# Evaluating and tuning the orographic gravity wave drag scheme in the RAP model

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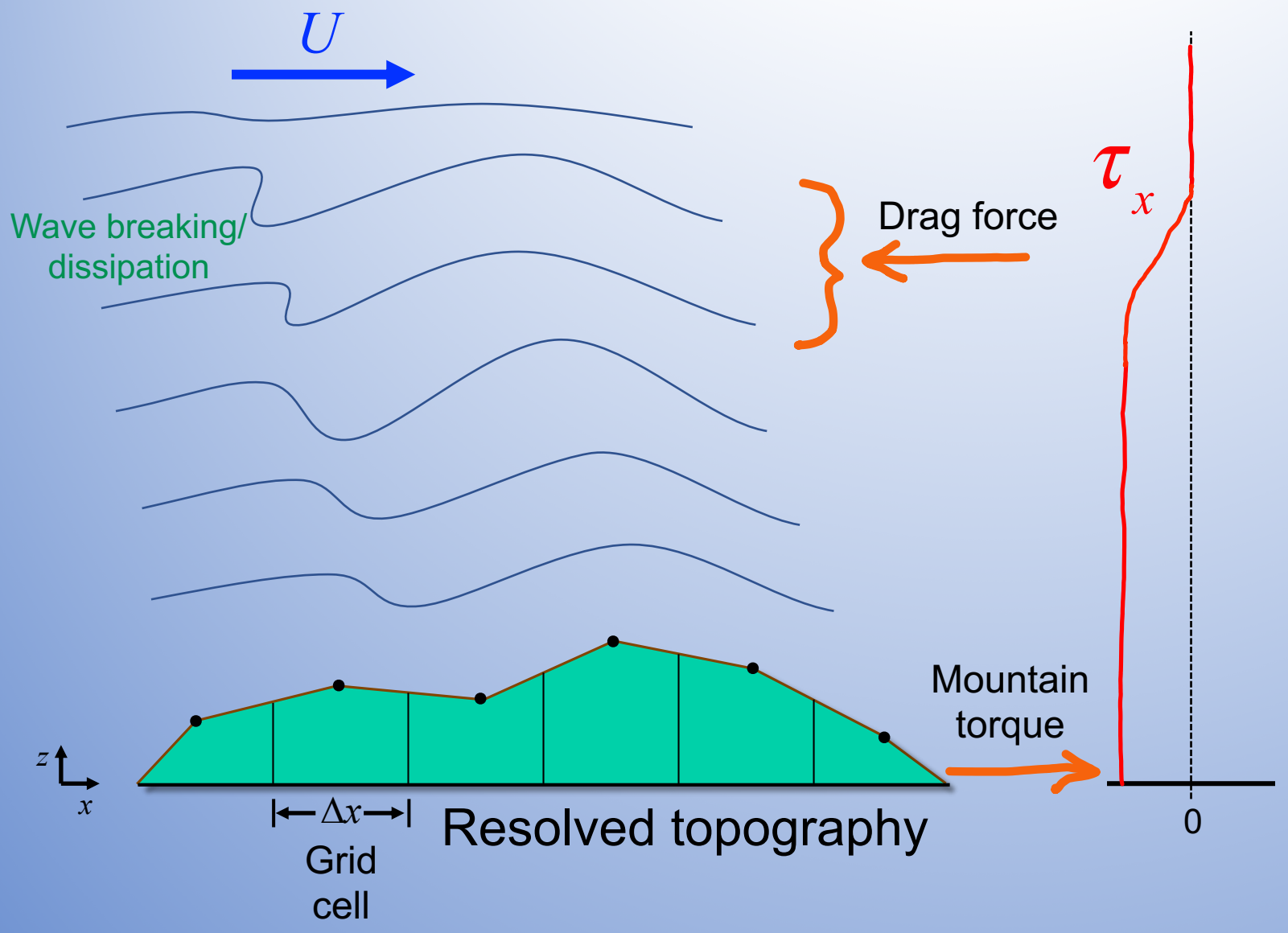
# Gravity waves, momentum flux, and drag

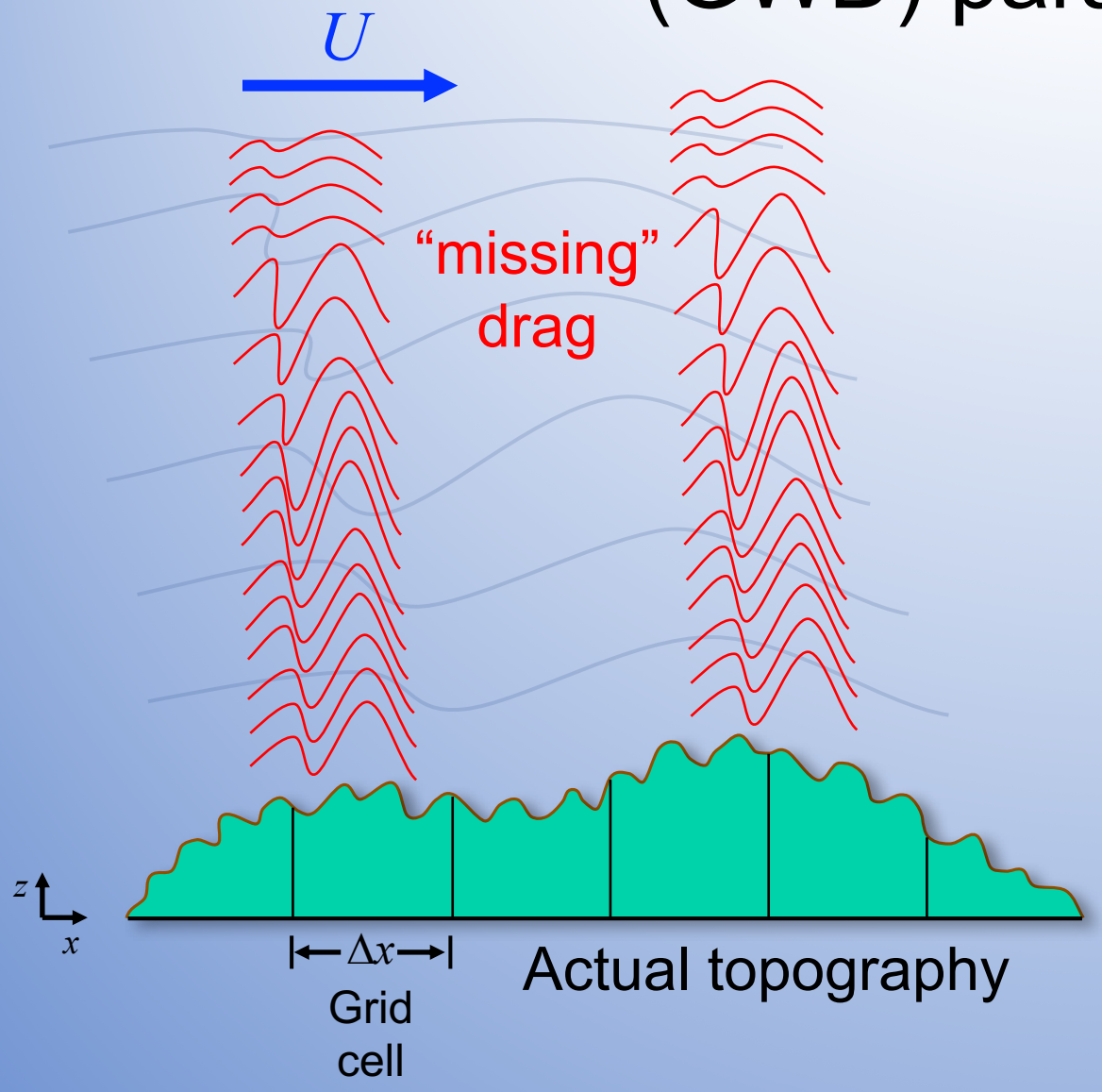



Wave stress: $\tau_x = \bar{\rho}\,\overline{u'w'}$

(vertical momentum flux, N/m²)

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) parameterization




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

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

- WRF namelist option: gwd_opt = 1
- Kim and Arakawa (1995); Kim and Doyle (2005)
- Includes drag from subgrid-scale low-level flow blocking
- Input topographic statistics variables (e.g., standard deviation of subgrid topography) from static files – available in WPS_GEOG

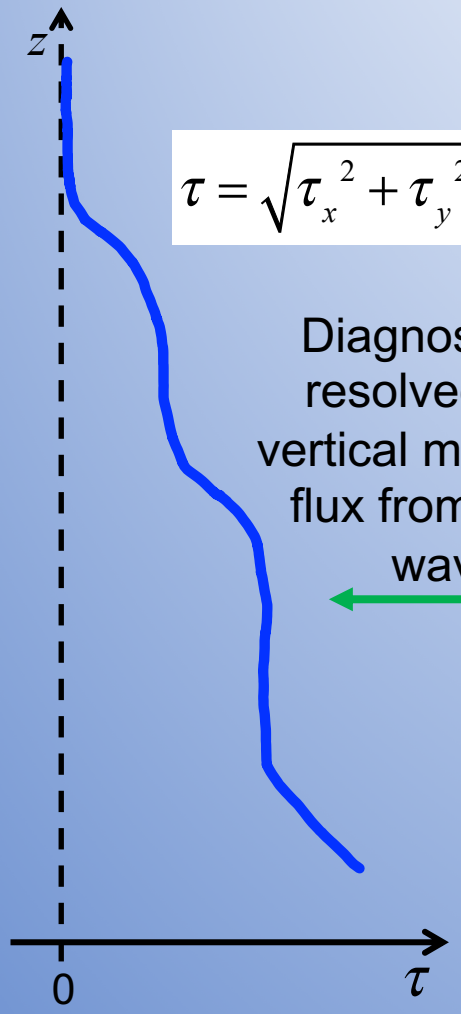
# Goals of this work

- To quantify the instantaneous vertical momentum flux profiles associated with resolved gravity waves in high-resolution simulations (we'll call these fluxes the "truth")
- To compare these with parameterized fluxes on coarse grids
  - Determine how well the GWD parameterization does "out of the box"
  - Verify tuned parameters based on past empirical studies
  - Determine the "gray zone" horizontal resolutions for the GWD parameterization

