# Attenuation Characteristics within a Mountain Wave "Valve Layer" and Quantification of Gravity Wave Drag

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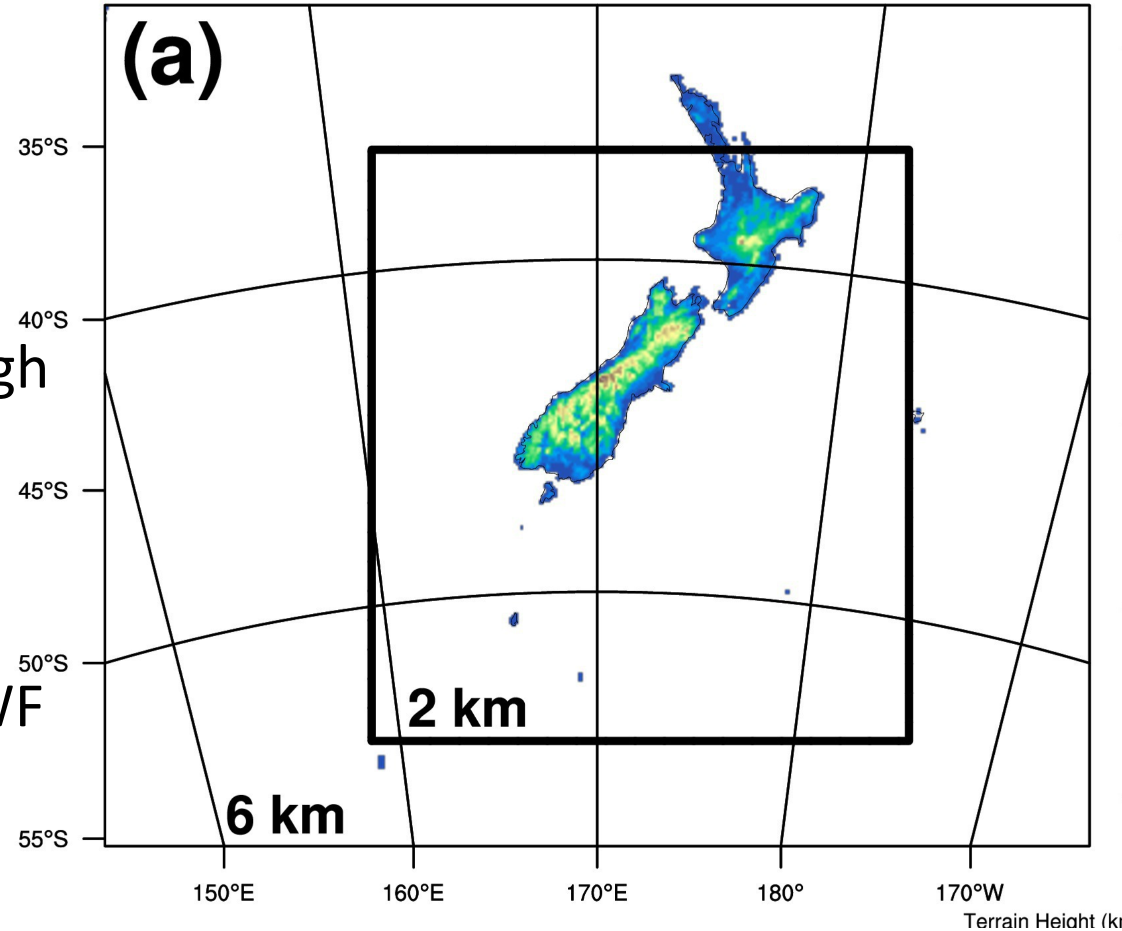
Supported by DEEPWAVE
NSF-AGS-1338655

