A new subgrid-scale orographic drag parameterization suite for the RAP/HRRR model

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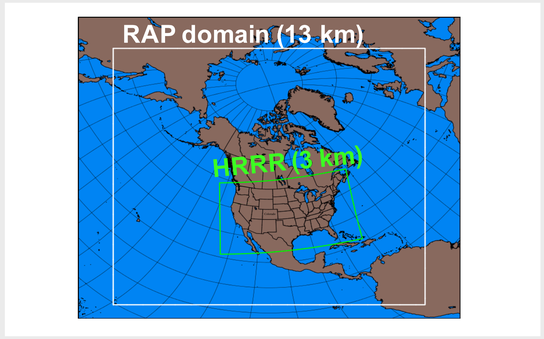
Introduction

The Rapid Refresh (RAP) numerical weather prediction model developed at NOAA covers North America on a 13km-resolution grid. The High-resolution Rapid Refresh (HRRR) model complements the RAP with a nested 3km-resolution, convection-allowing grid centered over the CONUS.



We have recently implemented a suite of subgrid-scale orographic drag parameterizations in the RAP/HRRR model to help reduce high surface wind biases associated with missing sources of drag from unresolved (subgrid-scale) topography. The suite consists of four components:

1) Large-horizontal-scale gravity wave drag
2) Small-horizontal-scale gravity wave drag
3) Turbulent orographic form drag
4) Low-level flow blocking

These drag parameterizations have improved the performance of coarse-grid models. We are now evaluating how they perform in the high-resolution framework of the RAP/HRRR, and we present our preliminary results.

Overview of the drag parameterizations

1) Large-scale gravity wave drag (LS-GWD):

$$\tau_{\mathrm{GWD}} = \rho_0 E \frac{m}{\lambda_{\mathrm{eff}}} G \frac{|U_0|^3}{N_0},$$
$$E \equiv (OA+2)^{c_E Fr_0/Fr_c}, \quad m \equiv (1+L_x)^{OA+1}, \quad G \equiv \frac{Fr_0^2}{Fr_0^2 + C_G OC^{-1}},$$
$$Fr_0 \equiv h \frac{N_0}{U_0} OD,$$

where the orographic height, h, is defined as $2\sigma_h$ in this study.

Kim and Doyle (2005); Kim and Arakawa (1995)

2) Small-scale gravity wave drag (SS-GWD):

$$\tau_{\mathrm{wave}} = \begin{cases} \frac{1}{2}\rho_0 k_s H^2 N U, & \text{if } \frac{N}{U} \geq k_s, \\ 0 & \text{if } \frac{N}{U} < k_s. \end{cases}$$

Tsiringakis et al. (2017); Steeneveld et al. (2008)

3) Turbulent orographic form drag (TOFD):

$$\frac{\partial}{\partial z}\left(\frac{\tau_0}{\rho}\right) = -\alpha\beta C_{\mathrm{md}} C_{\mathrm{corr}} |\mathbf{U}(z)| |\mathbf{U}(z) 2.109\, \mathrm{e}^{-(z/1500)^{1.5}} a_2 z^{-1.2}$$

Beljaars et al. (2004)

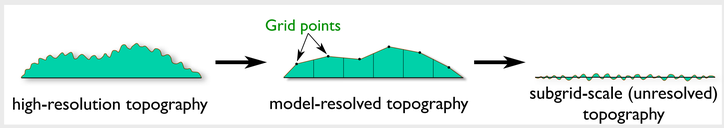
4) Low-level flow blocking (BL):

$$\tau_{\mathrm{BLD}} = \frac{1}{2}\rho_0 \frac{m}{\Delta_x^2} C_{\mathrm{d}} \Delta_x^{\perp} L_x^{\perp} h_{\mathrm{B}} |U_0|^2$$

Kim and Doyle (2005)

τ = stress (N m^{-2})

Note the dependence of these schemes on the standard deviation of the subgrid-scale topography σ_{TOPOG}

