The NOAA RAP/HRRR orographic drag suite addition to WRF

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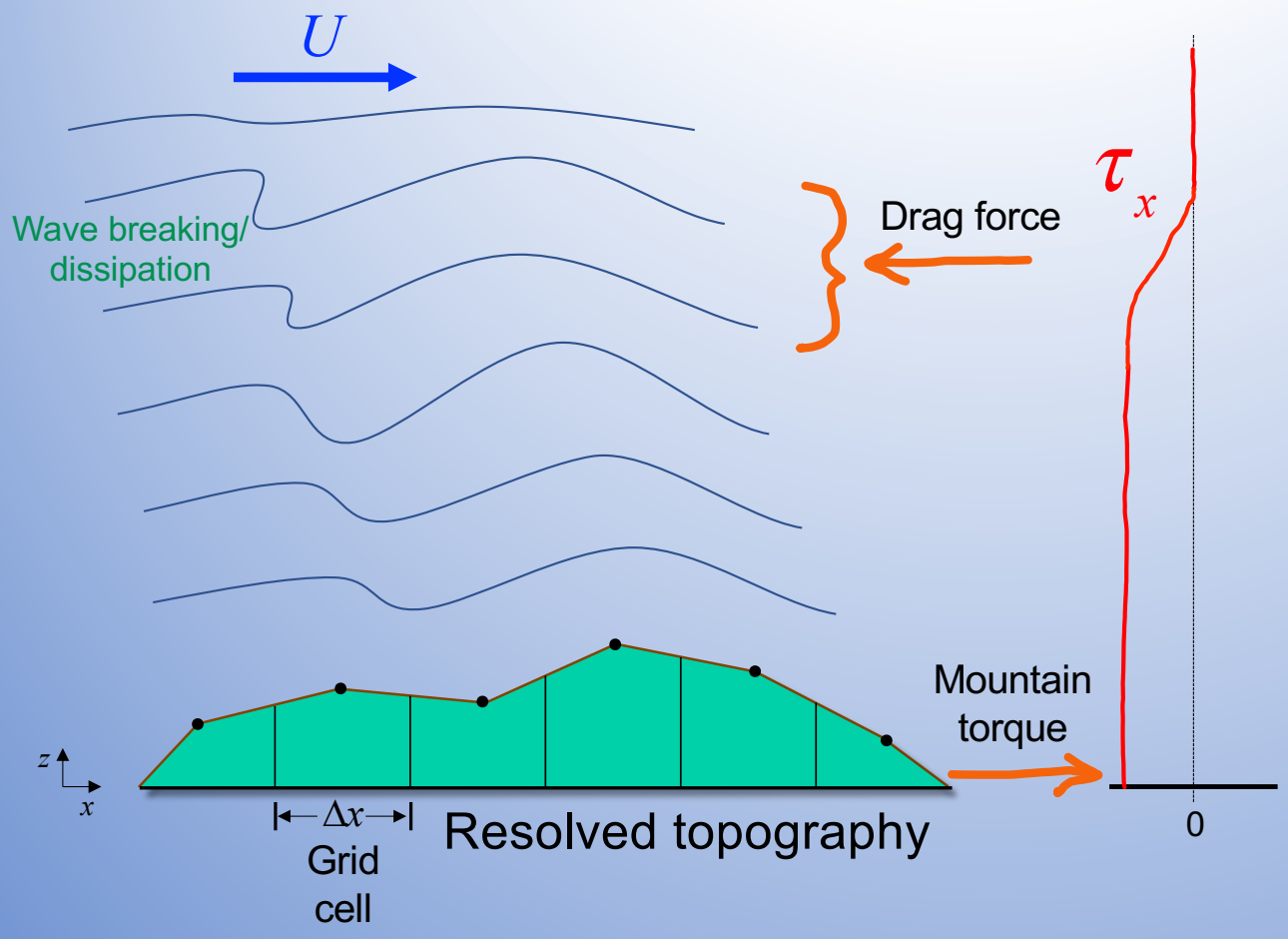
Outline

- Description of the orographic drag parameterizations
  - Two traditional: Gravity wave drag and low-level blocking
  - Two new: Small-scale gravity wave drag and turbulent orographic form drag
- Implementation of the drag suite in WRF version 4.3
  - Static orographic data generated by WPS
  - WRF namelist settings
- Results

Gravity waves, momentum flux, and drag

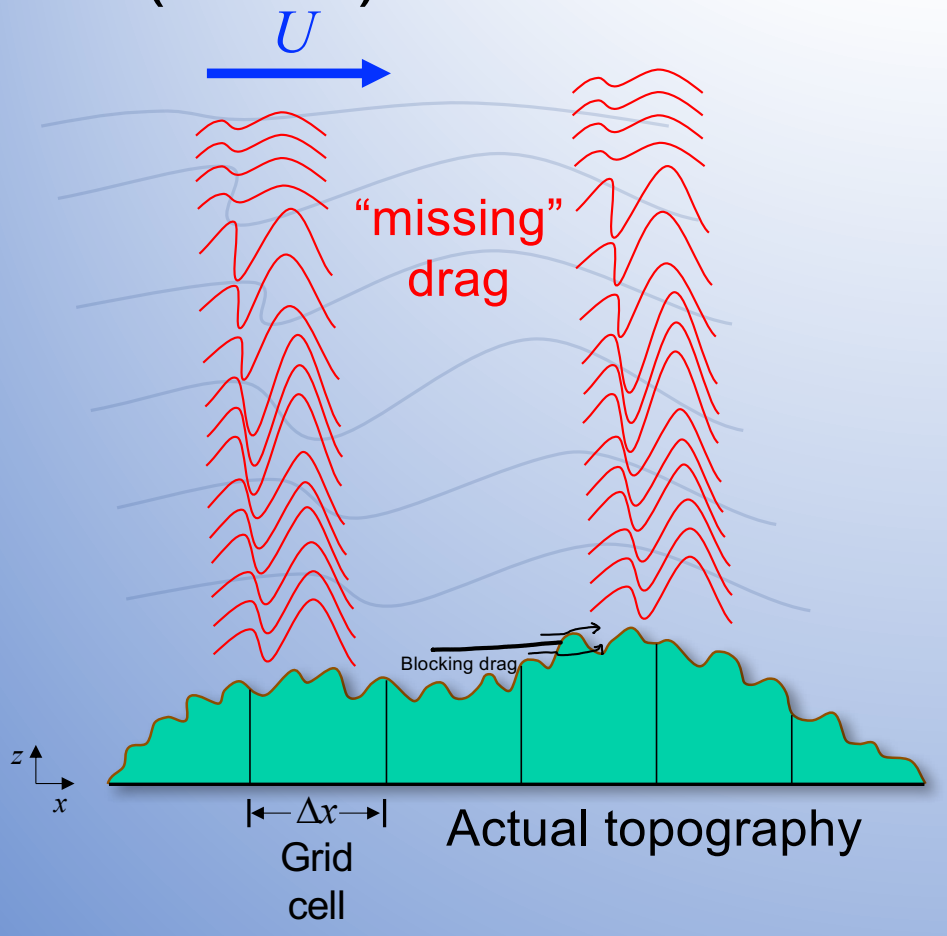


Wave stress: $\tau_x = \bar{\rho}\,\overline{u'w'}$

(vertical momentum flux, N/m^2)

