The effect of wind direction on flow past South Georgia

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Introduction

- The Met Office sub grid-scale orographic drag parametrization is based on simulations of idealised flow past idealised orography

- We want to look at the sensitivity of the drag and flow features to real complex orography

- Therefore we ran numerical simulations of idealised flow past South Georgia

- We chose to look at South Georgia because it is an example of high, anisotropic, isolated multi-scale orography that is unresolved by our current operational global model

Summary of talk

- Experimental set-up
- Description of flow when the incident wind is perpendicular to the main axis of South Georgia
- Comparison of flow features for various incident wind directions
- Drag variation with wind direction
- Summary

Experimental set-up

- Non-hydrostatic Blasius model

- Vertical resolution: 60 levels, lowest at 10m, sponge layer above 12km

- Horizontal resolution: $\Delta x = \Delta y = 2$km in a periodic domain that is sufficiently large that the perturbations do not wrap around

- Free-slip lower boundary condition (sensitivity tests with a no-slip BC revealed that the flow features are qualitatively similar and the drag changed by <10%)

- Run duration = 20,000s

- Upstream flow: Geostrophic wind $U=10ms^{-1}$, Brunt-Väisälä frequency=$N=0.01s^{-1}$

- Coriolis effects included: $f=10^{-4}\ s^{-1}$ (northern hemisphere value!)

South Georgia

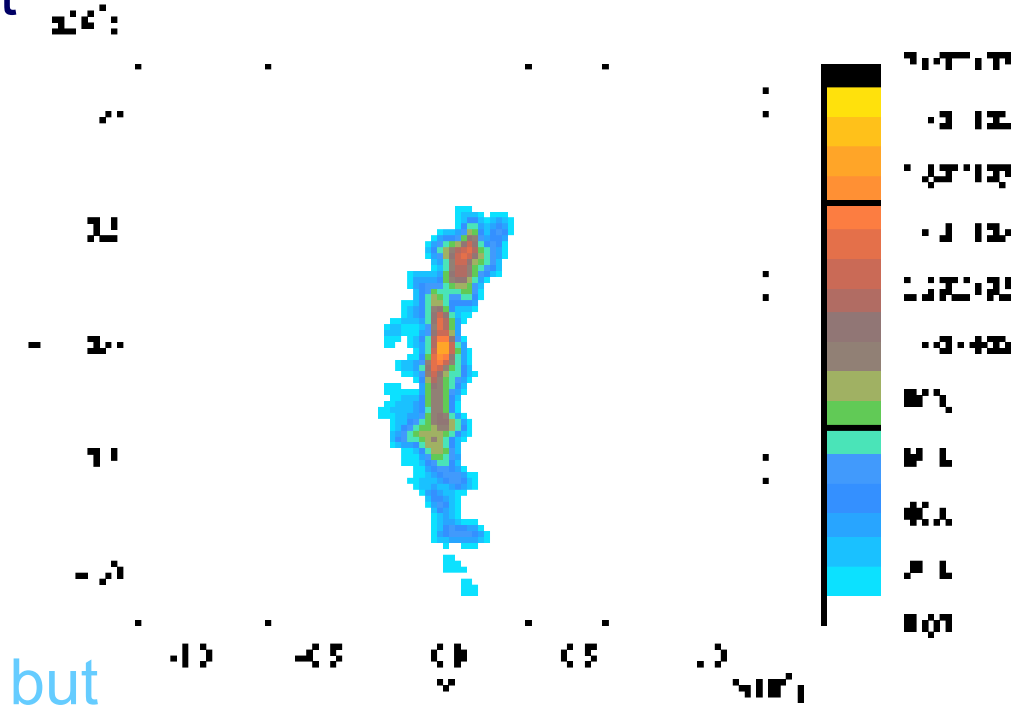
- Orography data from GLOBE (~1km grid spacing) smoothed to remove features which are not well resolved on a 2km grid

- Maximum height: h~1800m. Non-dimensional mountain height=Nh/U=1.8
→low-level flow blocking