# WRF Setup

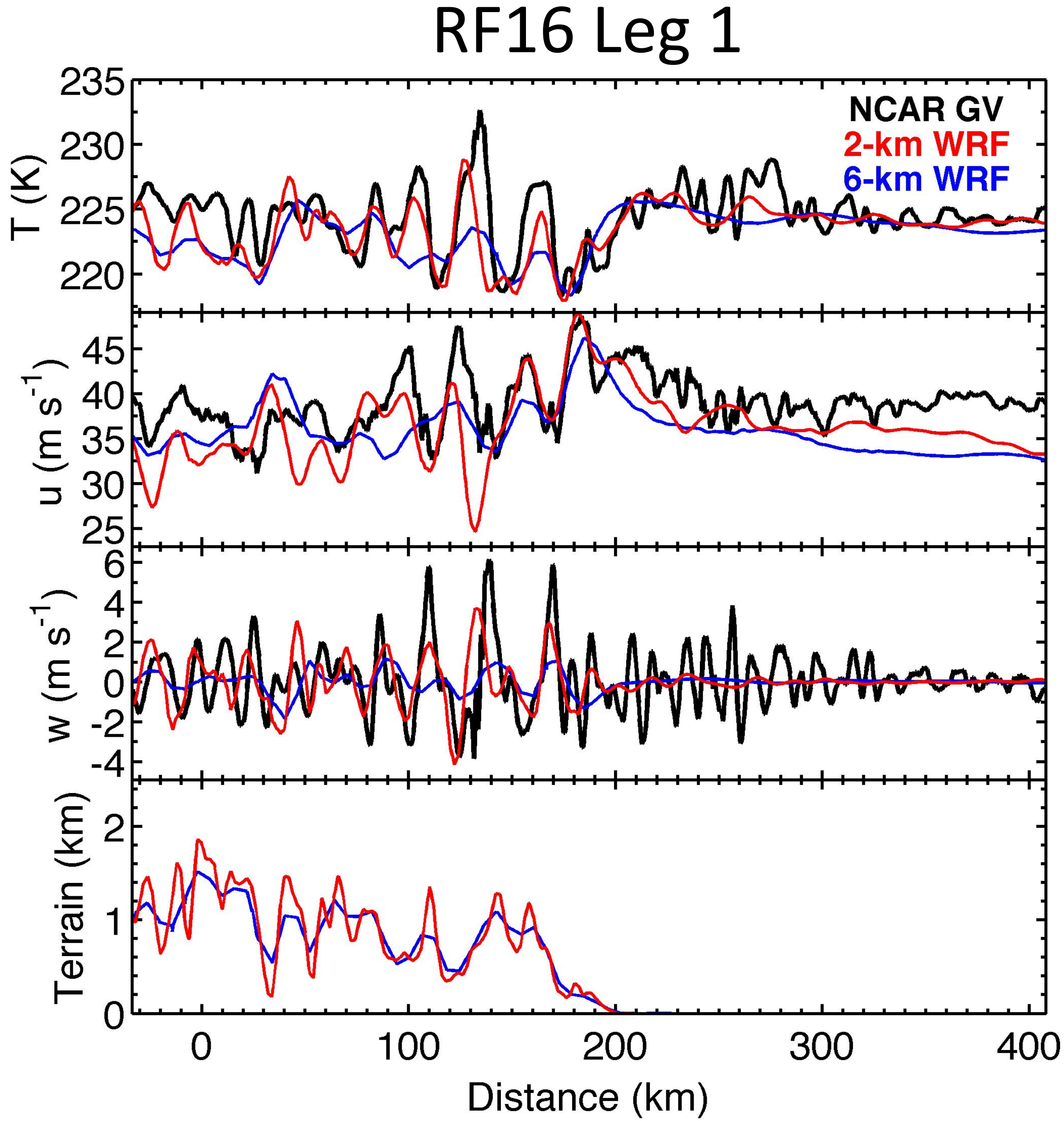
- The "Long Run"
  - 6km resolution
  - Initialized 24 May 2014
  - Run continuously through 1 Aug 2014 (DEEPWAVE period)
  - Top @ 100Pa, ~45 km
  - Forced by ~16km ECMWF
  - Δz = ~50 m – 600 m




Please ignore the 2km nest!

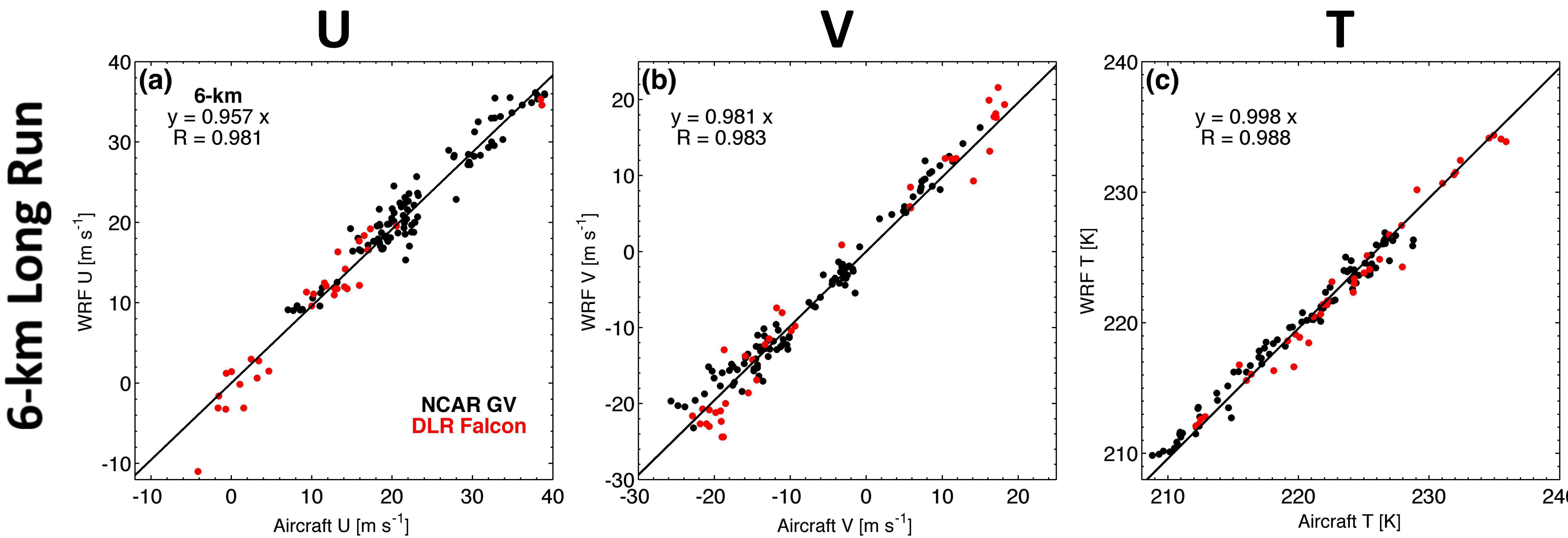
# Flights Through Simulated and Actual Atmospheres

- WRF 4-D linearly interpolated to flights
- Strongest $EF_z$ and $MF_x$ observed on this leg
- **One of the better comparisons!**



