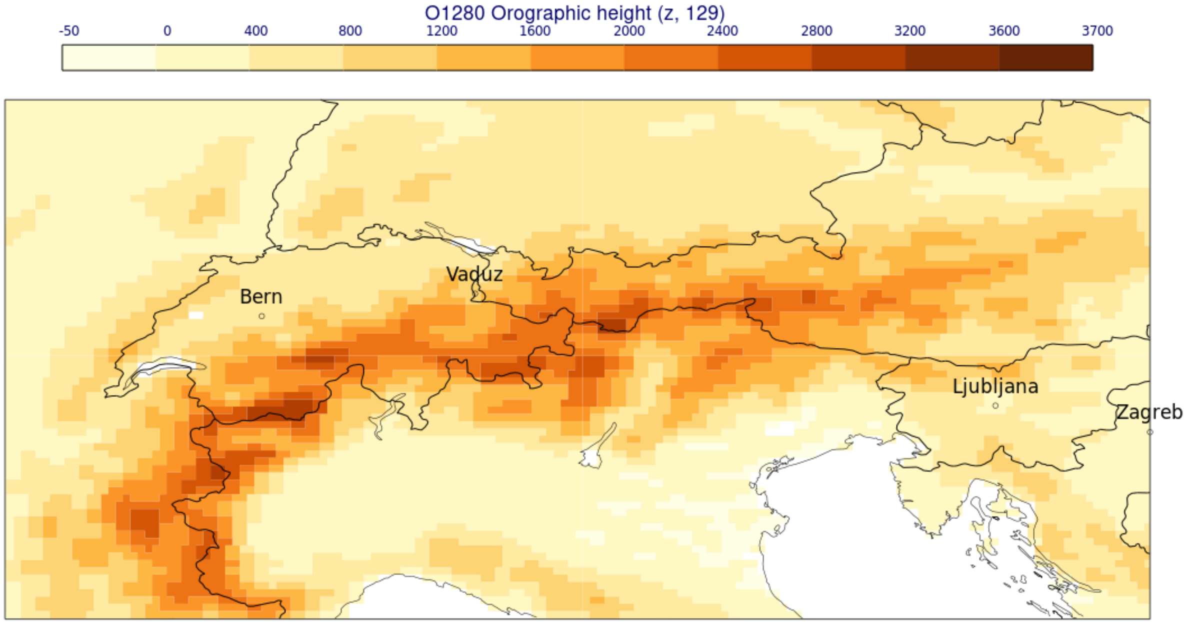

9 km
(operational IFS)

REPRESENTATION OF OROGRAPHY

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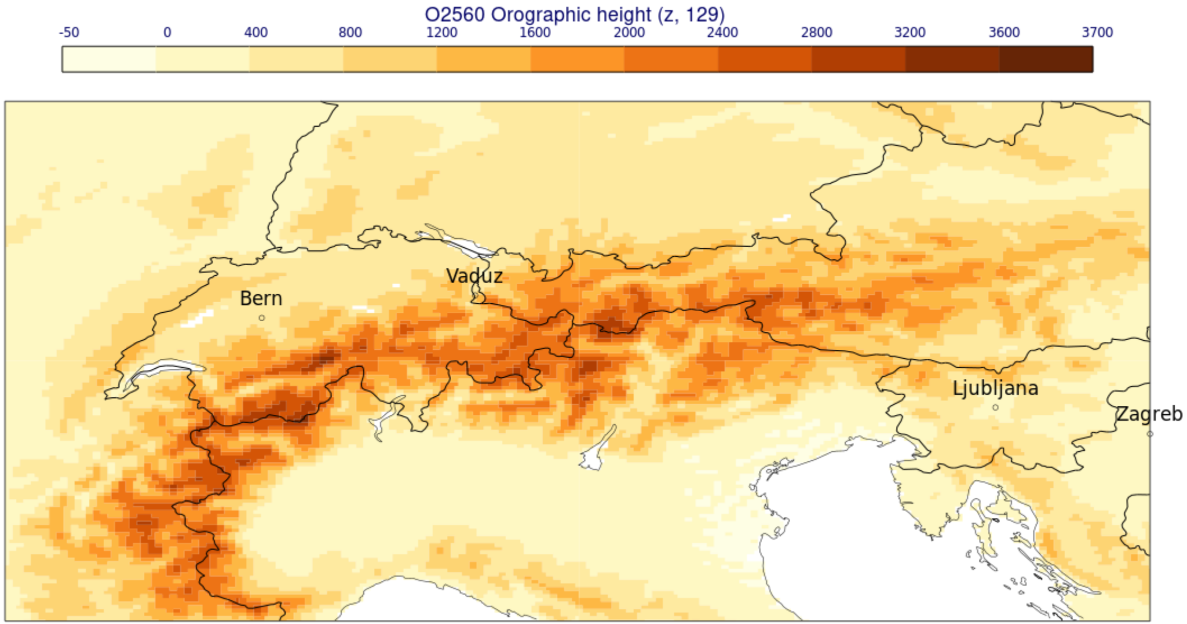
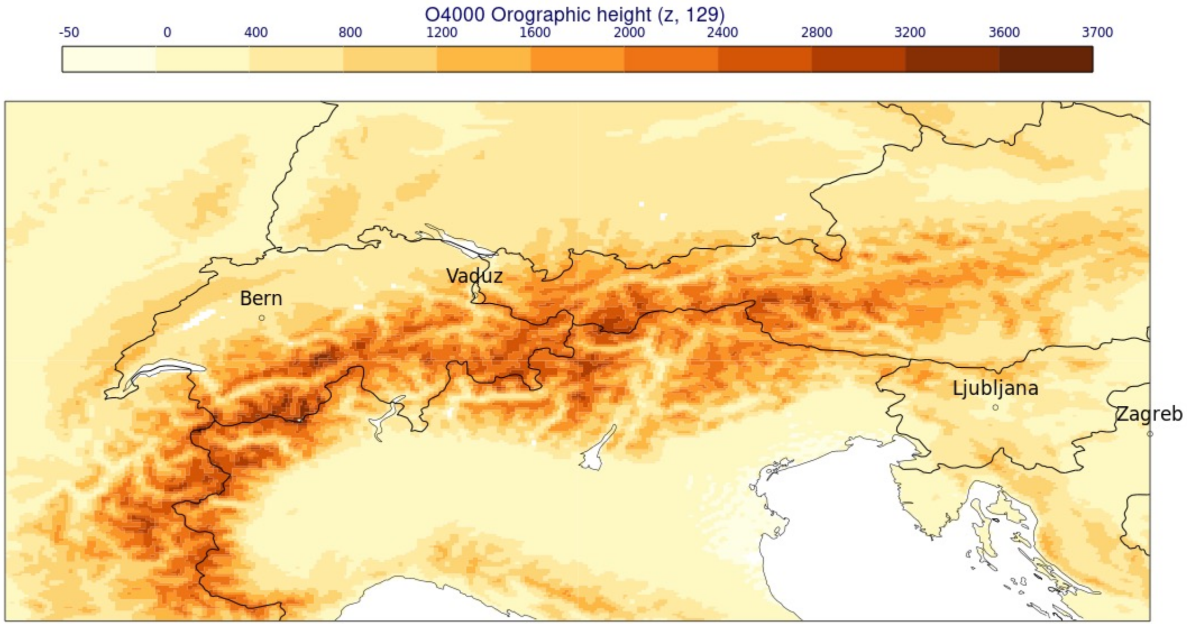


