Orographic drag on islands in the NWP “mountain grey zone”

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Motivation

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- Despite decades of research orographic drag processes are still poorly represented in global NWP and climate models.
  - NWP and Climate predictions are highly sensitive to the tuning of drag parametrization schemes, yet these remain crude and unconstrained.
  - There is a need to better understand how well drag is represented in GCMs.

- Global models are increasingly run at high (~10km) resolutions.
  - Some orographic drag processes are starting to become explicitly resolved.
    - But when poorly resolved, are they represented well?
    - How do drag parametrizations work when the mountains are partially resolved?

  - To what extent are drag parametrization schemes well behaved across the range of resolutions, especially in this “grey zone” ?

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Hypothetical behaviour of resolved and parametrized orographic drag

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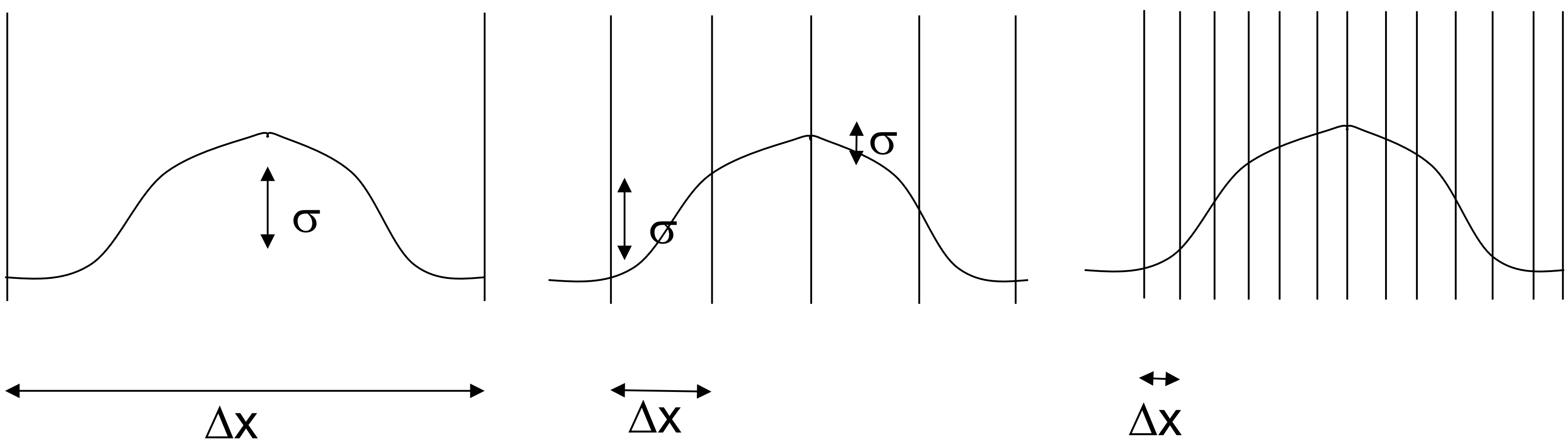
Consider a simple drag parametrization, where the drag is a function of the variance of the sub grid orography, σ^2

Mountain entirely subgrid	Mountain partially resolved	Well resolved mountain range
Zero resolved drag	Small resolved drag	Large resolved drag
Large $\sigma \rightarrow$ large parametrized drag	Variable σ	Small $\sigma \rightarrow$ small parametrized drag
	Total drag ????	



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Aims

- Use high resolution model simulations to understand:
  - How does model resolved and parametrized drag (from GWs, flow blocking etc) behave across a range of resolutions?

- Focus on southern hemisphere mountainous island barriers
- Consider two such islands, with different length scales:
  - South Georgia Island (λ~40km)
  - New Zealand South Island (λ~240 km)

- Use limited area Unified Model simulations at a range of resolutions and assume highest resolution simulations represent the "truth".
  - More detail in Vosper et al. (2016) Orographic drag on islands in the NWP mountain grey zone, QJRMS, in press.

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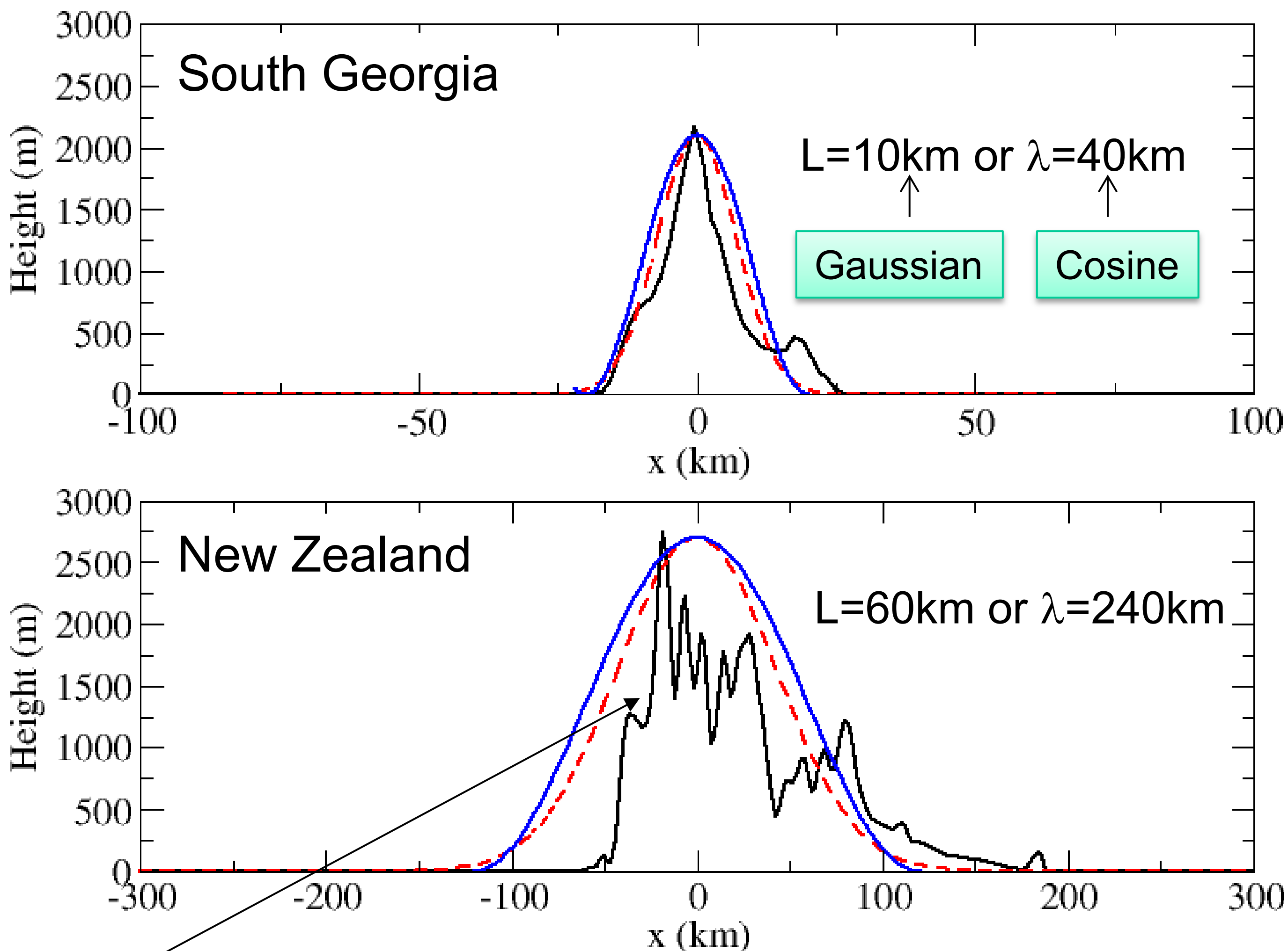
Mountain length scales