# Method

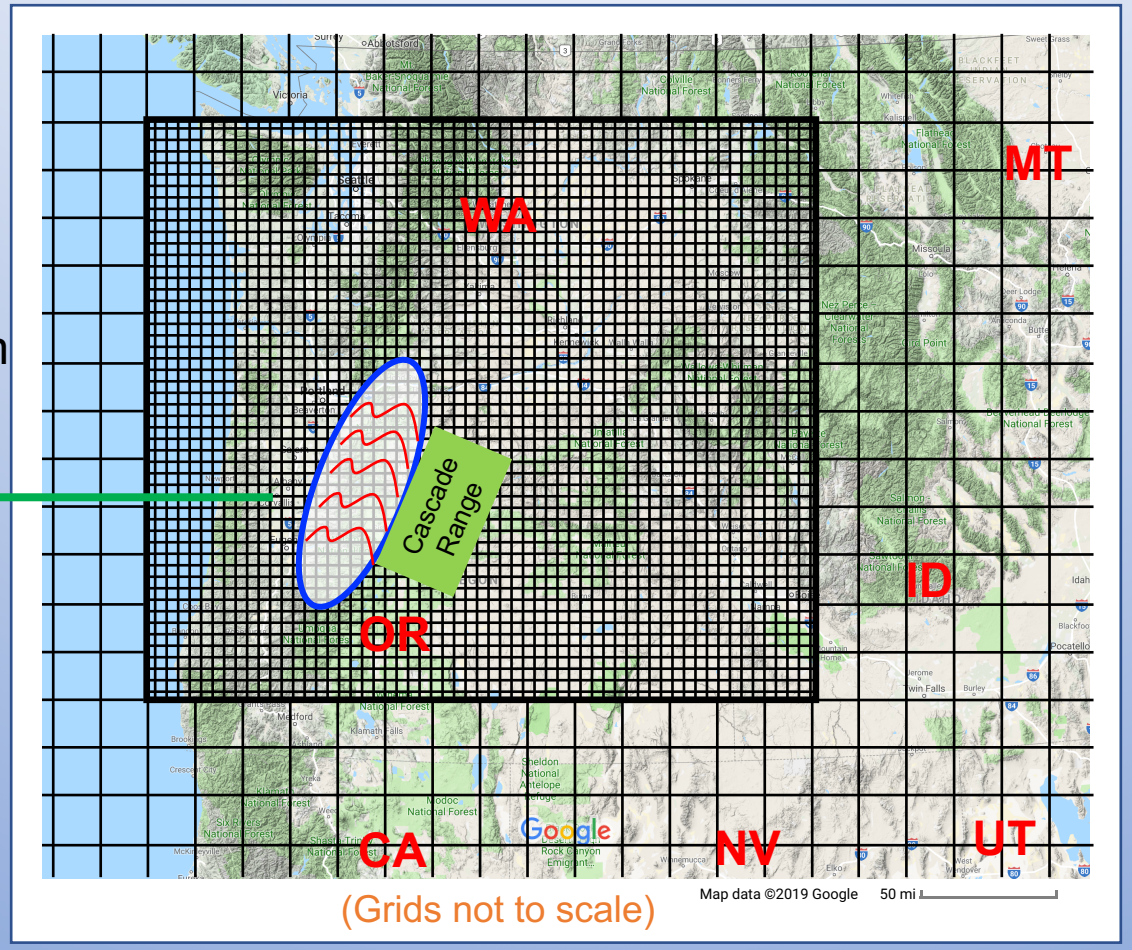
Use high-resolution WRF reforecasts run during the Wind Forecast Improvement Project 2 (WFIP2)

- Field campaign to improve wind forecasts over complex terrain
- 750m grid nested within 3km HRRR grid




$$\tau = \sqrt{\tau_x^{\,2} + \tau_y^{\,2}}$$

Diagnose fully-resolved "true" vertical momentum flux from gravity waves



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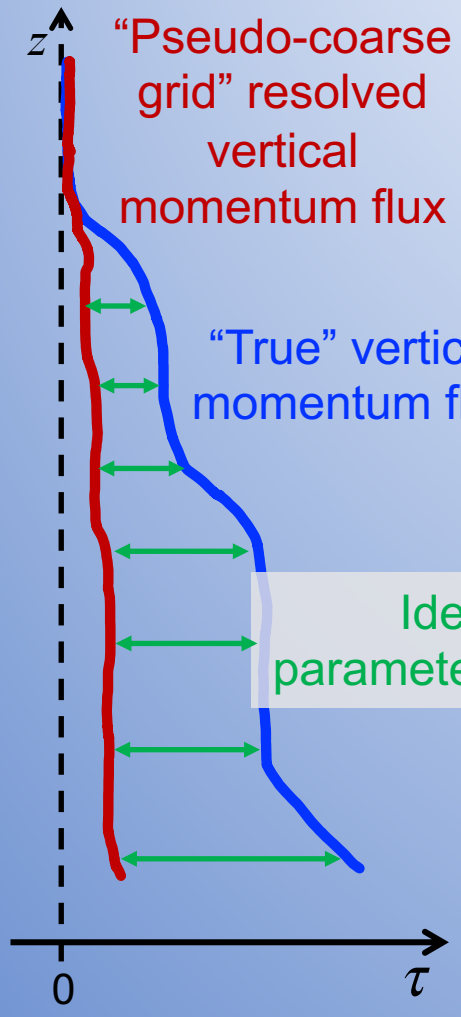
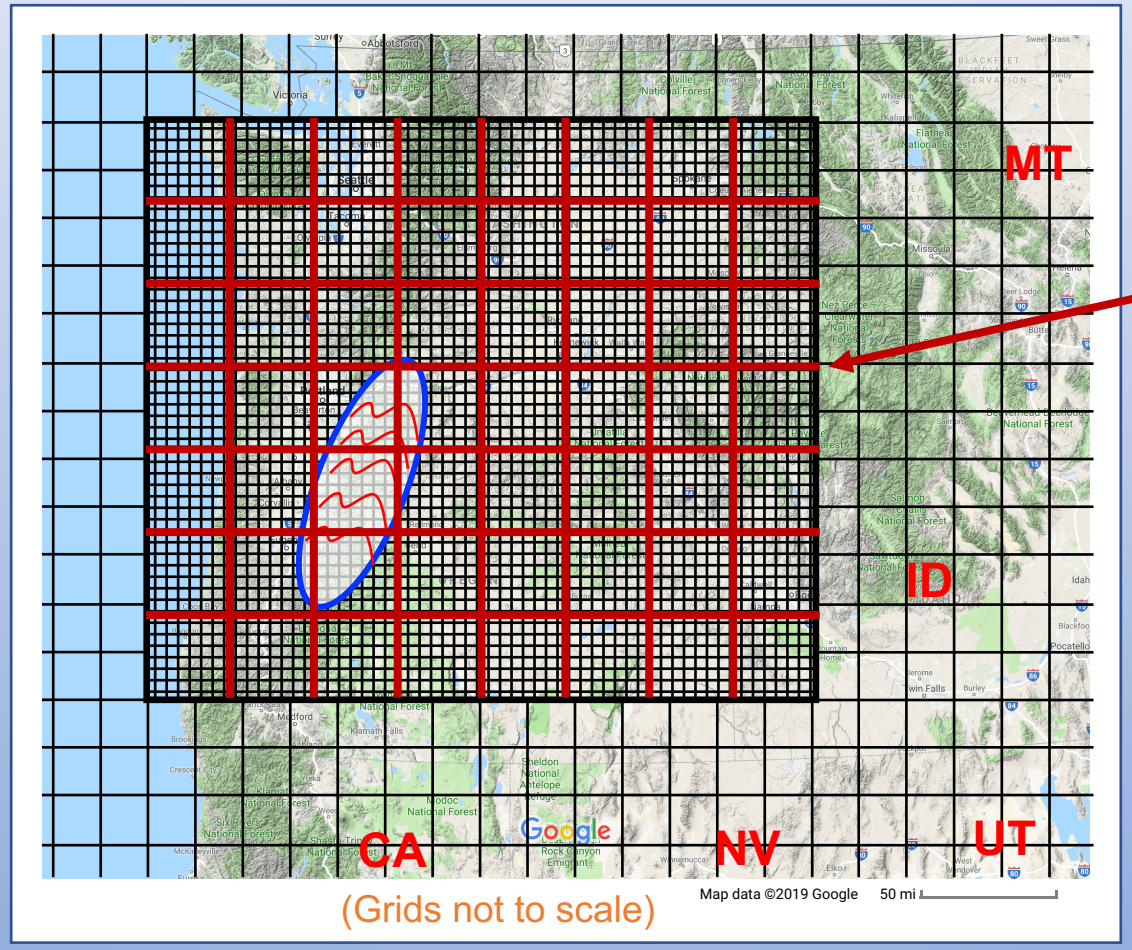