4.4 km
(DestinE daily runs)

REPRESENTATION OF OROGRAPHY

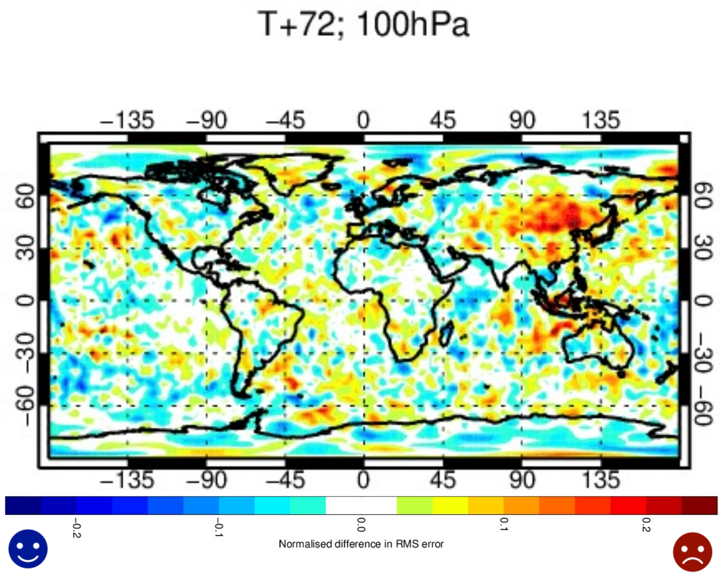
- High-resolution (km-scale) global simulations with Destination Earth (DestinE) requires adequate representation of orography including orographic fine-scale features.
- Aim to improve the representation of orography in the IFS across scales.



2.8 km
(DestinE testing)

REPRESENTATION OF OROGRAPHY

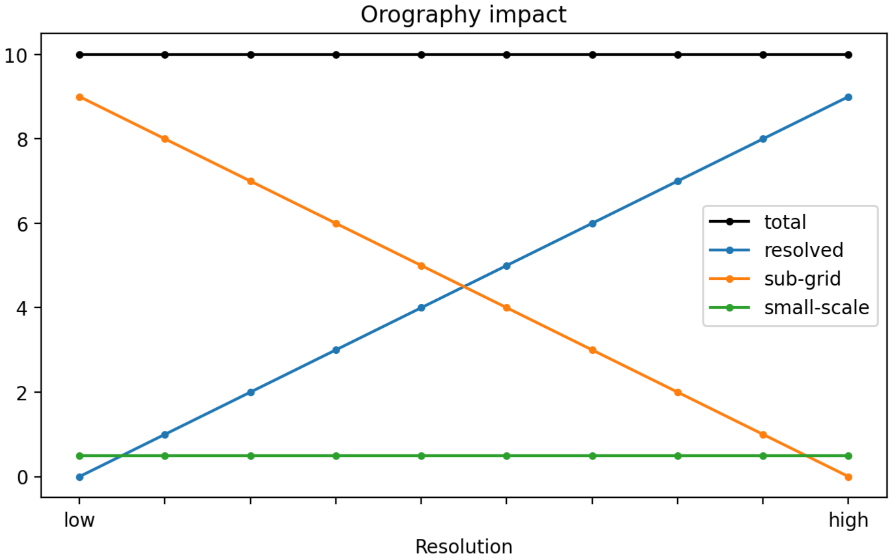
- Increasing resolution does not automatically lead to increased forecast skill.
- DestinE simulations at 4.4 km horizontal grid resolution have shown a negative wind bias over Eastern Asia and increasing forecast error.
- Higher resolution of resolved orography causes additional small horizontal-scale orographic gravity waves breaking above the mid-latitude jet, affecting the global circulation in northern hemisphere winter.



4.4 km vs. 9 km (change in RMSE of winds)

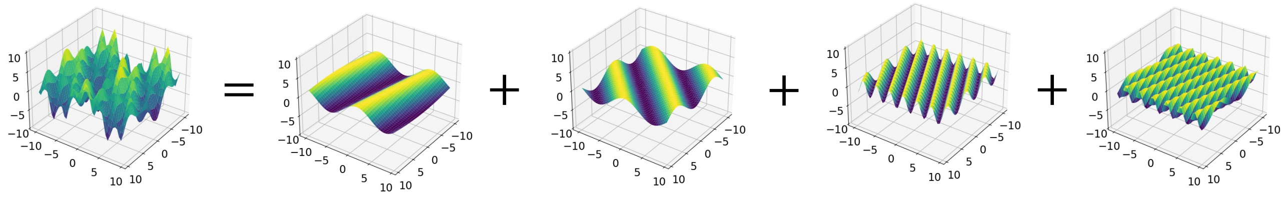
REPRESENTATION OF OROGRAPHY

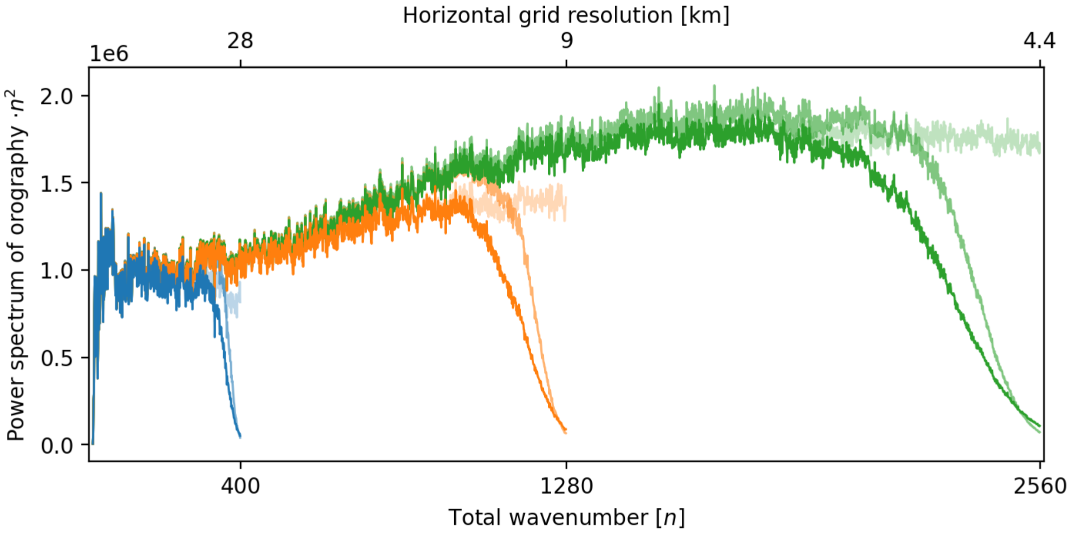
- High-resolution (km-scale) global simulations with Destination Earth (DestinE) requires adequate representation of orography including orographic fine-scale features.
- Aim to improve the representation of orography in the IFS across scales.
- Challenging because there is always a part of orography that is parameterised – the contributions of mean (resolved) orography and sub-grid orography change with different scales.