Zonal cross sections



Note multiple scales

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Recent studies of drag over South Georgia (Vosper, 2015, QJRMS)

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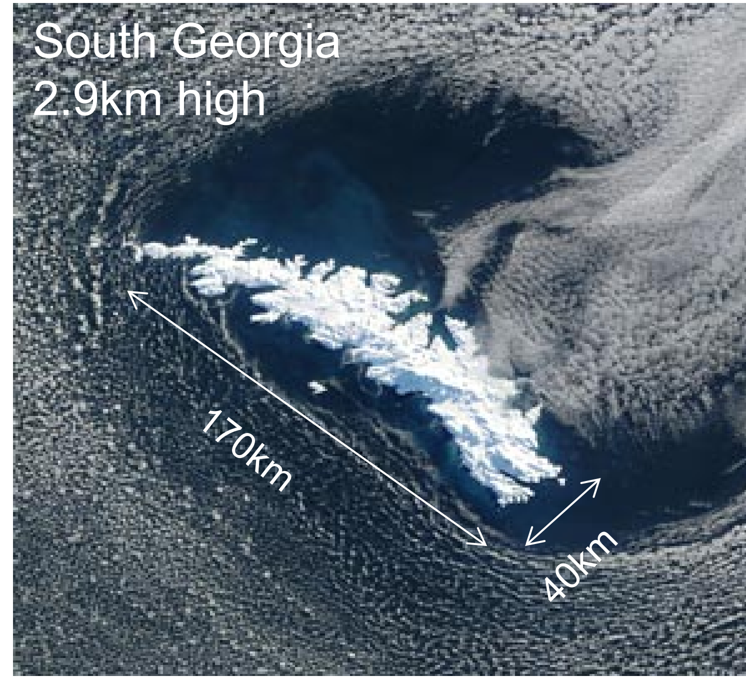
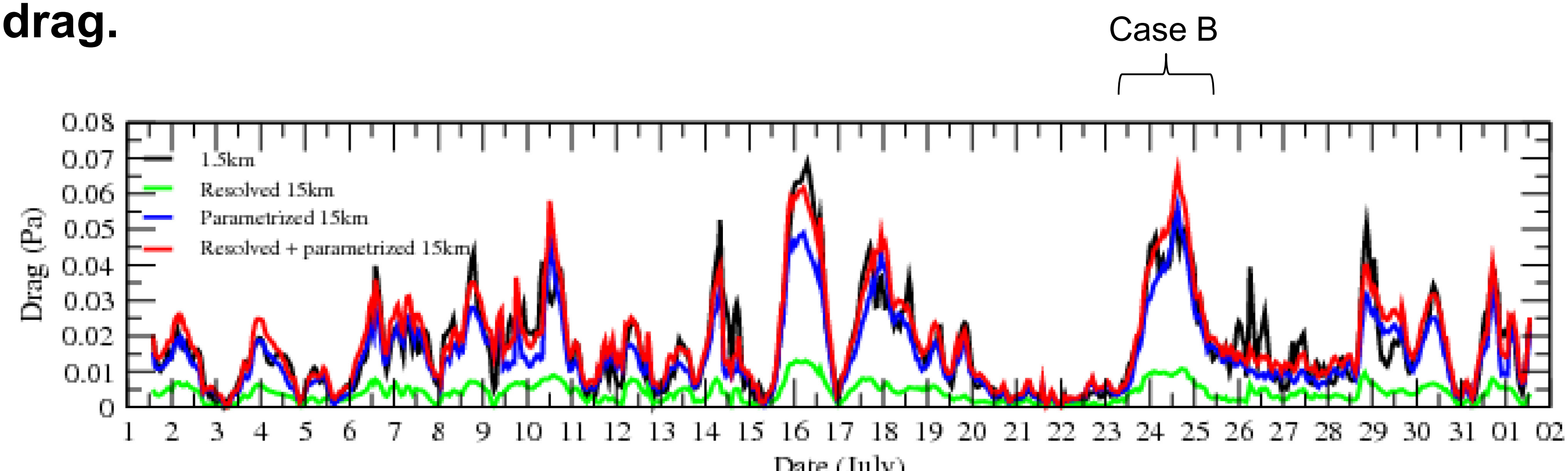


- One-month limited area simulations at 1.5km and 15km resolution.
- Drag is under-resolved on 15km grid
- Parametrized drag correlates well with drag in 1.5km simulation
- **Sum of resolved and parametrized drag in 15km simulation agrees well with 1.5km drag.**



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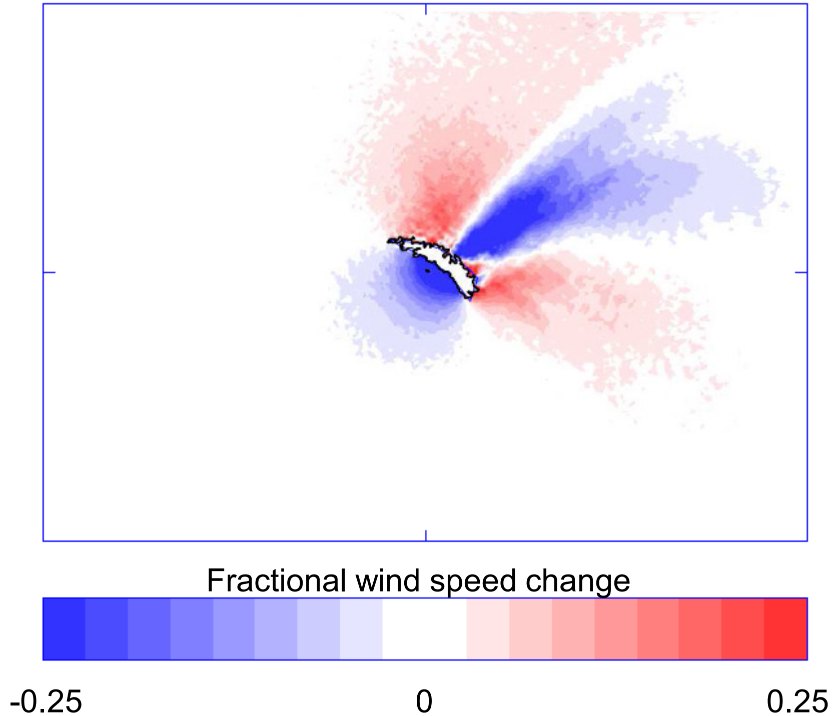
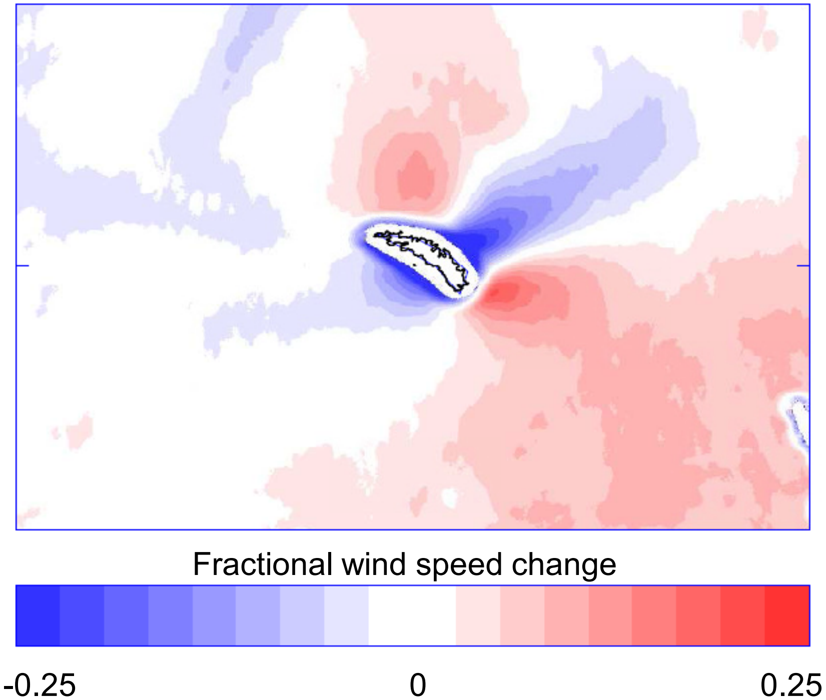
Model vs satellite wake observations

