Using a Process-Based Analysis to Optimize the Orographic Drag Parameterization in the NOAA Unified Forecast System

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Introduction

Topography has a profound effect on atmospheric flow. Drag forces result from low-level blocking near the surface and vertically propagating mountain waves impart a drag on the mean wind from the lower troposphere up to as high as the mesosphere (Fig. 1). Numerical weather prediction (NWP) models are able to explicitly represent these processes caused by grid-resolved topography. At typical global NWP grid spacings of ~10-20km, the substantial drag contribution from sub-grid, unresolved topography would be missing without orographic drag parameterizations. Here we analyze the orographic gravity wave drag (GWD) and blocking (BLK) parameterizations of the FV3GFS, the atmospheric component of the NOAA Unified Forecast System (UFS). The NOAA Global Systems Laboratory (GSL) is testing a new suite of orographic drag parameterizations for inclusion in the next release of the FV3GFS. We compare the performance of the new suite in the "Prototype 8 GFSv17" to the existing parameterization as in the operational Version 16 GFS (GFSv16).

Gravity wave drag (GWD) | Low-level flow blocking (BLK)

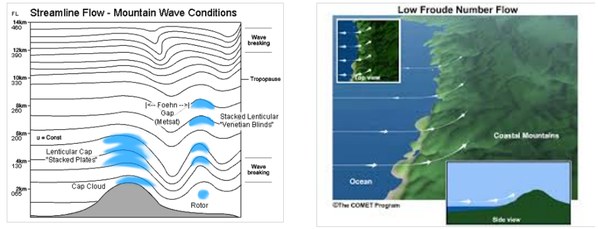

Fig. 1: Graphical representation of GWD and BLK processes.

Drag parameterization overview

Parameterization type	Operational GFSv16/ Prototype 8 GFSv17 (p8_control)	Prototype 8 GFSv17 – GSL (p8_GSL)
Orographic Gravity wave drag (GWD)	GFS based: Kim and Doyle (2005)	WRF based: Kim and Doyle (2005), Choi and Hong (2015), Toy et al. (2023)
Low-level flow blocking (BLK)	GFS based: Lott and Miller (1997)	WRF based: Kim and Doyle (2005), Toy et al. (2023)

FV3GFS "Tuning" Tests

An orographic drag parameterization comparison study (COORDE), which had participation from the major NWP modeling centers, was recently published to help constrain the uncertainty of orographic drag effects on the atmosphere (van Niekerk et al. 2020). We used this study to both evaluate the status of the GFSv16 (p8_control) drag physics and to guide the tuning of the new p8_GSL version. Here we present the results with the C384 global grid.

C384 Global Grid (Δx~26km)
1-14 Jan 2015
24-hr cold-start reforecasts, 00UTC init

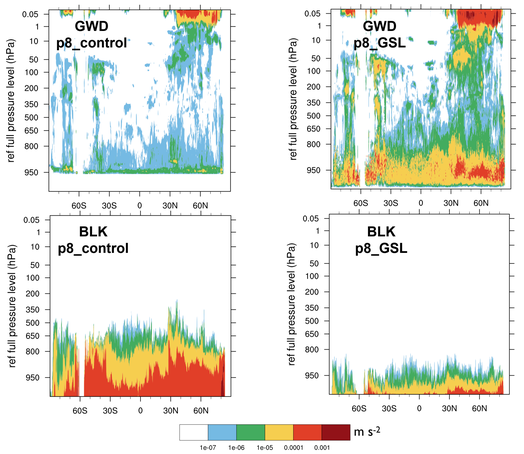

Fig. 2: Zonal and time averages of windspeed tendency for the GWD and blocking schemes (land points only) (m s^{-2}).

C384 Global Grid (Δx~26km)
1-14 Jan 2015
24-hr cold-start reforecasts, 00UTC init

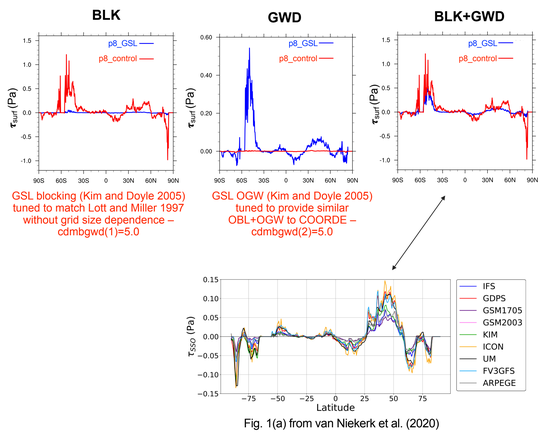

Fig. 1(a) from van Niekerk et al. (2020)

Fig. 3: Zonal and time averages of surface stress for the GWD and blocking schemes (land points only) (Pa).

Takeaway from "tuning" tests: Current tuning in GFSv16 and p8_control is overly heavy on blocking and light on gravity wave drag. Blocking is excessive and extends to levels much higher than we expect to find subgrid-scale topography (Fig. 2). Next we look at the impact of this tuning exercise on 10-day forecast skill.

FV3GFS Reforecast Tests

We conducted a series of reforecasts with both orographic drag parameterization configurations to look at the effect on verified forecast skill.

C384 Global Grid (Δx~26km) | 10-day forecasts, 00UTC init every 5 days, 2 Jan to 16 Feb 2020

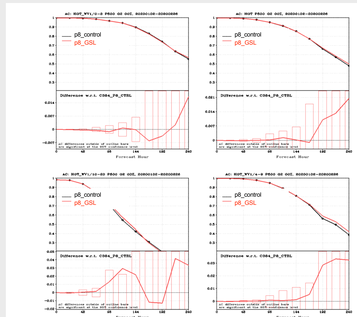

Fig. 4: 500 hPa geopotential height anomaly correlation coefficient (ACC) die-off plots.

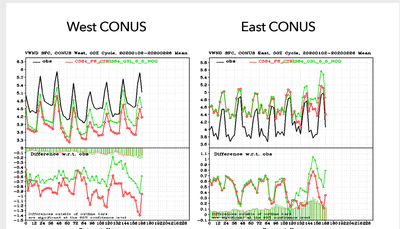

Fig. 5: Surface (10m) windspeed bias.

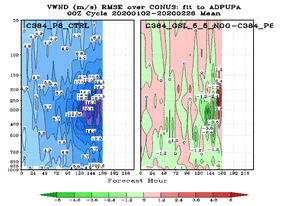

Fig. 6: Windspeed RMS error profile over CONUS.

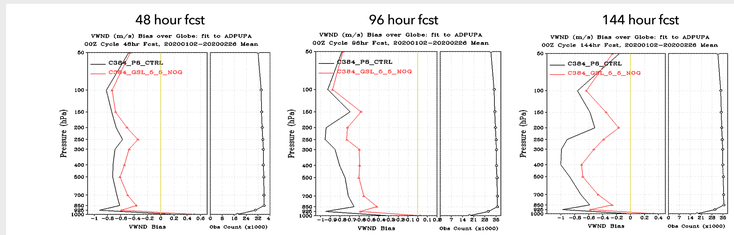

Fig. 7: Windspeed bias profiles compared to RAOBS.

Conclusion

Using the process-based orographic drag parameterization COORDE study results in a more physically reasonable representation of orographic gravity wave drag and low-level blocking in tests with the global FV3GFS. Forecasts with the re-tuned parameterizations show improved bulk skill scores such as height ACC, windspeed biases and RMS errors.

References

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Acknowledgments

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