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# Orographic drag and the mountain-wave grey zone


Annelize van Niekerk

Simon Vosper

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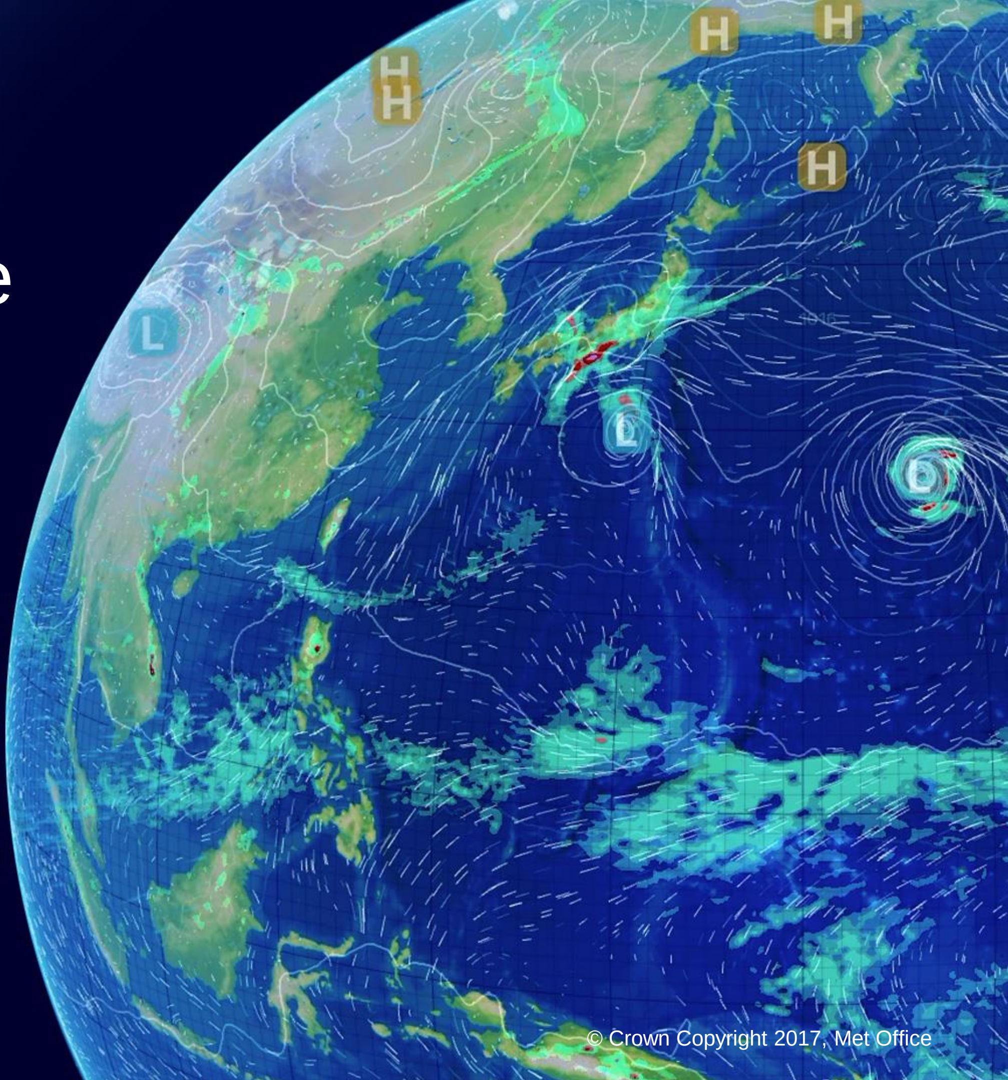

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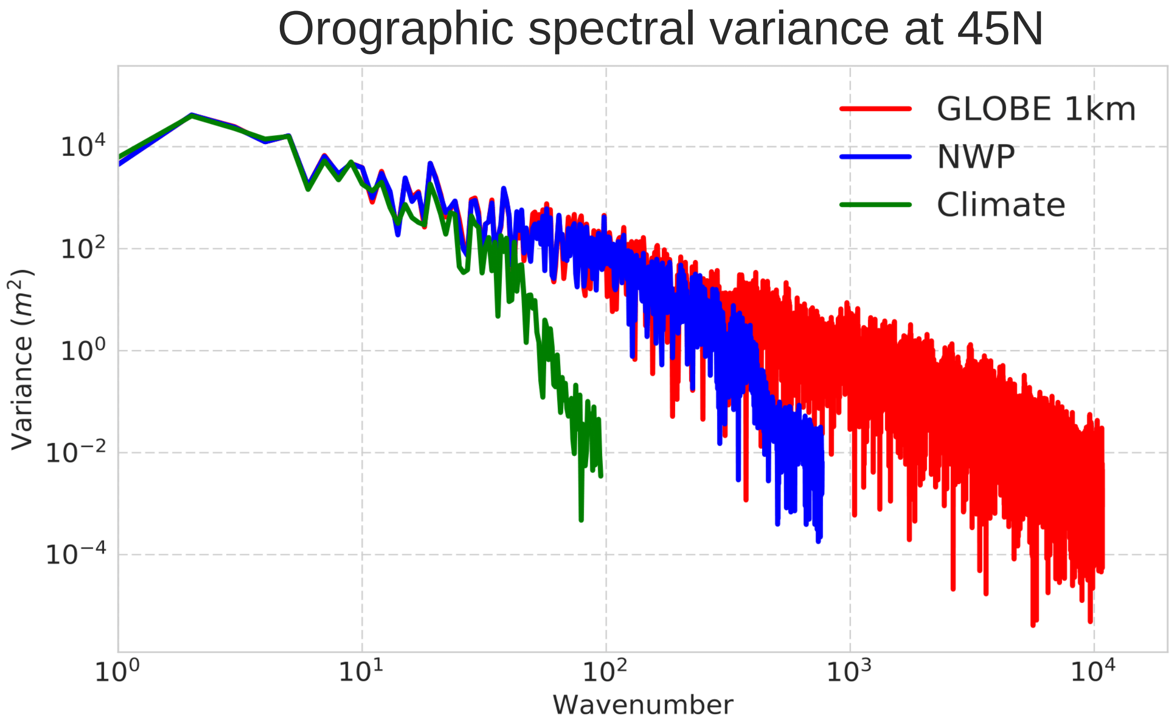
# Orography in a 'grey-zone' at all resolutions



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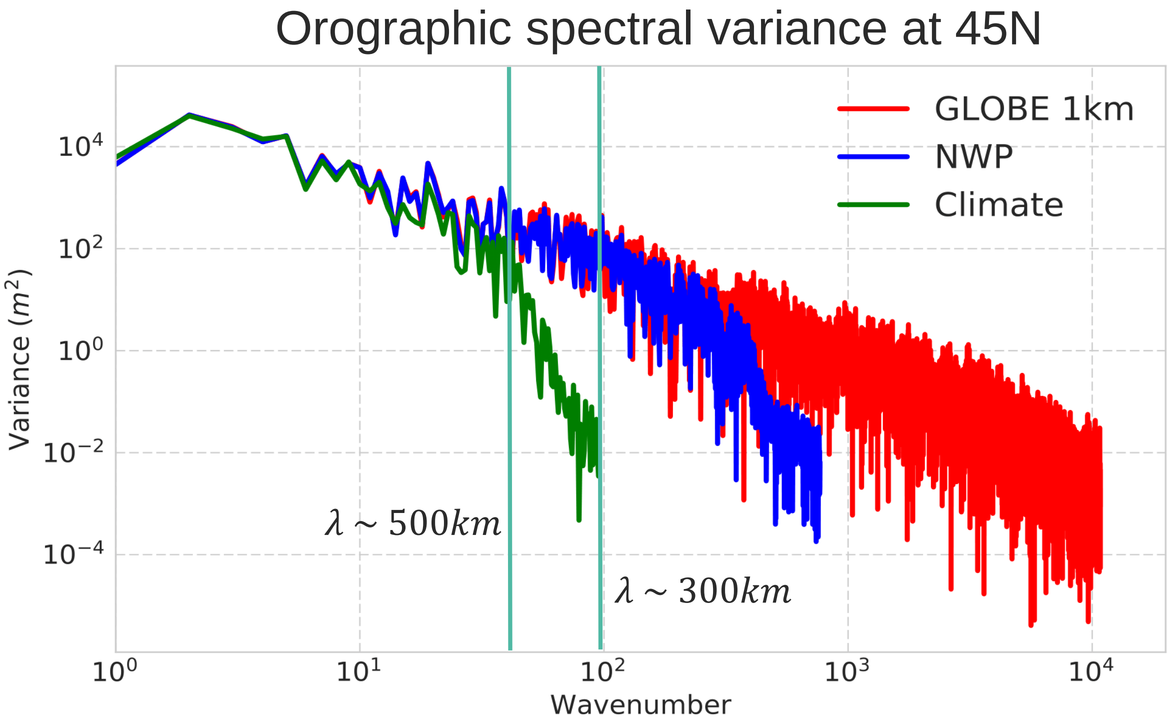

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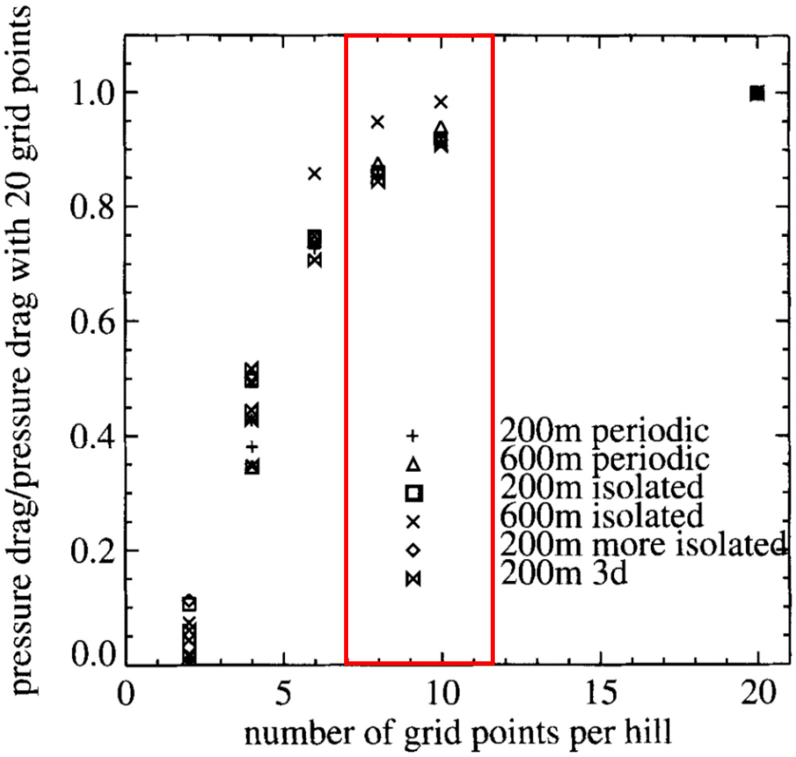
# Effective resolution

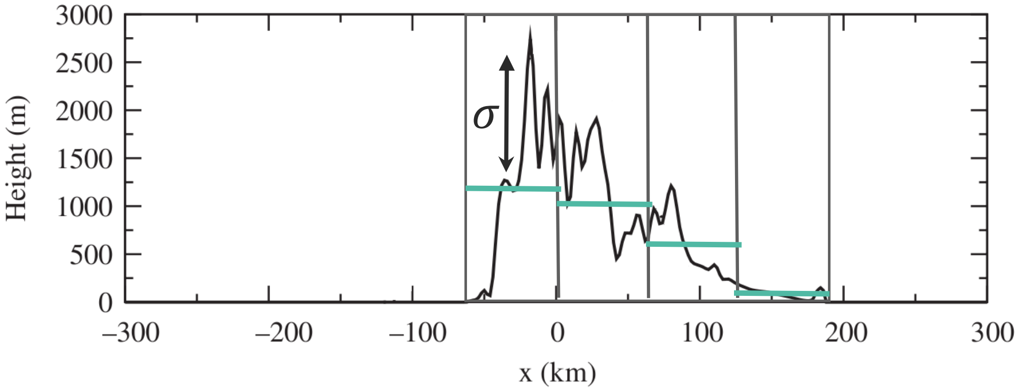


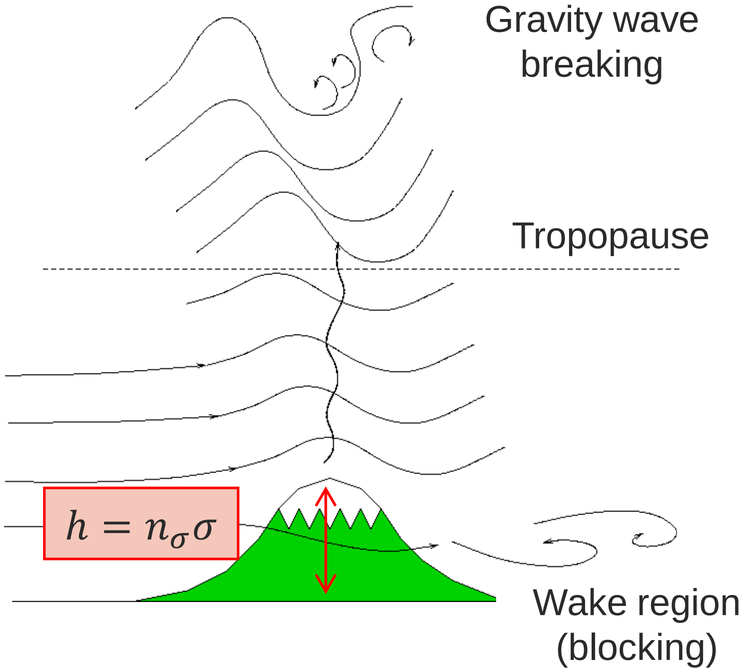

10 grid points over length of hill are required to fully represent pressure drag →