•Direct measurements of surface drag are difficult, but we can validate other aspects of models





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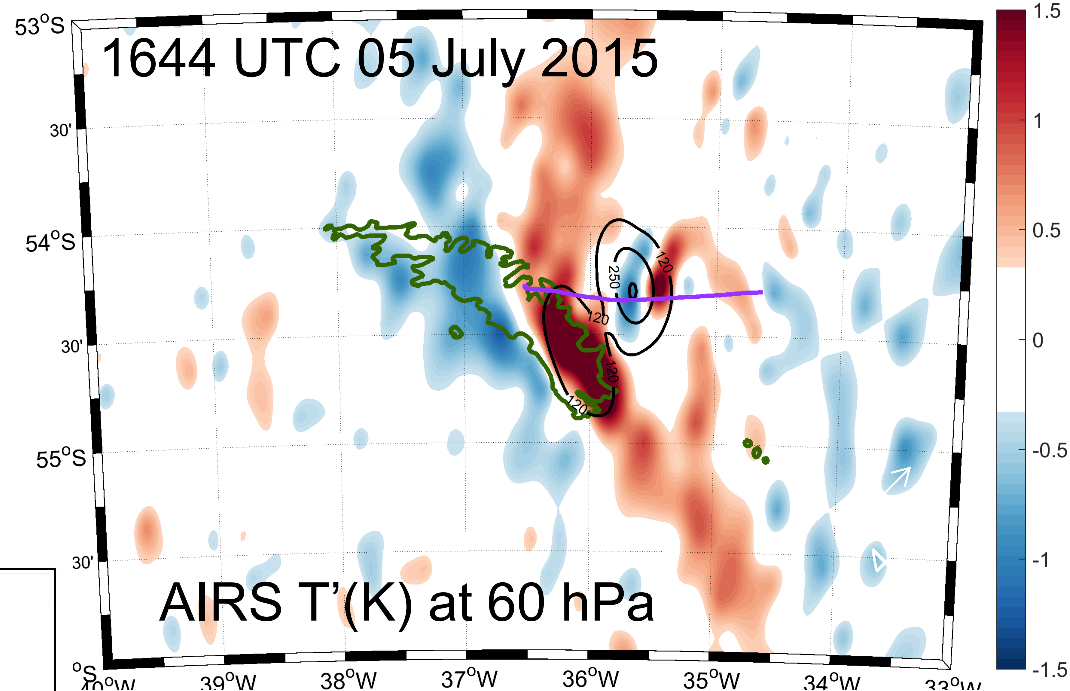
•ASCAT surface wind measurements

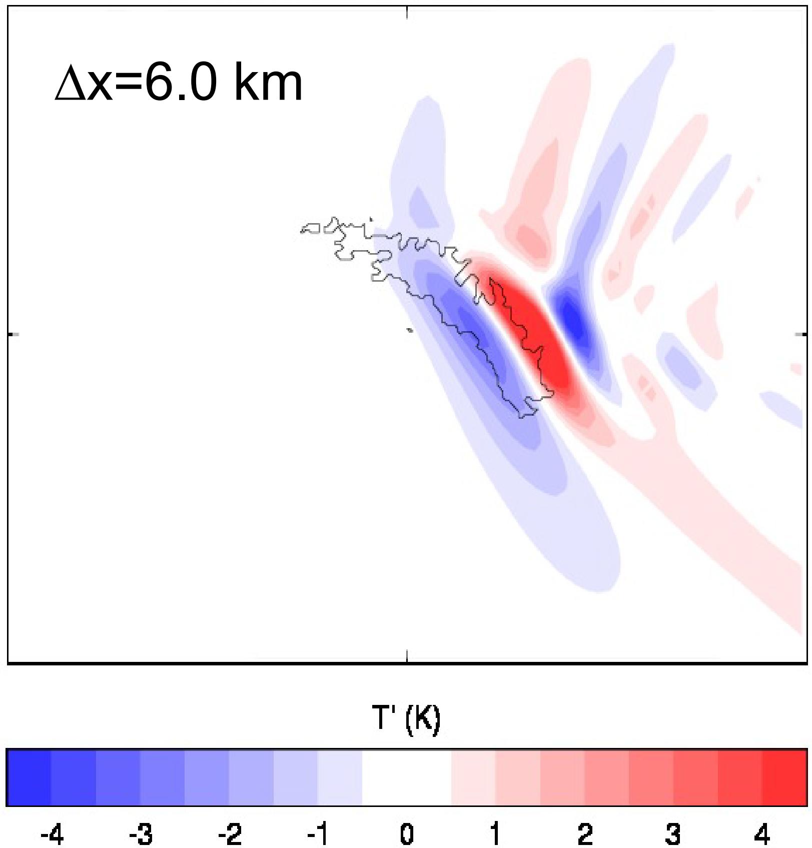
•Sampled for 1-month of SW'ly flow across South Georgia (July 2014)

•Model wakes similar to observed

(John Hughes, Univ. Leeds)