- Rossby radius=Nh/f~180km (Maximum length~120km)
→rotational effects significant but not dominant

- Aspect Ratio~3

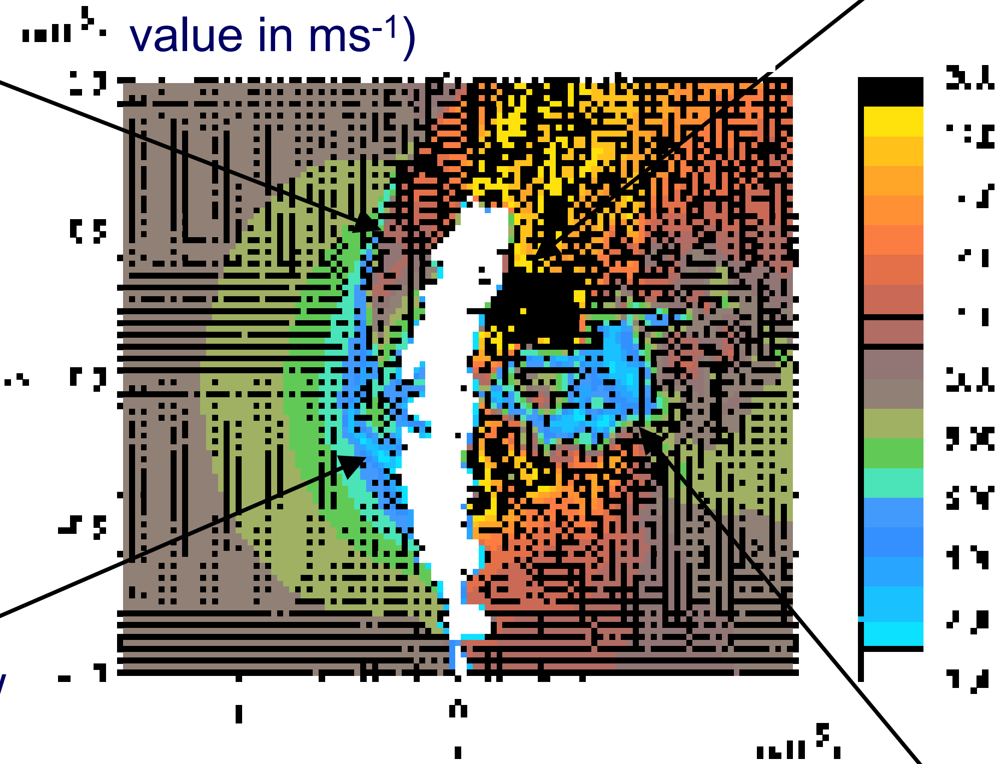
The orography of South Georgia



Incident wind perpendicular to orography

North

Horizontal Wind at 50m above sea level (coloured contours indicate absolute value in ms^{-1})