Demonstrates the need to parametrize orography larger than the grid scale

Davies and Brown (2001), QJRMS

# Orographic drag scheme



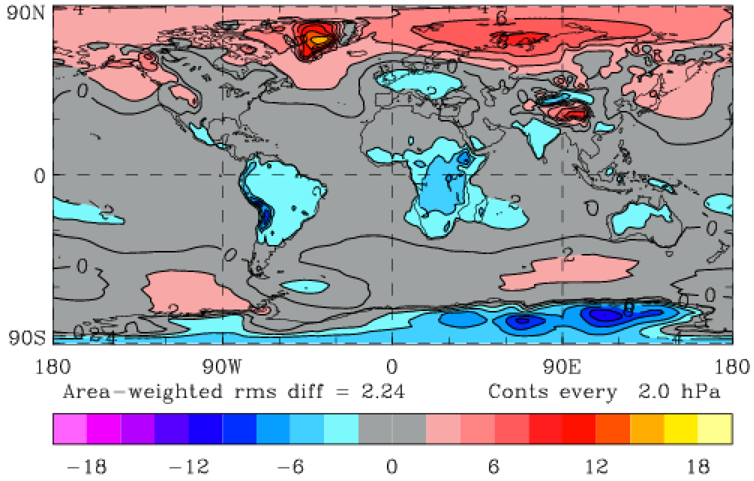




Parametrization schemes represents sub-grid orography as standard deviation of orography in grid and scale it by $n_\sigma$ → Effective resolution can be accounted for by scaling $n_\sigma$

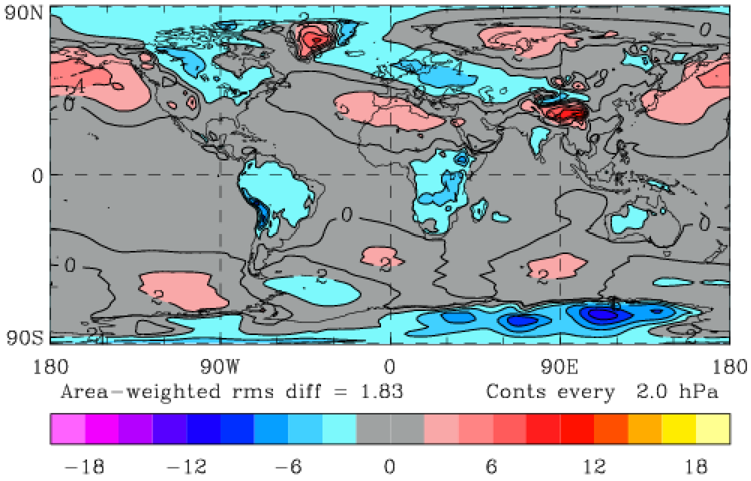
# Orographic drag is important for circulation across timescales and resolutions

## Climate timescales and low resolutions (~150km)

Standard UM ($n_\sigma$=2.5) – ERAinterim




reduced $n_\sigma$ (=1.5) – ERAinterim



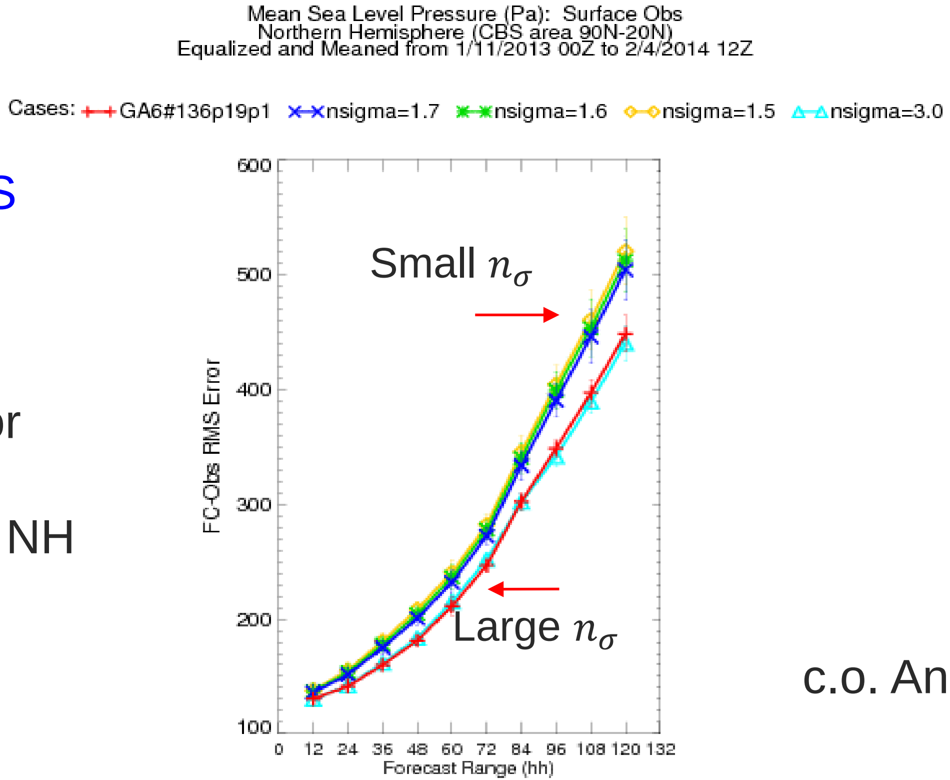

DJF pressure at mean sea level (1988 - 2008) , c.o. Keith Williams.

# Orographic drag is important for circulation across timescales and resolutions

## Short range forecasts and high(er) resolutions (~50km)

Plot shows PMSL RMS error for NH winter

Reducing scaling factor significantly increases PMSL RMS error over NH
→ lose one day of skill




c.o. Andy Elvidge

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# Aims

- Use short range (24 hour) limited area Unified Model simulations at a range of resolutions and assume highest resolution simulations represent the "truth".
  - e.g. Vosper et al. (2016) Orographic drag on islands in the NWP mountain grey zone, QJRMS.
- Use high resolution model simulations to:
  - Constrain the uncertain parameters in orographic drag scheme
  - Understand how model resolved and parametrized drag (from GWs, flow blocking etc) behaves across a range of resolutions.
  - Understand how this varies for different orographic shapes/regions across the globe.

# Isolated islands in the Southern Ocean

South Georgia


New Zealand

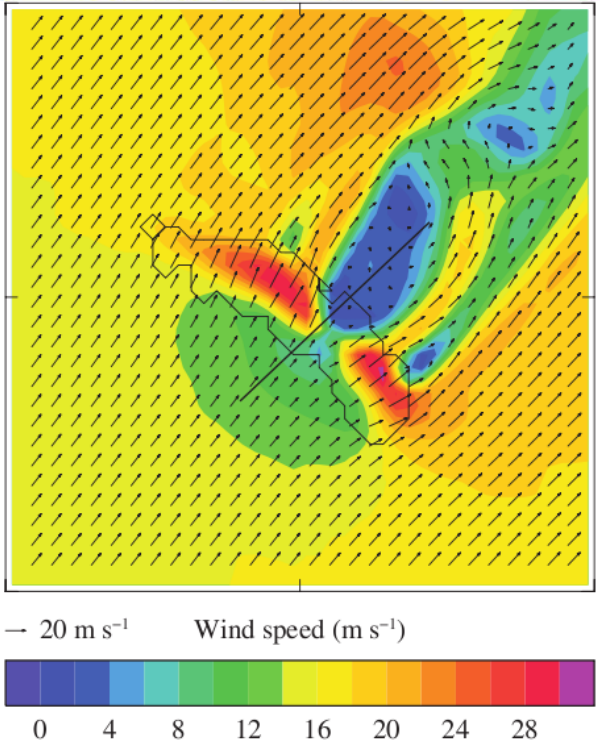

## Consider simpler orography:

- Closer to the approximations made in parametrization schemes – i.e. isolated, unaffected by rotation ($\lambda < 1000km$) etc

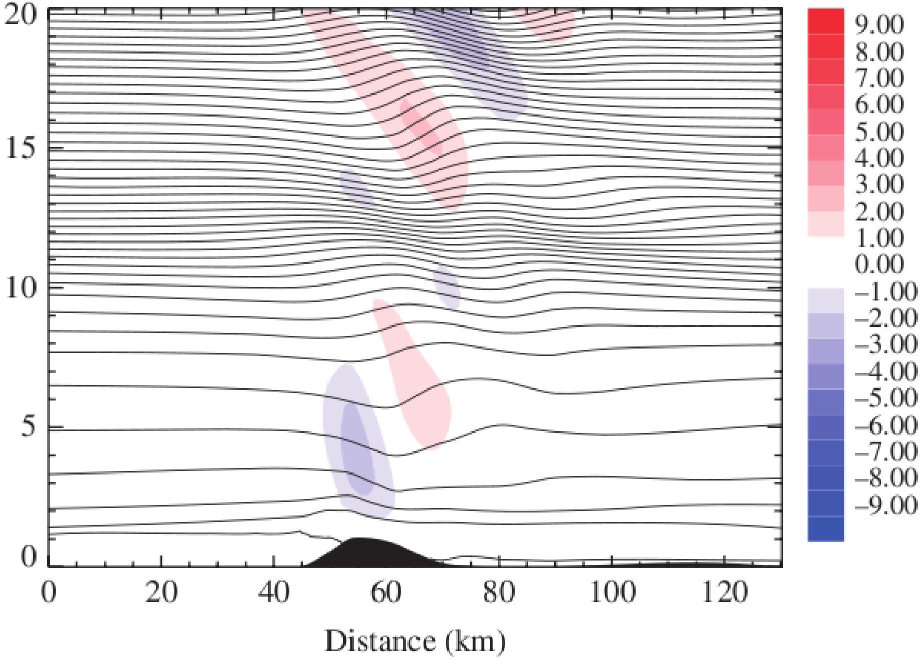
- Simpler flow regimes (compared with other orography)

# South Georgia – 6km

Near surface winds



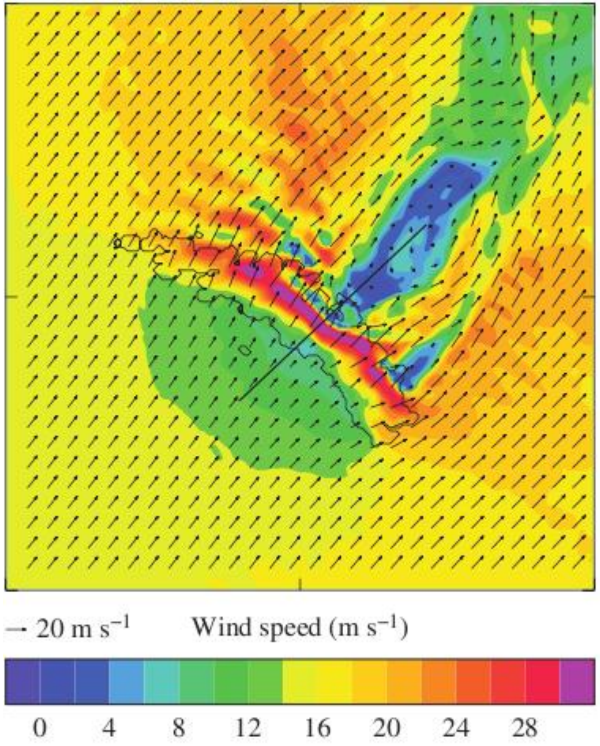

Vertical wind (w')



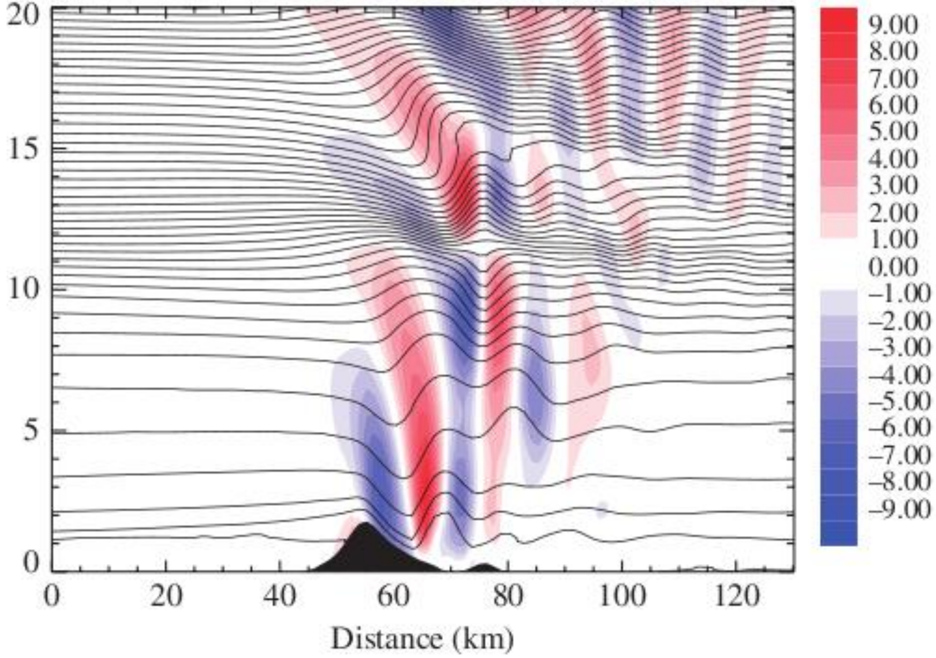

Perturbation quantities are computed as the deviation from runs with no orography