# Ambient Atmosphere Validation: Aircraft

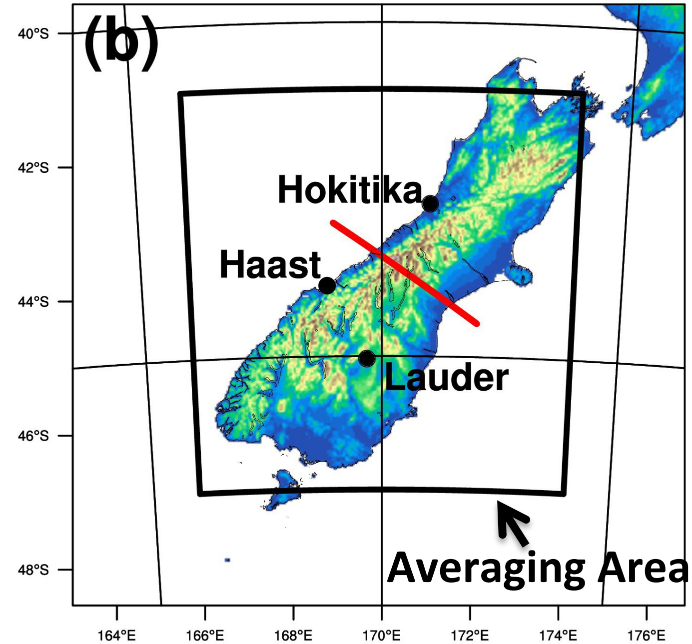
- Leg Mean Quantities
- WRF vs Aircraft
- Very good validation @ z = 12.1 km

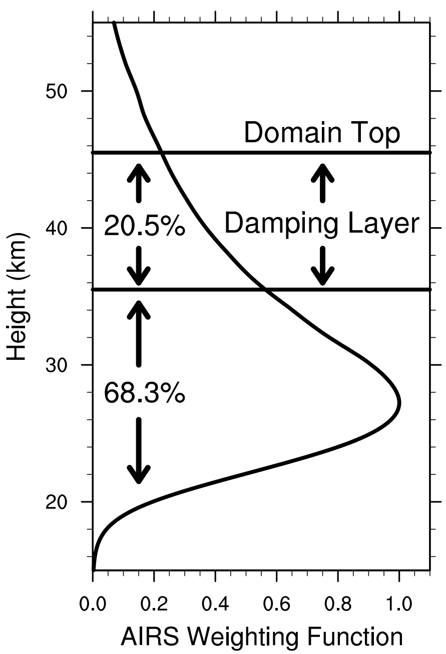


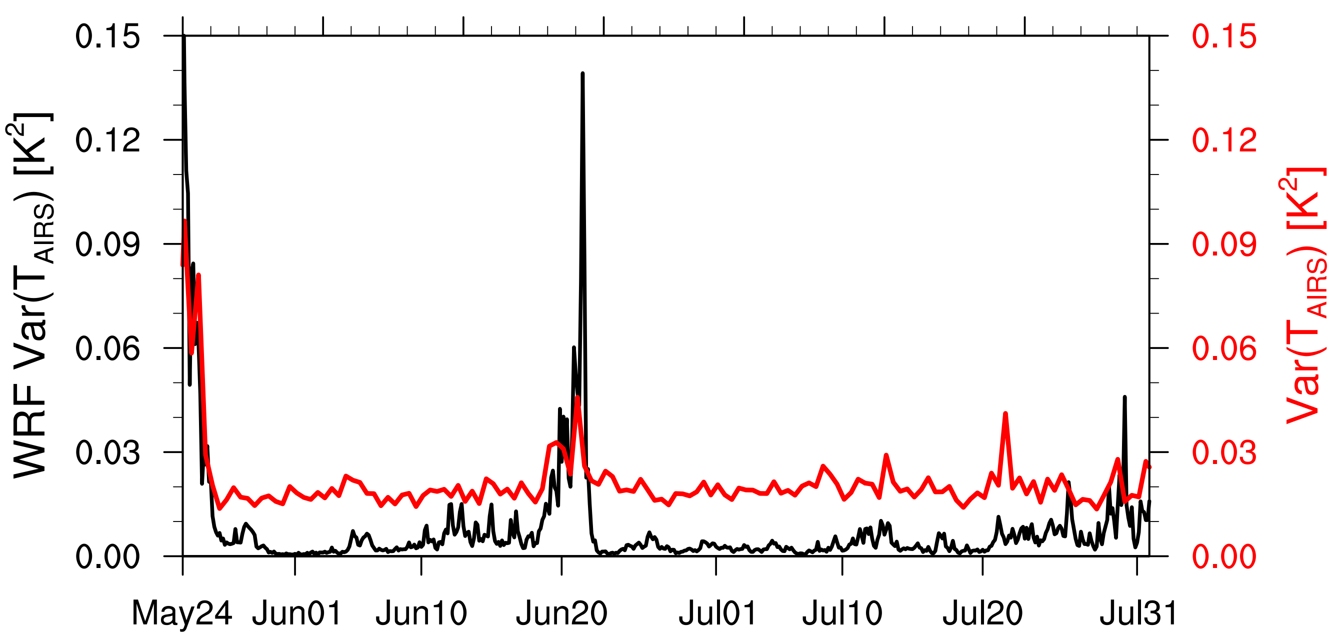

| | | |
|---|---|---|
| Mean Error = -0.80<br>Mean Absolute Error = 1.81 | ME = 0.60<br>MAE = 1.73 | ME = -0.44<br>MAE = 0.77 |