Average fine-grid variables

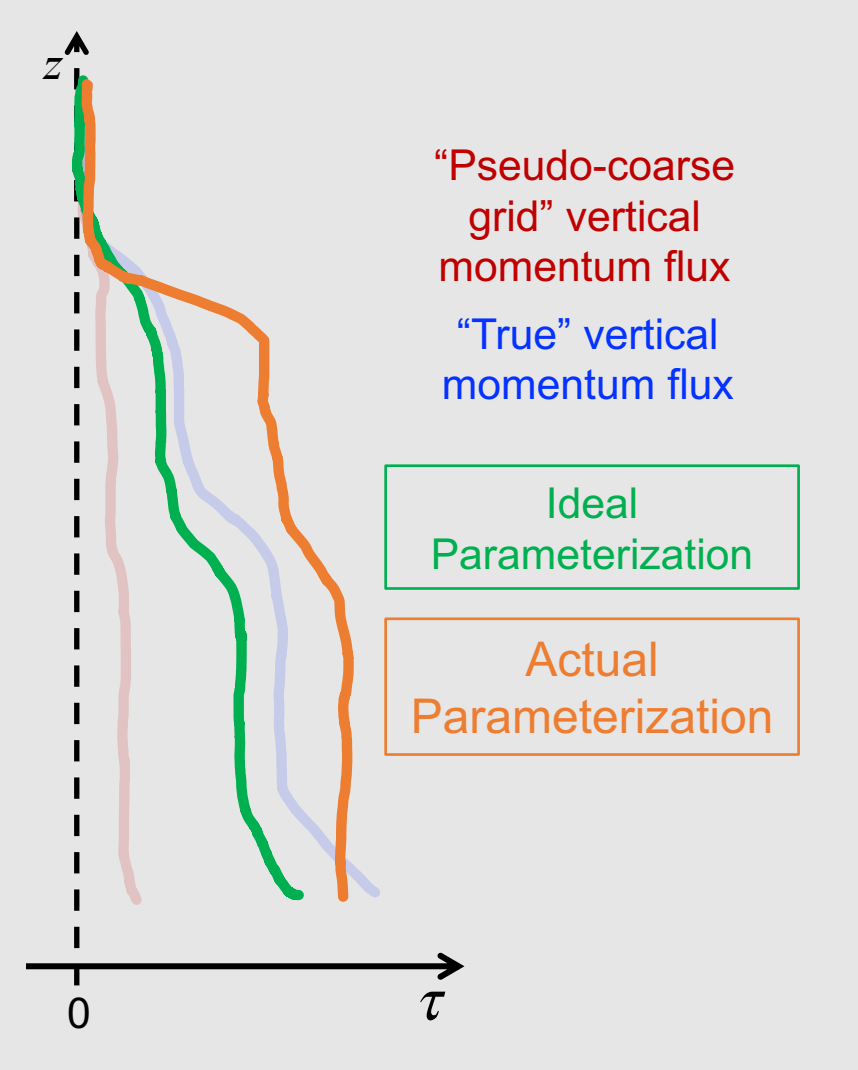
$$(\rho, \theta, u, v, w, \text{etc})$$

onto a coarse grid, giving a "pseudo-coarse grid" model result, and calculate resolved GW momentum flux

Define an "ideal parameterization" as the difference between "true" and "pseudo-coarse" momentum fluxes

# Method

Use high-resolution WRF reforecasts run during the Wind Forecast Improvement Project 2 (WFIP2)




Feed pseudo-coarse grid variables into the parameterization code -- module_bl_gwdo.F -- to get the parameterized momentum flux.

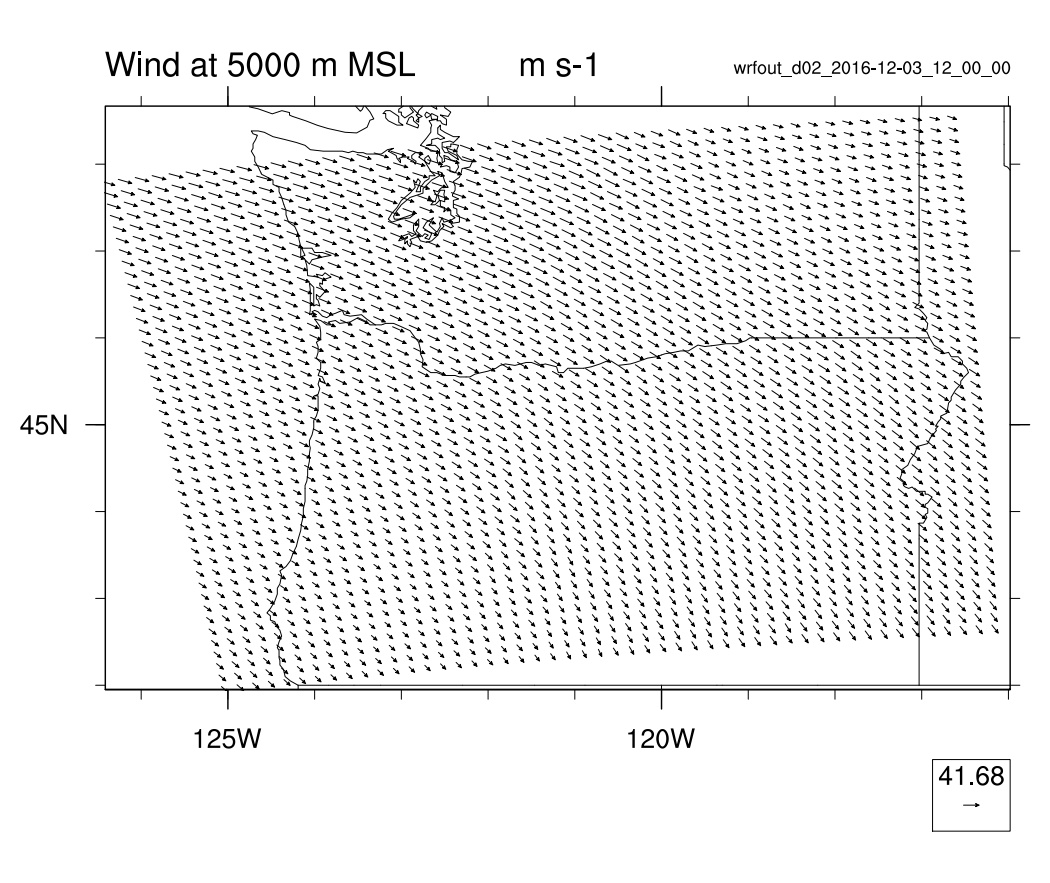
Note: This is facilitated by the NCL "WRAPIT" script feature, in which Fortran functions are called from NCL.

# Diagnosing momentum flux in the 750m resolution model

## Following the method of Kruse and Smith (JAS, 2015)

Example: Find $u'$ for calculation of $\tau_x = \bar{\rho}\overline{u'w'}$ at $z$ = 5km

2016 Dec 03 1200UTC (12hr reforecast)



# Diagnosing momentum flux in the 750m resolution model

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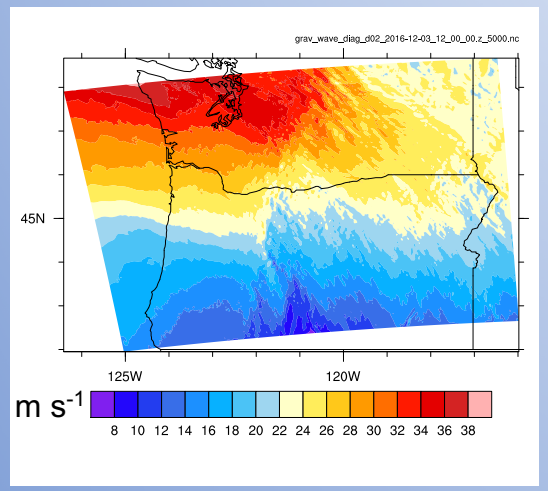
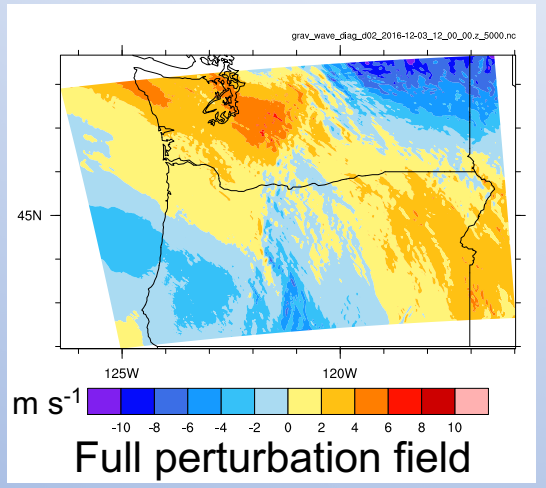
Example: Find $u'$ for calculation of $\tau_x = \overline{\rho u' w'}$ at $z$ = 5km