# South Georgia – 1.5km

Near surface winds



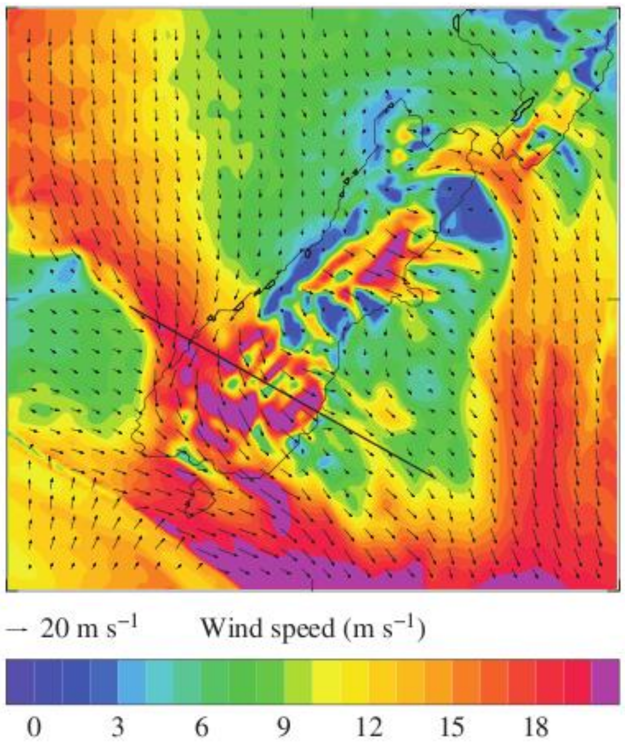

Vertical wind (w')




Perturbation quantities are computed as the deviation from runs with no orography

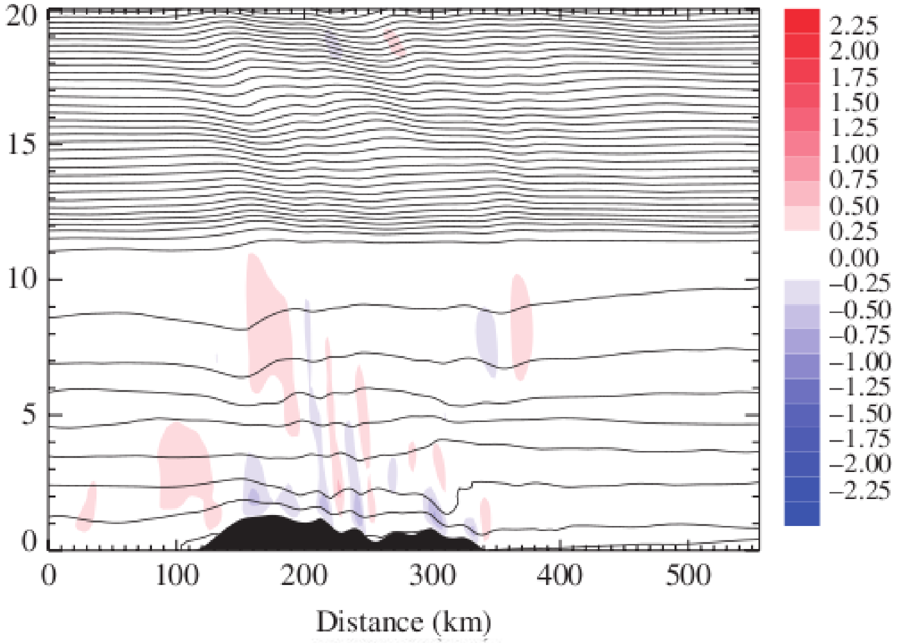
# New Zealand – 8km

## Near surface winds



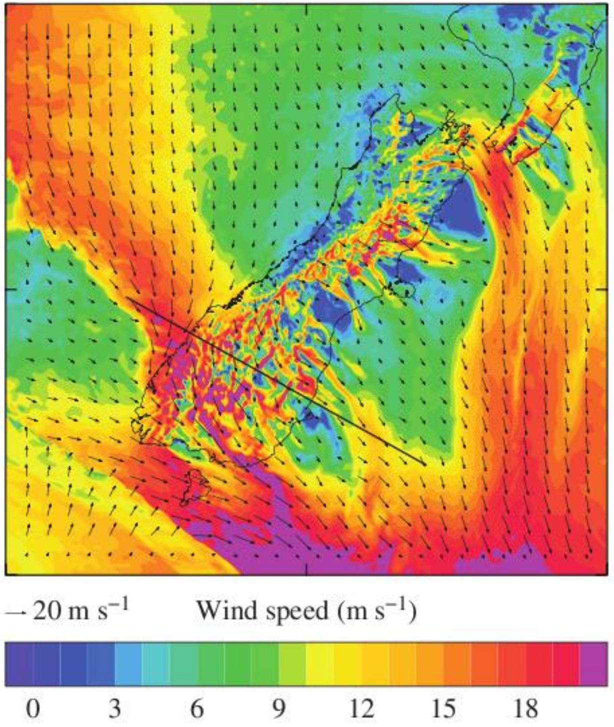

Perturbation quantities are computed as the deviation from runs with no orography

## Vertical wind (w')



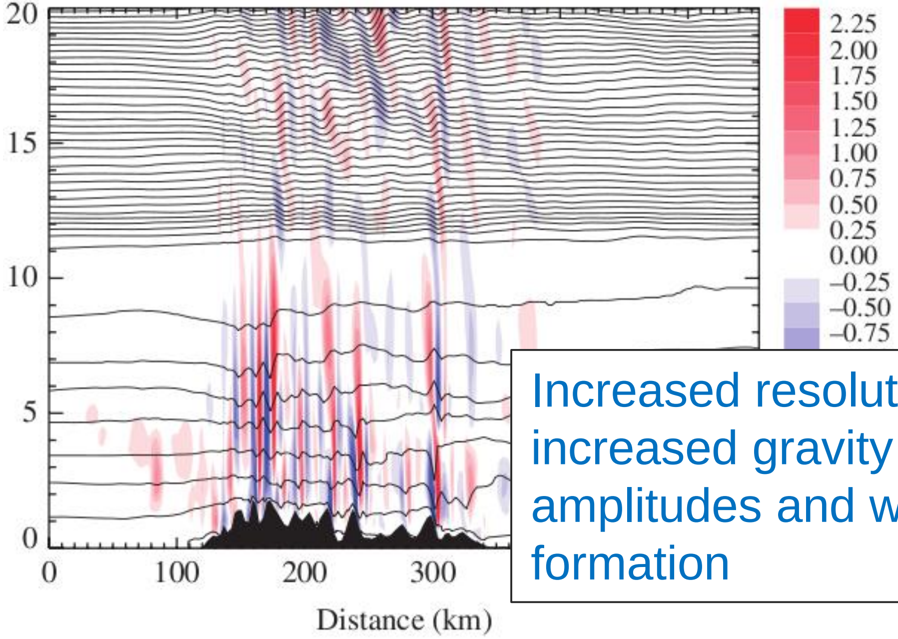
# New Zealand – 2km

Near surface winds




Perturbation quantities are computed as the deviation from runs with no orography

Vertical wind (w')




Increased resolution → increased gravity wave amplitudes and wake formation

# Resolved mountain pressure drag:

$$\mathbf{D} = (D_x, D_y) = \frac{1}{A}\int\int p'(\partial h/\partial x, \partial h/\partial y)\, \mathrm{d}x\mathrm{d}y,$$

Pressure perturbation due to orography

Orographic gradient in x and y directions

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

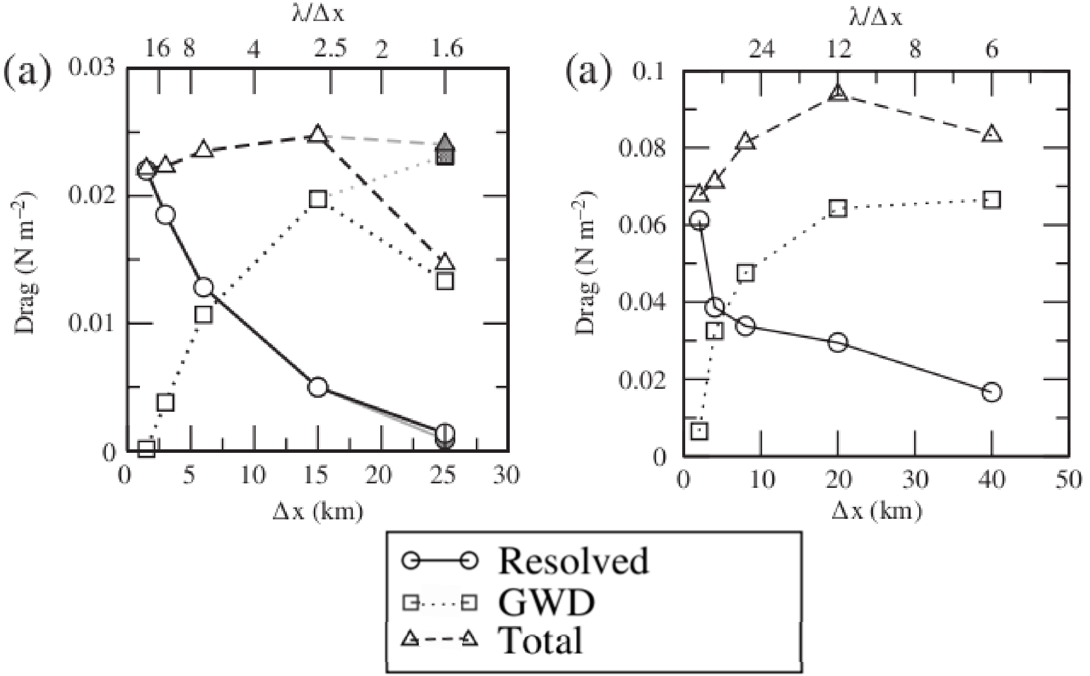
Plots shows time-mean resolved and parametrized surface pressure drag

Resolved drag decreases monotonically with increasing grid spacing and parametrized drag increases with increasing grid spacing

With the same tuning as South Georgia ($n_\sigma = 5$), parametrized drag over NZ increases too rapidly with $\Delta$x

South Georgia

New Zealand



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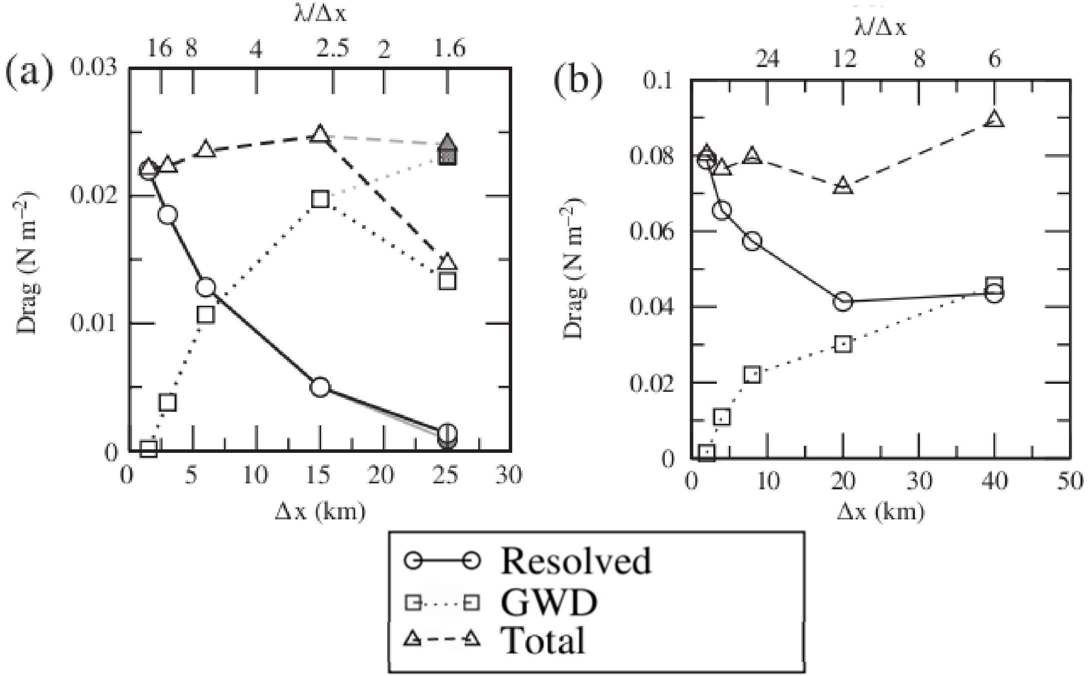
Resolved drag decreases monotonically with increasing grid spacing and parametrized drag increases with increasing grid spacing

With the same tuning as South Georgia ($n_\sigma = 5$), parametrized drag over NZ increases too rapidly with $\Delta$x

With retuning of scaling factor ($n_\sigma = 2.5$), SSO drag is much better over NZ