# AIRS Validation (Courtesy of Steve Eckermann)

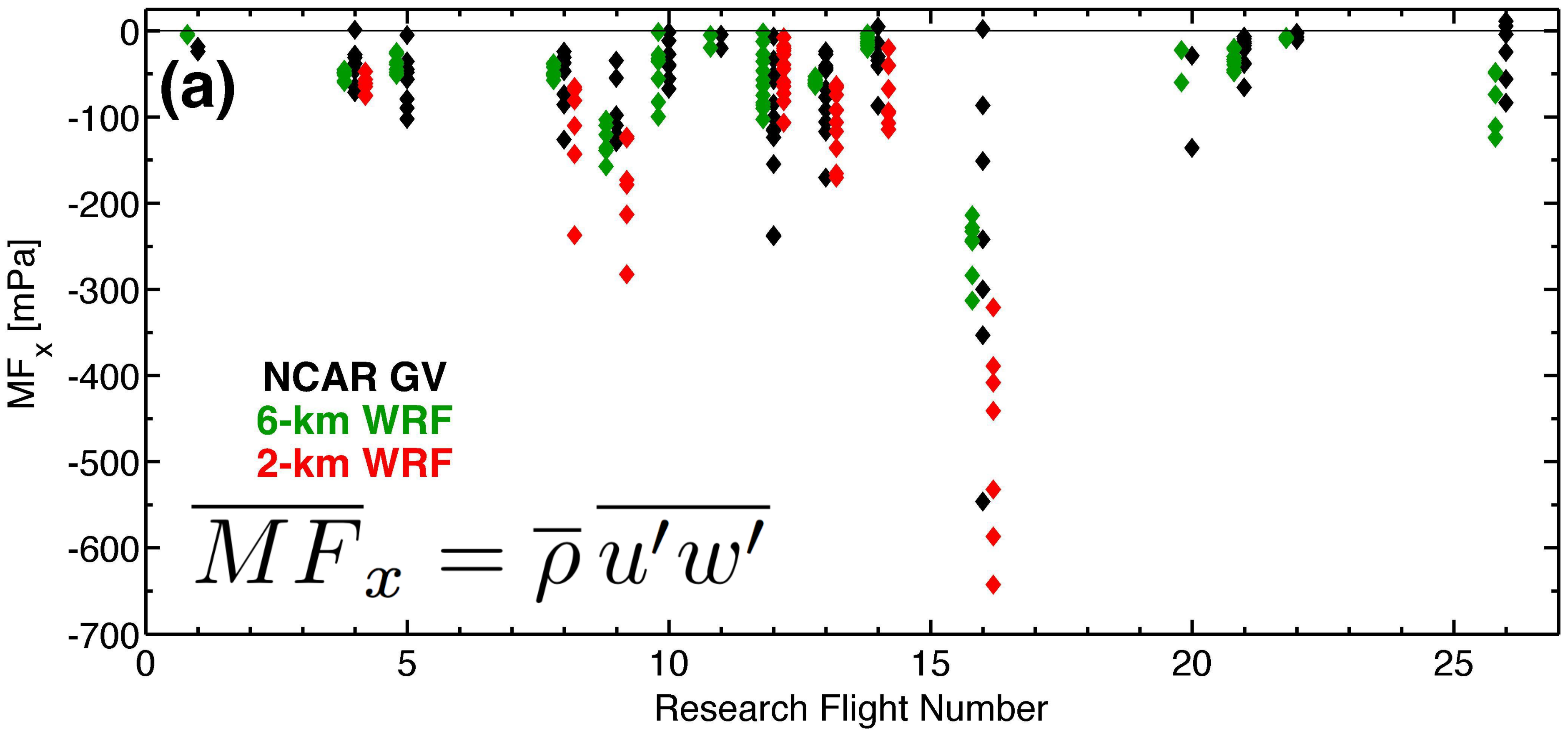
- Applied AIRS weighting functions to 3-D WRF fields to produce 2-D forward modeled AIRS temperatures within WRF
- Computed temperature variance over the box at right
- 20 mb, λ = 14.9381 μm, channel