Drag: $\left(\frac{\partial U}{\partial t}\right)_{\text{drag}} = -\frac{1}{\bar{\rho}}\frac{\partial \tau_x}{\partial z}$

Subgrid-scale orographic gravity wave drag (GWD) and low-level blocking parameterizations



Parameterized wave stress: $\tau_x = \bar{\rho}\,\overline{u'w'}$

Drag: $\left(\frac{\partial U}{\partial t}\right)_{\text{drag}} = -\frac{1}{\bar{\rho}}\frac{\partial \tau_x}{\partial z}$

Refs: Kim and Arakawa (1995); Kim and Doyle (2005); Choi and Hong (2015)

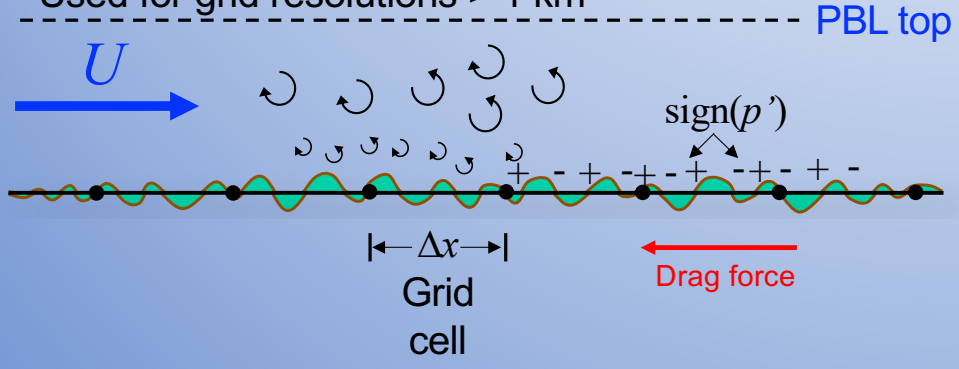
These parameterizations are recommended for horizontal grid resolutions > 5 km

- Original WRF version activated by namelist option *gwd_opt* = 1
- GSL drag suite version activated by namelist option *gwd_opt* = 3

Two additional orographic drag parameterizations

Turbulent orographic form drag (TOFD)
Beljaars et al. (2004)

- Positively correlated turbulent pressure perturbations and terrain slope cause an opposing drag force (Note: This is not gravity wave drag)
- Drag force decays exponentially with height (e-folding height is ~ 1.5 km)
- Terrain height is band-pass filtered to remove horizontal variations >20 km and <2 km before calculating the standard deviation of the subgrid topography
- Used for grid resolutions > 1 km



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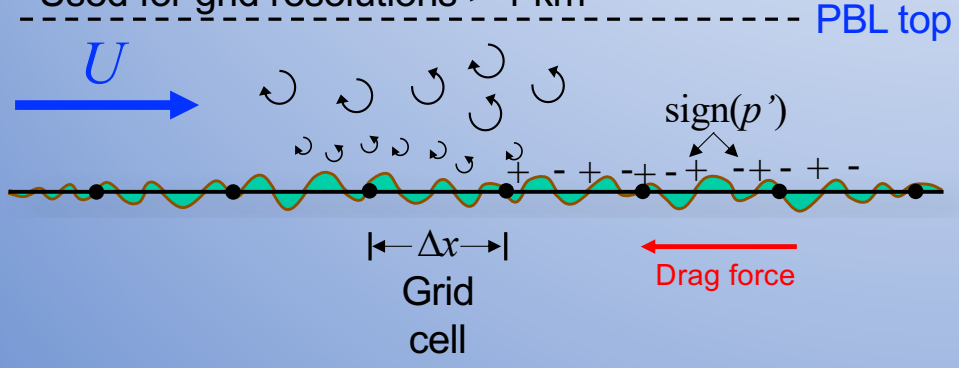
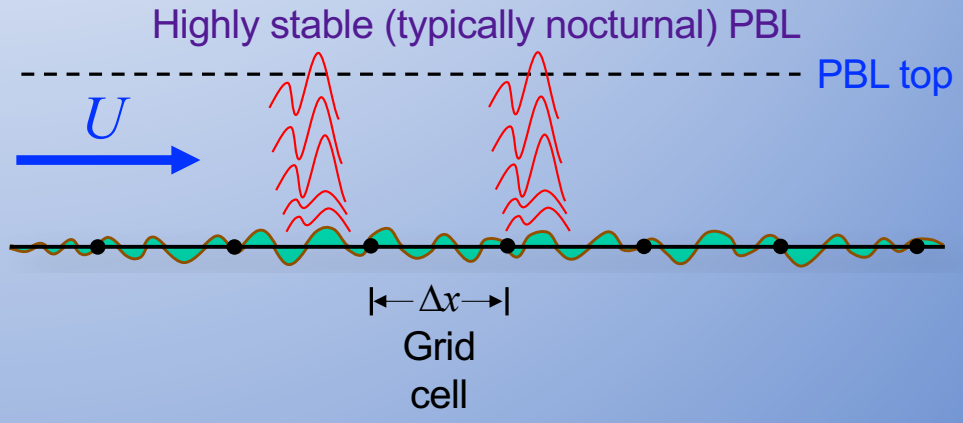
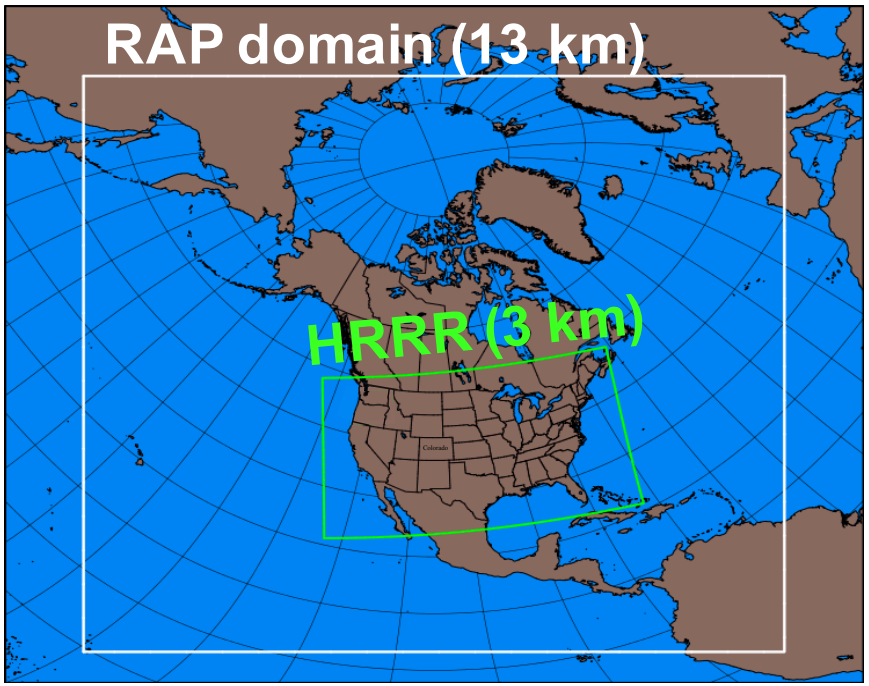