THE MEAN (RESOLVED) OROGRAPHY

- IFS is a spectral model – lower atmospheric boundary (orography) is represented in spectral space.

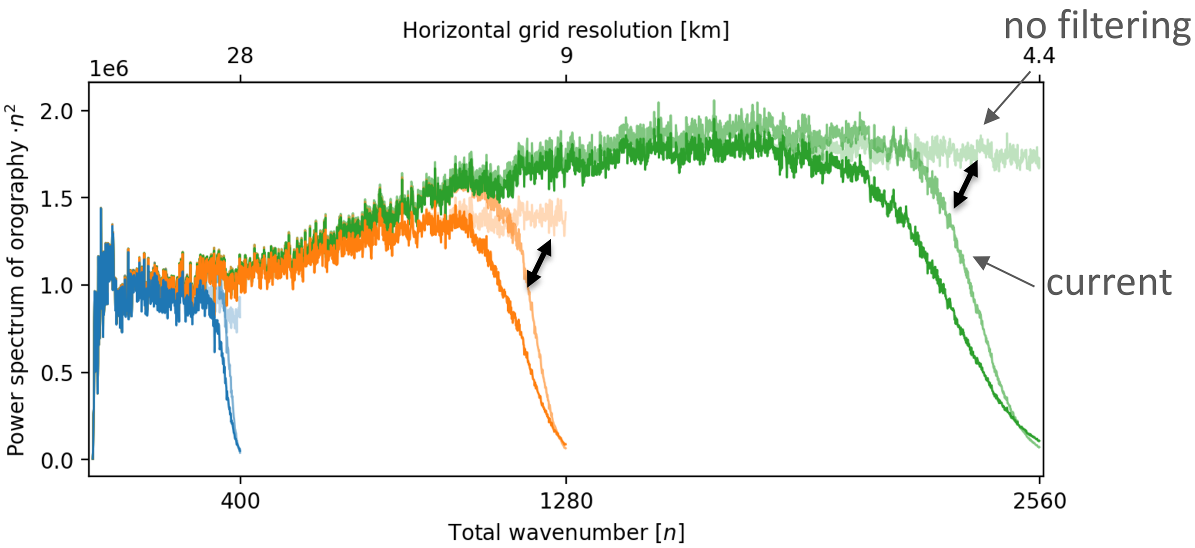


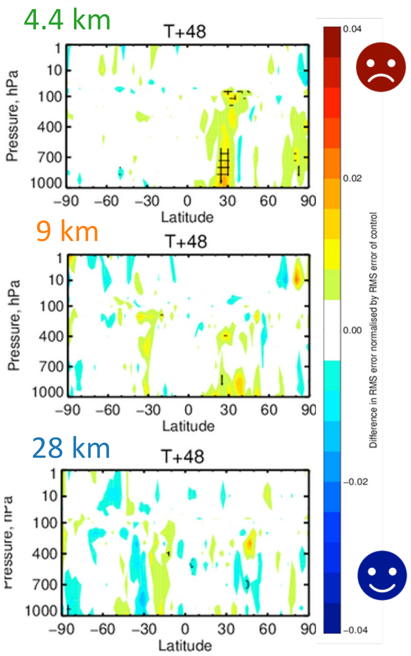


Scaled power spectrum of orography represents the height variability of different horizontal scales

THE MEAN (RESOLVED) OROGRAPHY

- IFS is a spectral model – lower atmospheric boundary (orography) is represented in spectral space.
- Poorly resolved small scales (high wavenumbers) degrade the model circulation at high resolution.

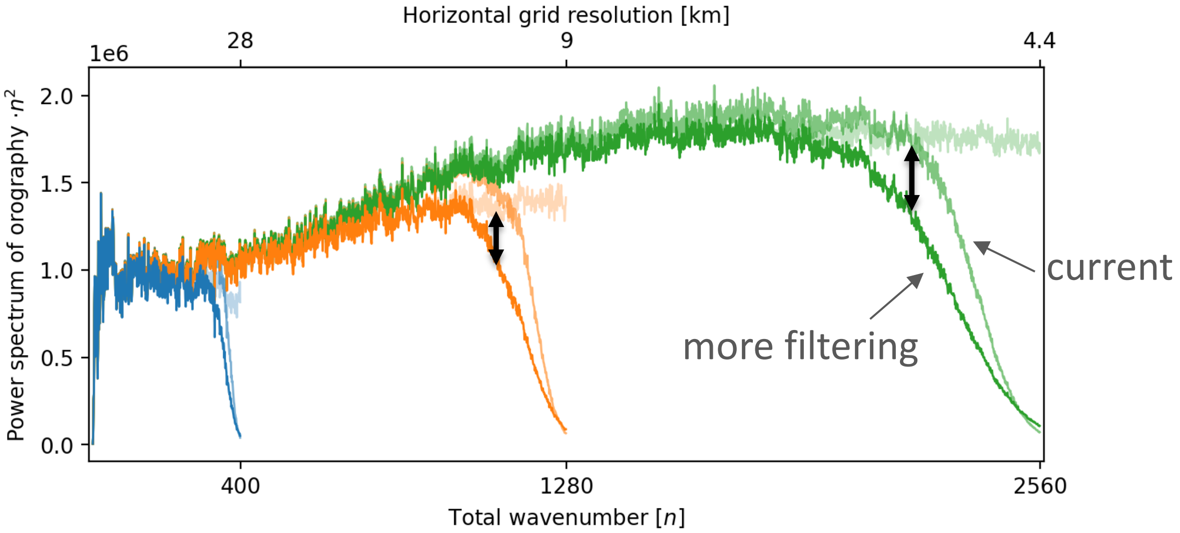


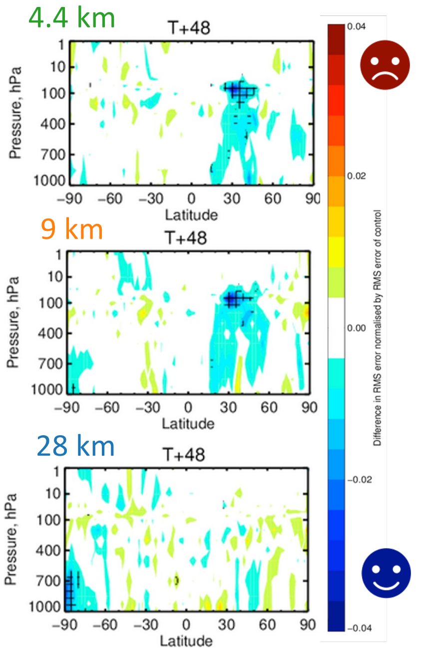


No filtering vs. current (change in RMSE of winds)

THE MEAN (RESOLVED) OROGRAPHY

- IFS is a spectral model – lower atmospheric boundary (orography) is represented in spectral space.
- Poorly resolved small scales (high wavenumbers) degrade the model circulation at high resolution.
- Dampening of small scales reduces bias from high amplitude gravity waves (e.g. Tibet plateau).