Model vs satellite gravity wave observations



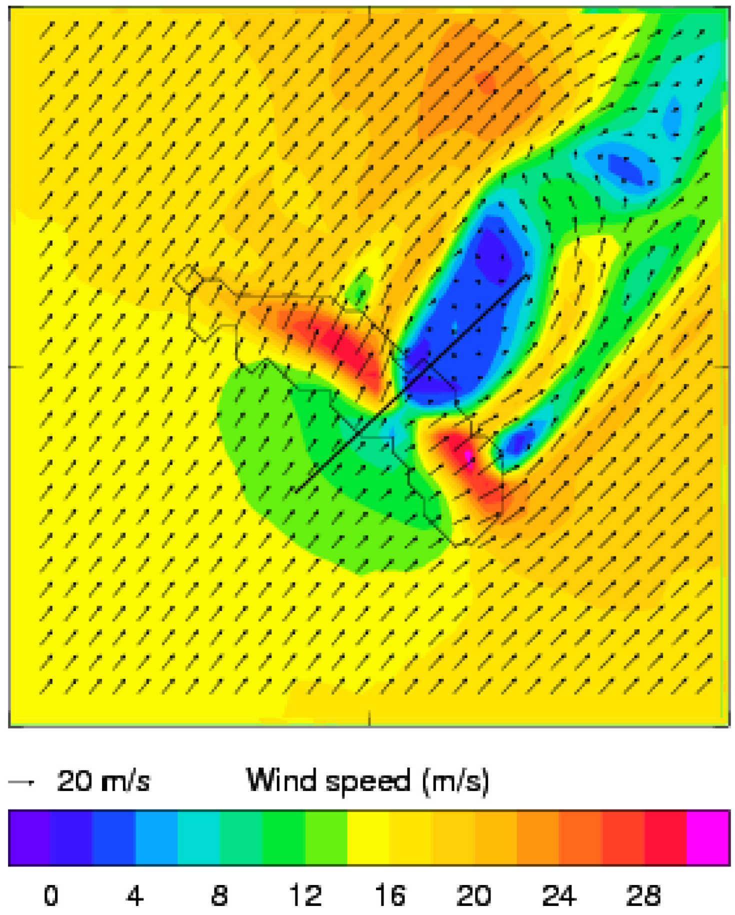


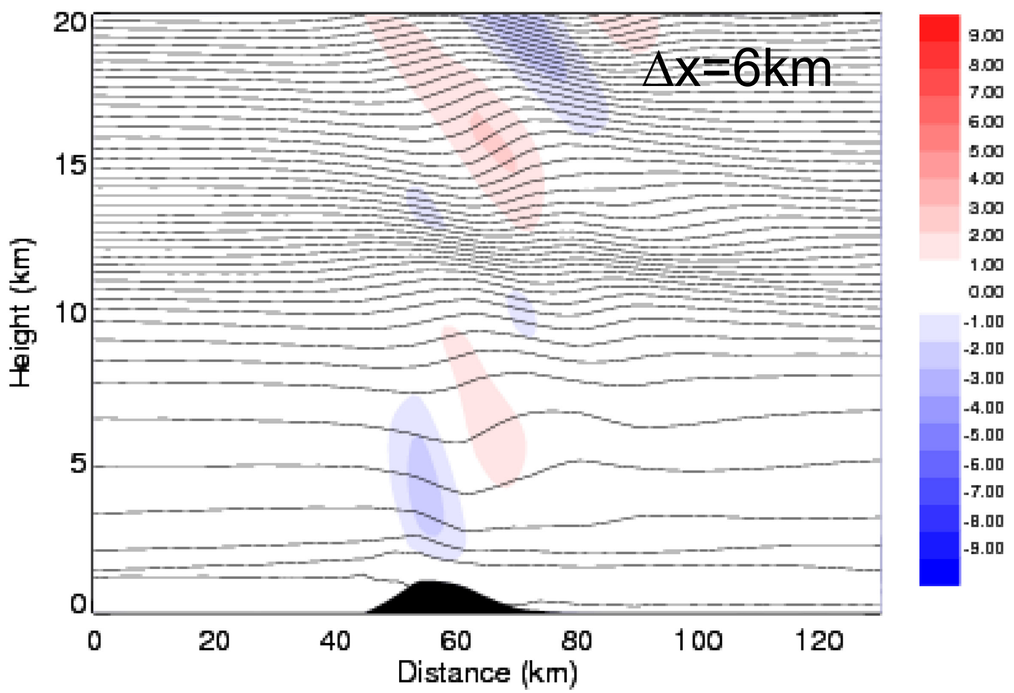
- AIRS measurements during SG-WEX
- Model T' field similar to observed
- Agreement better at coarser model resolution: short wavelength trailing waves absent!

(Corwin Wright, Univ. Bath)

South Georgia

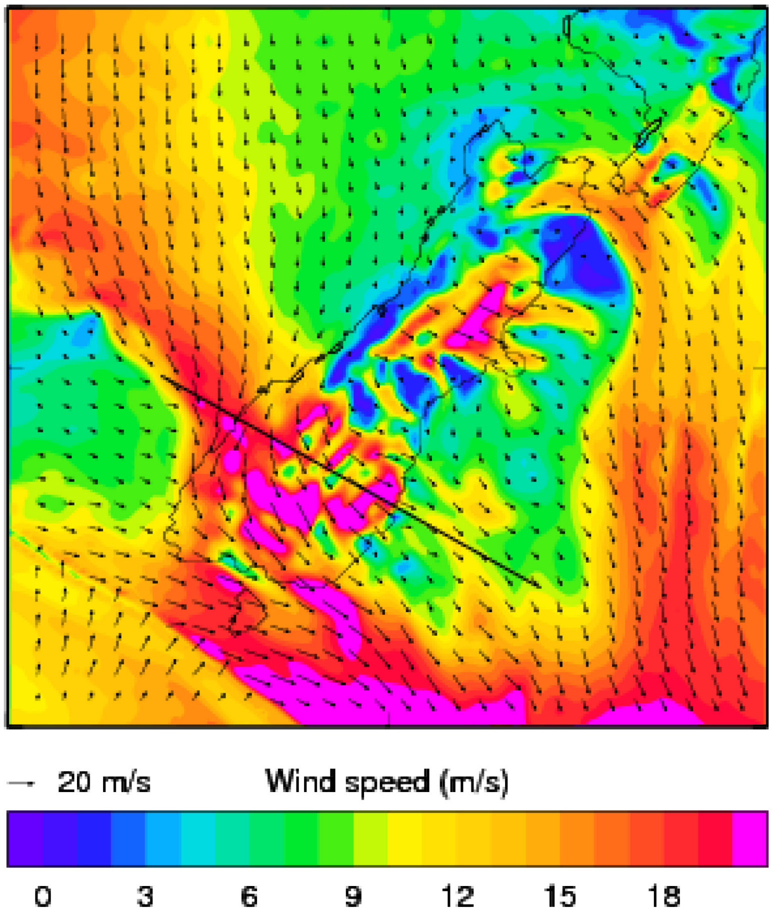
- A 72h high drag case run at a range of resolutions (Δx=1.5 - 25 km)
- Deep gravity wave propagation (Case B in Vosper 2015).

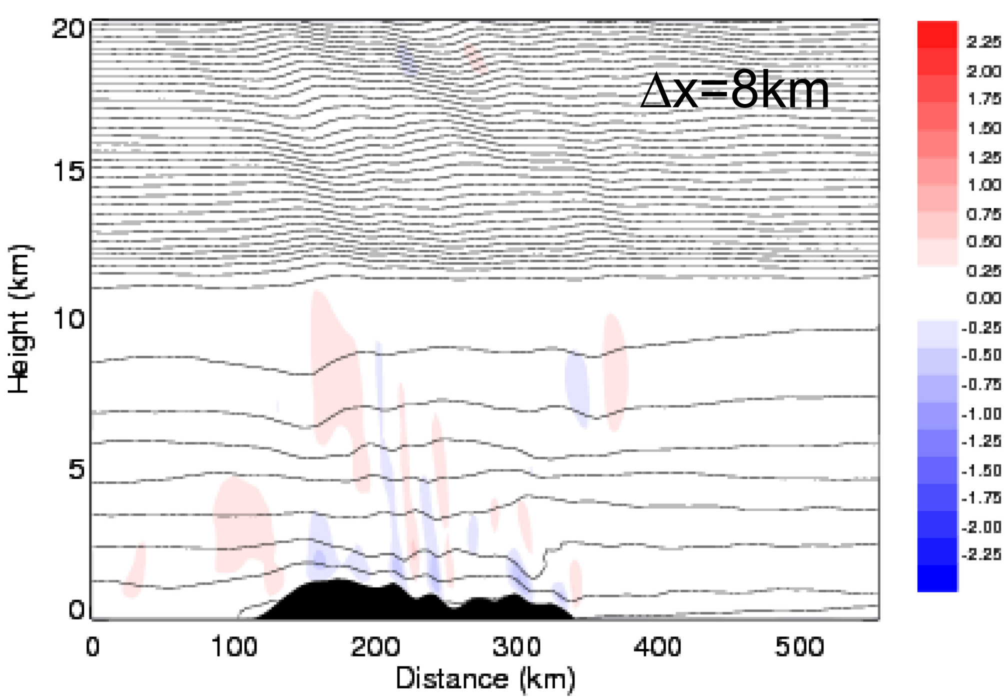




New Zealand

- A 48h forecast from 18 UTC 13 June.
- Run at range of resolutions (Δx=2 -40km)
- Coincides with DEEPWAVE RF04.