Barrier jet

Strong down-slope winds

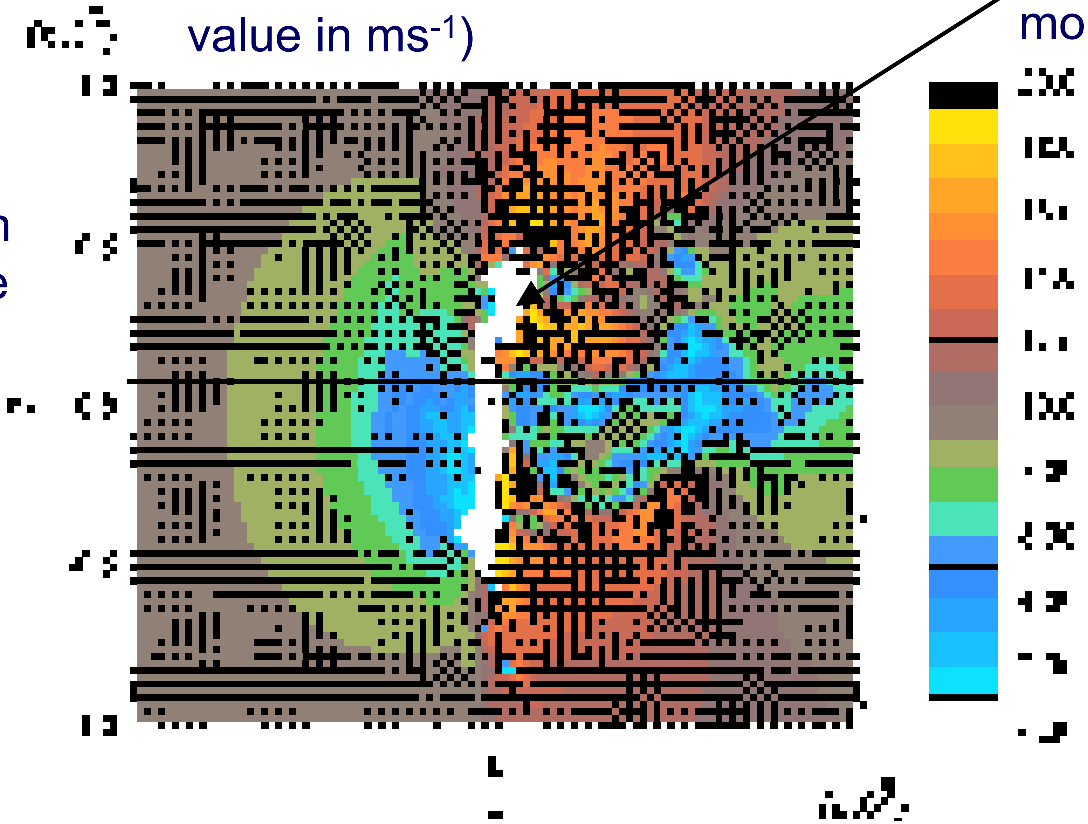
Note: This is not the full domain

Low-level flow blocked by mountain

Wake vortices shed from mountain

Incident wind perpendicular to orography

Horizontal Wind at 500m above sea level (coloured contours indicate absolute value in ms^{-1})