Small-scale gravity wave drag (SSGWD) in stable PBLs
Tsiringakis et al. (2017); Steenveld et al. (2008)

- Highly stable PBL allows vertical propagation of gravity waves at smaller horizontal scales
- Drag force imparted throughout PBL depth
- Used for grid resolutions > 1 km



Rapid Refresh (RAP)/High-resolution Rapid Refresh (HRRR) NWP system developed at NOAA's Global Systems Laboratory (GSL)

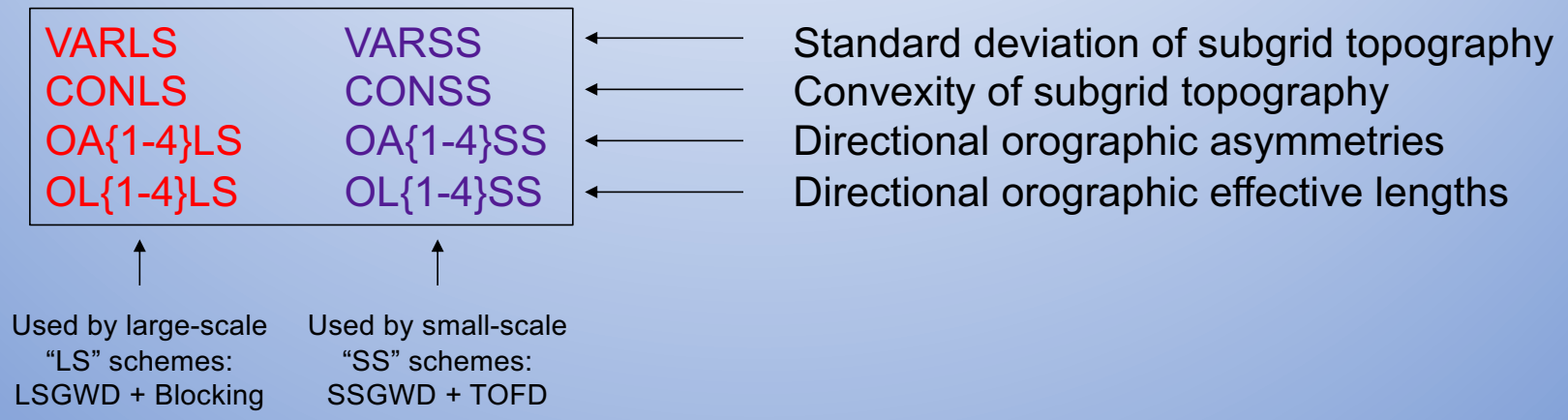


https://rapidrefresh.noaa.gov

- Built on WRF-ARW dynamical core
- HRRRv4/RAPv5 operational since 2 Dec 2020
- GWD physics used:
  - 13km RAP – Full GSL orographic drag suite
  - 3km HRRR – TOFD + SSGWD only

The GSL drag suite included in WRF Version 4.3

- New physics module: module_bl_gwdo_gsl.F
- Suite is activated by WRF namelist option *gwd_opt* = 3 (original scheme is *gwd_opt* = 1)
- New geographical input data required for the WRF preprocessing system (WPS)
  - Download from: https://www2.mmm.ucar.edu/wrf/users/download/get_sources_wps_geog.html
  - Under "WPS Geographical Input Data Mandatory for Specific Applications", download the files *orogwd3_** files from the "GWDO Data for GSL GWD" section
- If you've downloaded these files, then the following variables will be included in your *geo_em.d*.nc* files generated by *geogrid.exe*:



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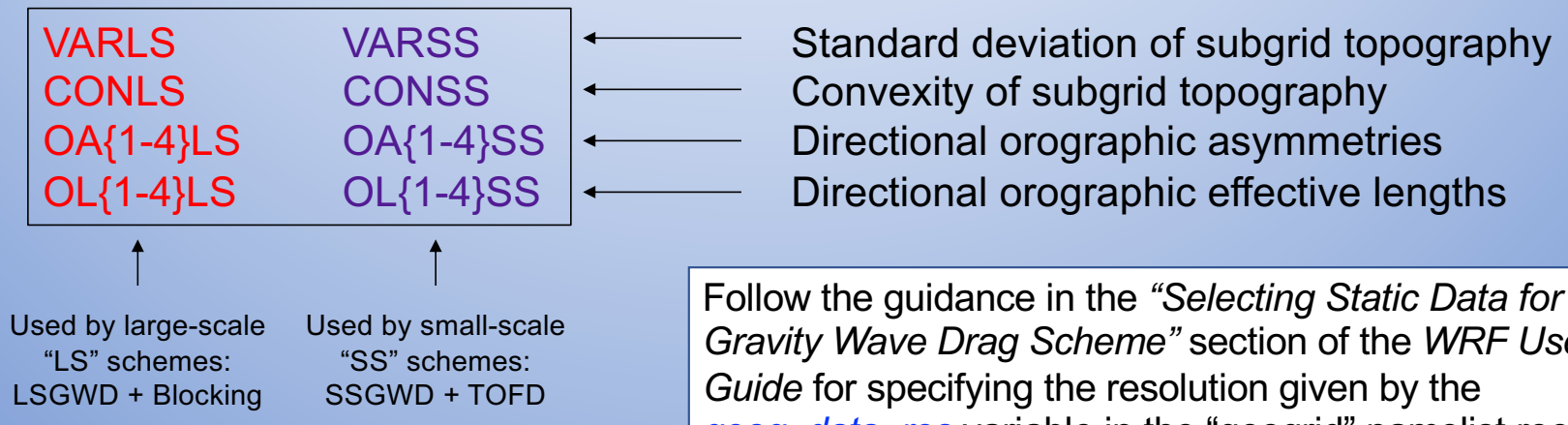
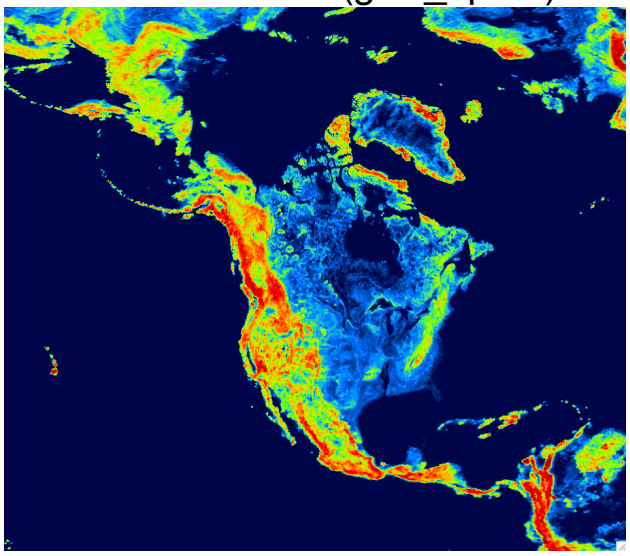


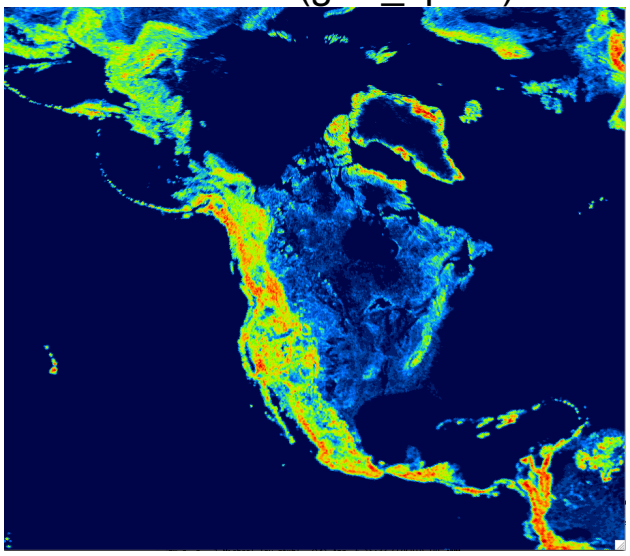
Follow the guidance in the *"Selecting Static Data for the Gravity Wave Drag Scheme"* section of the *WRF Users' Guide* for specifying the resolution given by the *geog_data_res* variable in the "geogrid" namelist record.

Standard deviation of subgrid topography
RAP domain (13km grid)

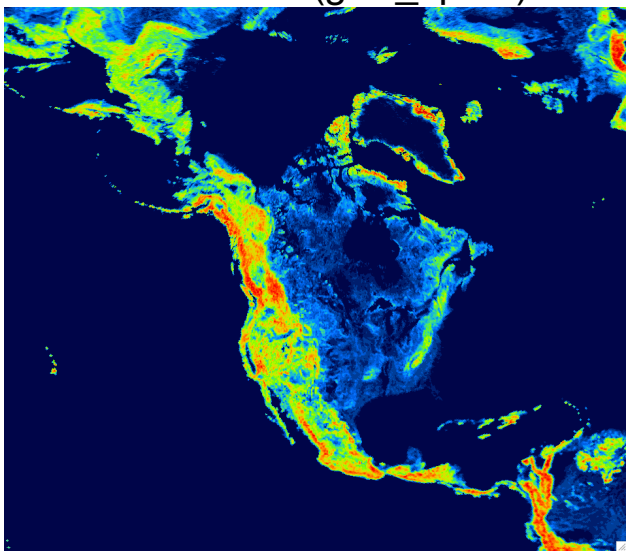
VAR
Traditional WRF (gwd_opt=1)



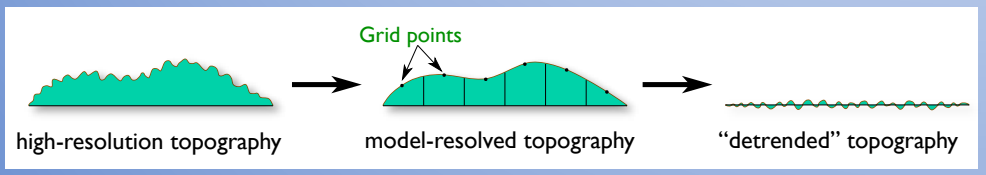
VARLS
GSL GWD (gwd_opt=3)