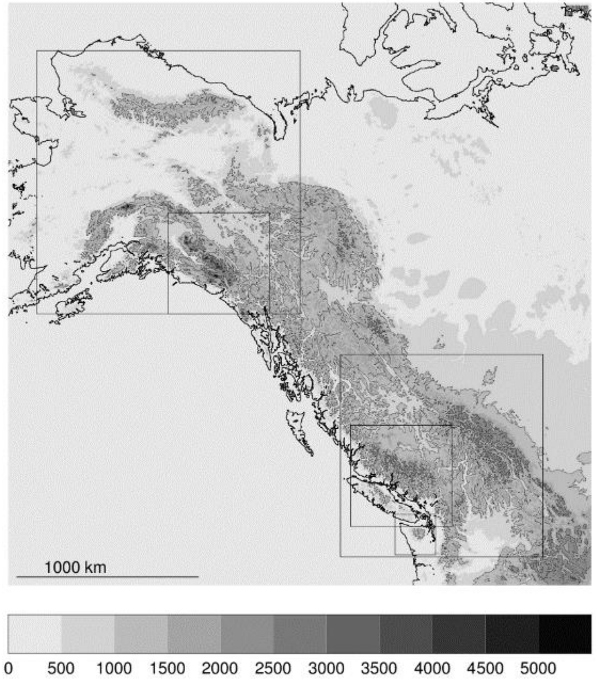
South Georgia

New Zealand

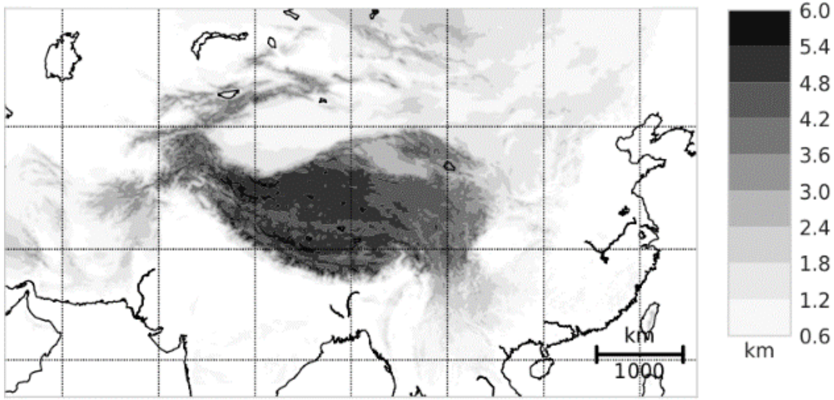


# Large scale extended mountain ranges

## Rockies



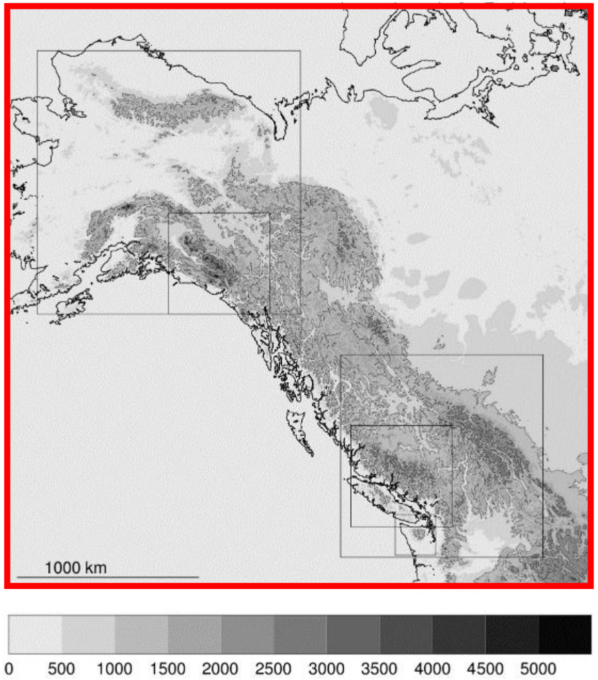

## Himalayas

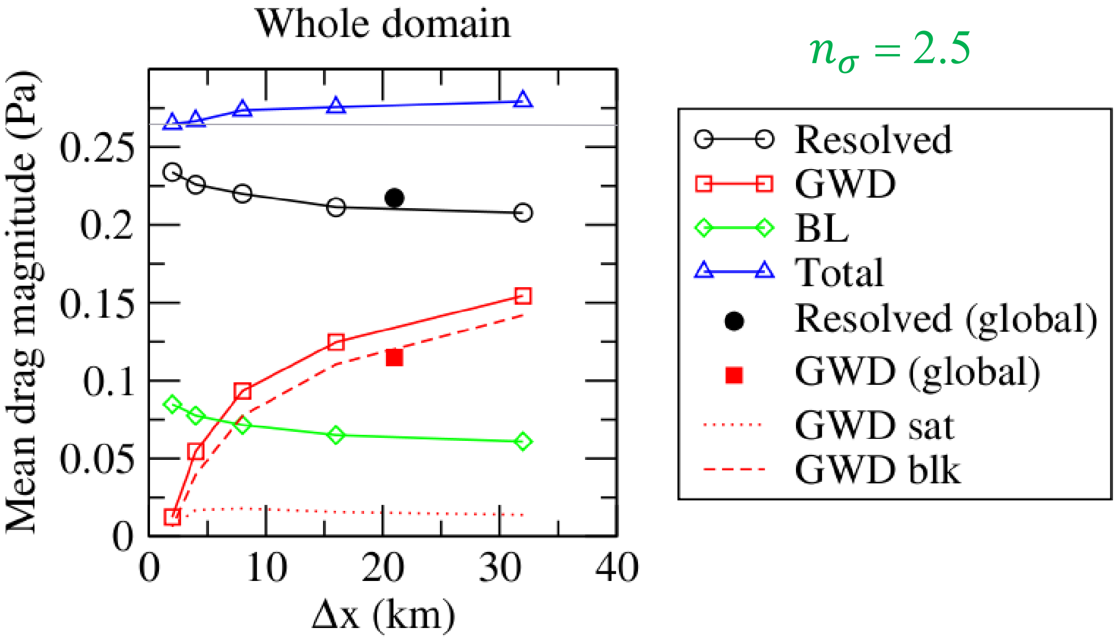



- More complex flow regimes
- Complex and multi-scaled orography

# Rockies

Plots shows time-mean surface pressure drag



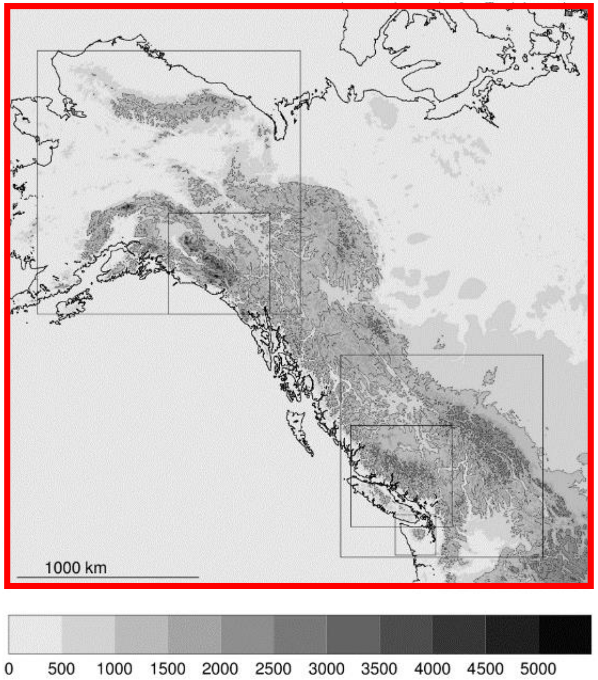



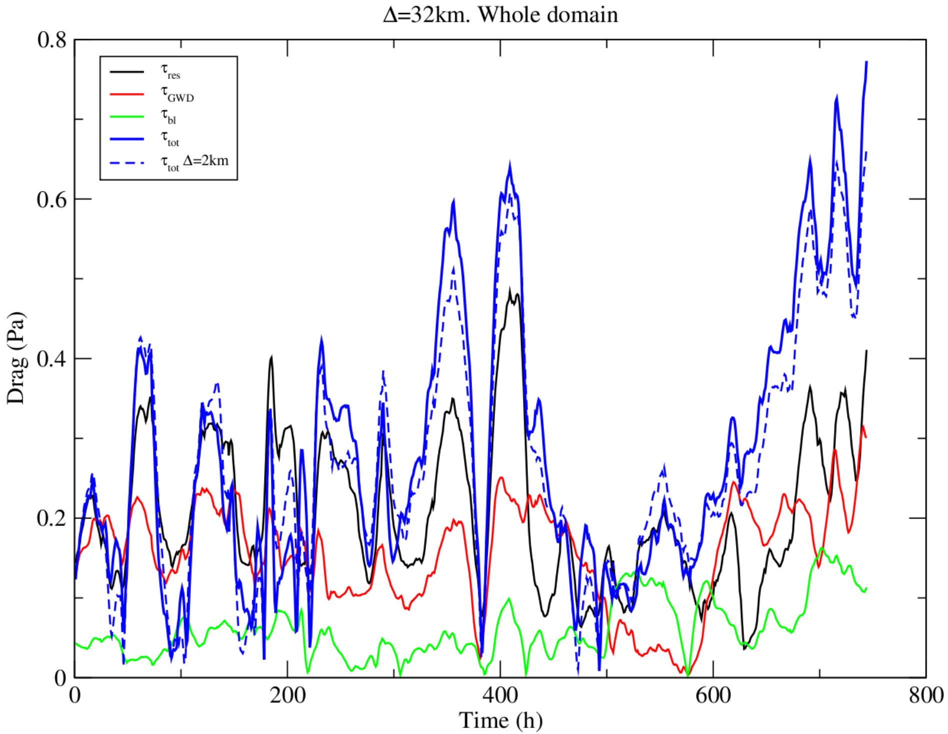

$n_\sigma = 2.5$

Parametrized and resolved drag exchange well over the whole domain

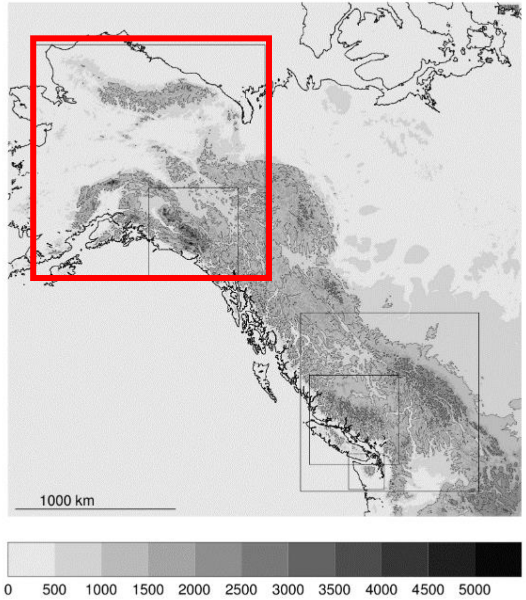
# Rockies

Parametrized and resolved drag variability is also well matched



# Rockies

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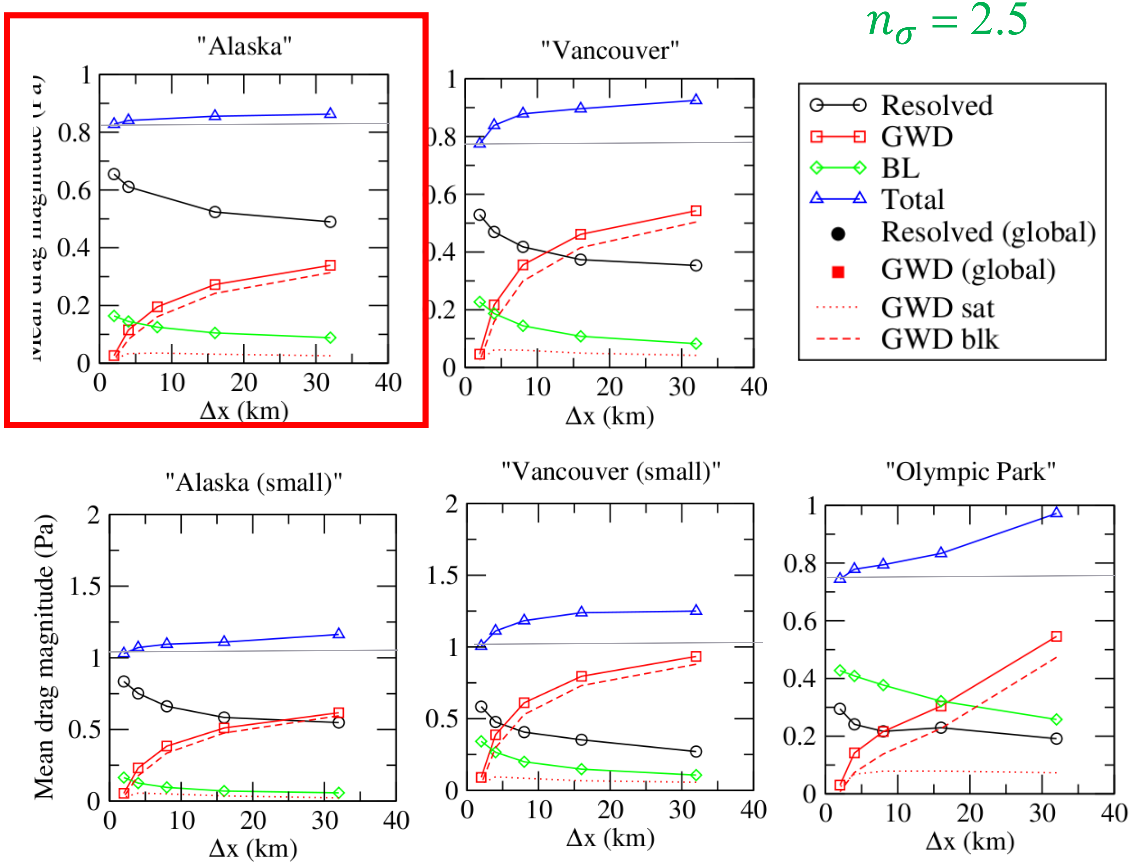


Parametrized and resolved drag exchange well over 'Alaska'

# Rockies

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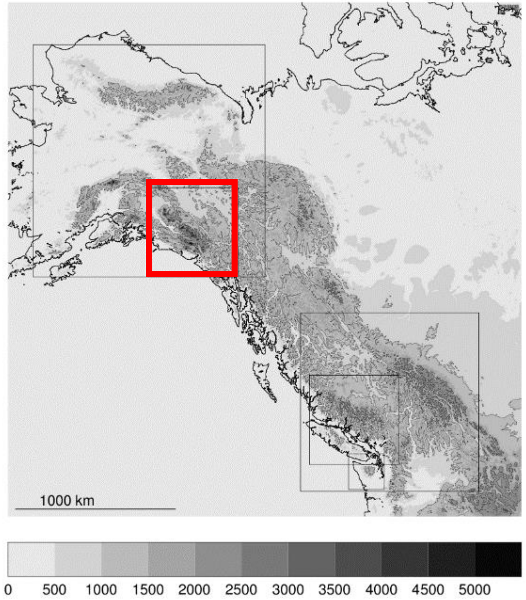