More filtering vs. current (change in RMSE of winds)

THE MEAN (RESOLVED) OROGRAPHY

- IFS is a spectral model – lower atmospheric boundary (orography) is represented in spectral space.
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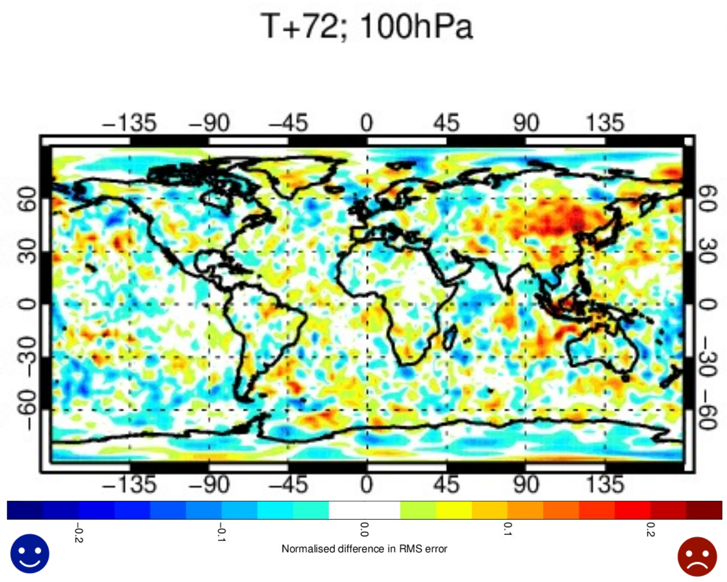
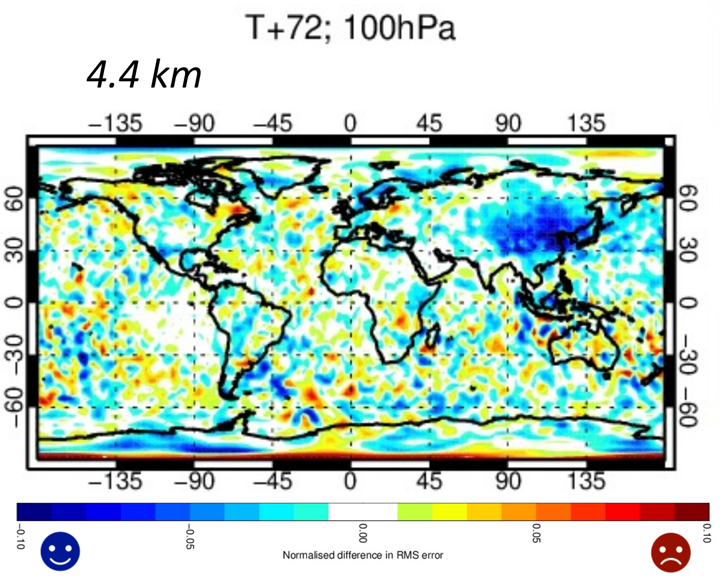


4.4 km vs. 9 km (change in RMSE of winds)

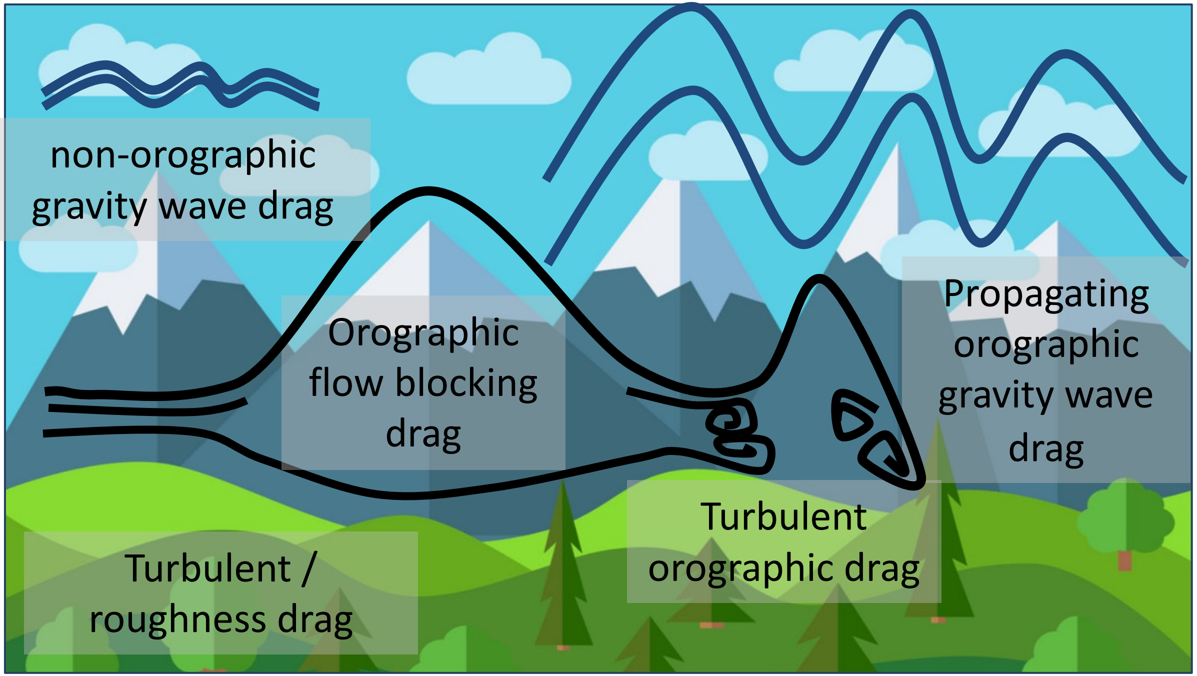


More filtering vs. current (change in RMSE of winds)

SUBGRID-SCALE (UNRESOLVED) OROGRAPHY

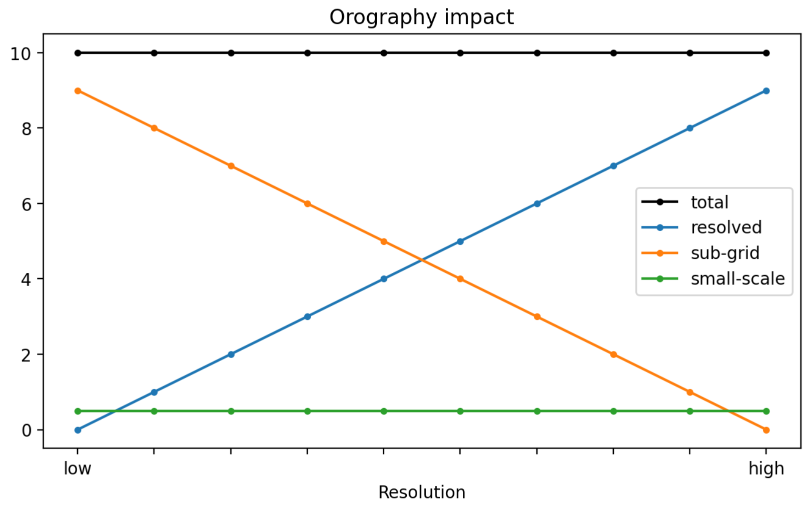
- Turbulent orographic form drag (TOFD) scheme parameterises orographic effects with horizontal scales < 5 km.
- Sub-grid scale orographic drag (SSO) scheme parameterises breaking of orographic gravity waves and flow-blocking by orography at low levels for horizontal scales between 5 km and the effective grid resolution.