2016 Dec 03 1200UTC (12hr reforecast)

1) Zonal wind ($u$)

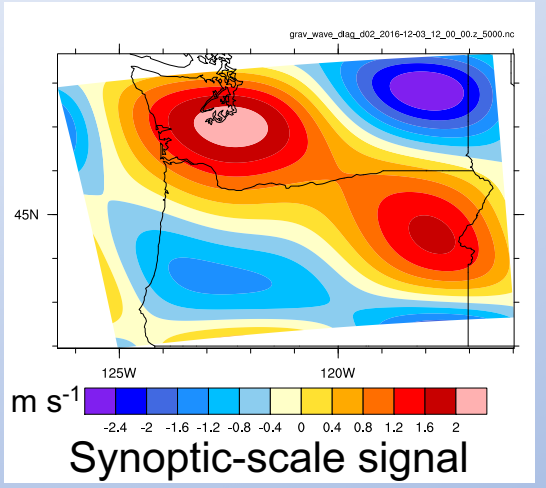



2) Deplaned $u$



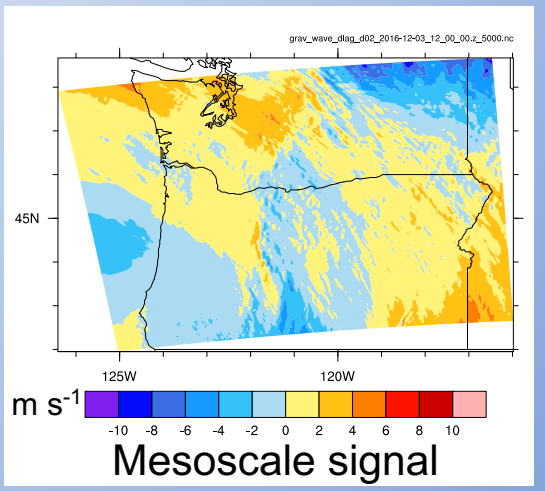

Full perturbation field

3) Low-pass filtered $u$




Synoptic-scale signal

4) High-pass filtered $u$ ($u'$)




Mesoscale signal

Subtract best-fit plane

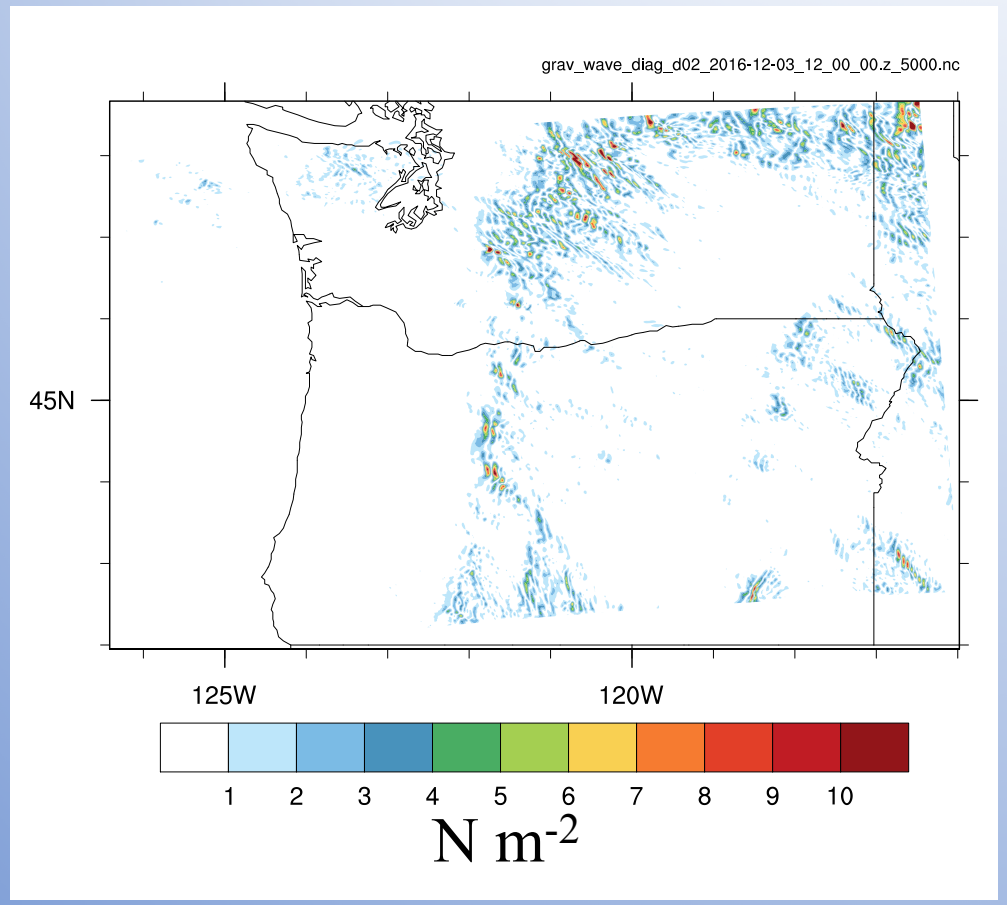
Low-pass filter (Cutoff length scale = 400km)

Subtract (3) from (2)

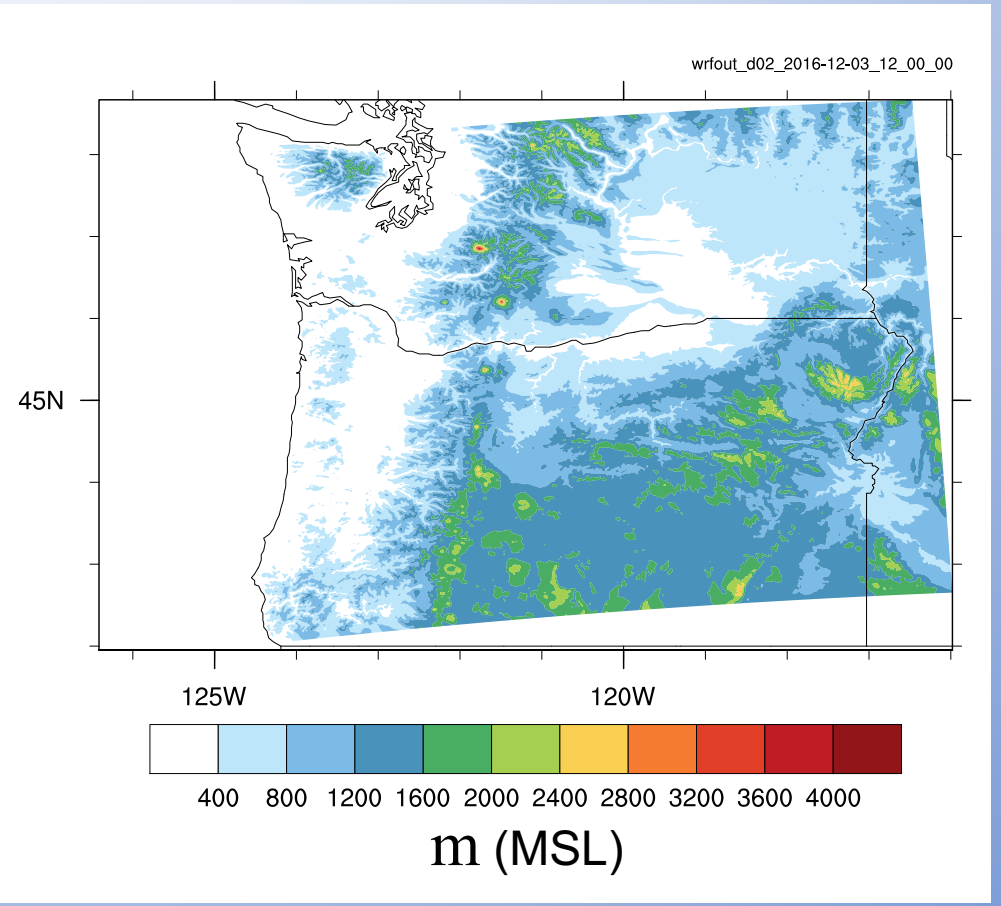
# Diagnosing momentum flux in the 750m resolution model