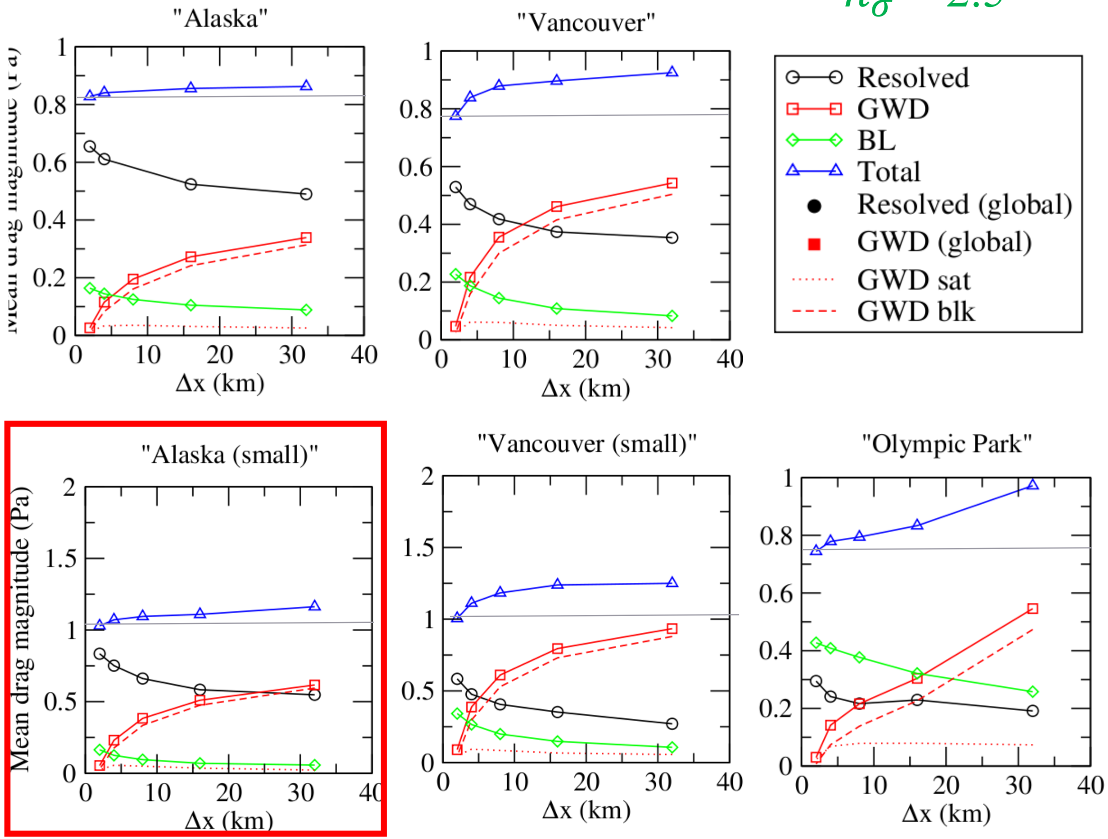


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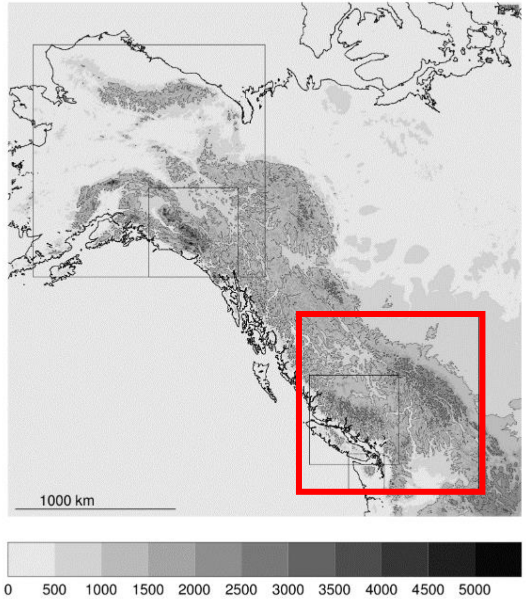


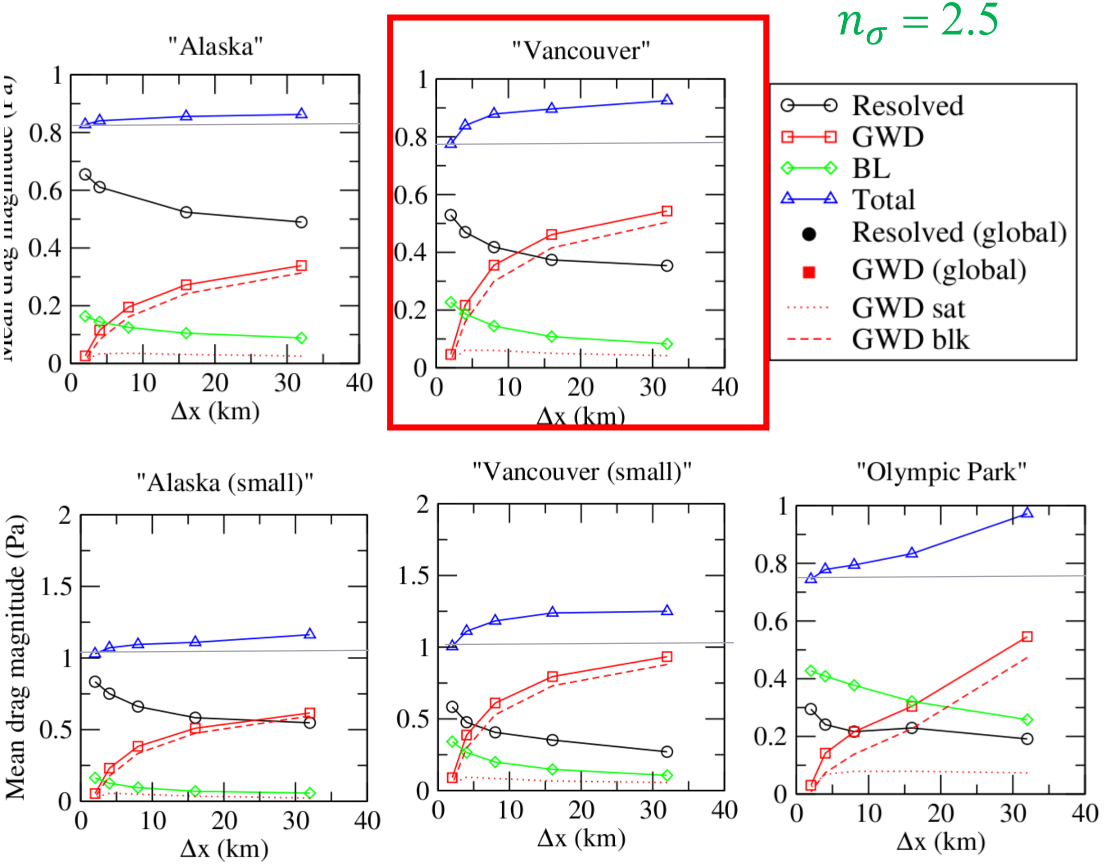


Parametrized drag increases too rapidly with grid size over 'Vancouver'

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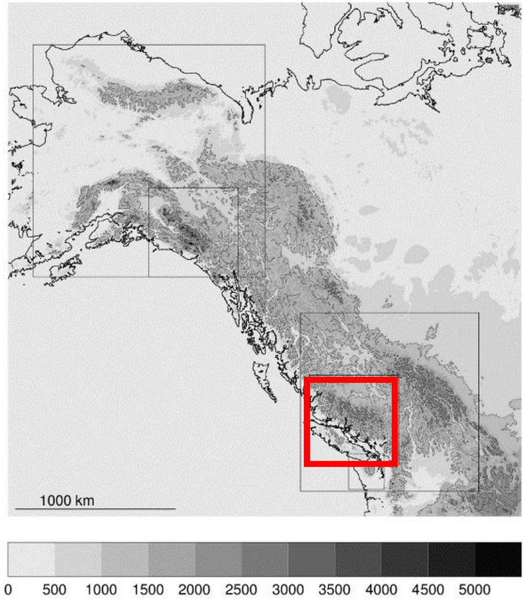
# Rockies

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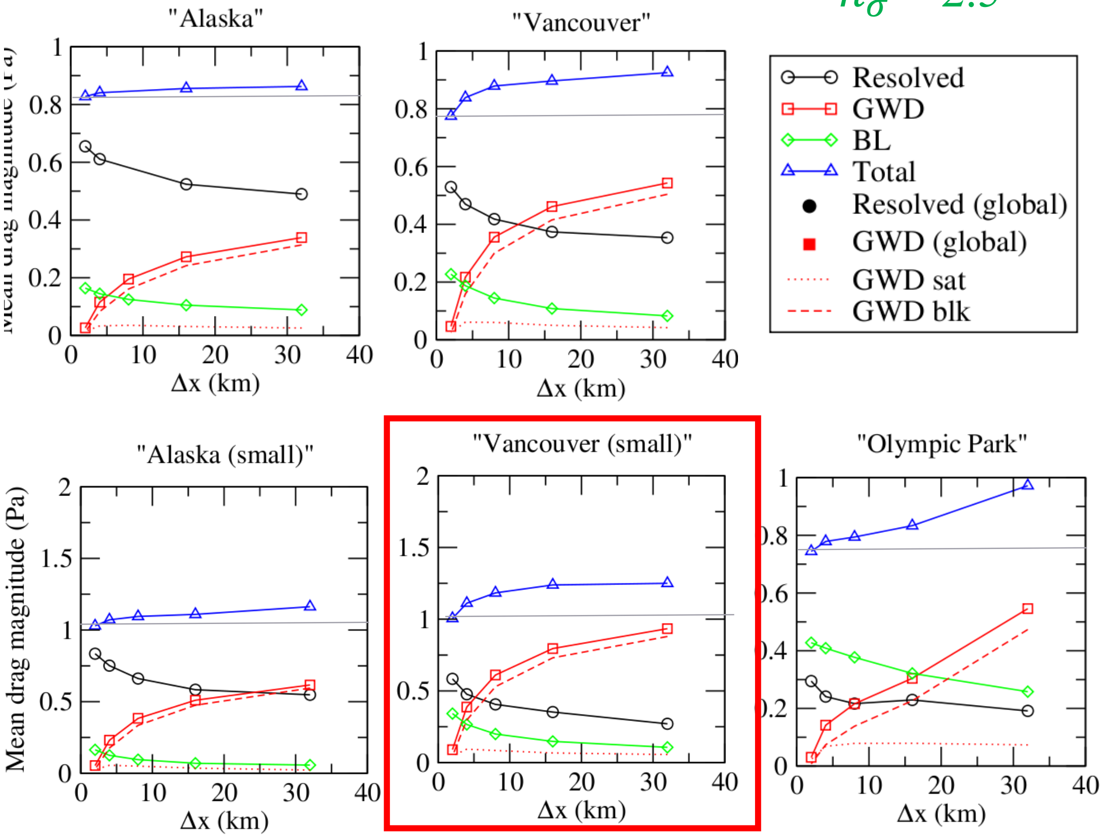


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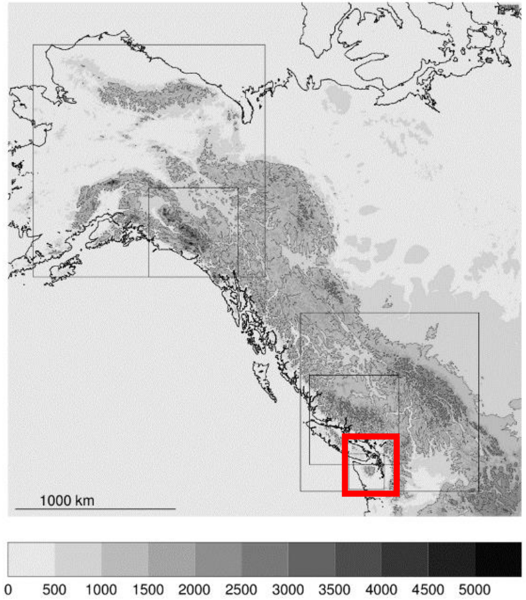
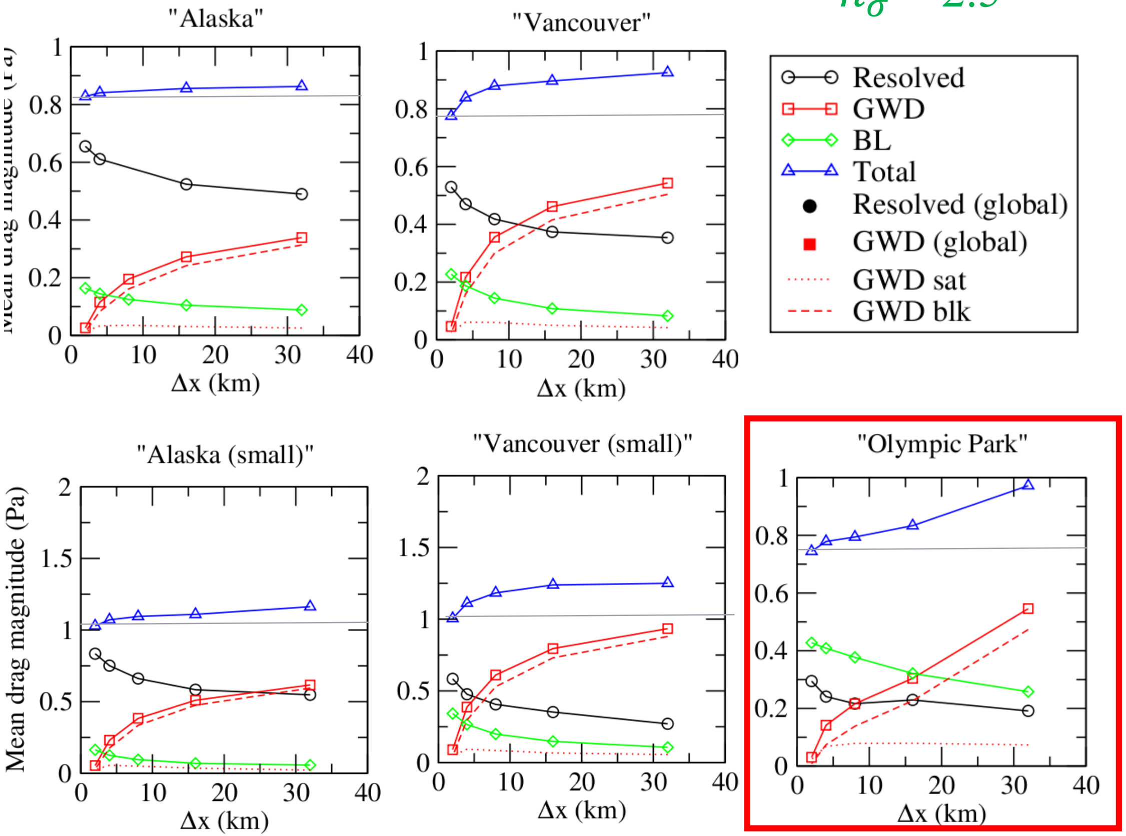
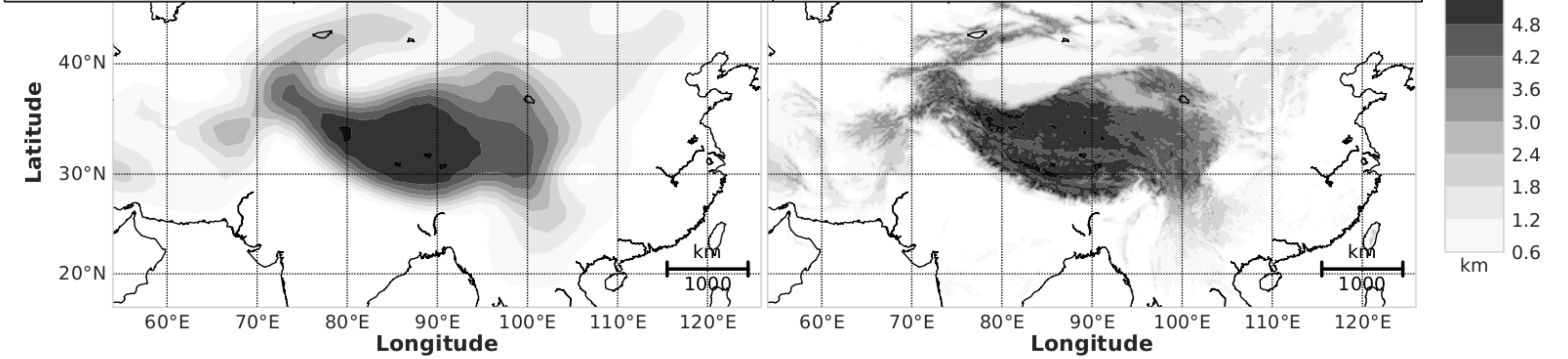