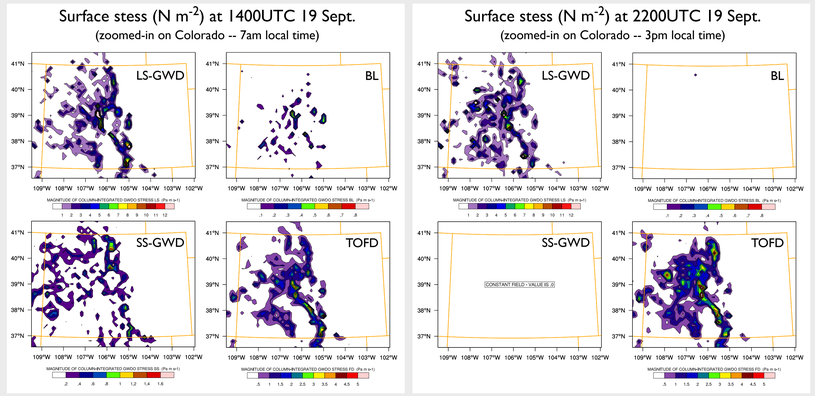


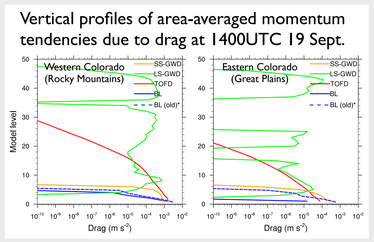
Relevant scales, depths and regimes of the schemes

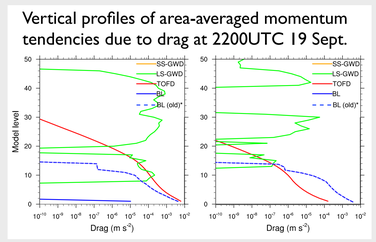
Scheme	Depth/Regime	Grey Zone	Reference
Large-scale GWD	All regimes/1-25 km AGL	15 to 5 km (?)	Kim and Arakawa (1995, JAS) Kim and Doyle (2005, QJRMS)
Blocking drag	All regimes/lowest ~500 m	15 to 3 km (?)	Kim and Doyle (2005, QJRMS)
Small-scale GWD	Stable PBL only/ lowest ~500 m	5 to 1 km (?)	Steeneveld et al. (2008, JAMC) Tsiringakis et al. (2017, QJRMS)
Form drag	All regimes/lowest ~1 km	5 to 0.5 km (?)	Beljaars et al. (2004, QJRMS)