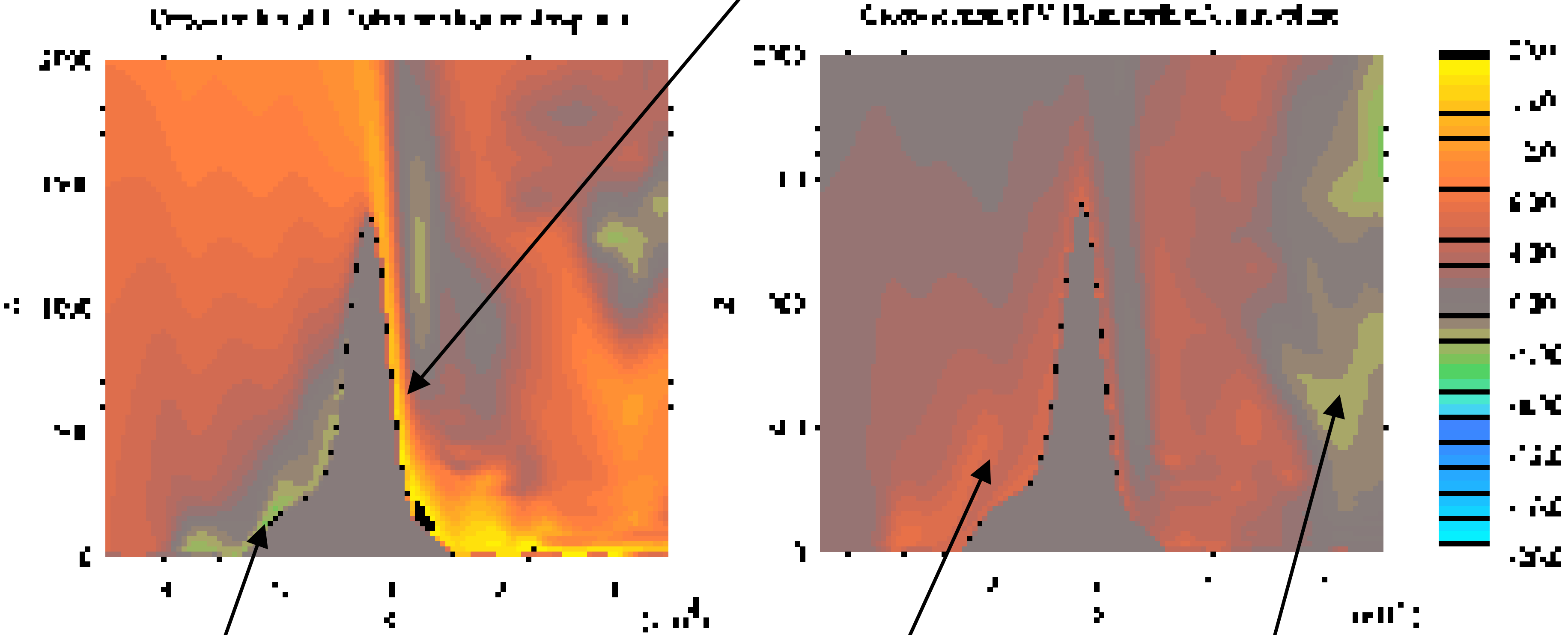


Winds channelled between two main mountain peaks

Cross-sections on following slide are taken along thick solid line

Jet around northern tip is stronger than that around southern tip due to Coriolis effects