Parametrized drag increases too rapidly with grid size over 'Vancouver'

# Himalayas

| High resolution (4km) simulation with low resolution (150km) orography | High resolution (4km) simulation with high resolution orography |
|---|---|



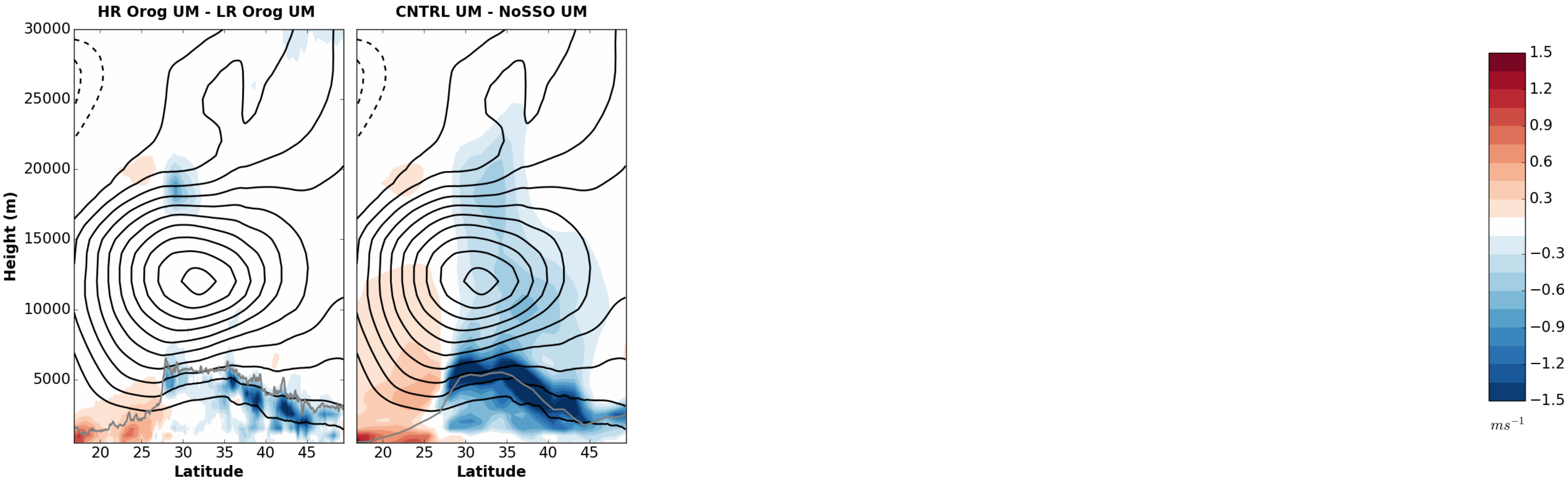

1) Global low resolution experiments with and without parametrized drag used to determine impact of parametrized orographic drag

2) LAM high resolution experiments with high and low resolution orography used to determine impact of resolved orography

# Himalayas

Plot shows change in zonal wind longitudinally averaged over Himalayan region

$$n_\sigma = 2.5$$




Standard configuration leads to far too much orographic drag at low-levels

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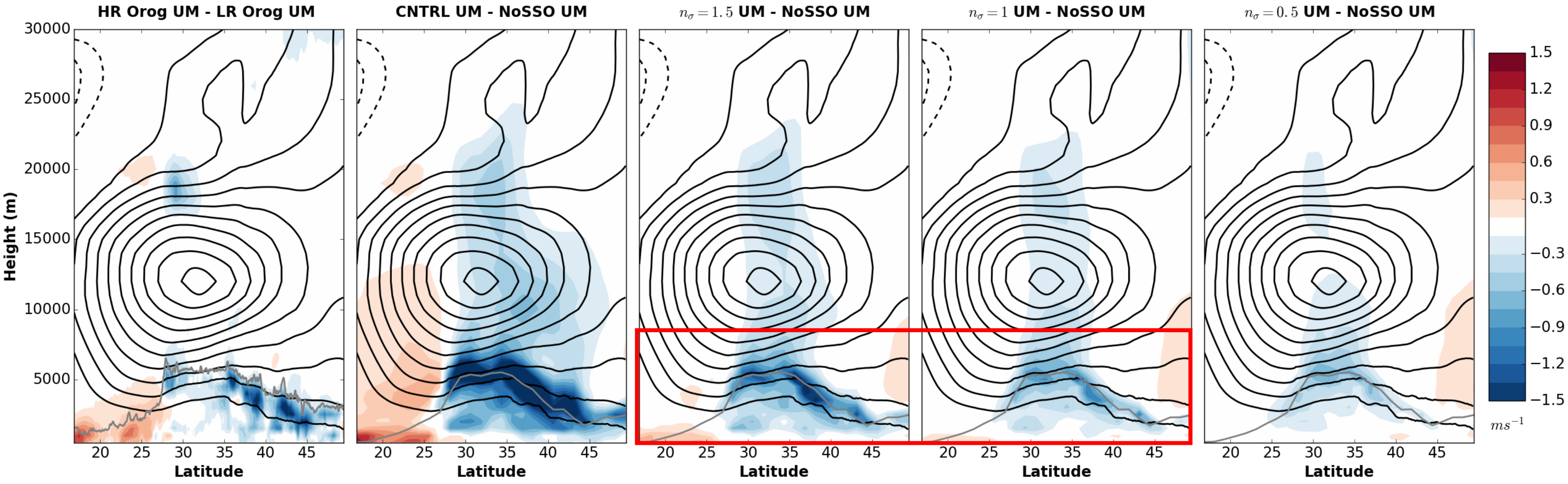
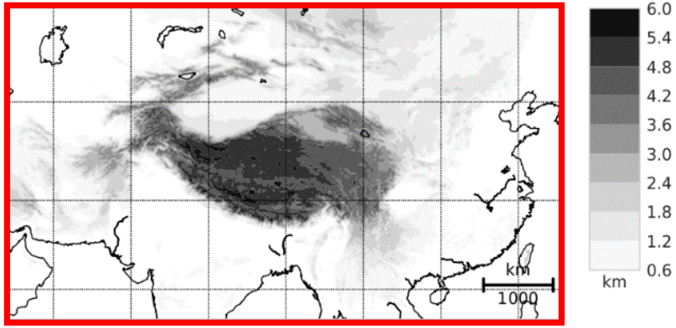


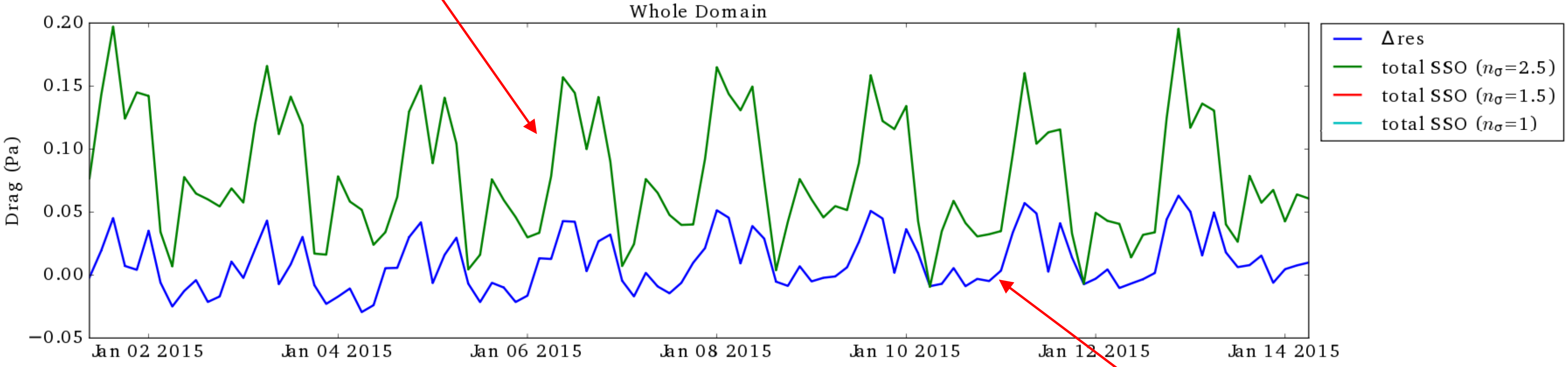

Standard configuration leads to far too much orographic drag at low-levels→
Reducing $n_\sigma$ can bring near-surface drag closer to resolved

# Himalayas

Plot shows $D_x = \frac{1}{A}\int\int p'(\partial h/\partial x)\,\mathrm{d}x\mathrm{d}y$




Parametrized orographic drag $n_\sigma = 2.5$




$D_x$ (high res. orog) – $D_x$ (low res. orog)

# Himalayas

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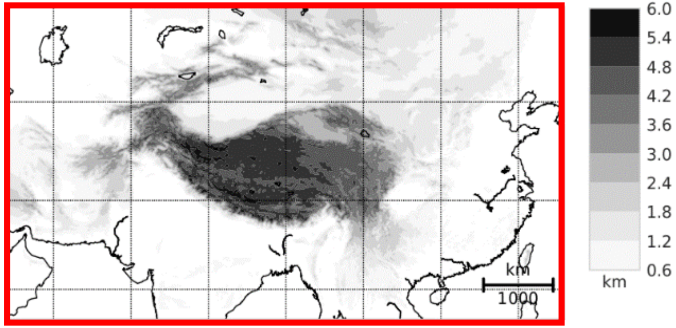
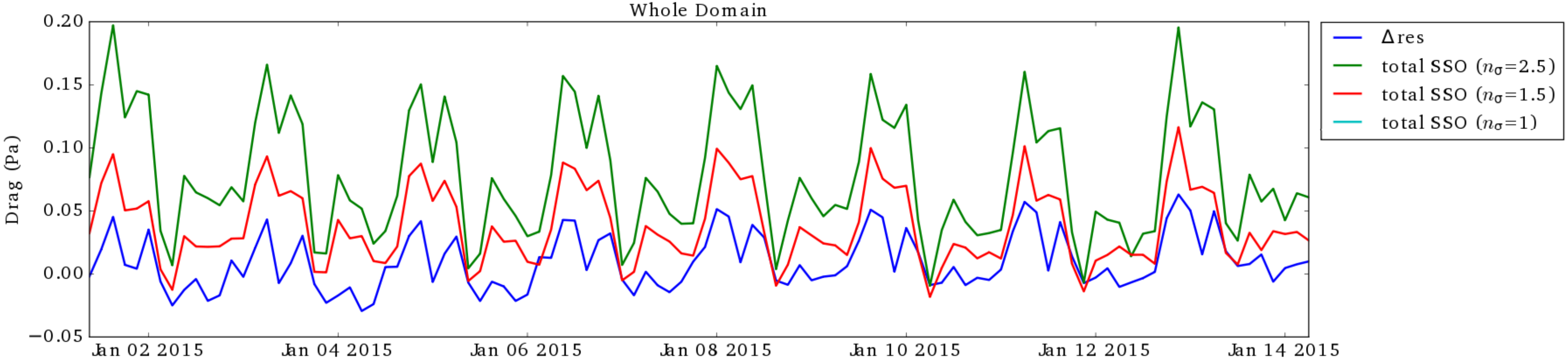
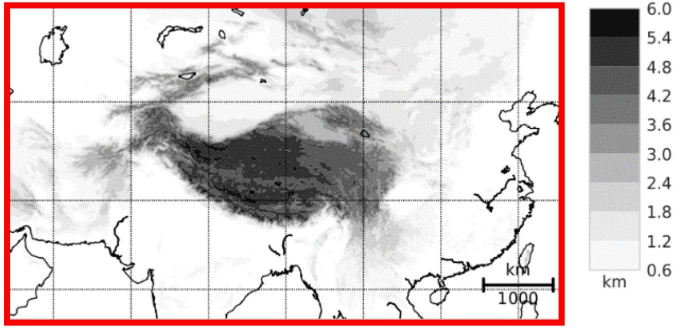