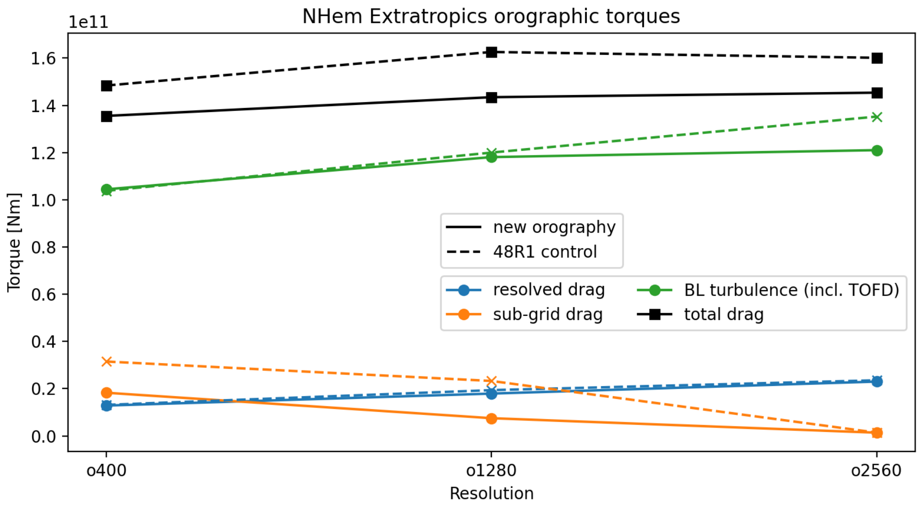
Different types of atmospheric drag



SUBGRID-SCALE (UNRESOLVED) OROGRAPHY

- Updated processing changes the fields. They vary more smoothly and consistently with resolution.
- Corrected some coefficients in the turbulent orographic form drag (TOFD) parameterisation.
- More consistent fields across resolutions, more consistent momentum budget across resolutions.
- Sub-grid scale processes still important at high resolution and contribute to improved scores.





INTERACTION OF OROGRAPHIC DRAG PARAMETRIZATIONS

- Parameterisations have some uncertain coefficients – they are not optimal any more with new fields.
- Parameterisations highly interdependent – difficult to improve one by one.
- Aim to re-tune some highly uncertain coefficients in the parameterisations all in one go.

Turbulent orographic form drag

$$TOFD = \alpha_{TOFD} C_{coll} e^{-(z/1500)^{1.5}} z^{-1.2} U|U| \, \sigma_T^2$$

Orographic flow-blocking drag

$$BLOC = C_d \rho \frac{\alpha}{4\sigma} \left(\frac{z_{blk} - z}{z + \sigma} \right)^{0.5} U|U| f_1(\gamma, \theta)$$

blocking depth $\int_{z_{blk}}^{3\sigma} \frac{N(z)}{U(z)} dz \geq Fr_{crit}$

Orographic gravity-wave drag

$$OGWD = G \rho N \frac{\alpha}{4\sigma} h_{eff}^2 U f_2(\gamma, \theta)$$

effective height $h_{eff} = 3\sigma - z_{blk}$

waves break where $\frac{Ri\left(1 - \frac{N\eta}{|U|}\right)}{\left(1 + \frac{Ri^{0.5} N\eta}{|U|}\right)^2} < Ri_{crit}$

Sub-grid orography fields

- σ_T std. deviation (< 5 km)
- σ std. deviation (> 5 km)
- α slope
- γ anisotropy (aspect ratio)
- θ orientation

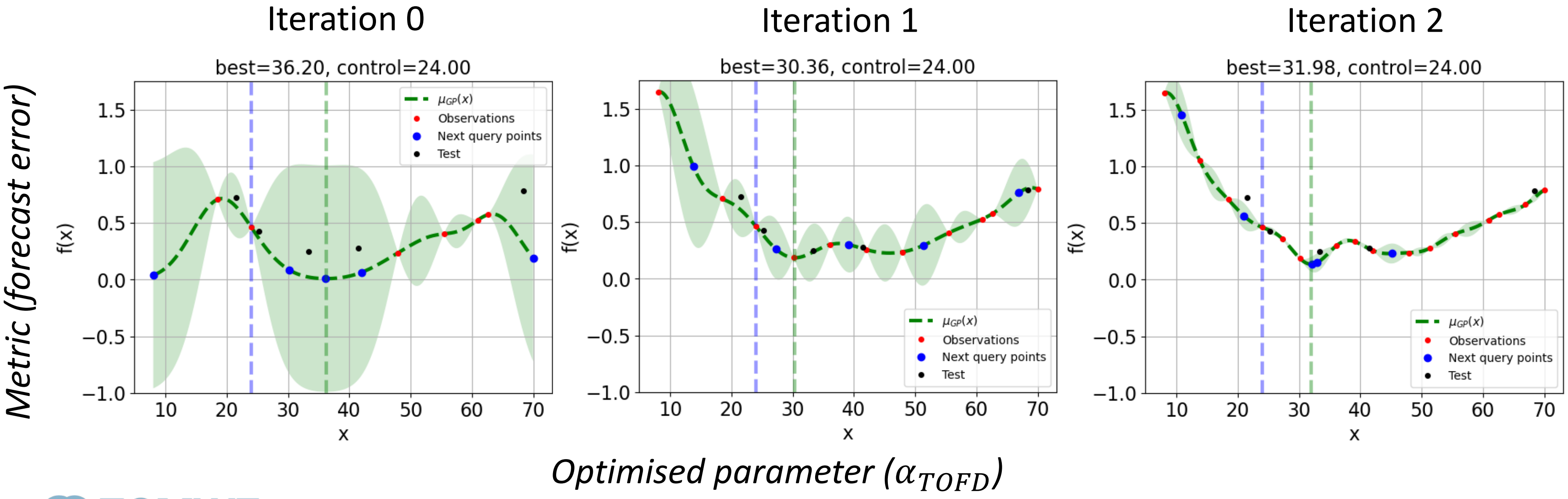
Tuning parameters

- α_{TOFD} magnitude TOFD
- C_d magnitude blocking
- G magnitude GWD
- Fr_{crit} partition blocking/GWD
- Ri_{crit} wave-breaking height
- U wind