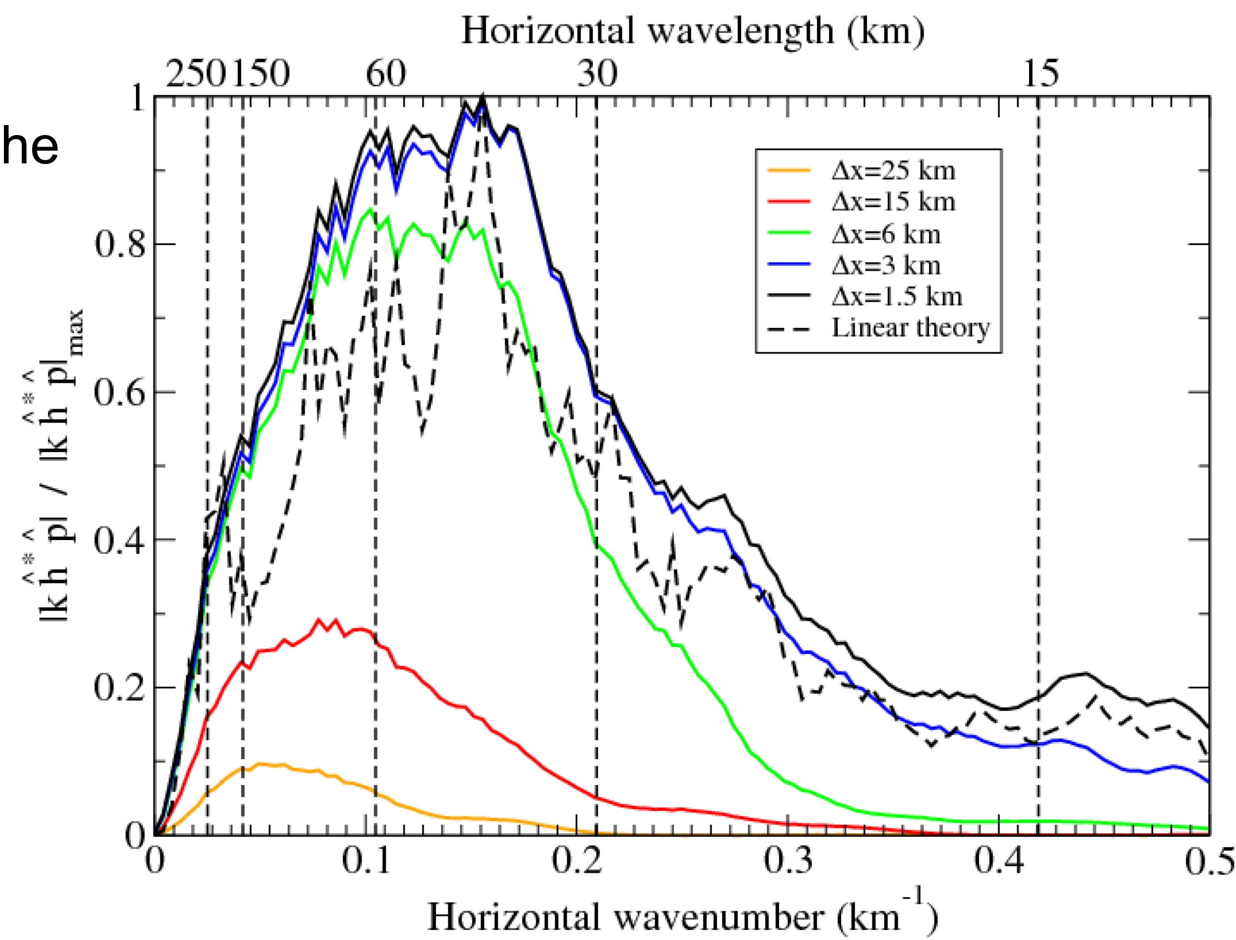




Spectral contributions to surface pressure drag

- Peak in drag at λ~40 km, for South Georgia
- This is well represented in the finest resolution models but missing at coarse resolution
- Contributions from shorter wavelengths poorly represented at coarse resolution
- Missing drag at coarse resolution needs to be parametrized

Time averaged spectral decomposition of pressure drag



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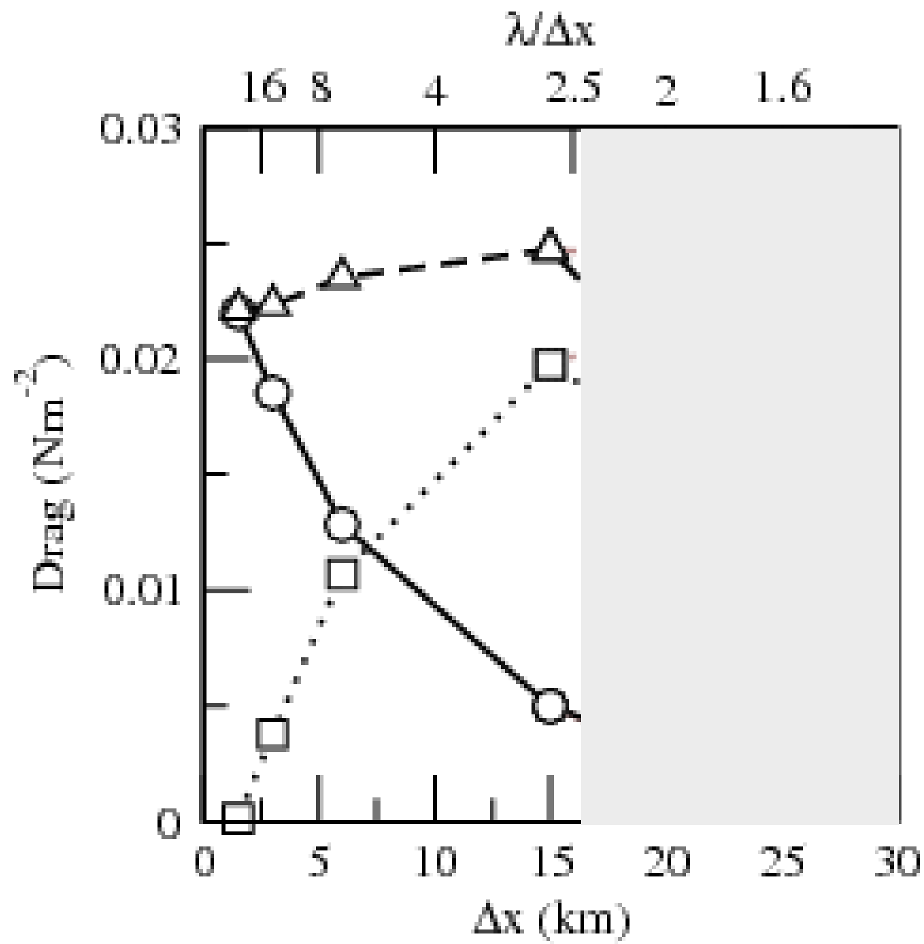
How well is the drag represented across a range of model resolutions?