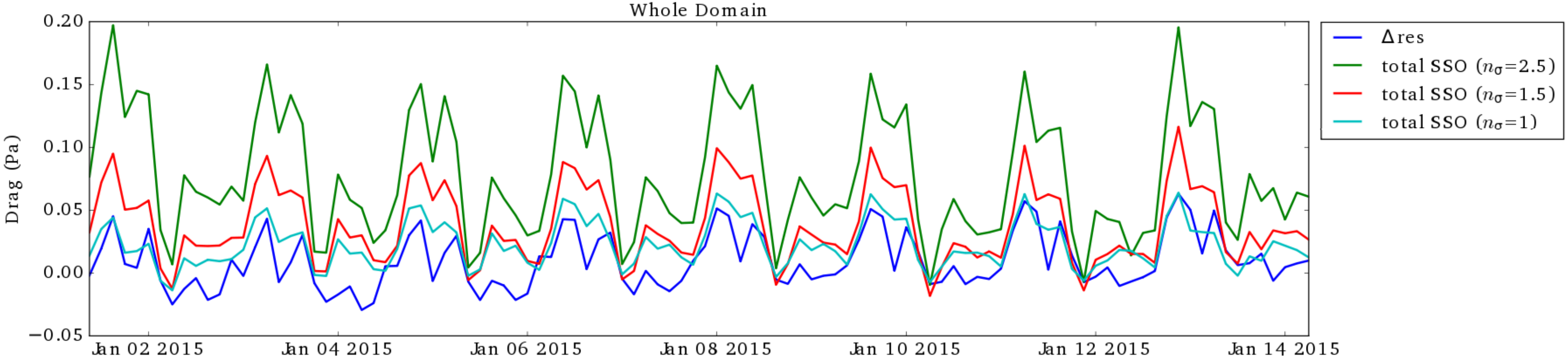



# Himalayas

Plot shows $D_x = \frac{1}{A}\int\int p'(\partial h/\partial x)\,\mathrm{d}x\mathrm{d}y$

Parametrized drag can get close to resolved but has the wrong sign at certain points



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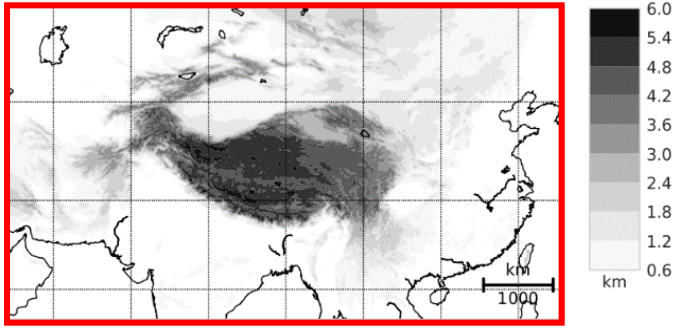


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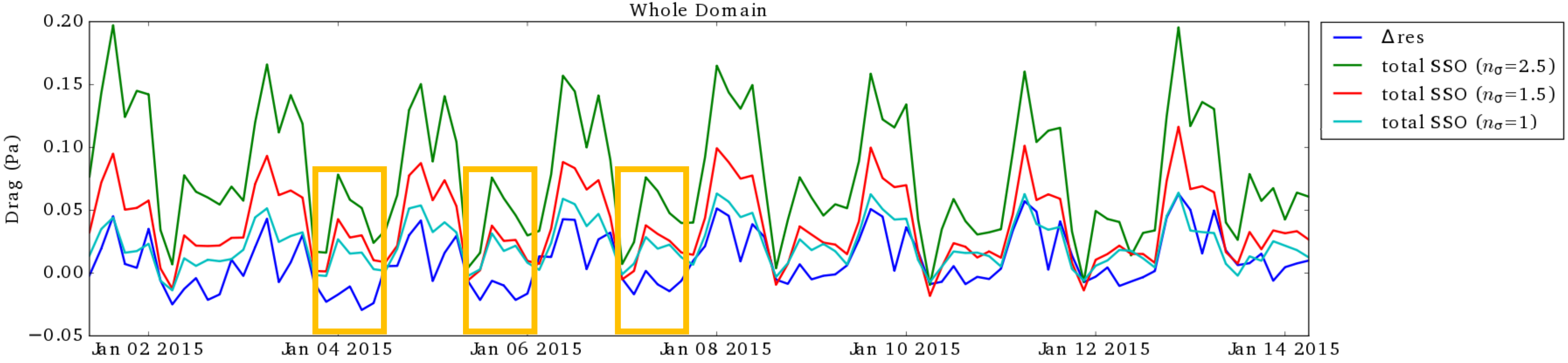
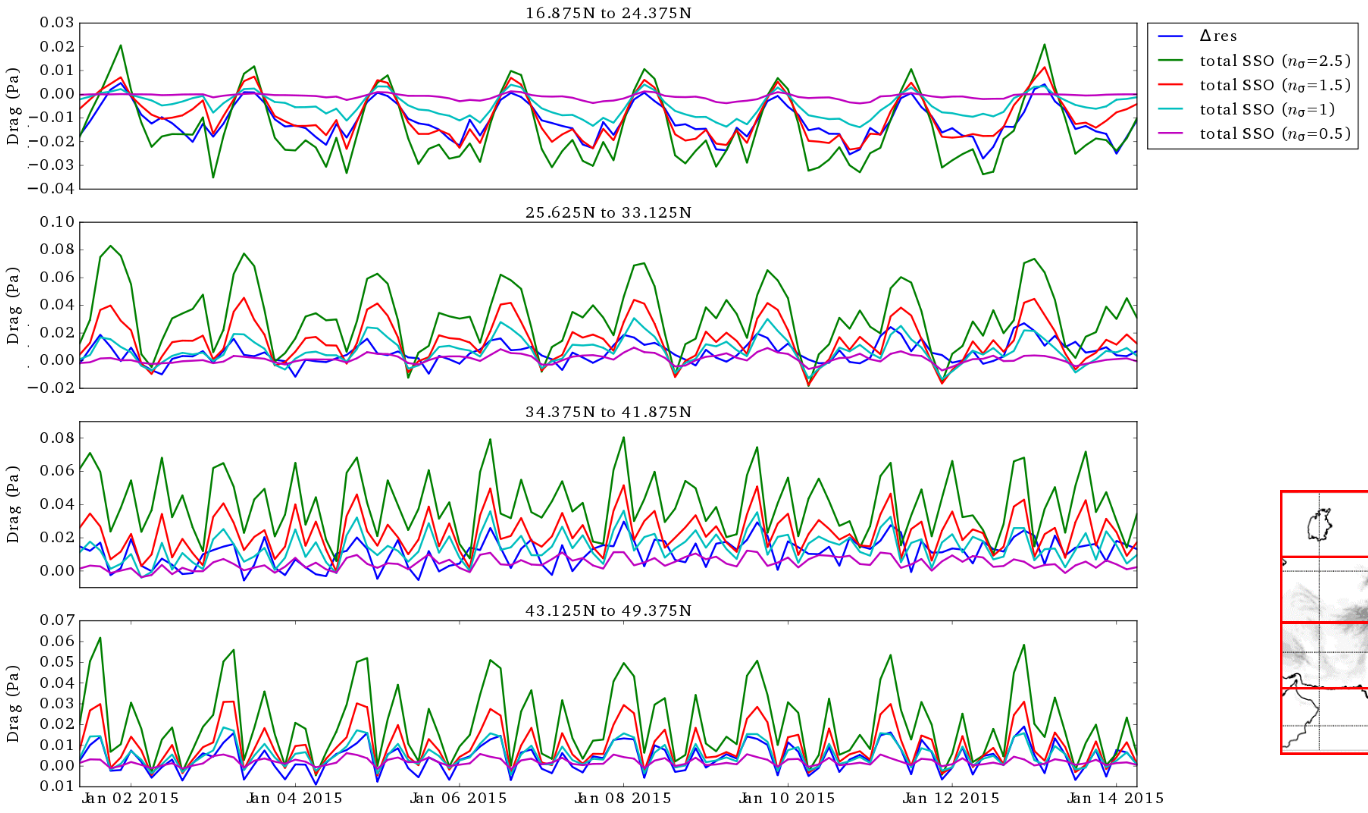
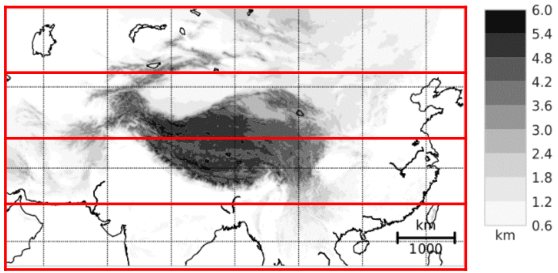
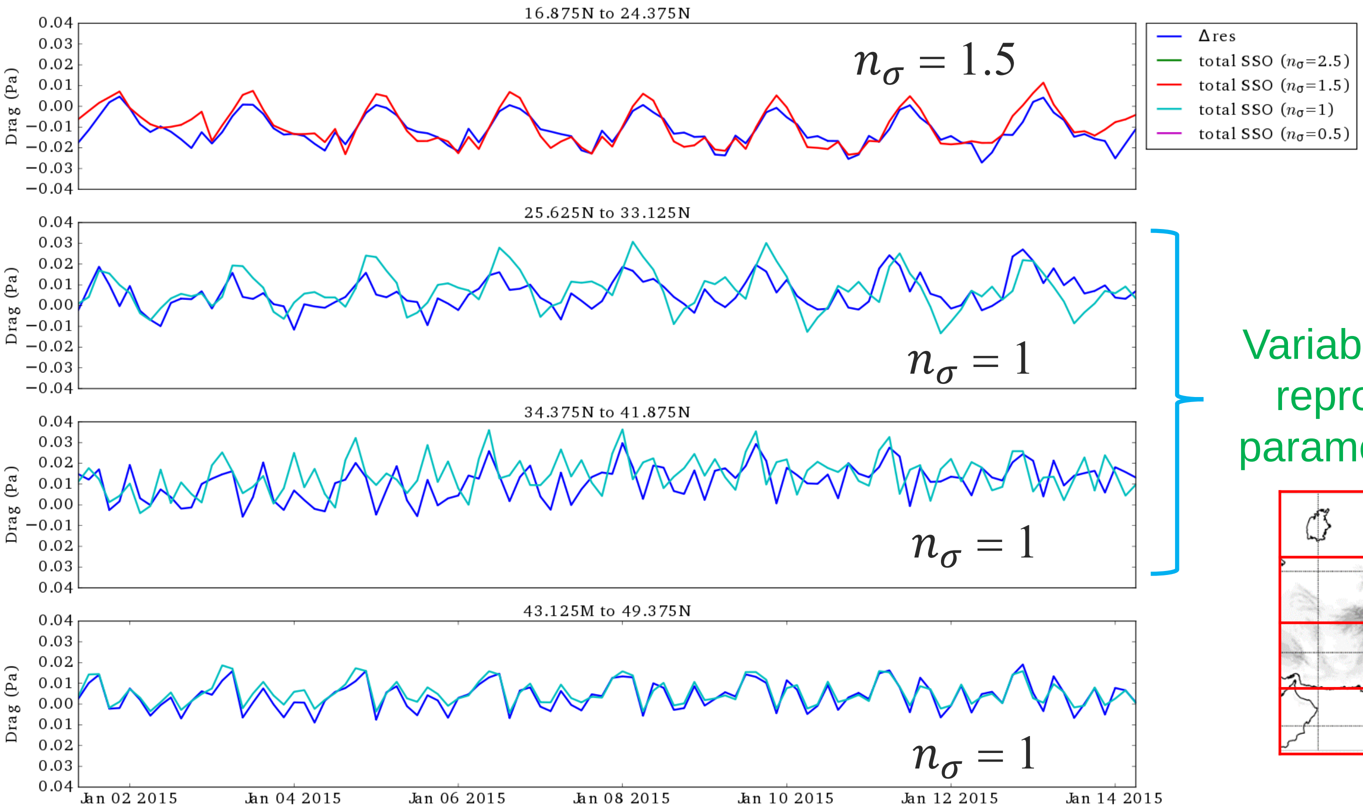