Incident wind perpendicular to orography



Strong down-slope flow forms lower part of vertically propagating gravity wave

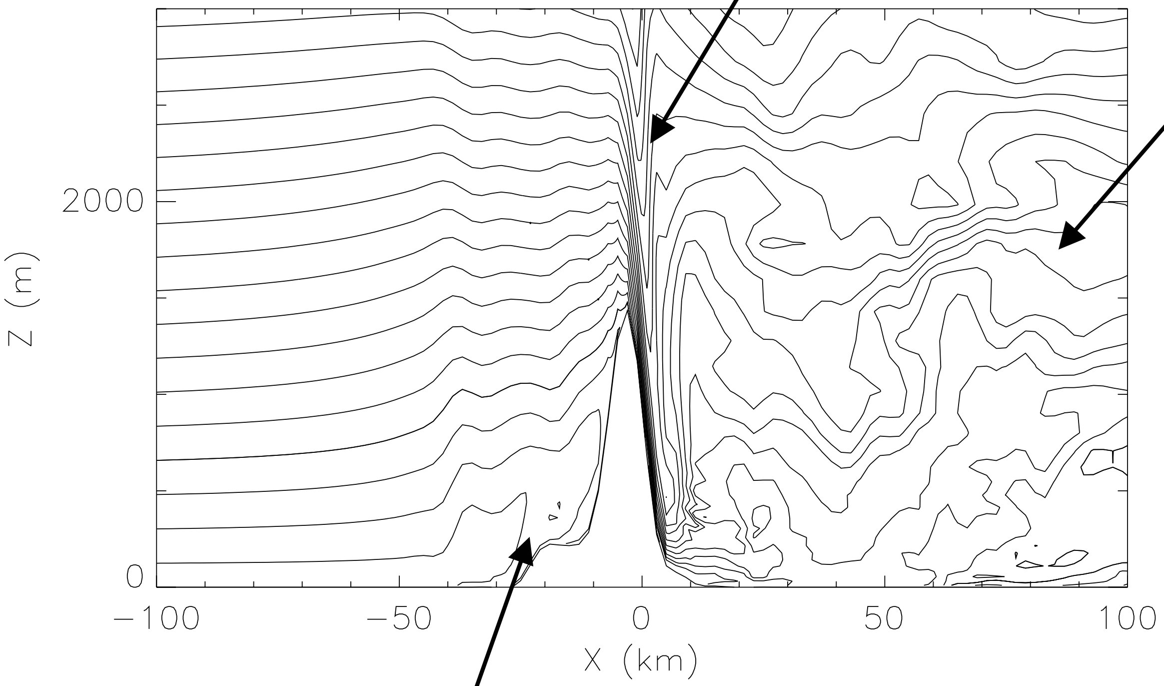
Low-level flow blocked

Barrier jet

Wake vortex

Incident wind perpendicular to orography

Cross-section of potential temperature 10km north of centre-plane



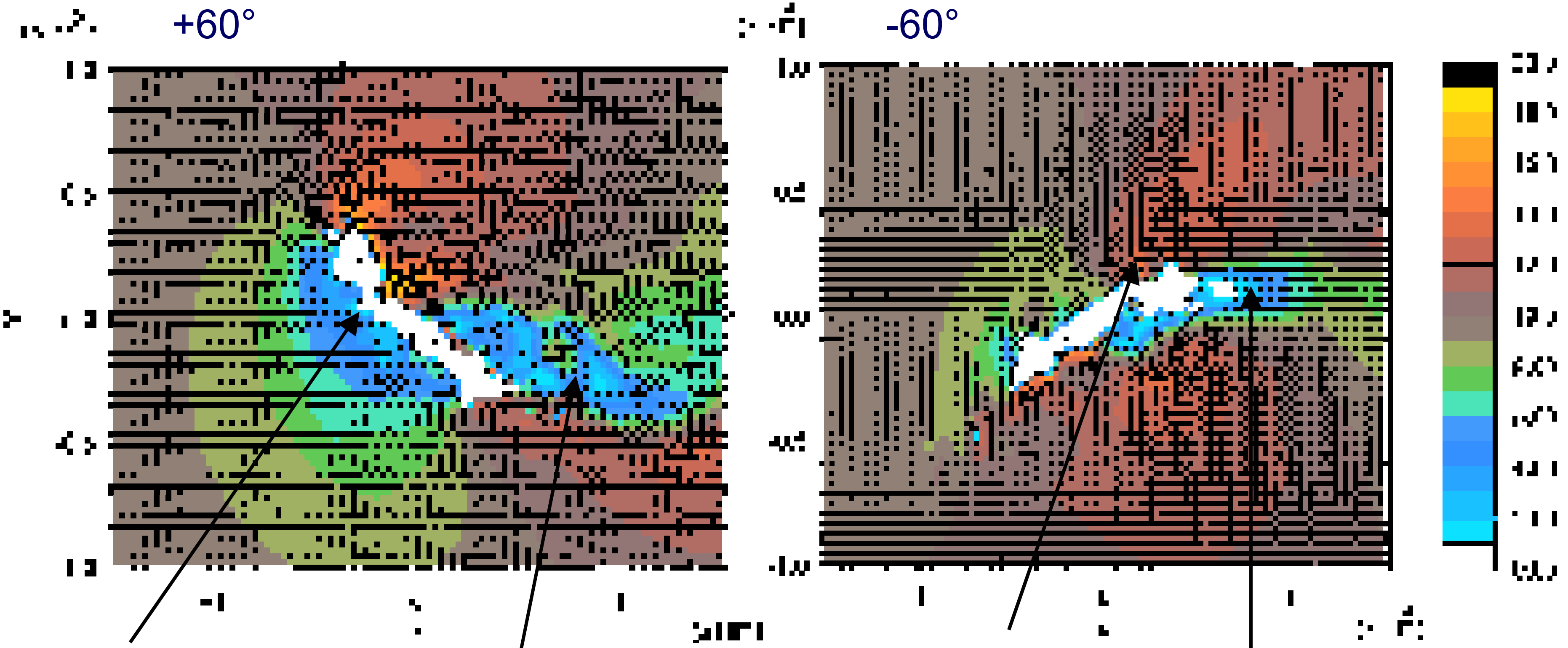
Low-level wave breaking

Turbulent wake

Low-level flow blocked

+/- not equivalent

Horizontal wind vectors at a height of 500m above sea level. Coloured contours represent absolute wind speed in ms^{-1}.