South Georgia

- Time-mean surface pressure drag
- Resolved drag decreases monotonically with increasing grid spacing
- Parametrized drag increases with increasing Δx
- Hand-over occurs at ~$\lambda/\Delta x$=8
- Total (resolved + parametrized) drag is roughly invariant



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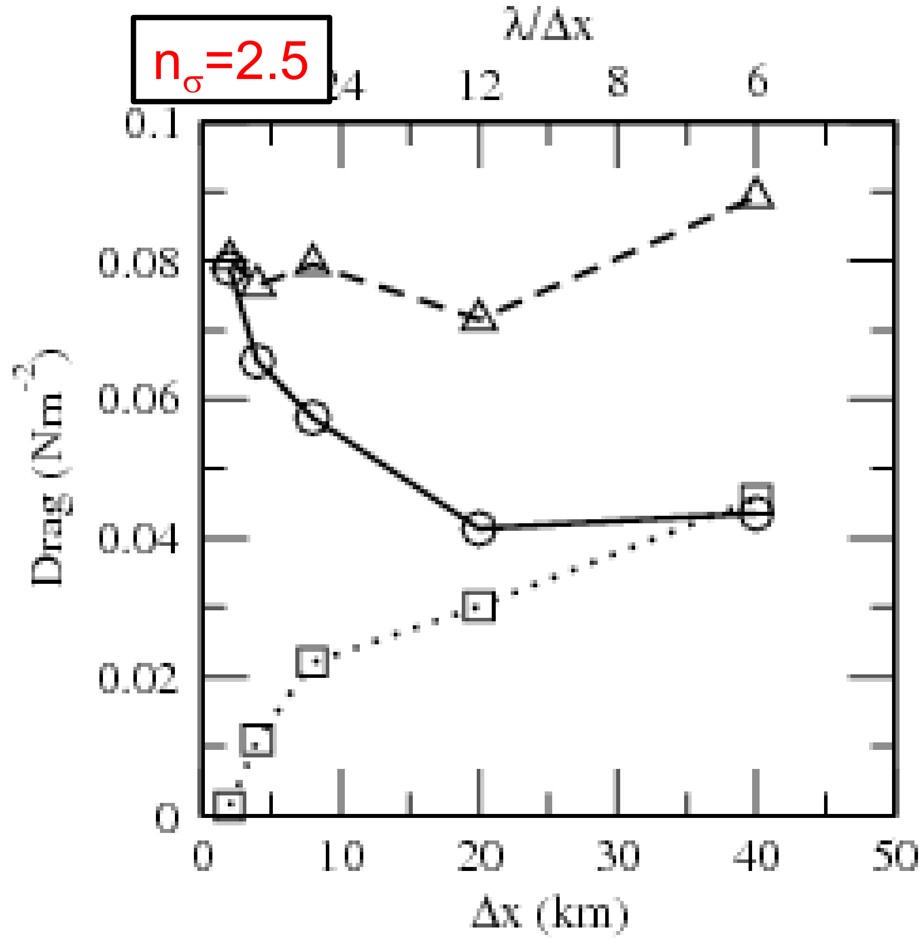
How well is the drag represented across a range of model resolutions?

New Zealand

- For same tuning as South Georgia, parametrized drag increases rapidly with increasing Δx
- Not so well behaved: the total drag increases as Δx increases
- But total drag is well behaved for smaller value of $n_\sigma=2.5$
- And handover now occurs again at $\lambda/\Delta x \sim 8$



Why is a different tuning needed for South Georgia vs New Zealand?

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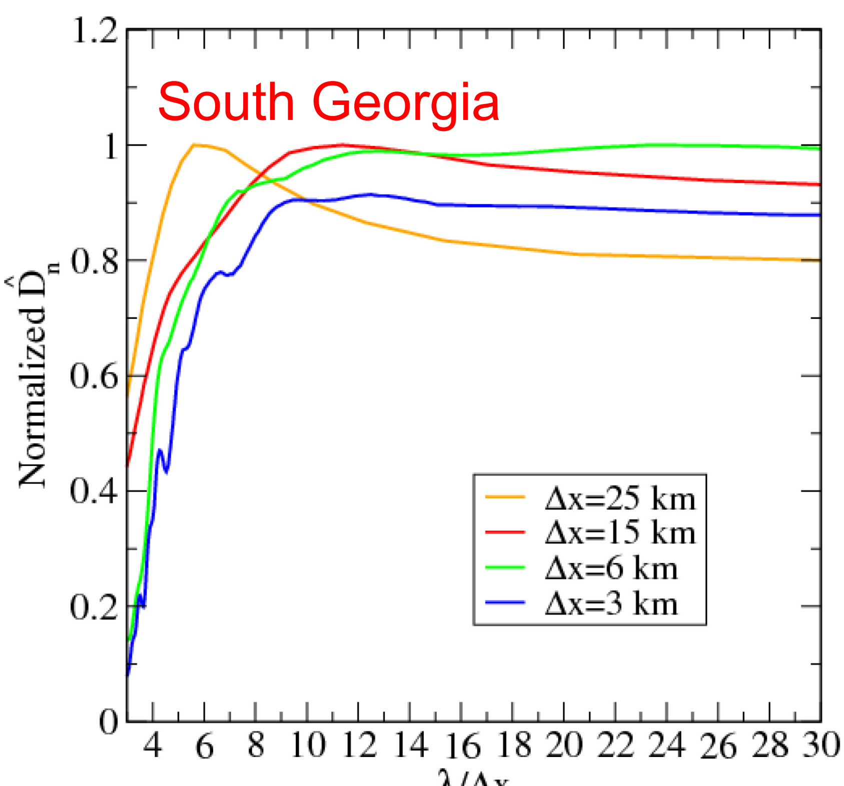
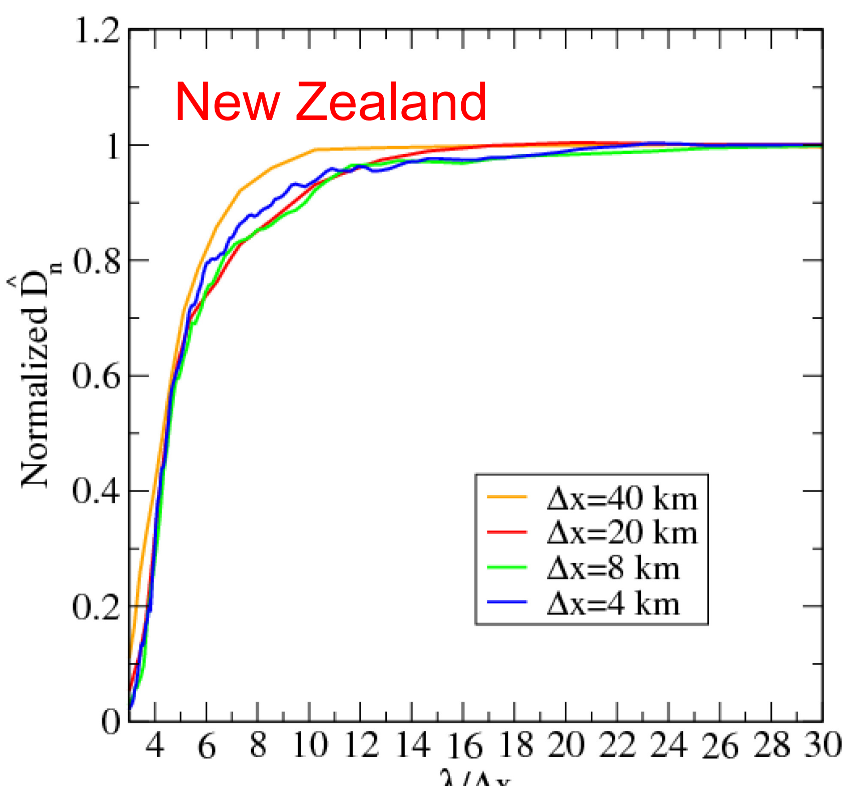
- Drag spectra, normalised by spectrum in highest resolution model
- Reveal that contributions to resolved drag are missing for wavelengths smaller than ~8 Δx
- **Parametrizations need to represent these missing scales, not just Δx**