Himalayas

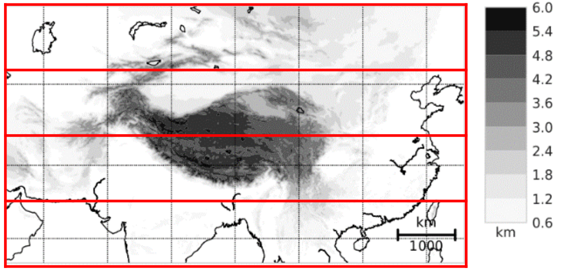

16.875N to 24.375N
25.625N to 33.125N
34.375N to 41.875N
43.125N to 49.375N
Drag (Pa)
Jan 02 2015
Jan 04 2015
Jan 06 2015
Jan 08 2015
Jan 10 2015
Jan 12 2015
Jan 14 2015
Δres
total SSO ($n_\sigma$=2.5)
total SSO ($n_\sigma$=1.5)
total SSO ($n_\sigma$=1)
total SSO ($n_\sigma$=0.5)


km
1000
6.0
5.4
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
km

# Himalayas

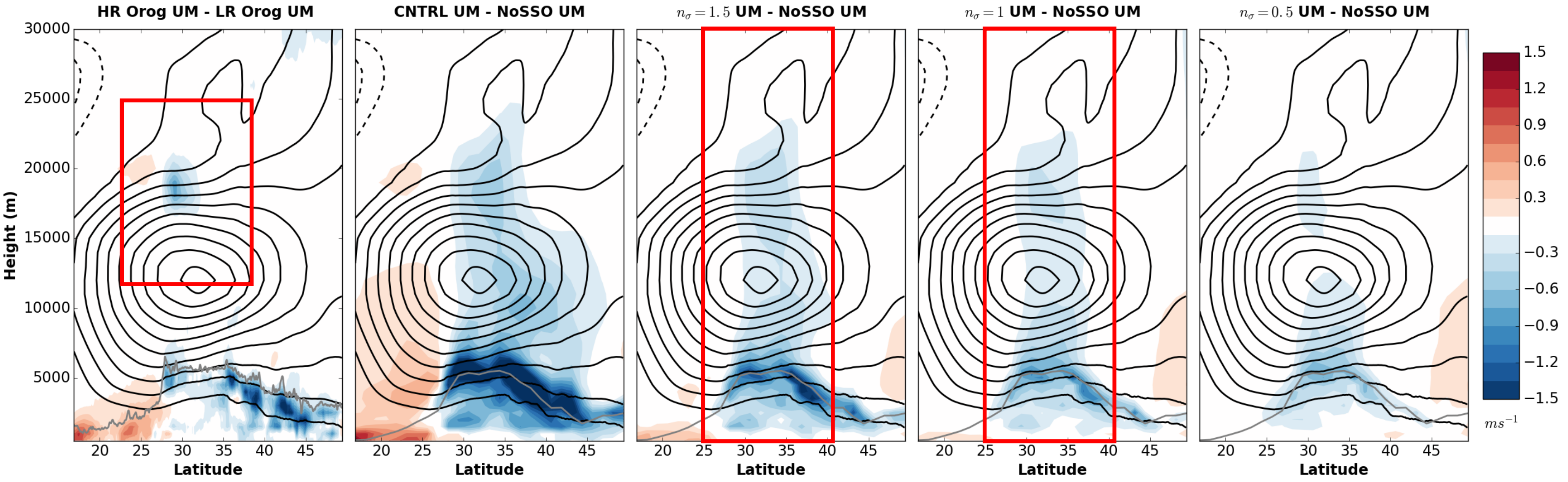



Variability not well reproduced by parametrized drag



# Himalayas

$n_\sigma = 2.5$

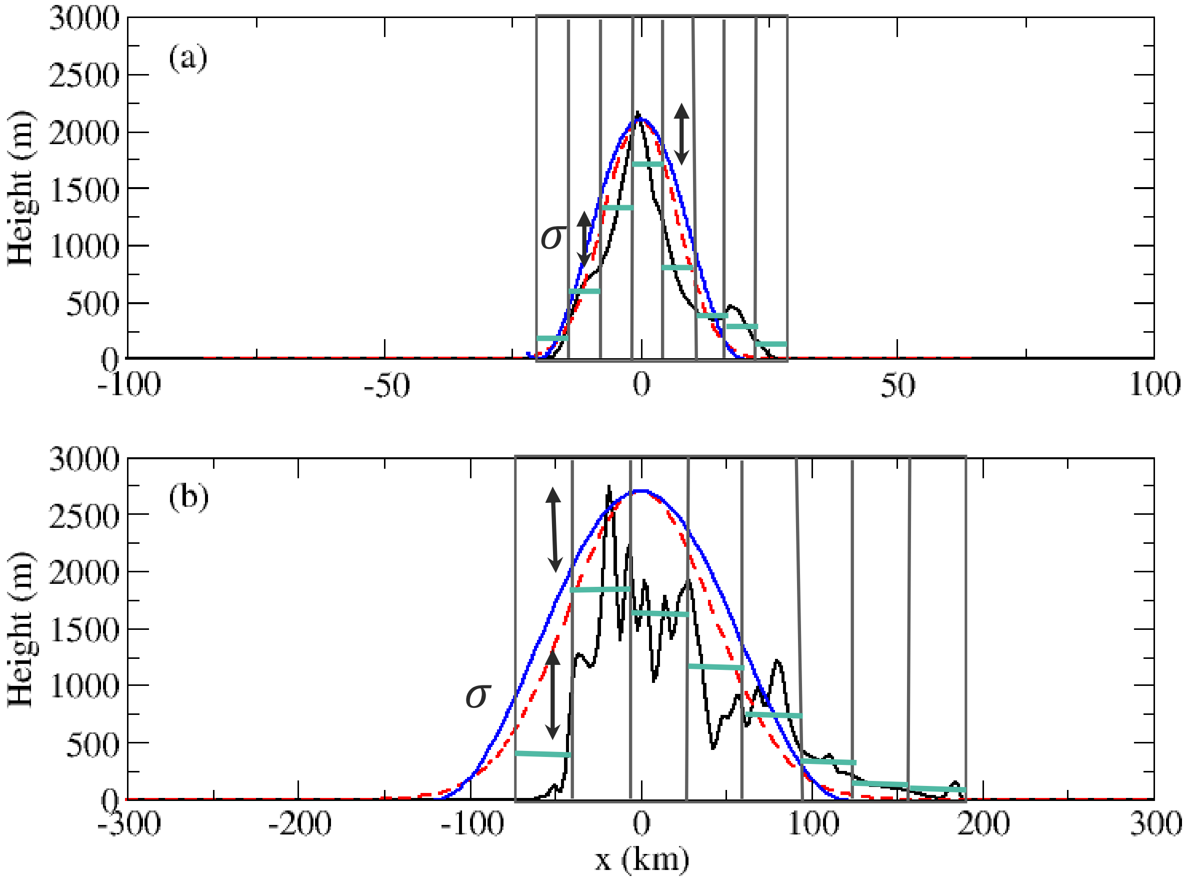



GWD acting over a very deep layer compared with the resolved drag

# So why should different mountains require a different value of “$n_\sigma$” ?

South Georgia

New Zealand



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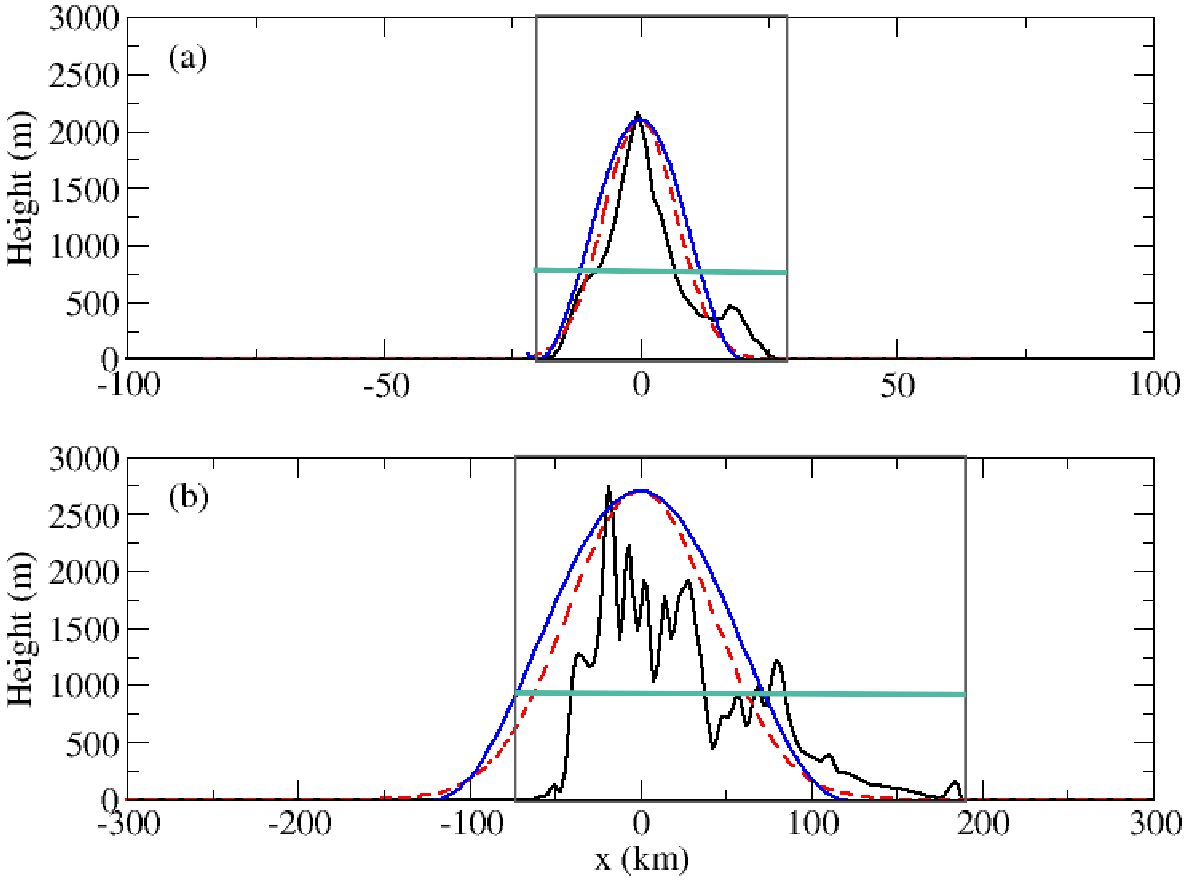

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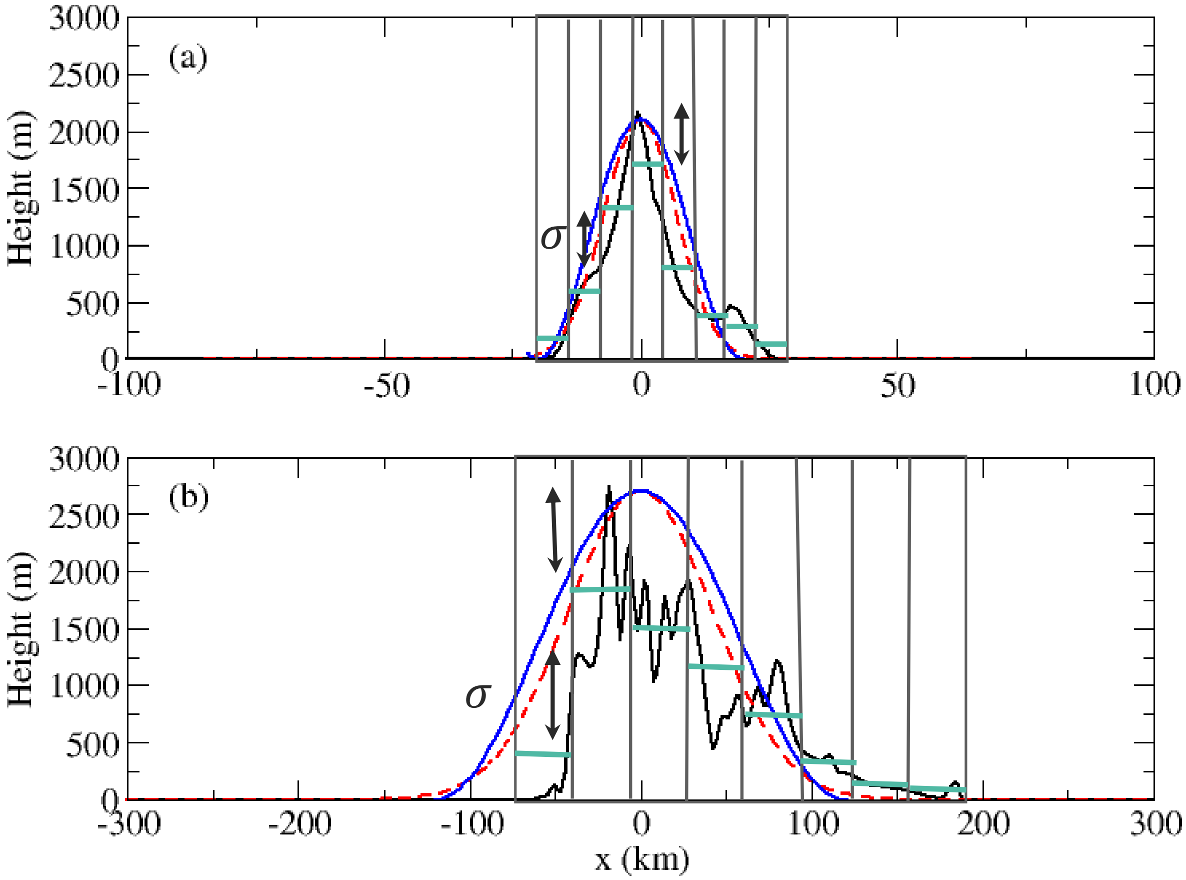

# Conclusions

- High resolution simulations are useful for understanding interactions with orography and for constraining parametrized drag

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- The orographic drag scheme, *when suitably tuned*, can represent the resolved drag well
- …but results suggest this requires different tuning for different mountain ranges (and regions within mountain ranges)
- May be explained by the need for the drag scheme to represent processes on scales as large as ~10Δx, not just sub-grid processes
- Suggests that drag schemes should explicitly represent scales larger than the grid scale

# Conclusions

- High resolution simulations are useful for understanding interactions with orography and for constraining parametrized drag
- The orographic drag scheme, *when suitably tuned*, can represent the resolved drag well
- …but results suggest this requires different tuning for different mountain ranges (and regions within mountain ranges)
- May be explained by the need for the drag scheme to represent processes on scales as large as ~10Δx, not just sub-grid processes
- Suggests that drag schemes should explicitly  represent scales larger than the grid scale
- Other aspects of the scheme (e.g. wind shear) also need to be considered over more complex and higher mountain ranges (i.e. the Himalayas)