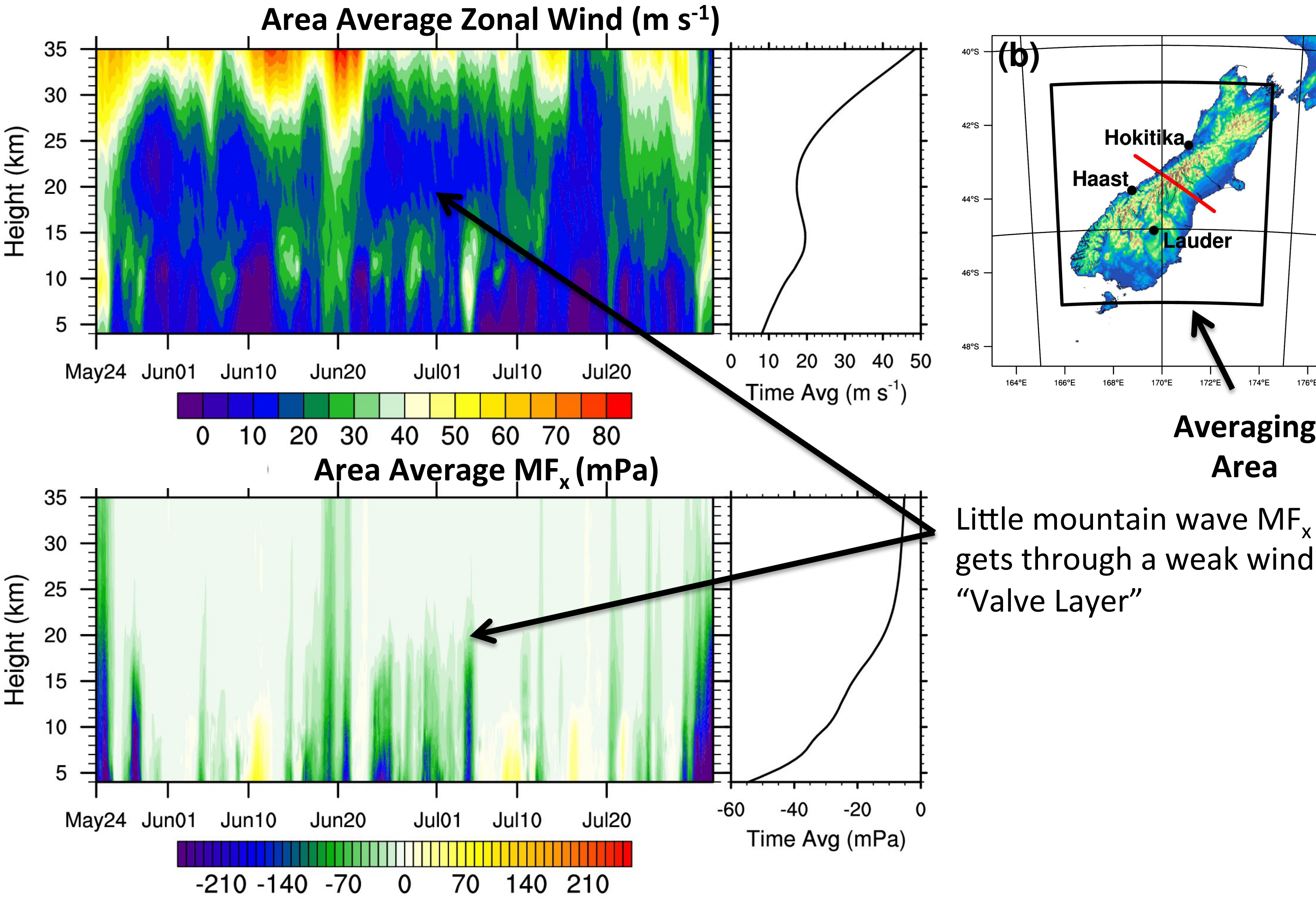



# Momentum Flux Validation



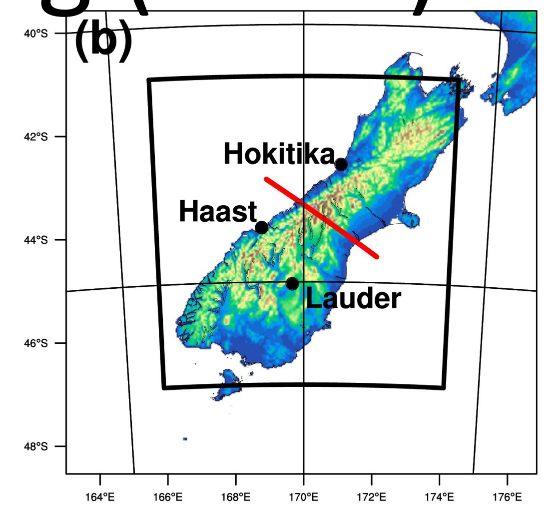

- Leg/Distance Averaged Quantities
- Long Run doesn't reproduce $MF_x$ variability, **but reproduces event averages**
- Long Run Mean Error = +3.838 mPa, +5.56%