VARSS
GSL GWD (gwd_opt=3)



meters



Based on 2.5-minute "detrended" topography

Based on 30-second band-pass filtered topography

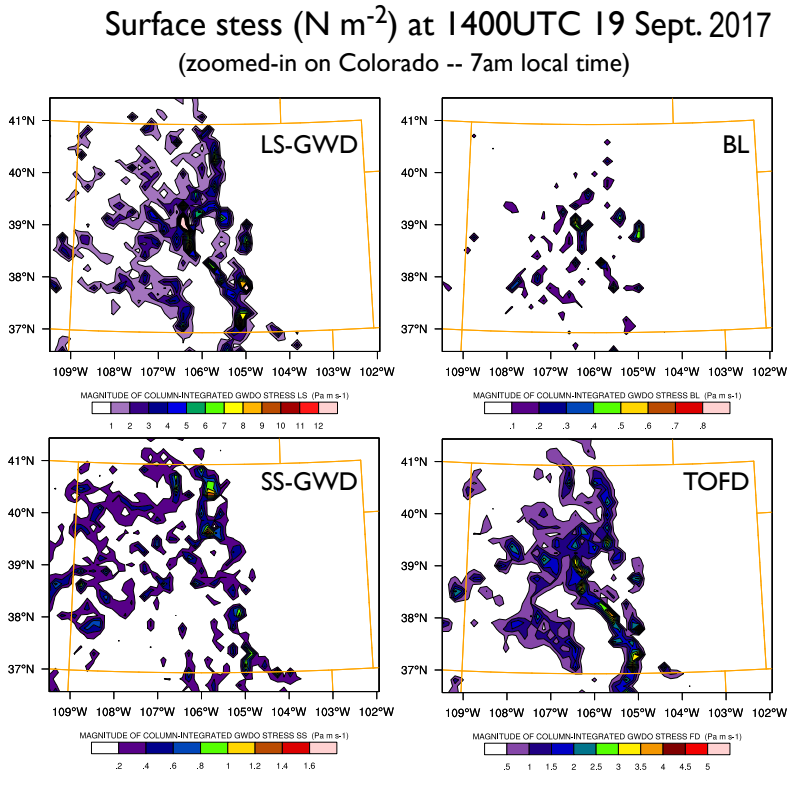
Horizontal resolution “scale awareness”

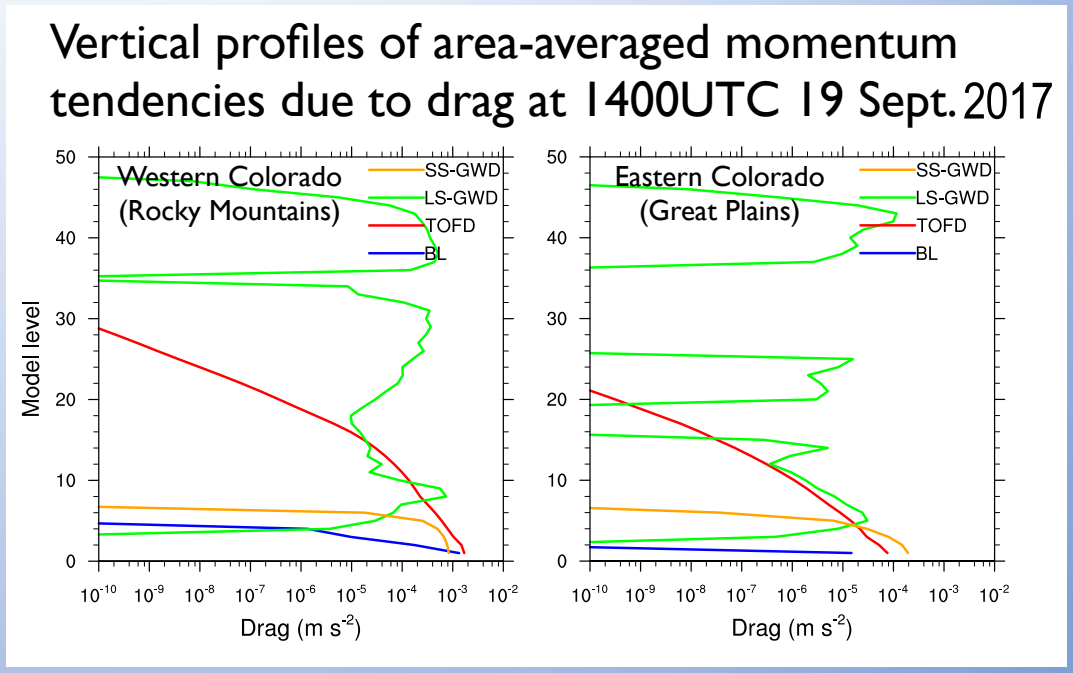
- The large-scale gravity wave drag scheme has built-in scale awareness of the horizontal grid spacing based on empirical tuning of the GFS model and experiments with high-resolution simulations
  - The user may change the tuning parameters in the code if desired
  - Any future updates to the default parameters will be passed on to the WRF repository
- Large-scale GWD and blocking is tapered down to zero at 5 km grid spacing
- Small-scale GWD and turbulent orographic form drag is tapered down to zero at 1 km grid spacing

Drag contributions from each scheme

Diagnostic output can be switched on by setting the variable *gwd_diags* = 1 in the WRF namelist