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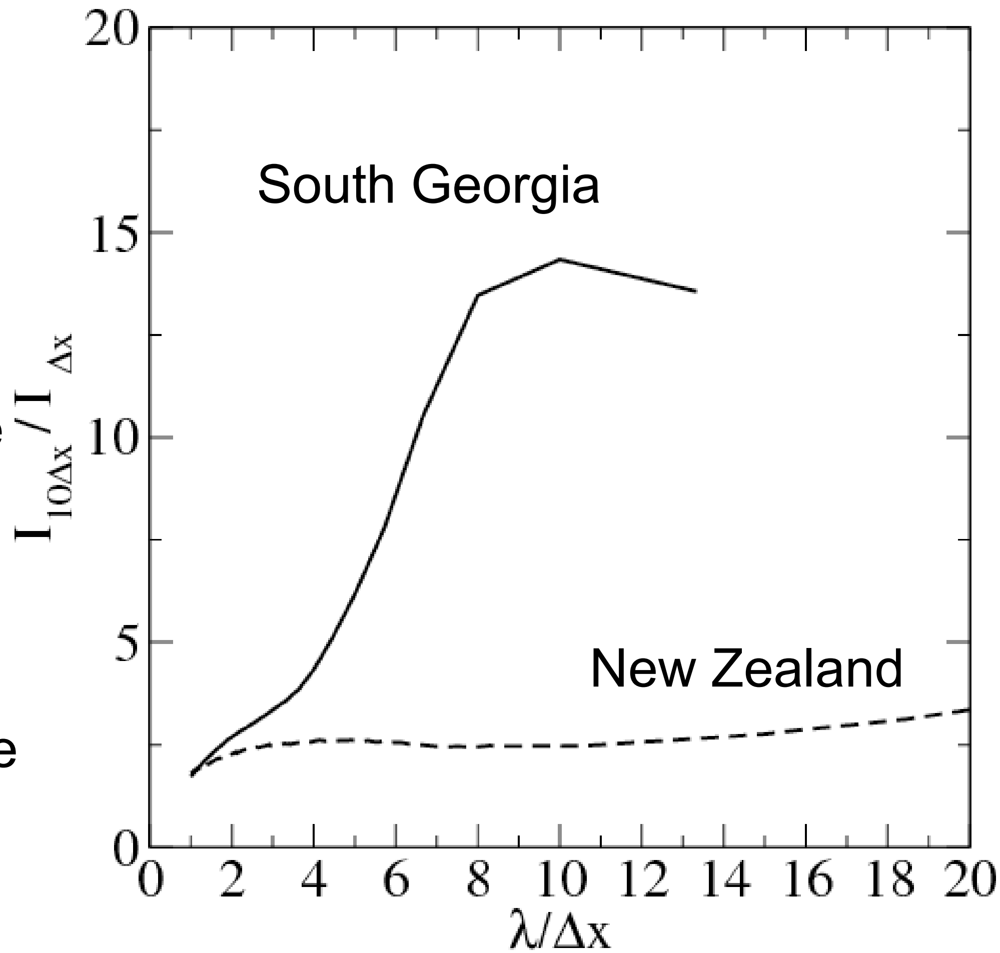
So why should different mountain ranges require a different value of “n_σ” ?

Ratio of RMS of height, $\overline{\hat{h}^2}^{1/2}$ integrated over wavelengths up to 10Δx, to wavelengths up to Δx

•New Zealand contains multiple small peaks, so has relatively large variability in orography at small scales vs large.

•South Georgia has less relative variability at small scales, so requires a larger scaling factor to represent the larger scales



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Conclusions

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- A parametrization scheme, *when suitably tuned*, can represent the low-level drag well, and compensates for the unresolved drag.
  - Total drag roughly invariant across resolution (*at least for NWP resolutions ~1km to ~40km).*
- But results suggest this requires different tuning for different mountain ranges
- Can be explained by the need for the drag scheme to represent processes on scales as large as ~8-10Δx, not just sub-grid processes.
- The relationship between the sub-grid orography and the 10Δx orography perhaps determines optimal tuning parameters for current schemes.
- Results suggest that drag schemes should explicitly represent scales larger than the grid scale.

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And finally ...

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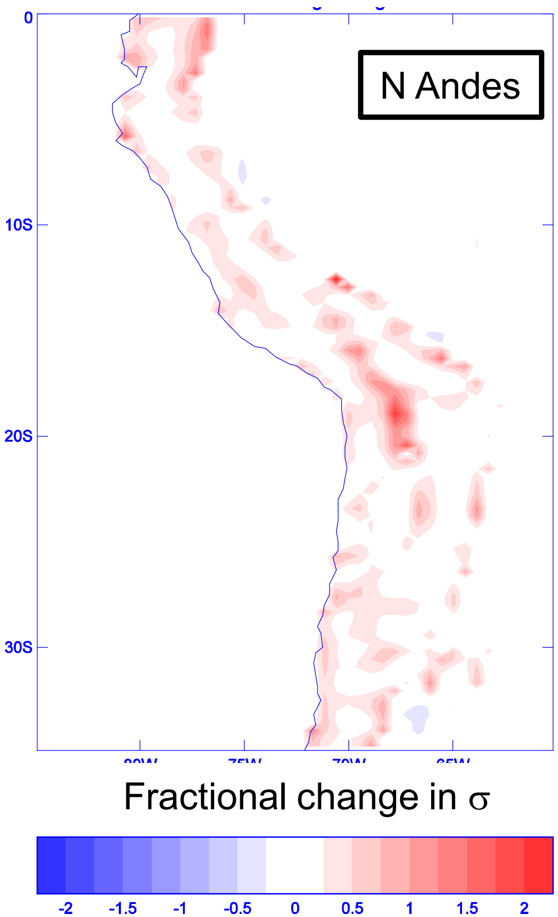
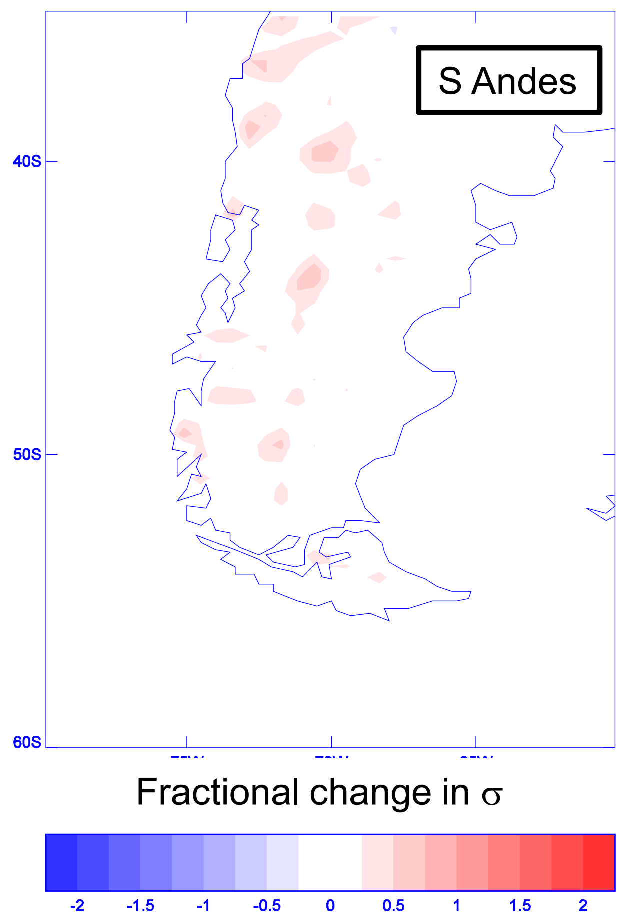
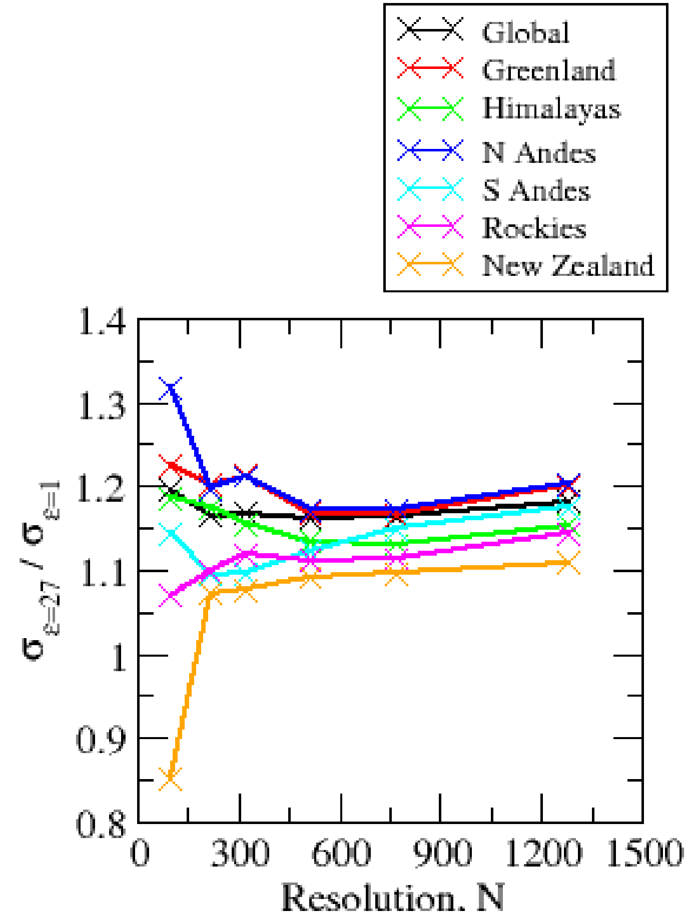
What happens if we account for longer scales in the SSO?