+60°

-60°

Blocked flow

Vortices shedding

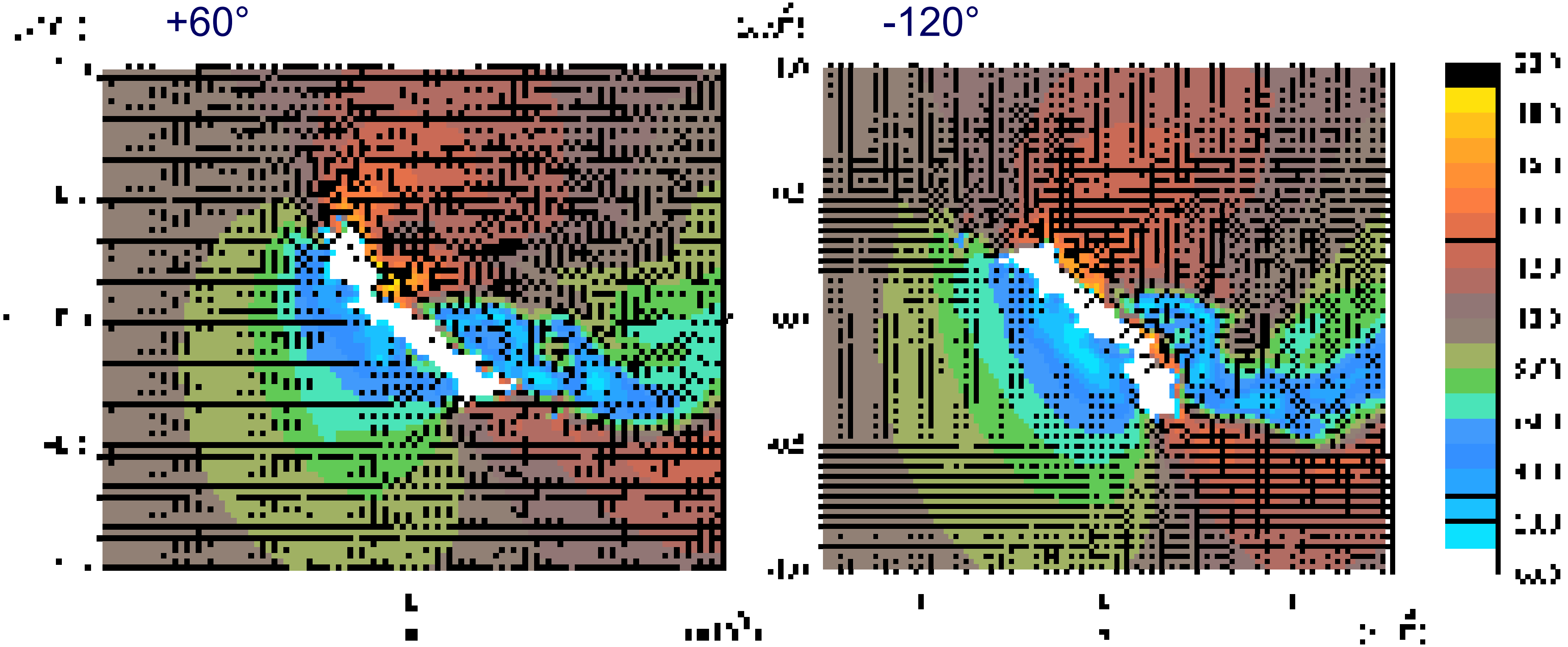
Weaker jet

Smaller, less turbulent wake with no vortices shedding

+/- are not the same due to both Coriolis effects and the asymmetrical real orography

180 degree rotation more similar

Horizontal wind vectors at a height of 500m above sea level.
Coloured contours represent absolute wind speed in ms^{-1}.