13km RAP





Drag contributions from each scheme

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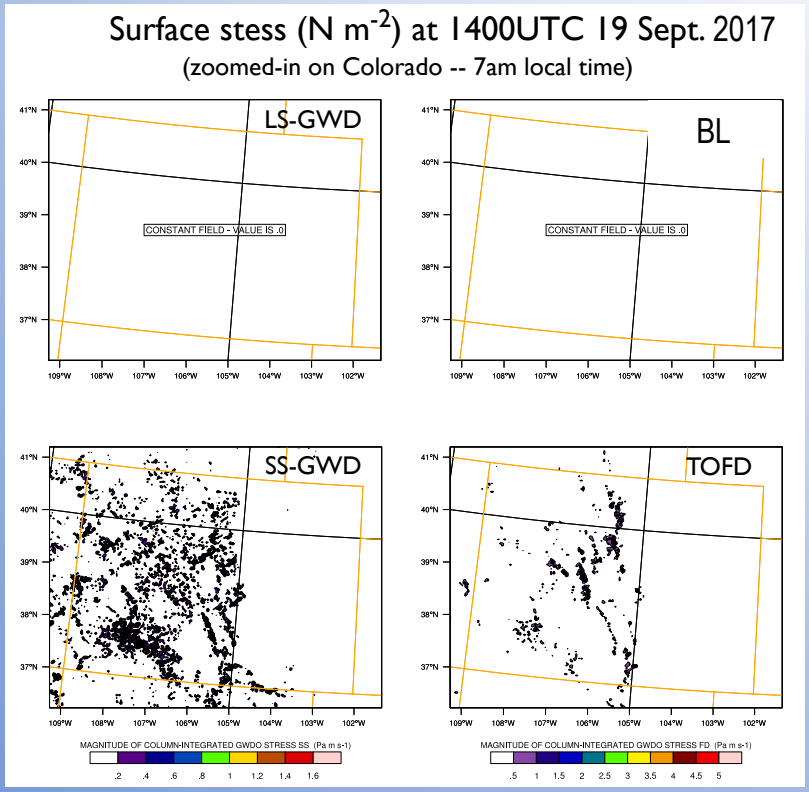
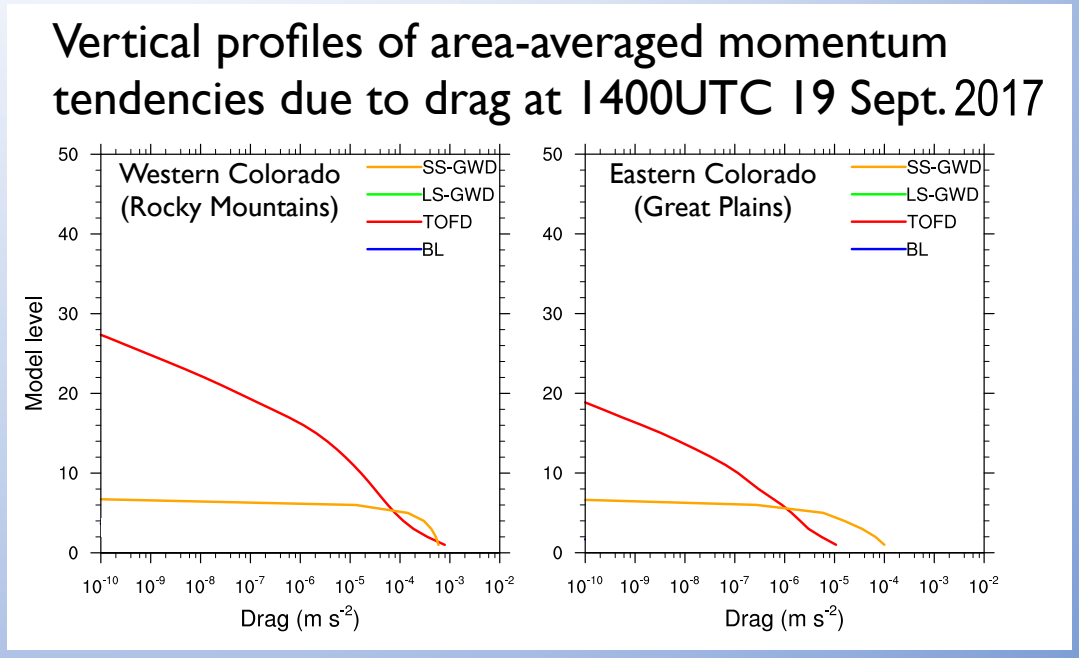
3km HRRR



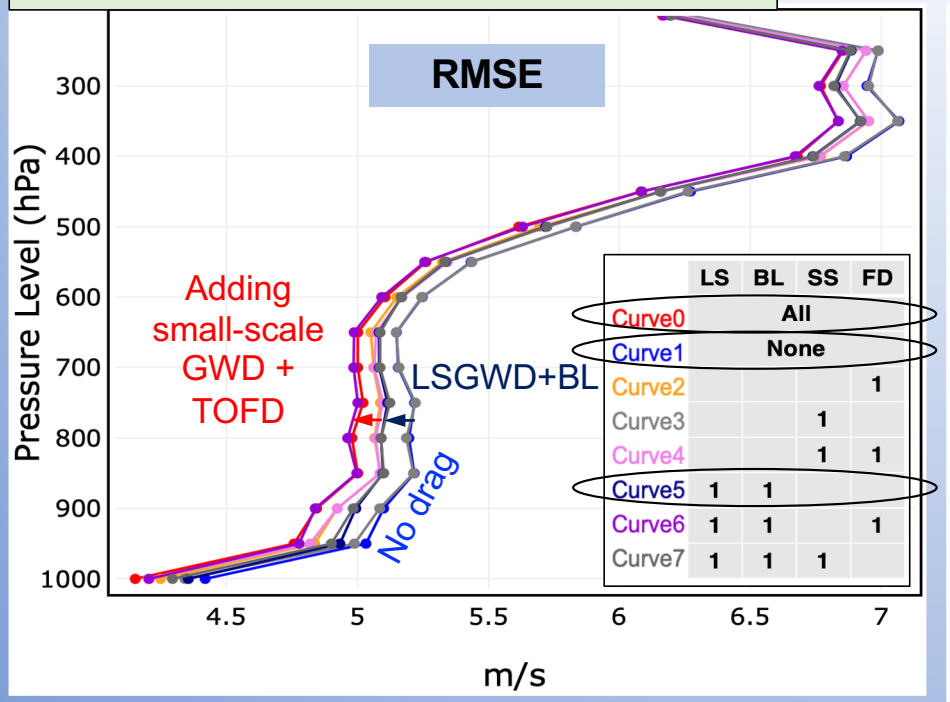


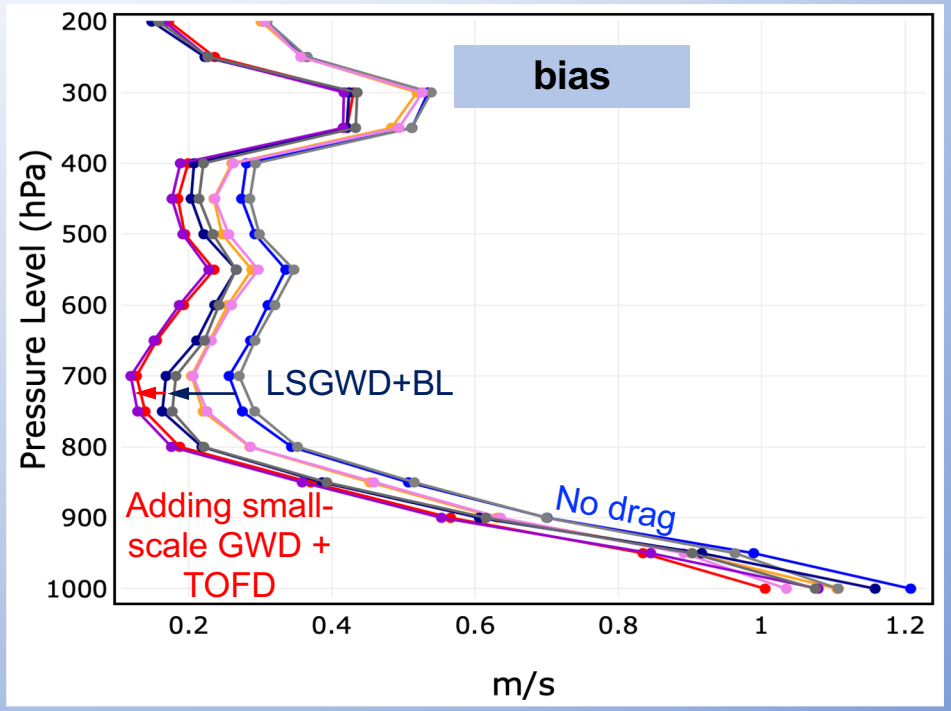
Drag suite performance in the RAP (13km grid)