## Following the method of Kruse and Smith (JAS, 2015)

Diagnosed $\tau_x = \overline{\rho u' w'}$ at $z$ = 5km




Topography

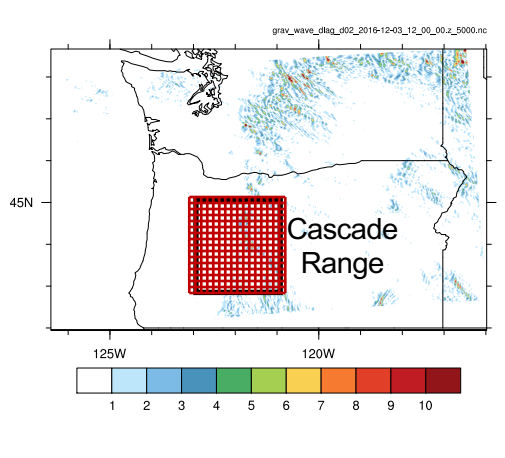


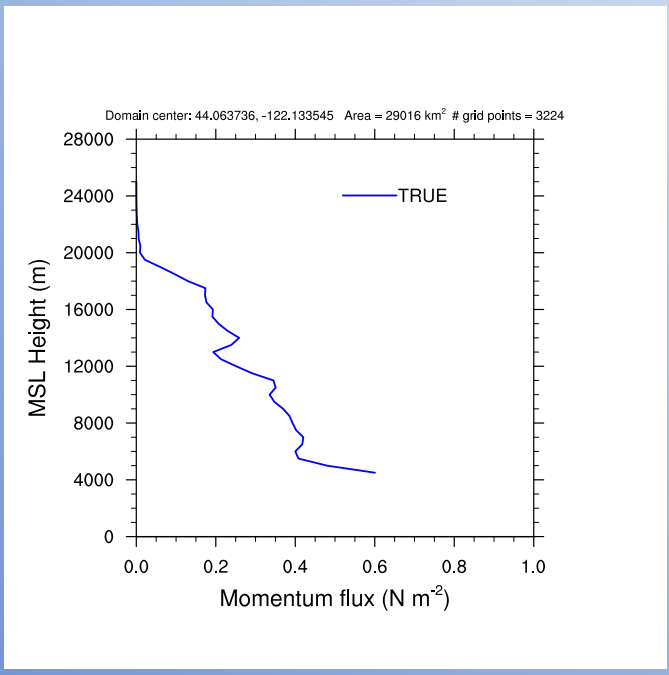

2016 Dec 03 1200UTC (12hr reforecast)

# Vertical momentum flux profiles

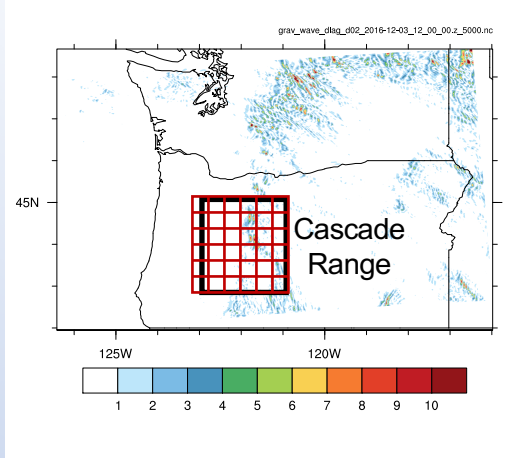
## Consider three pseudo-coarse grids

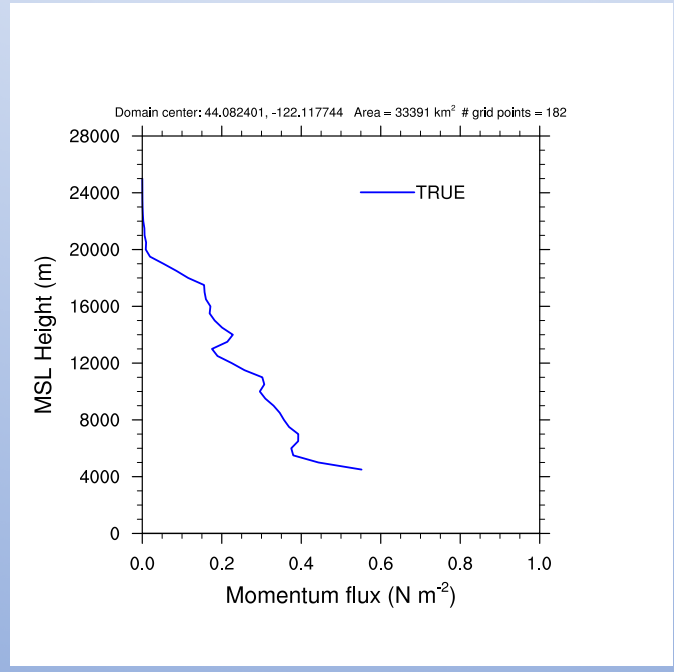
### 3km HRRR grid



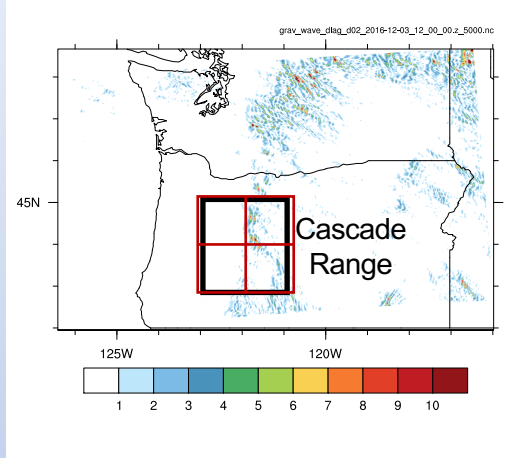



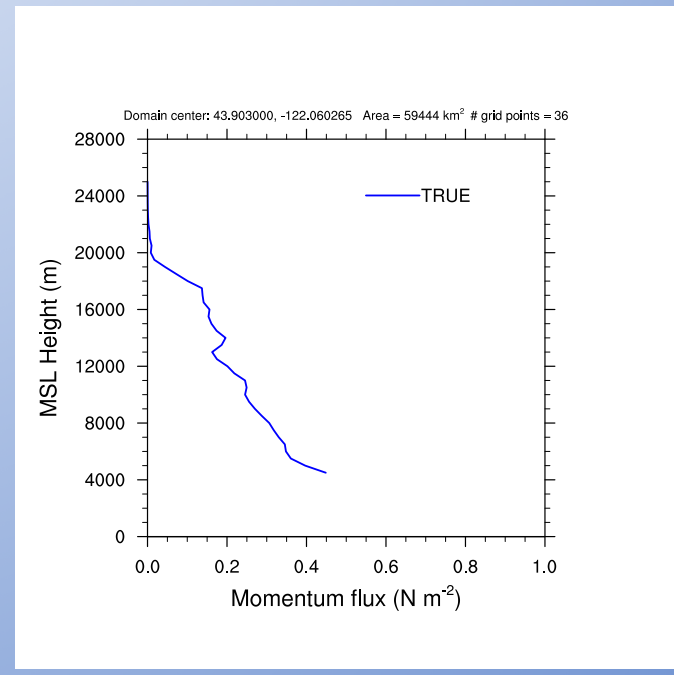

### 13km RAP grid



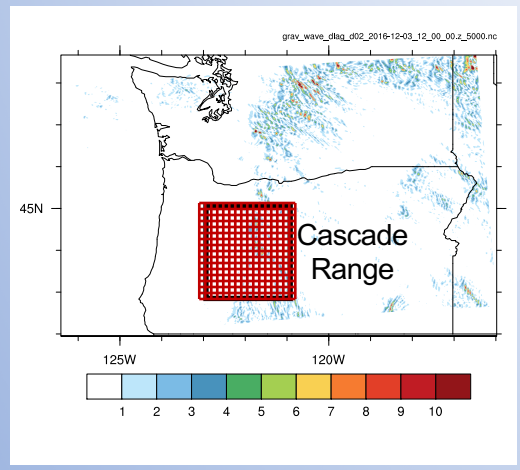

### 40km RAP-like grid



# Vertical momentum flux profiles

## 3km HRRR grid

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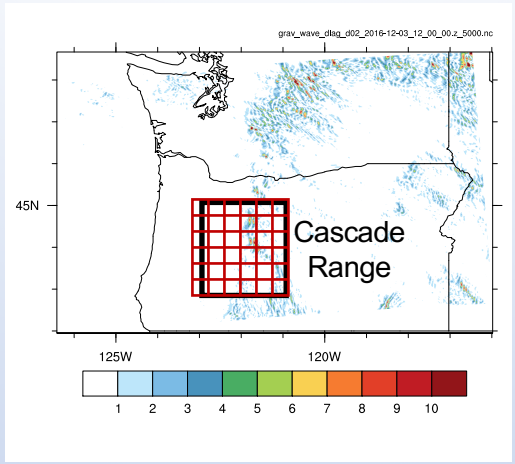
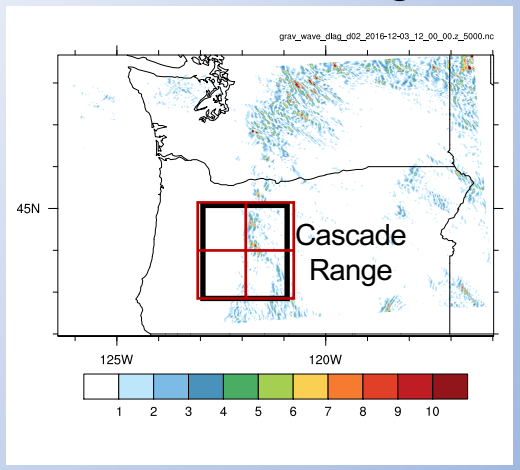
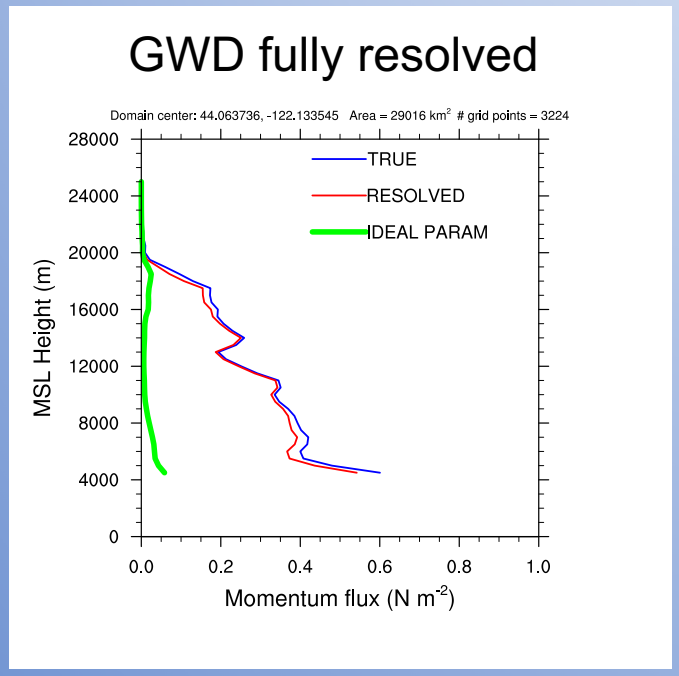