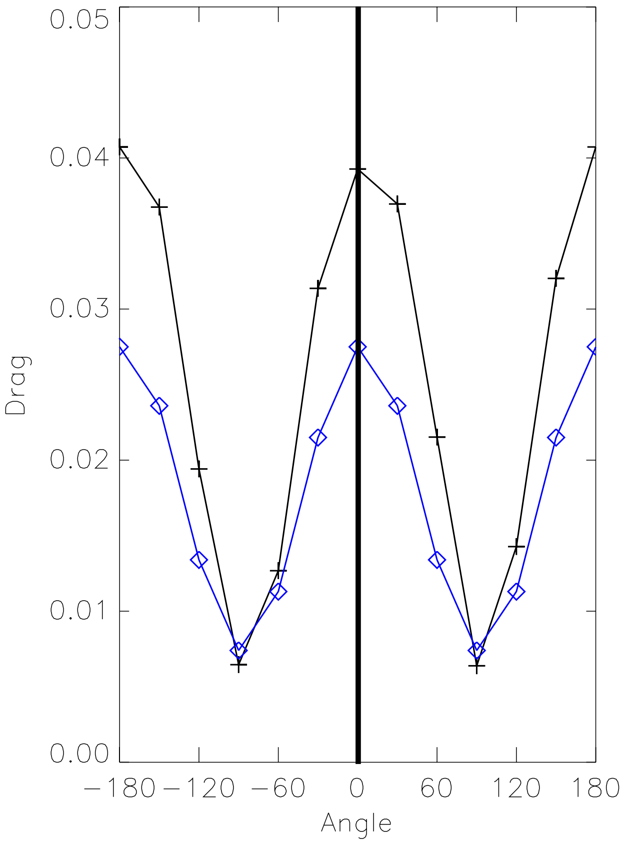


+60°

-120°

Any differences are due to the asymmetrical real orography

Drag



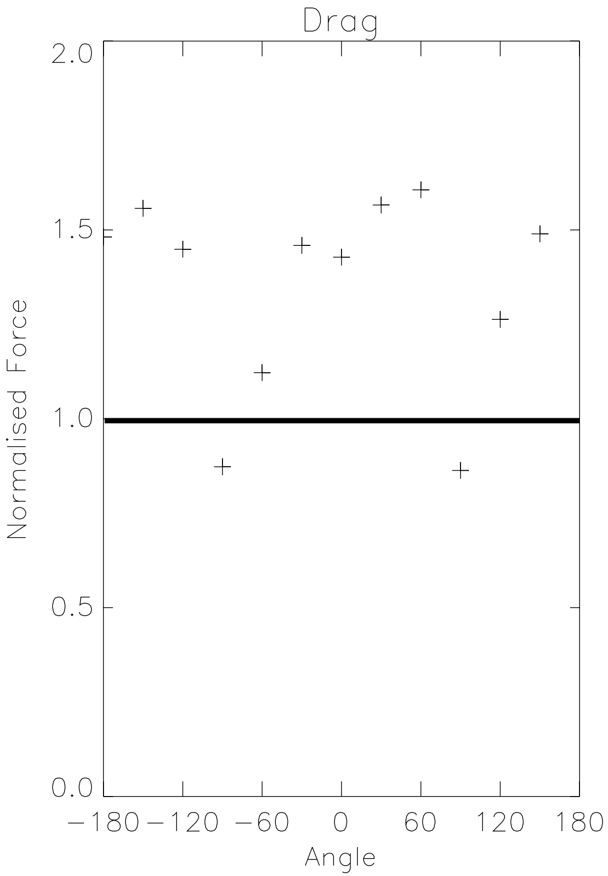
Modelled drag=black crosses

Linear drag=blue diamonds (no Coriolis prediction calculated using 2D FFT of orography)

- Drag is ~ same for pairs of simulations with orography rotated by 180° from any starting point.
- Drag is different for +/- orientations – but this dependence is predicted by linear theory without accounting for Coriolis effects

Drag

Drag normalised by linear prediction



- Most of the variation of drag is captured by linear theory although the flow is clearly non-linear (this is also true for simulations of flow past Hawaii and New Caledonia)

- Linear theory does not capture increase in drag due to transition from streamlined to bluff obstacle

Summary and future work

- The flows are clearly non-linear and affected by Coriolis effects

- However, linear theory does much better than we expected at predicting the drag variation with wind direction

- This is encouraging for our sub-grid scale orographic drag parametrization since it is based on linear theory

- In the future we will try to find the limits to using linear theory for drag prediction by considering flows around multiple real mountains

Questions & Answers