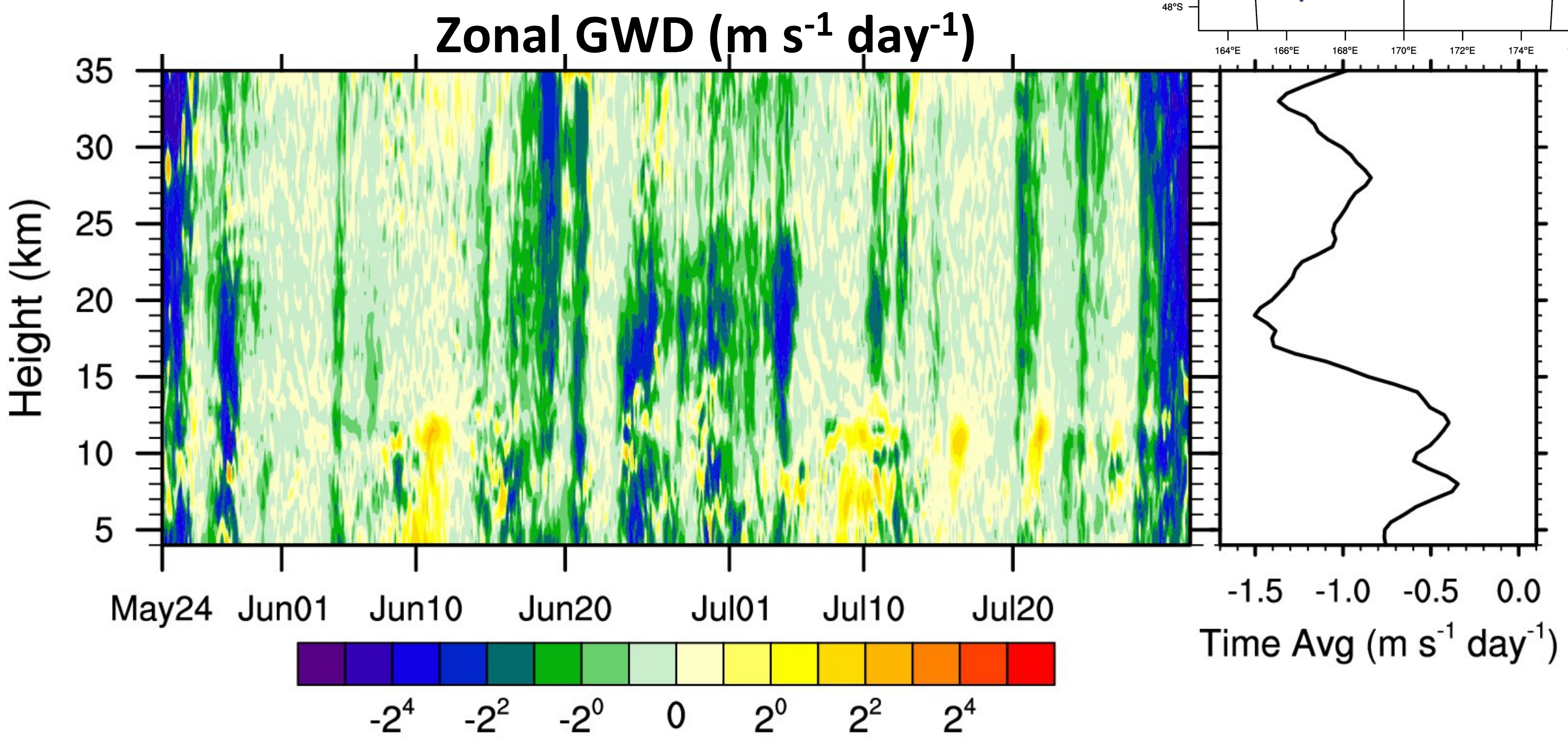
# Mountain Wave Propagation over NZ



# Long Run Gravity Wave Drag (GWD)

$$GWD_x = -\frac{1}{\bar{\rho}} \frac{\Delta \overline{MF}_x}{\Delta z}$$