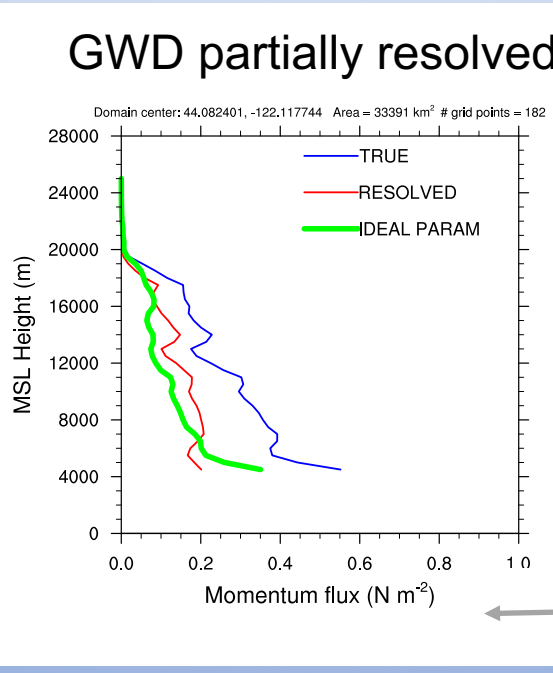

## 40km RAP-like grid



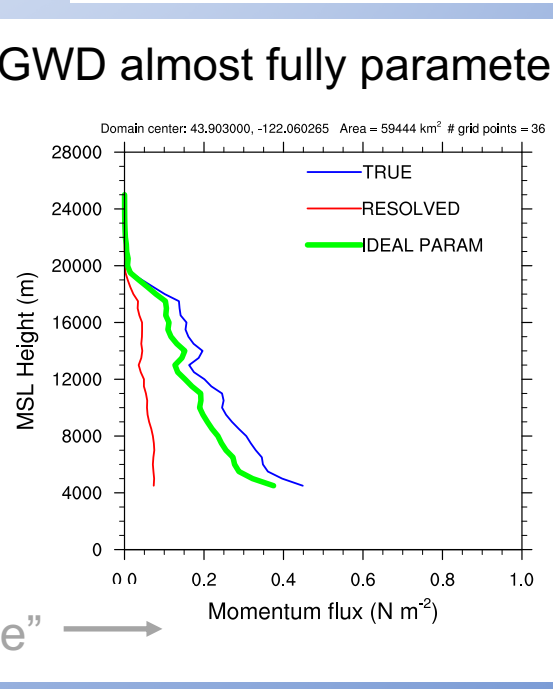

## GWD fully resolved




## GWD partially resolved



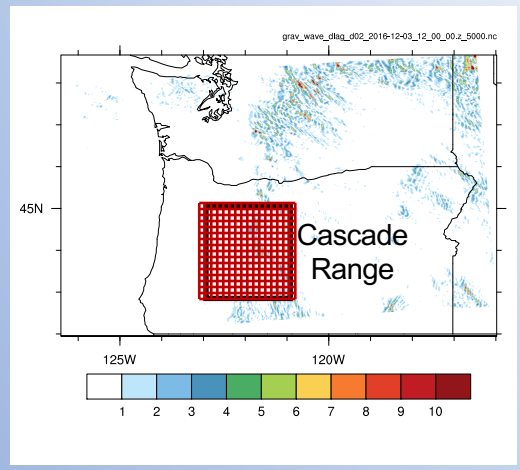

## GWD almost fully parameterized

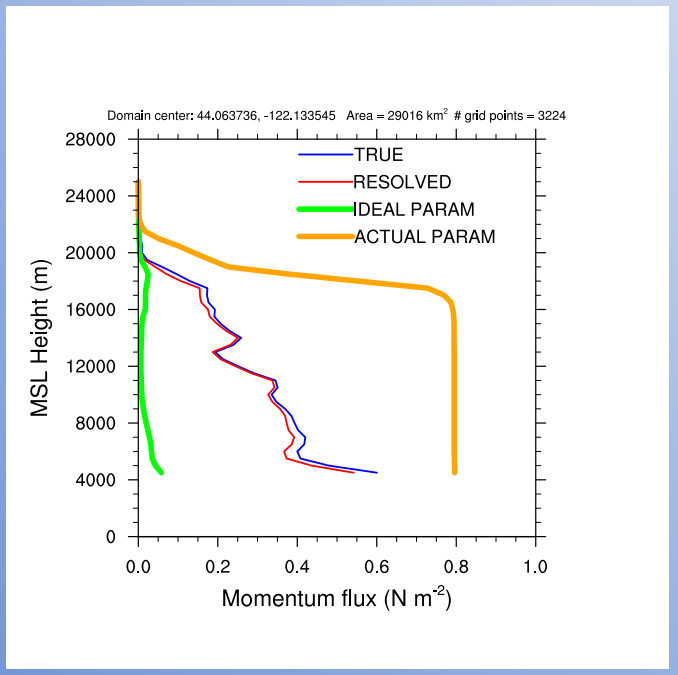



← “Gray zone” →

# Vertical momentum flux profiles

## 3km HRRR grid

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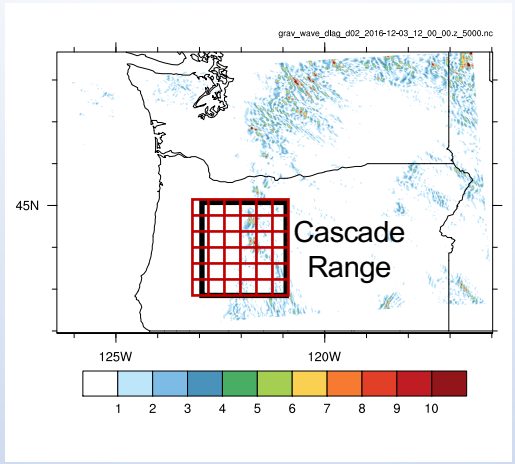