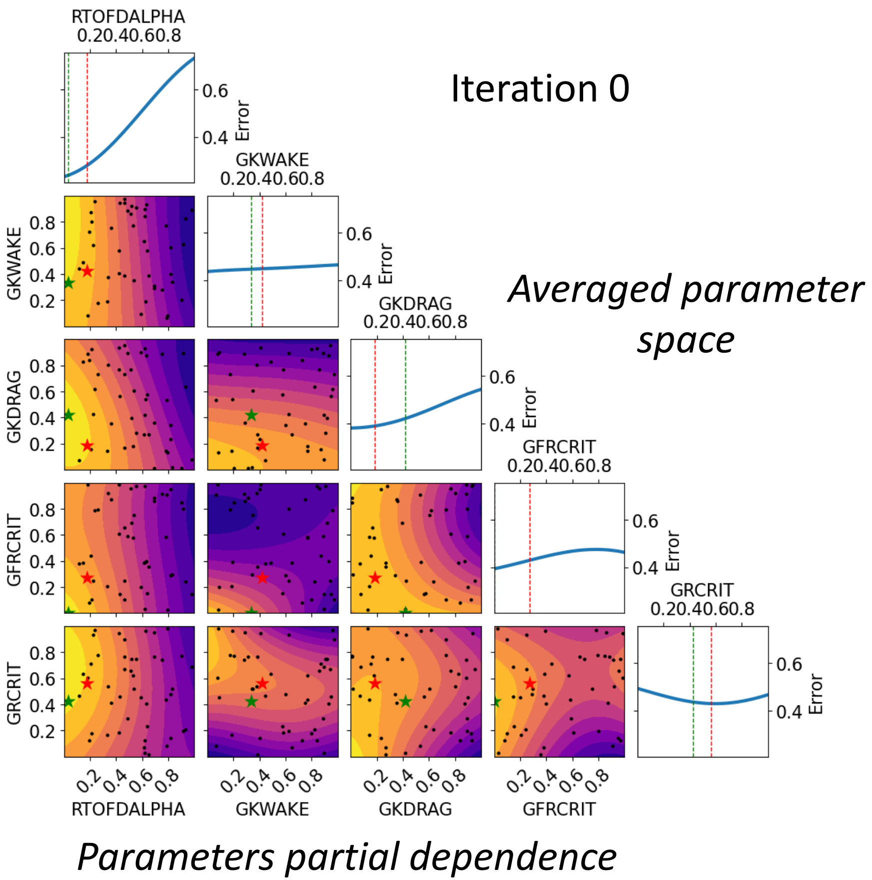
ECMWF

BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY

- Aim to re-tune some highly uncertain coefficients in the parameterisations all in one go.
- Gaussian process emulator estimates forecast error as a function of the parameter. It also estimates the uncertainty of this function.
- Each iteration of added values decreases uncertainty.
- The optimal parameter is the minimum of the emular function of forecast error.



BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY

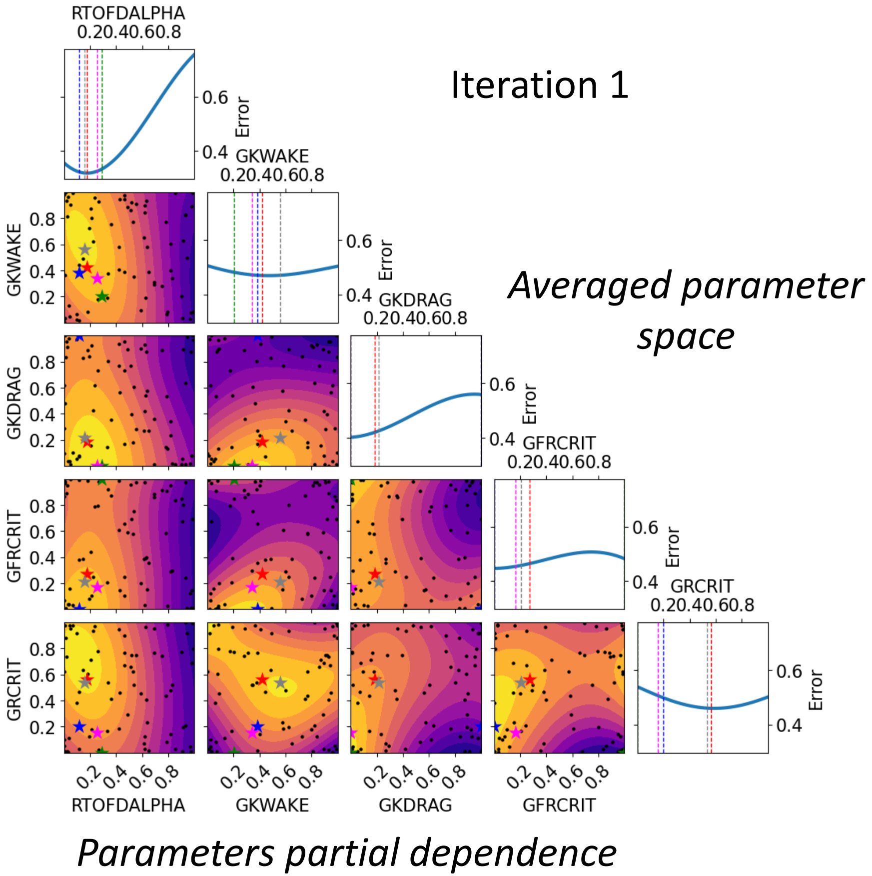


- 50 samples at low resolution (28 km).

Yellow – small forecast error

Purple – large forecast error

BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY



- 75 samples at low resolution (28 km).

Yellow – small forecast error

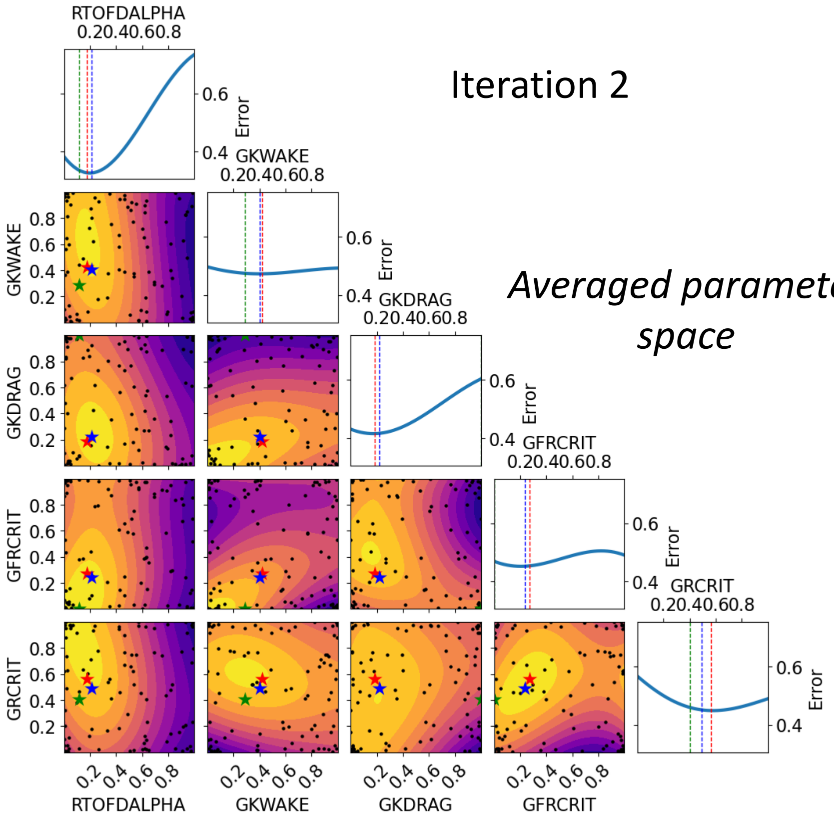
Purple – large forecast error

BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY

- 100 samples at low resolution (28 km).