Reforecasts
2–15 Feb 2019

27-h wind: full RAP domain, 00/12 UTC

Note the benefits of SSGWD and TOFD





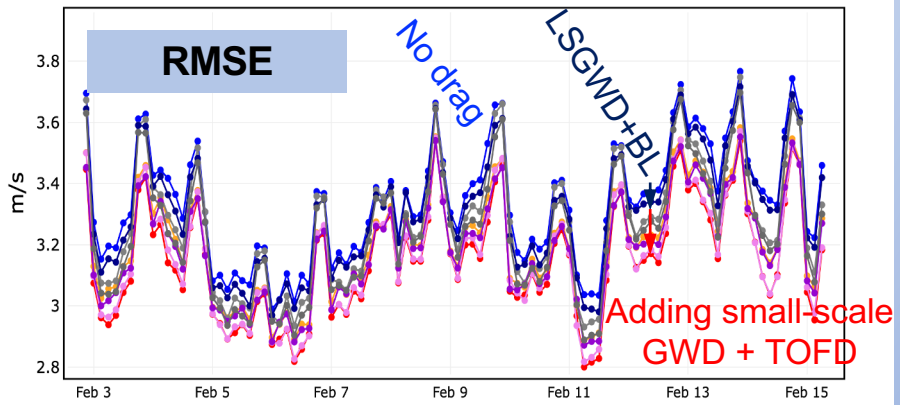
Slide courtesy of Jaymes Kenyon

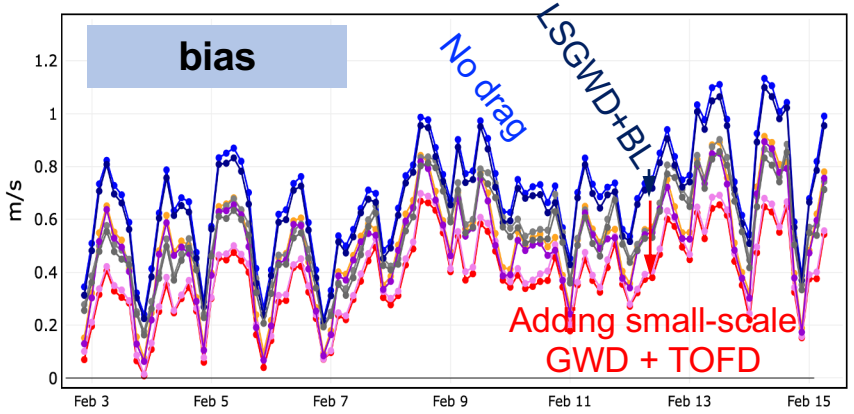
Drag suite performance in the RAP (13km grid)

Reforecasts
2–15 Feb 2019

21-h 10-m wind: full RAP domain

	LS	BL	SS	FD
Curve0	All			
Curve1	None			
Curve2				1
Curve3			1	
Curve4			1	1
Curve5	1	1		
Curve6	1	1		1
Curve7	1	1	1	