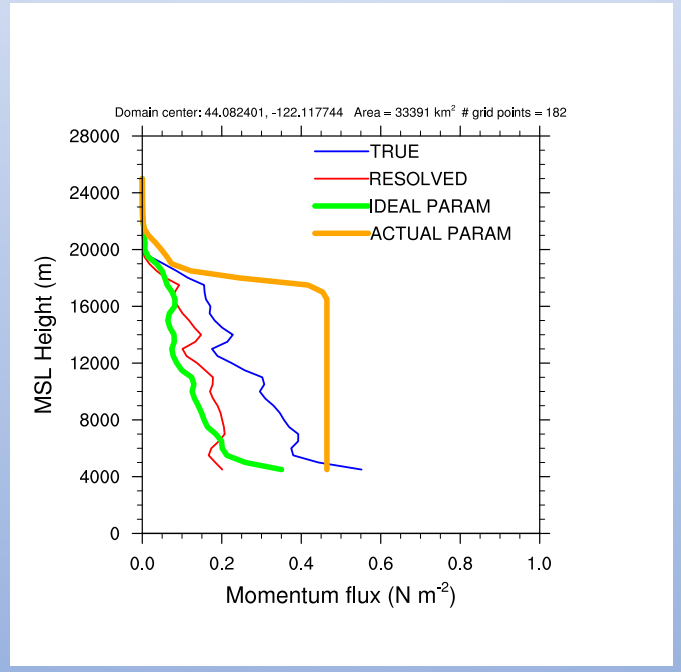


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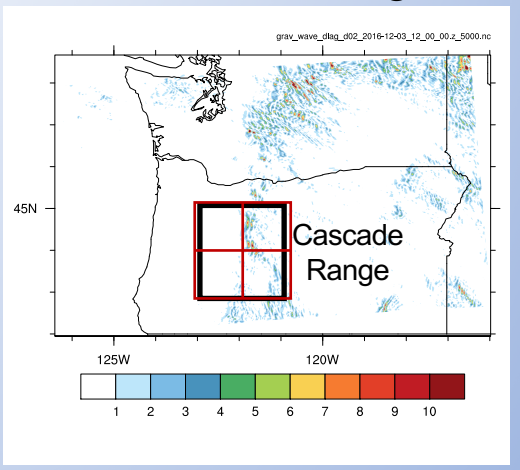
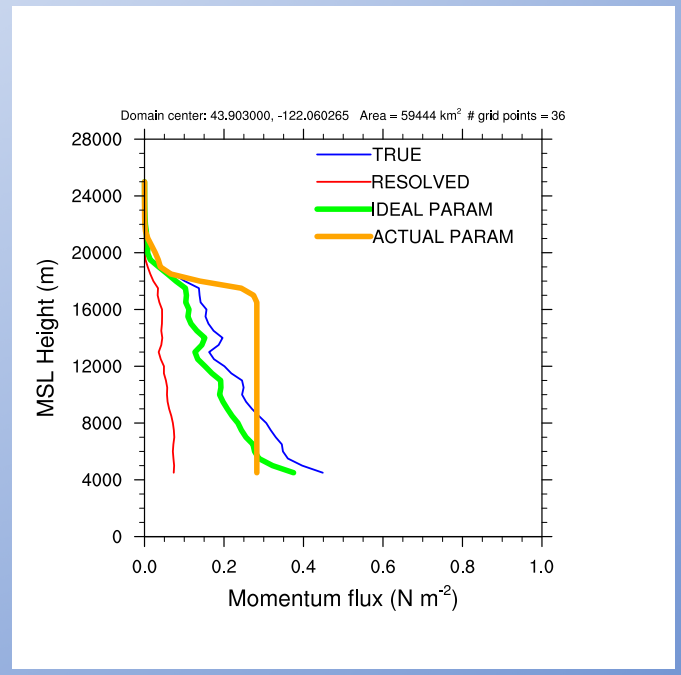


# Tuning coefficient: $\lambda_{\text{eff}}$ = effective grid length

(WRF code variable cleff)

Parameterized surface drag

$$\tau_{\text{GWD}} = \rho_0 E \frac{m}{\lambda_{\text{eff}}} G \frac{|U_0|^3}{N_0},$$

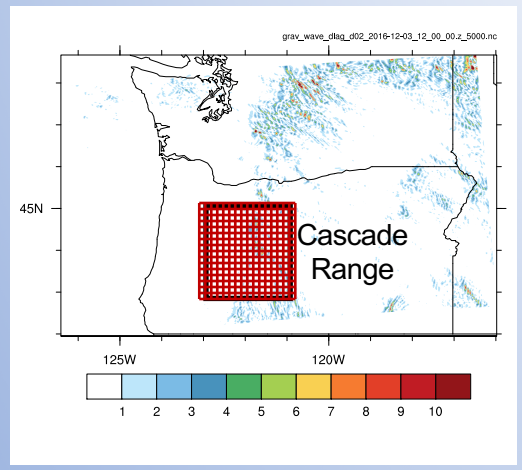
Kim and Doyle (2005)

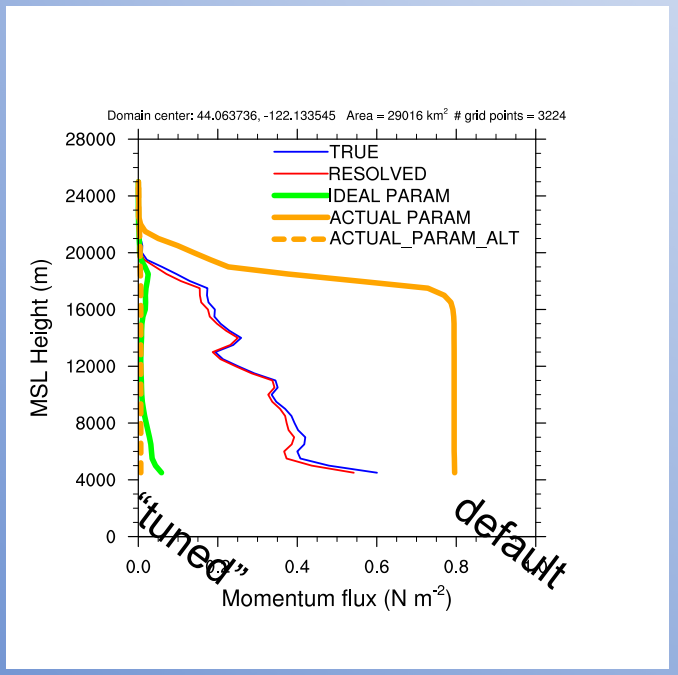
- Default value of cleff is the grid cell length ($\Delta$)
- Alternative "tuned" values of cleff used by NCEP in the GFS model (same GWD scheme) given by

$$\text{cleff} = \frac{2900}{\sqrt{\Delta}} \text{ km}$$

# Vertical momentum flux profiles

## 3km HRRR grid

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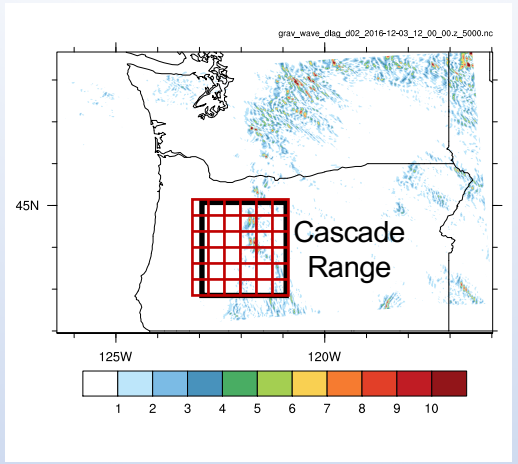