Iteration 2

Averaged parameter space



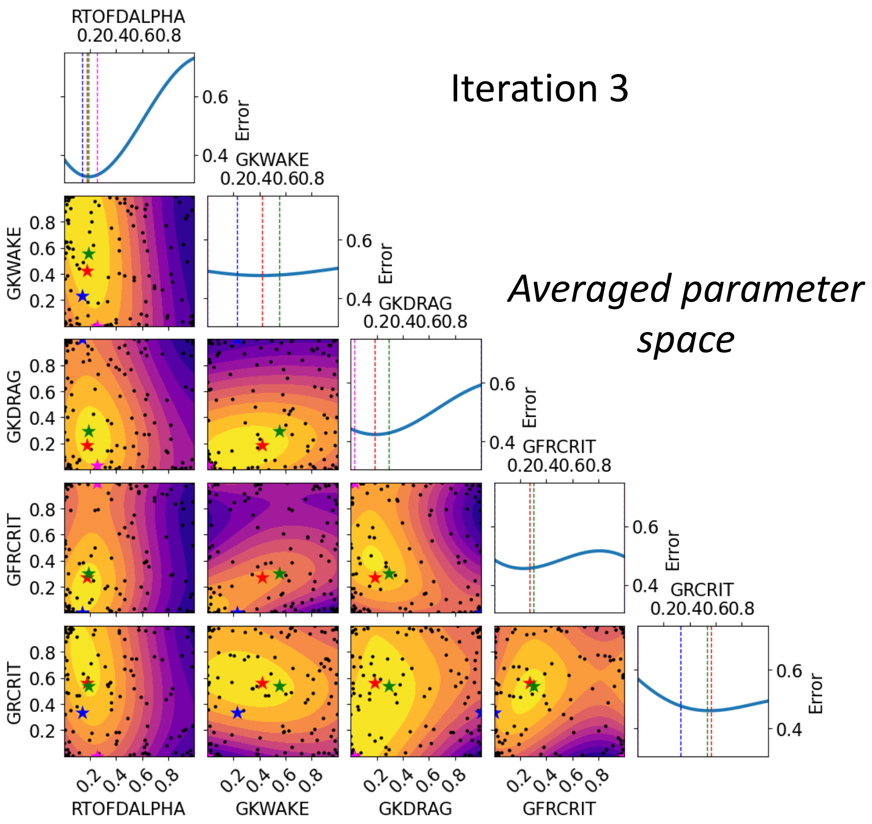
Parameters partial dependence

Yellow – small forecast error

Purple – large forecast error

ECMWF

BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY



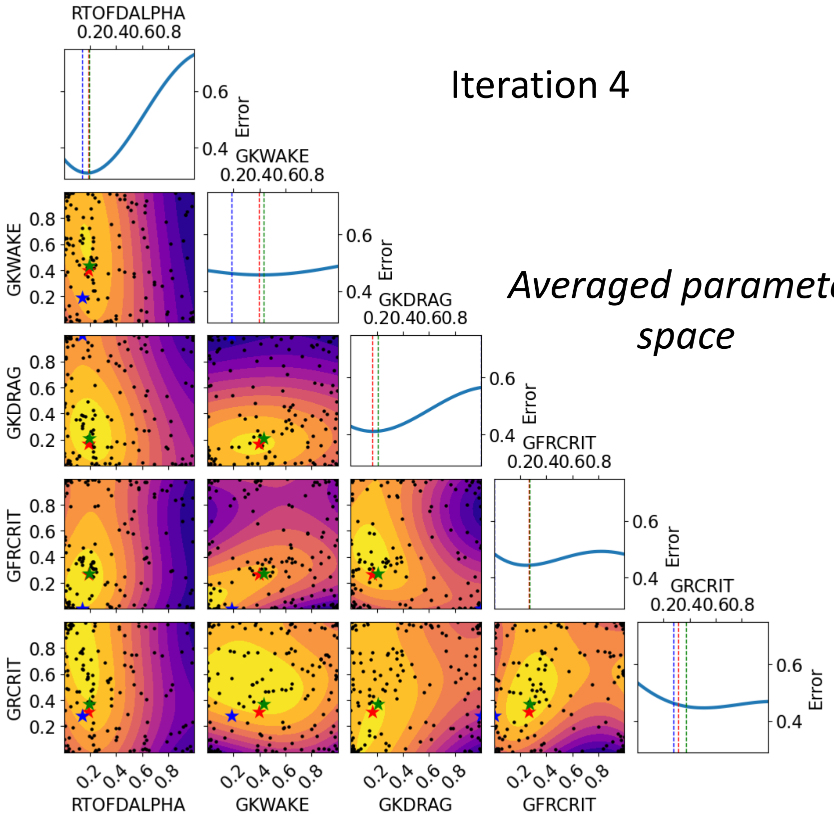
Parameters partial dependence

- 125 samples at low resolution (28 km).

Yellow – small forecast error

Purple – large forecast error

BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY



Iteration 4

Averaged parameter space

Parameters partial dependence

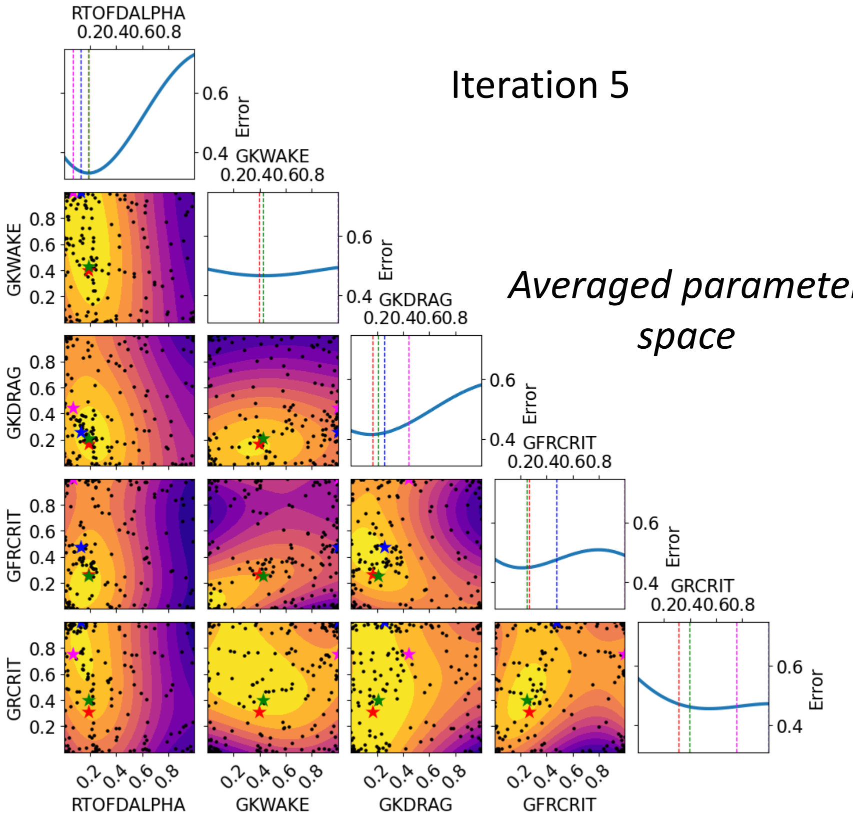
- 150 samples at low resolution (28 km).