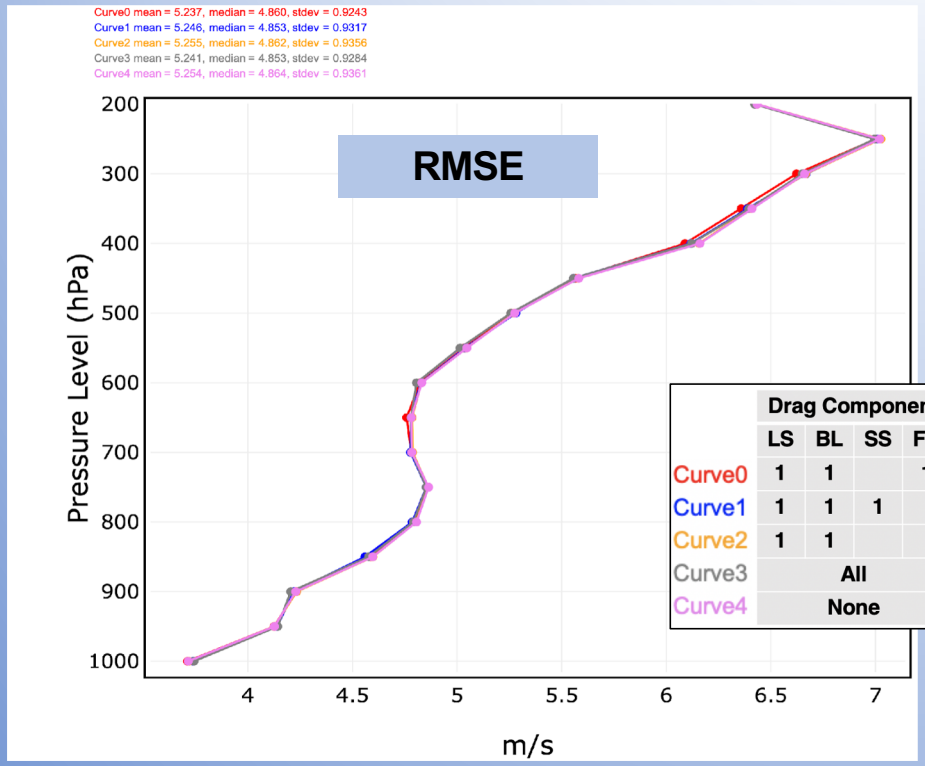
Slide courtesy of Jaymes Kenyon

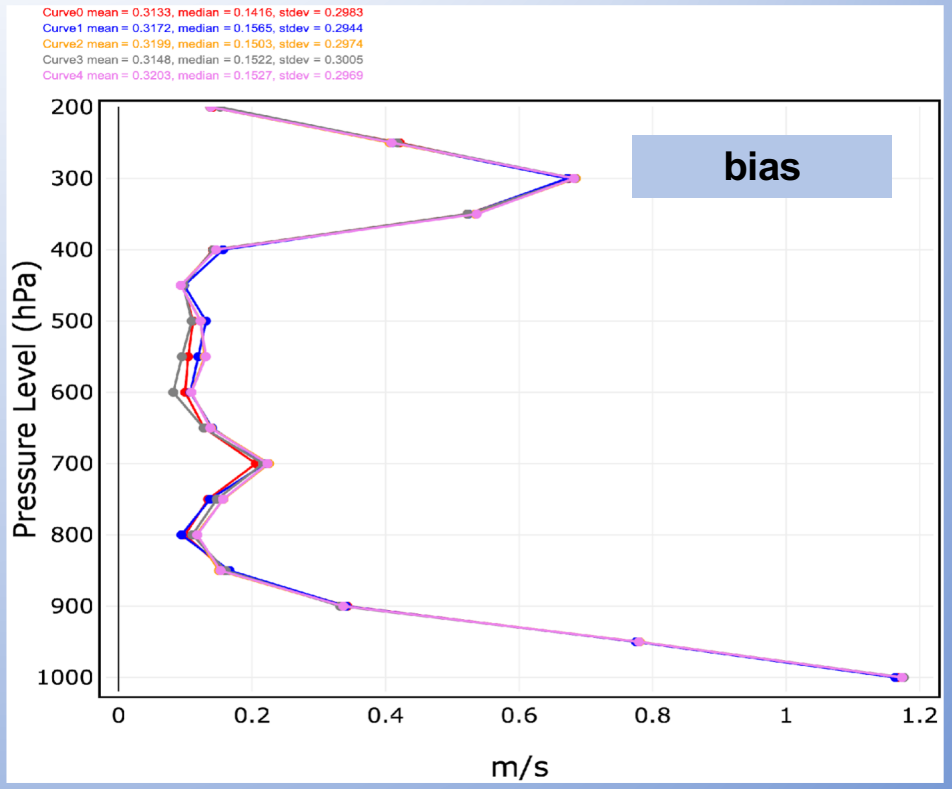
Drag suite performance in the HRRR (3km grid)

Reforecasts
2–15 Feb 2019

24-h wind: full HRRR domain, 00/12 UTC

Note the smaller impact of the drag suite at finer resolution





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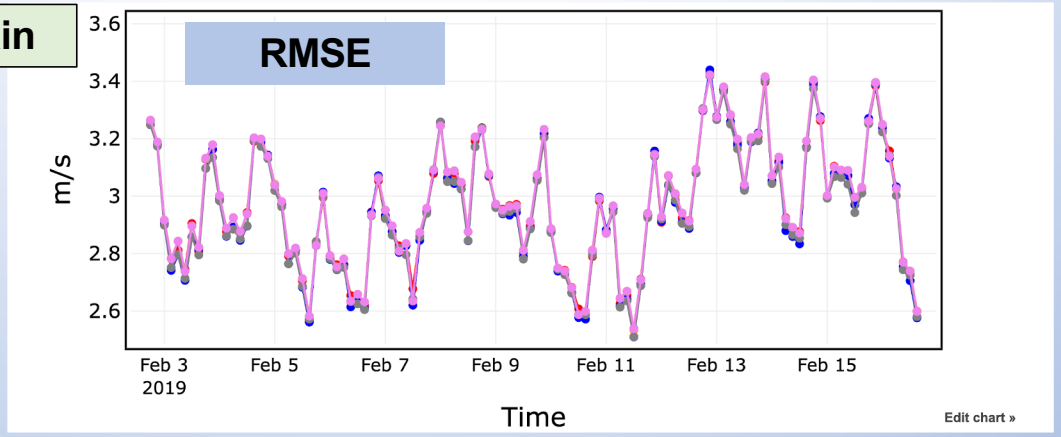
Drag suite performance in the HRRR (3km grid)

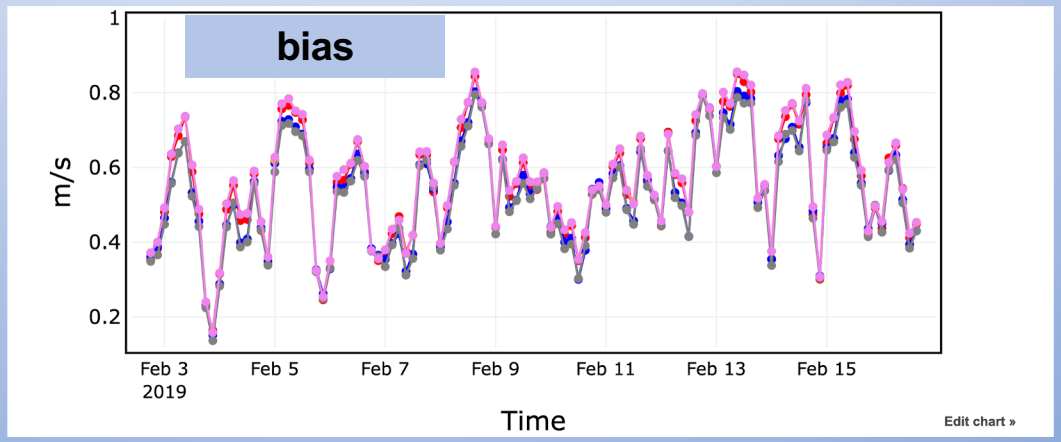
Reforecasts
2–15 Feb 2019

Note the smaller impact of the drag suite at finer resolution

18-h 10-m wind: full HRRR domain

	Drag Component			
	LS	BL	SS	FD
Curve0	1	1		1
Curve1	1	1	1	
Curve2	1	1		
Curve3	All			
Curve4	None			





Slide courtesy of Jaymes Kenyon

Summary

- The WRF Orographic Gravity Wave Drag + Blocking parameterization has been modified and two new physical processes have been added: Turbulent Orographic Form Drag and Small-scale Gravity Wave Drag
- Improved windspeed bias and RMS errors have been demonstrated in the 13 km RAP NWP model
- Modest improvements to the 3 km HRRR NWP model also demonstrated – We are testing to see if additional improvement can be made at these fine resolutions
- The GSL drag suite is included in the Common Community Physics Package (CCPP) library
- The suite may evolve into the UFS drag suite with time

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References

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