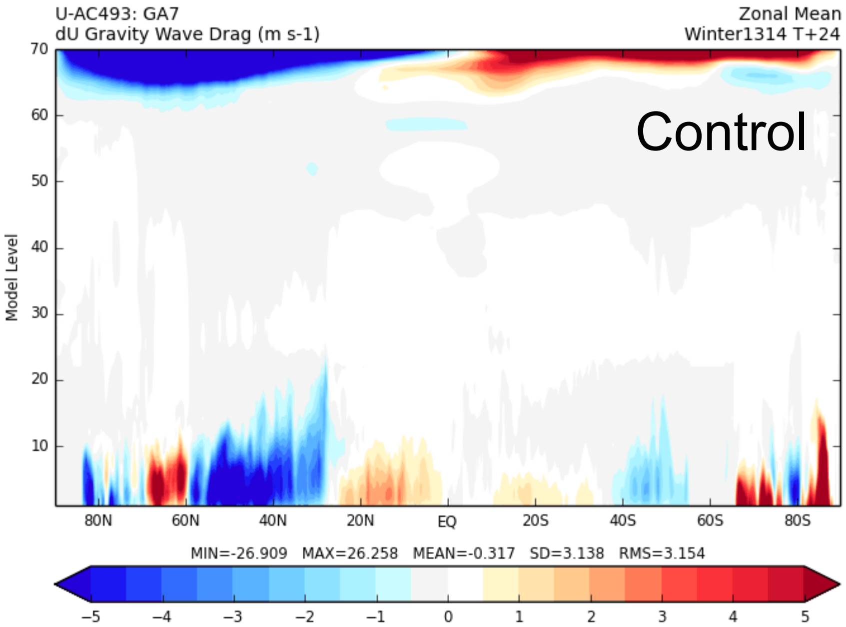
- SSO data including scales up to ~6Δx
- Increases σ in some regions more than others, consistent with regional differences in orographic "smoothness"

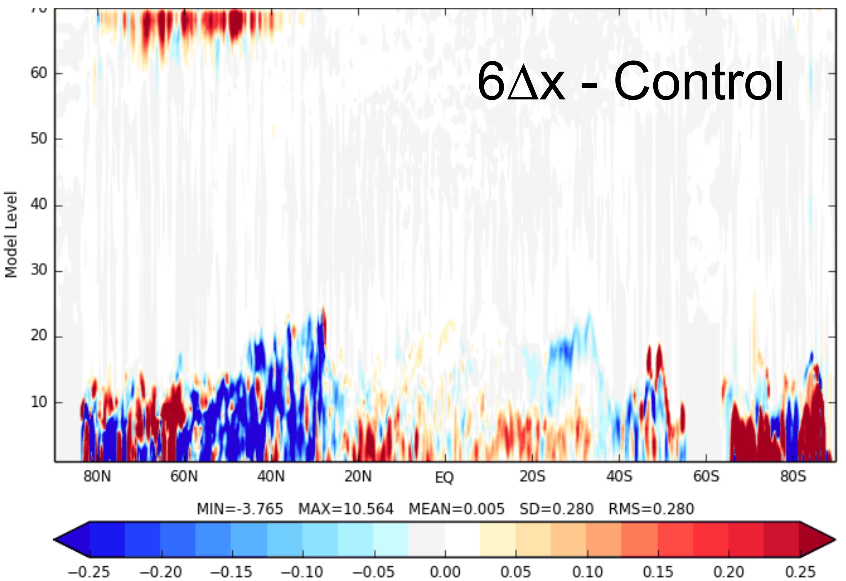






Zonal wind increments from GWD

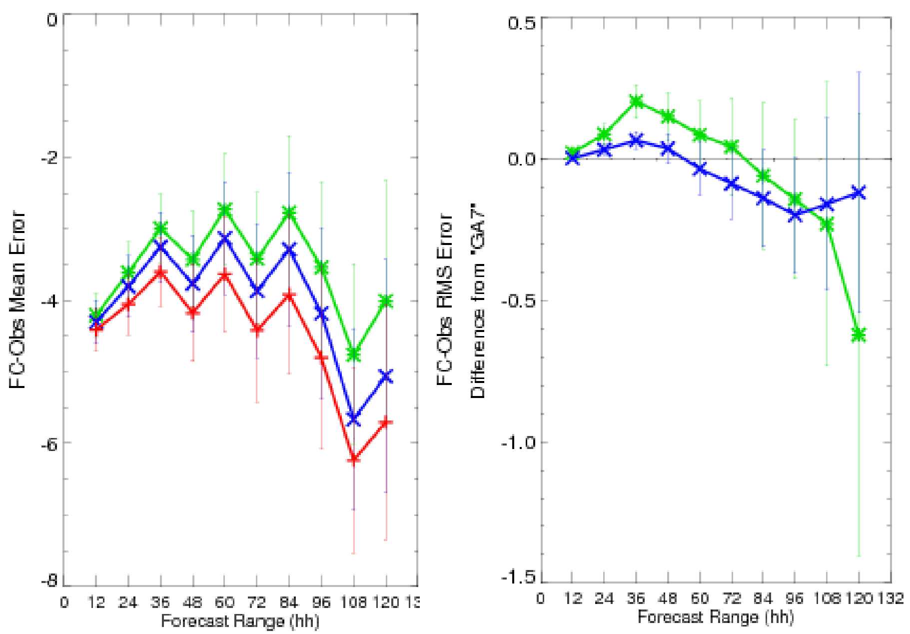




- Zonal mean impacts of including longer scales in SSO are:
  - Increases in flow blocking drag
  - Reduction in mountain wave drag

- Small improvements in NH winter Z500 bias and RMSE?

N320 forecast-only case studies
-Control (GA7) -6Δx -8Δx



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Thankyou for listening

Questions?

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