Yellow – small forecast error

Purple – large forecast error

BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY

Iteration 5



Averaged parameter space

Parameters partial dependence

- 175 samples at low resolution (28 km).

Yellow – small forecast error

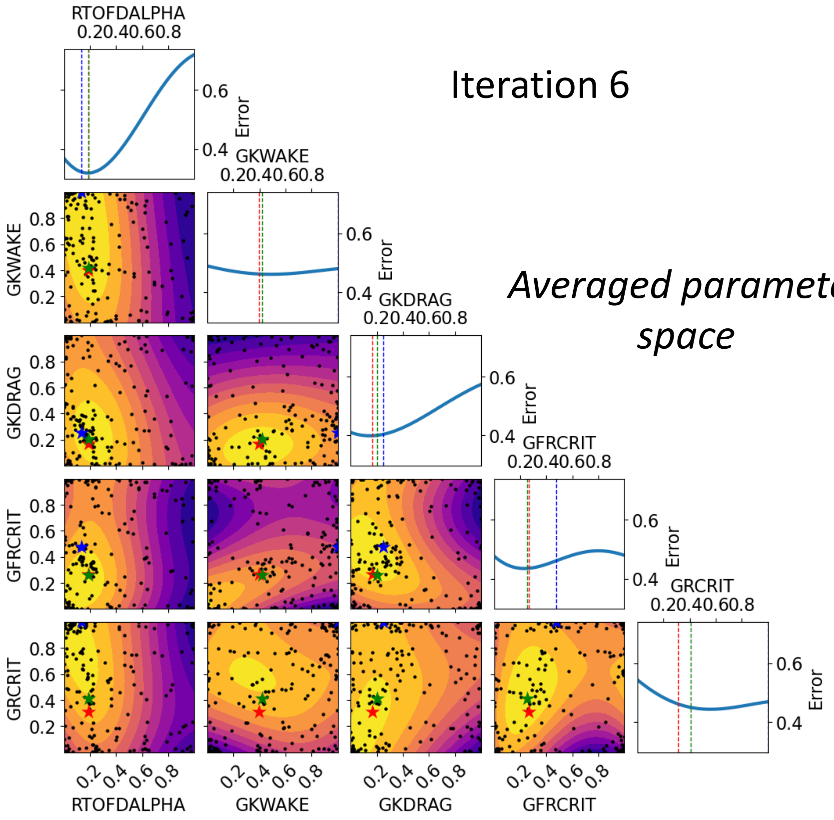
Purple – large forecast error

ECMWF

BAYESIAN PARAMETER OPTIMISATION FOR OROGRAPHY

Iteration 6

Averaged parameter space



Parameters partial dependence

Yellow – small forecast error

Purple – large forecast error

- 185 samples at low resolution (28 km).
- Averaged parameter function shows convergence.
- With suggested minima (dashed lines) converging too.
- Next step: test and fine-tune for higher resolution.

SUMMARY AND NEXT STEPS

- High-resolution (km-scale) global simulations with Destination Earth (DestinE) requires adequate representation of orography including orographic fine-scale features.
- Aim to improve the representation of orography in the IFS across scales in a scale-intepependent way.
- Changes to mean (resolved) orography including slightly increased dampening of small scales reduces bias from high amplitude gravity waves (e.g. Tibet plateau) in high-resolution simulations.
- Updated sub-grid (parameterised) orography processing yields more consistent fields and momentum budget across resolutions, but changes require re-tuning of uncertain parameters in schemes.
- Bayesian parameter optimisation is efficient in re-tuning several interdependent parameters at the same time and yields promising first results.
- Next steps for parameter optimisation:
  - update to newest model cycle,
  - expand testing range (winter + summer),
  - test and fine-tune for higher resolutions.
- Investigate effects of high-resolution source data.

CONTACT AND FURTHER INFORMATION

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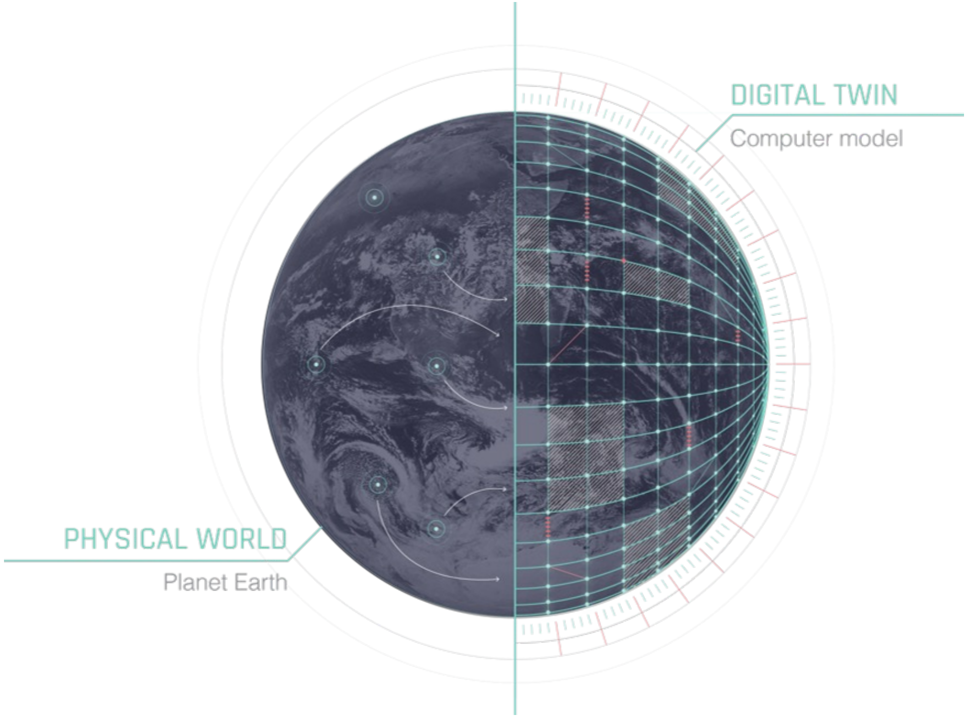
www.ecmwf.int/destine



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