RAP model parameterized drag

1200 UTC 19 Sept. - 0600 UTC 20 Sept., 2017

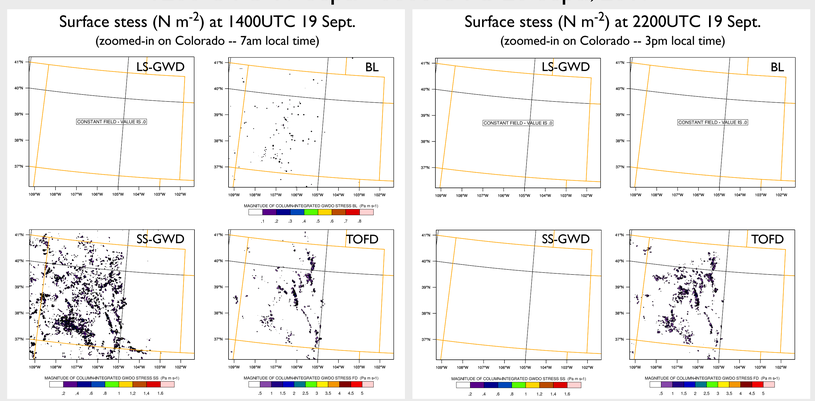


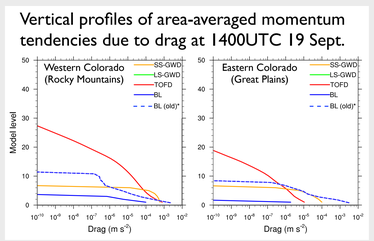


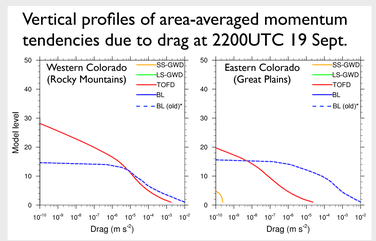


HRRR model parameterized drag

1200 UTC 19 Sept. - 0600 UTC 20 Sept., 2017

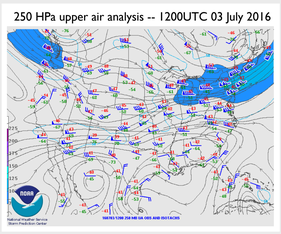






* An error was found in the coding of the blocking scheme in WRF, which resulted in excessive blocking through too deep a layer of the lower atmosphere. The problem has been resolved by KIAPS, NCAR and NOAA, and the fix will be incorporated in WRFV4.

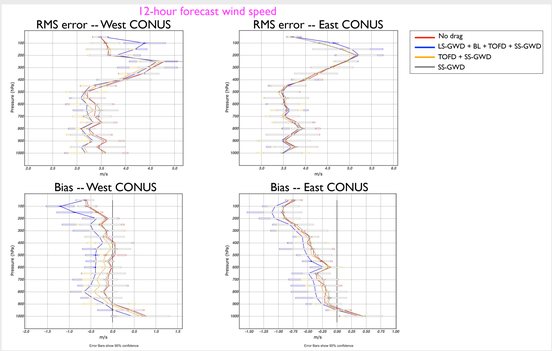
RAP retrospective forecast test

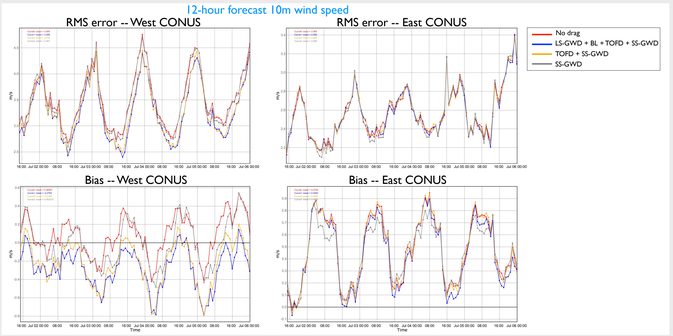


Results of a retrospective forecast for 2016 July 1-5, when westerly winds were conducive to orographic gravity wave generation across the CONUS.

Four experiments:

1) Drag parameterizations turned off
2) All drag schemes turned on
3) Form drag and small-scale GWD only
4) Small-scale GWD only





Summary and discussion

A suite of subgrid-scale orographic drag parameterizations was recently added to the RAP/HRRR NWP model with the goal of reducing high biases in the surface winds. Each parameterization of the suite is based on a distinct physical phenomenon with separate dependencies on scale. For example, the low-level flow blocking (BL) and small-scale GWD (SS-GWD) schemes are most active in the stable PBL, as shown in the 7am- vs. 3pm-local-time results. As for the dependency on horizontal resolution, the drag parameterizations are shown to be less active in the 3-km HRRR vs. the 13-km RAP. Preliminary forecast tests of the drag suite in the RAP show promising results. The RMS-error of the winds are reduced from the surface to about 200mb. The drag suite reduces the high-windspeed bias near the surface, but the low-windspeed bias at higher levels is increased. This effect is larger over the western CONUS, presumably due to the more rugged topography. Also, the form drag parameterization is the largest contributor in this region. We are in the early stages of testing the parameterizations, and are working to determine the optimal configuration of the schemes.

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