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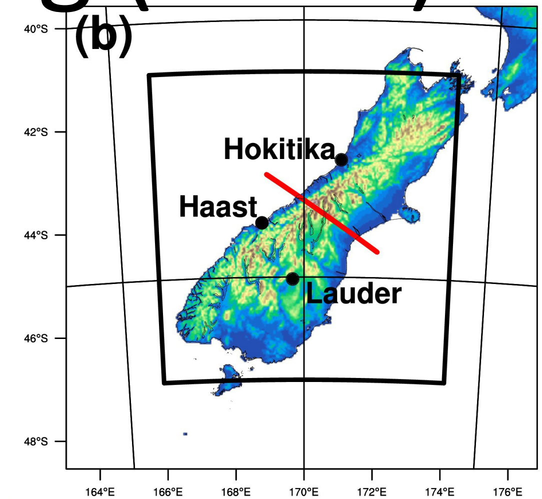
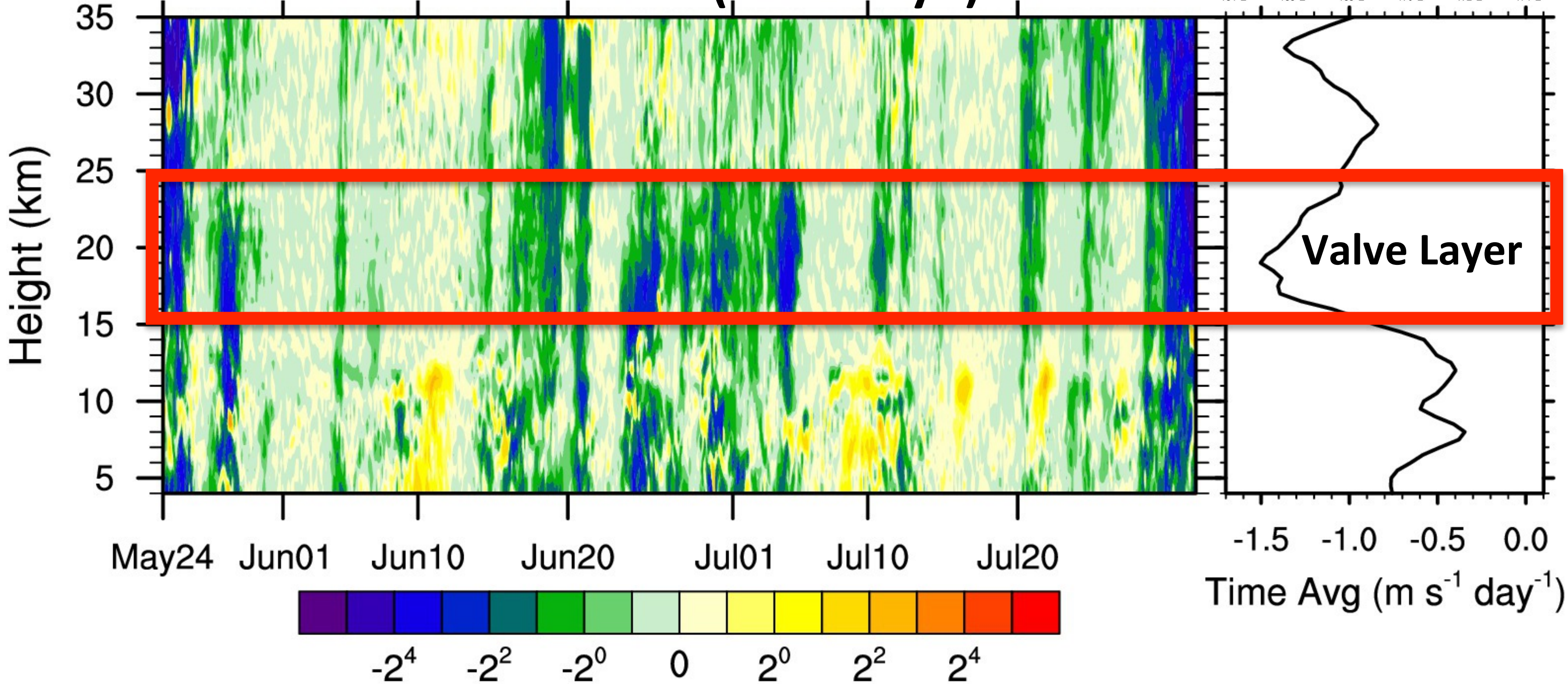
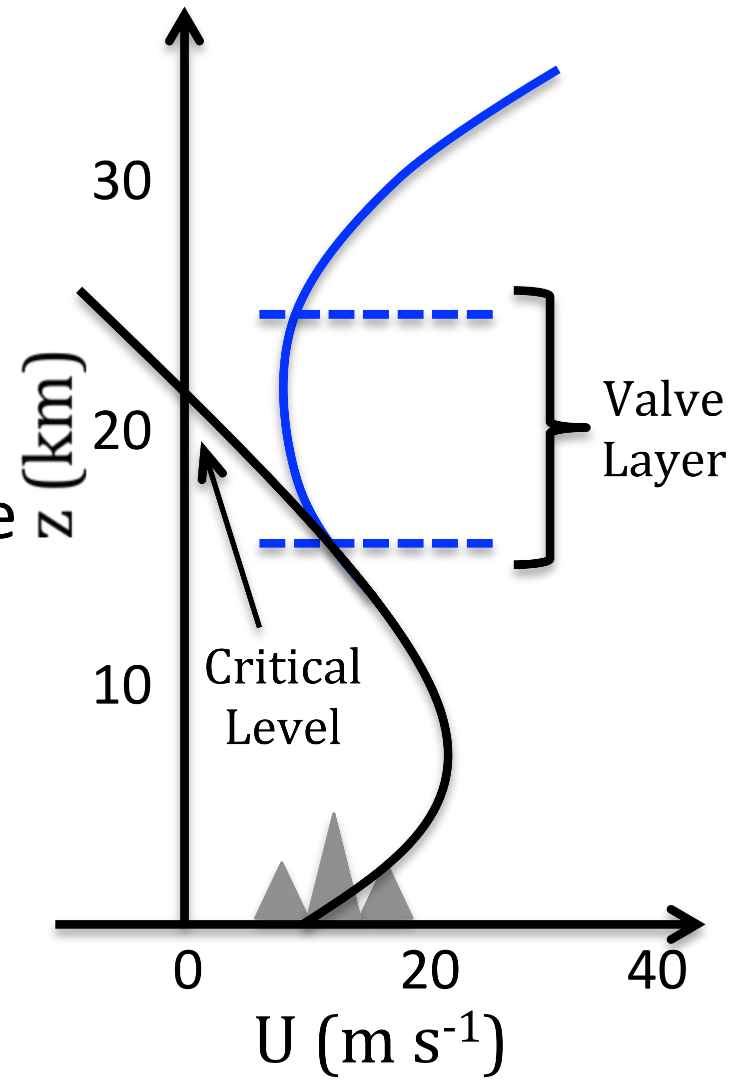