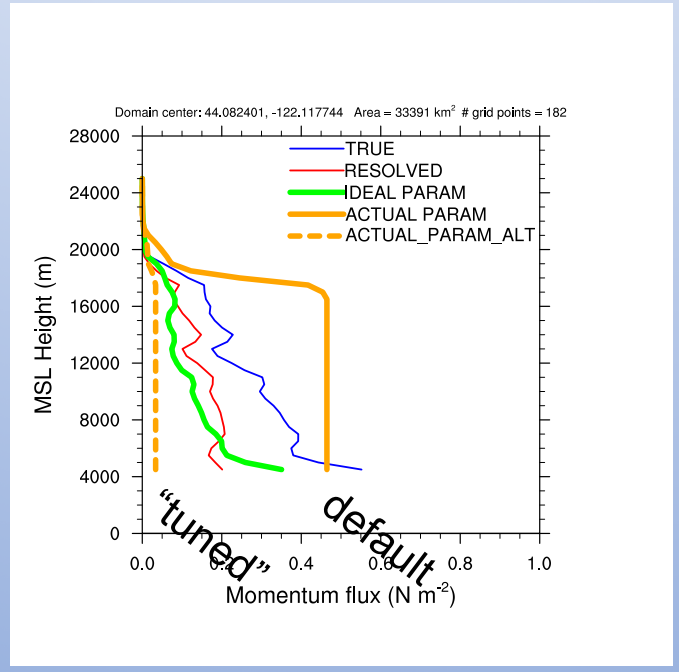


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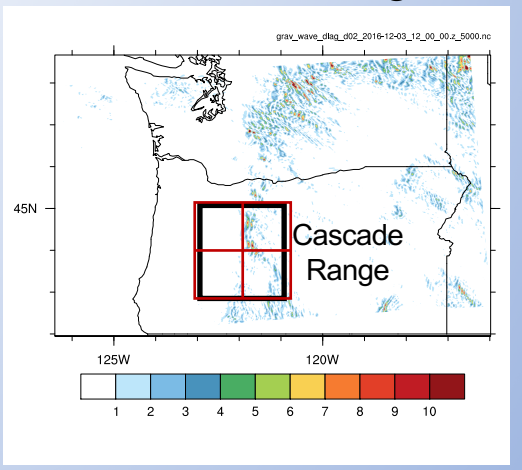
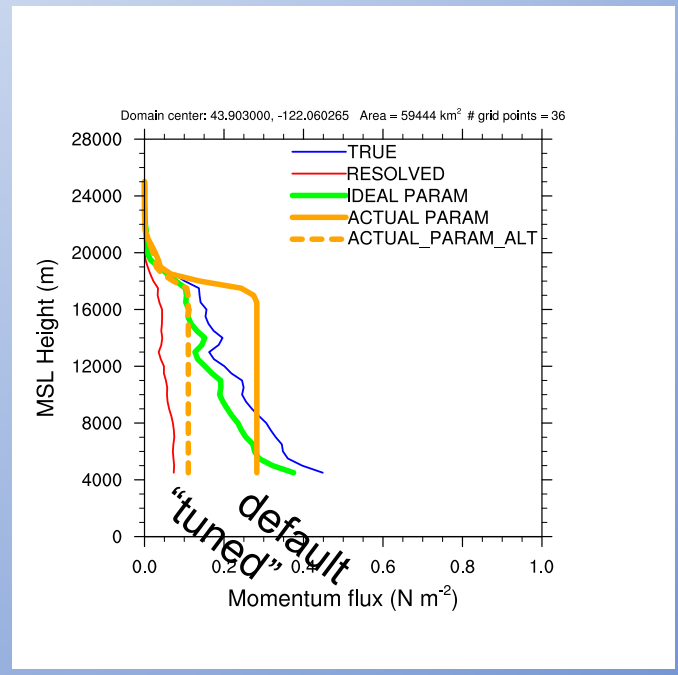
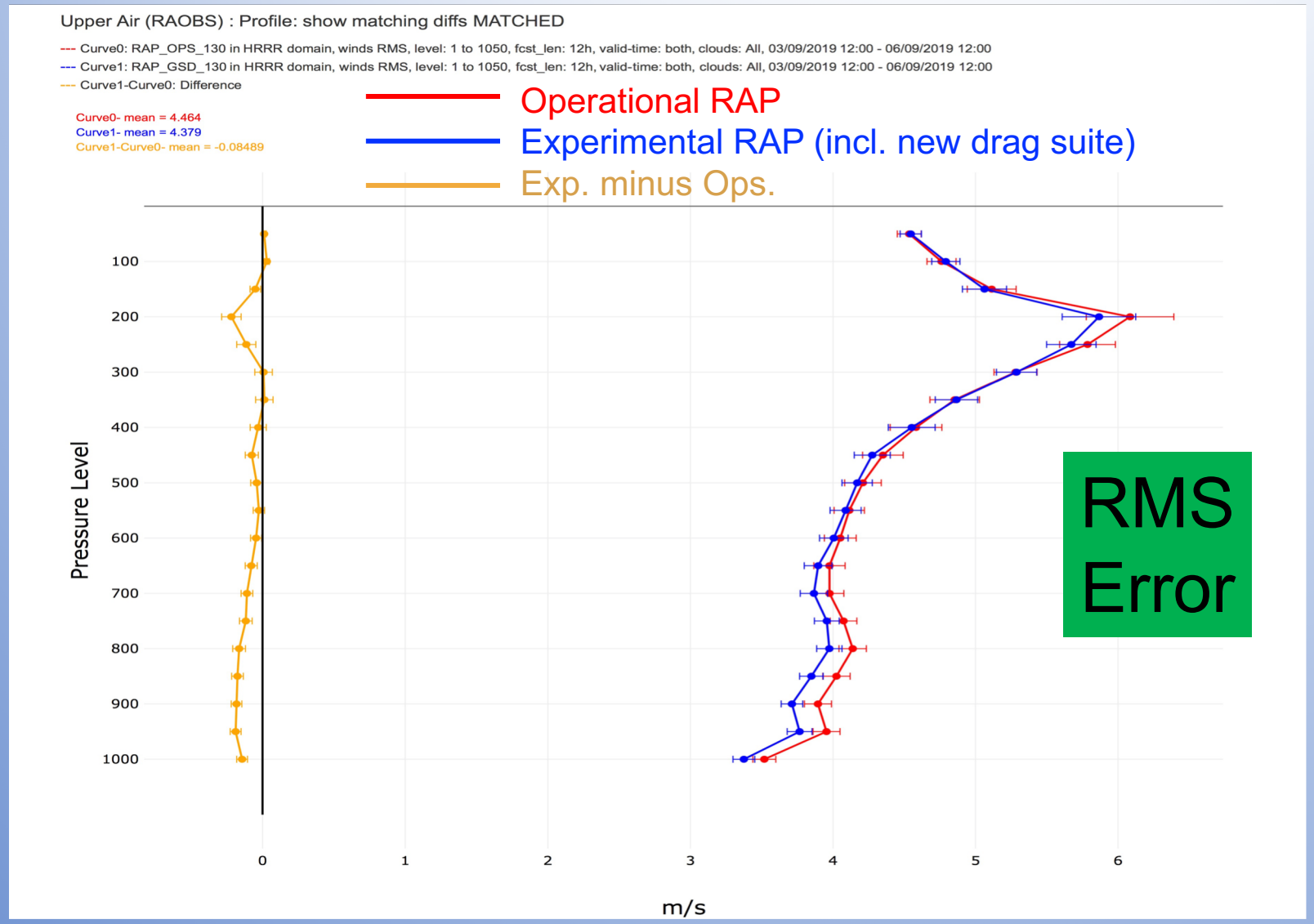


# Additional parameterizations implemented in the RAP/HRRR orographic drag suite

- Small-scale gravity wave drag scheme of Tsiringakis et al. (*J. Appl. Meteor.,* 2017)
  - Represents GWD drag in stable PBL
  - Grid cell lengths > 1km
- Turbulent orographic form drag scheme of Beljaars et al. (*Q. J. R. Meteorol. Soc.,* 2004)
  - Grid cell lengths > 1km

# Drag suite performance in the RAP
(13km grid)




Upper Air (RAOBS)
Wind Speed Verification

- HRRR CONUS Domain
- 12-hour forecast
- 2019 Mar 9 – Jun 9

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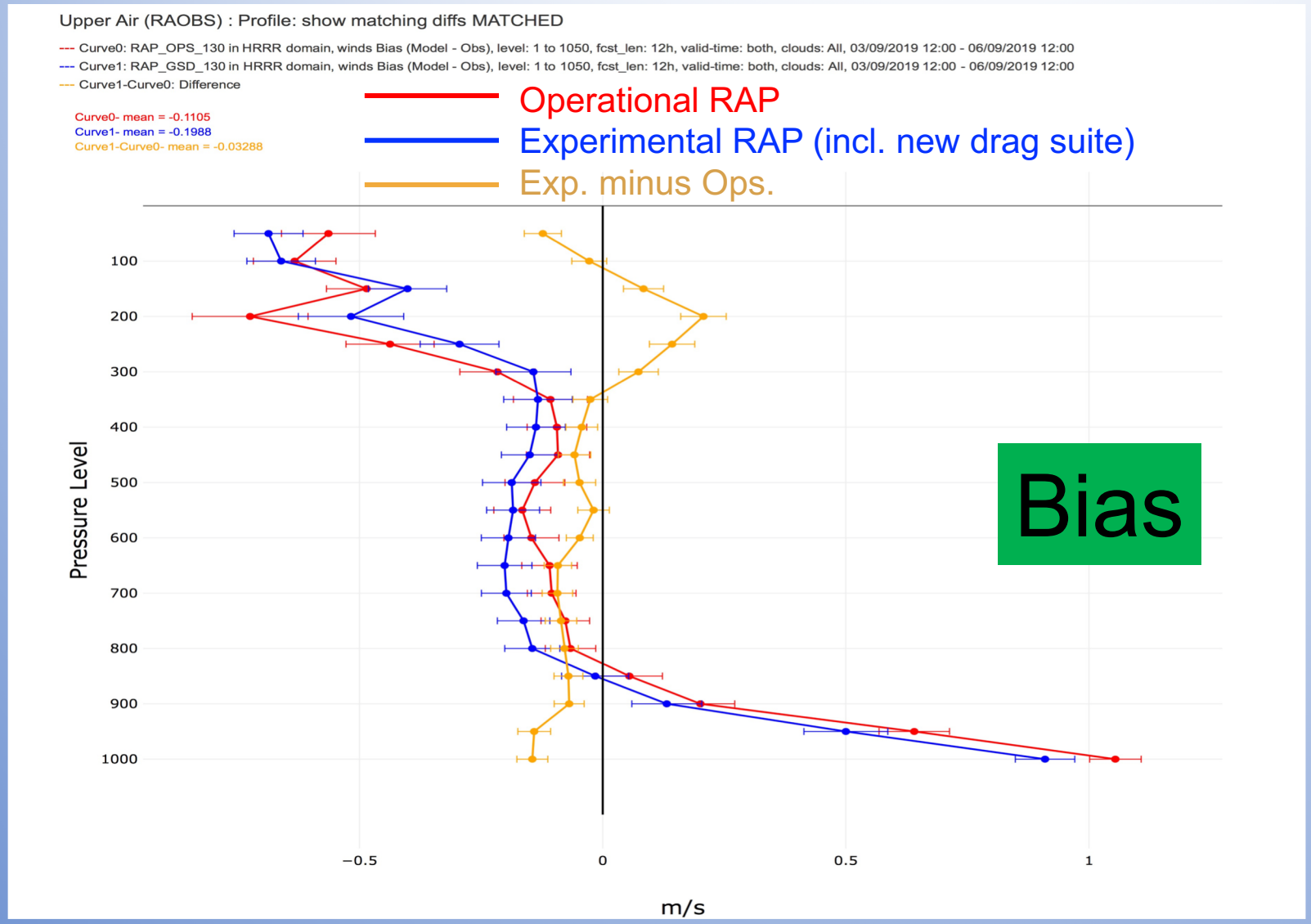
(13km grid)

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# Summary

- The WRF orographic subgrid-scale GWD parameterization provides vertical momentum fluxes that are reasonably close to those diagnosed from high-resolution simulations
- The study helped to verify previously determined tuning settings of the scheme
- GWD is fully resolved at ≤3km in the case study shown, so the parameterization is not needed at these grid resolutions
- The gray zone resolutions appear to be in the range ~ 5 - 40km
- The scheme is active in the next implementation of the 13km RAP for operational NWP as part of a new orographic drag suite developed at NOAA/GSD

# The future of orographic drag parameterizations

- You may have noticed that the parameterized GWD momentum fluxes could be improved
  - Non-linearity?
  - Transients?
  - Horizontal gravity-wave propagation from neighboring grid cells?
  - Proper representation of subgrid topography?
- There is renewed community interest in improving GWD parameterizations, e.g.,
  - GASS/WGNE *Surface Drag and Momentum Transport* project: http://www.gewex.org/panels/global-atmosheric-system-studies-panel/gass-projects
  - International Space Science Institute (ISSI), *New Quantitative Constraints on Orographic Gravity Wave Stress and Drag: http://www.issibern.ch/teams/consonorogravity*


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