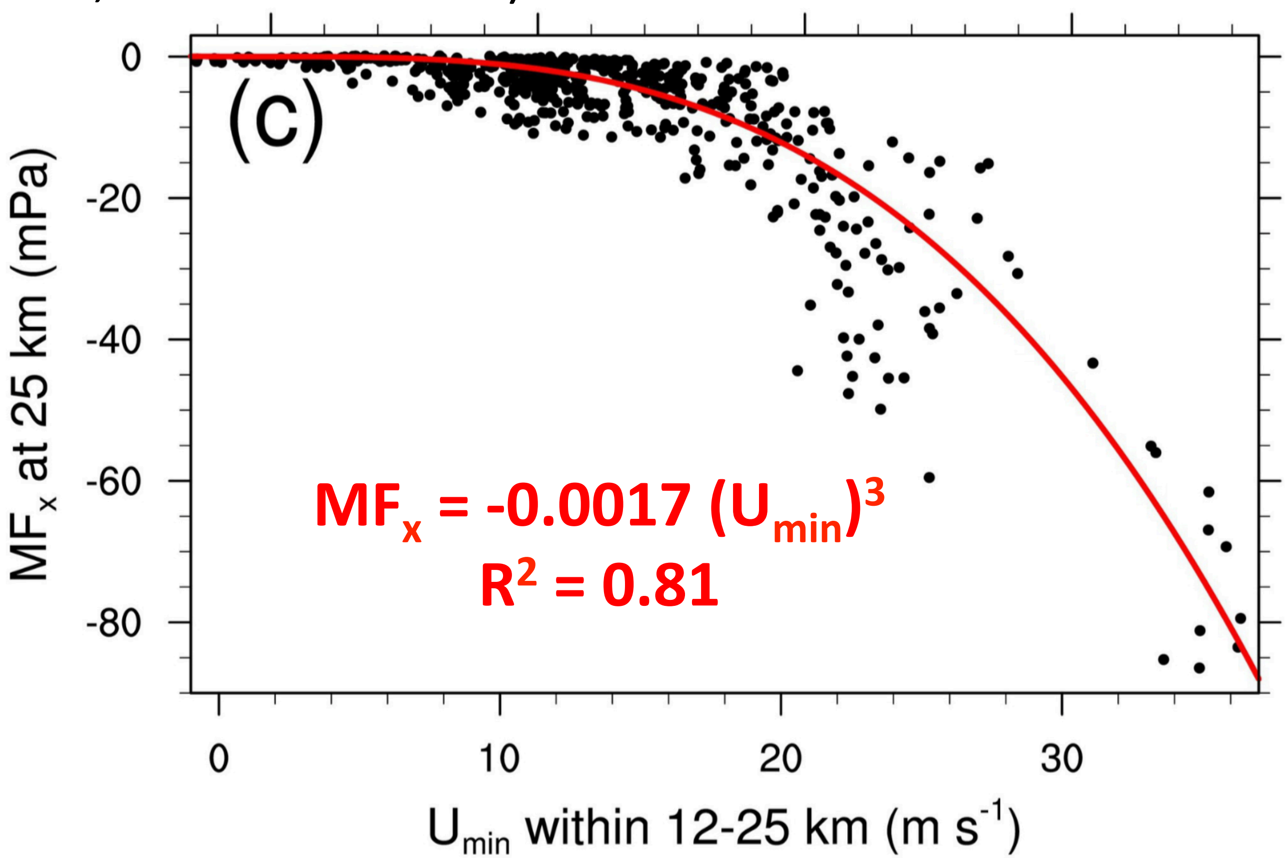
# Valve Layer Definition

- Valve Layer: layer with weak winds, but no critical level
  - Waves sometimes transmitted, sometimes attenuated, depending on incident amplitude and layer conditions (primarily wind speed)
  - Typical during DEEPWAVE!!



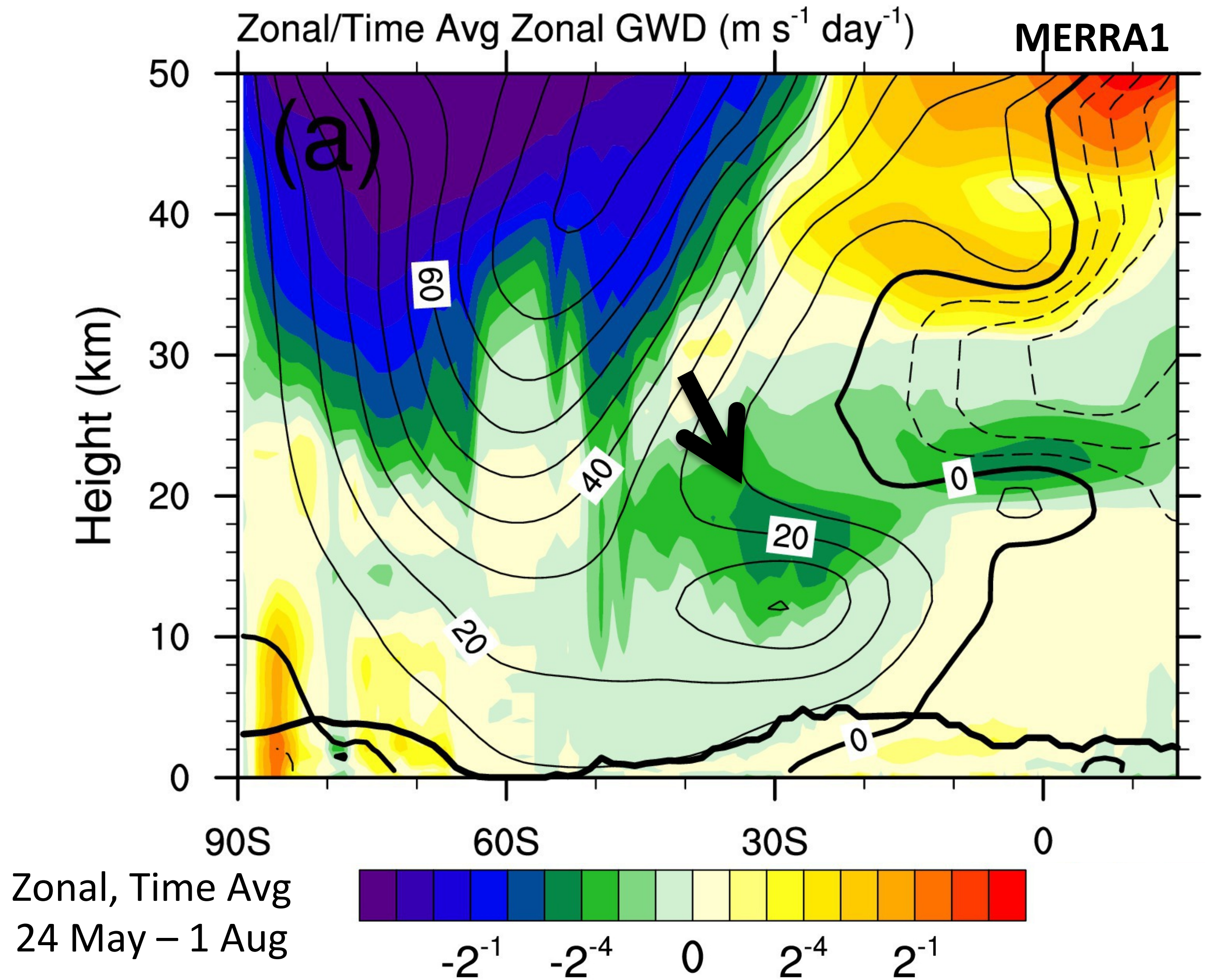
# What Controls $MF_x$ Transmission?

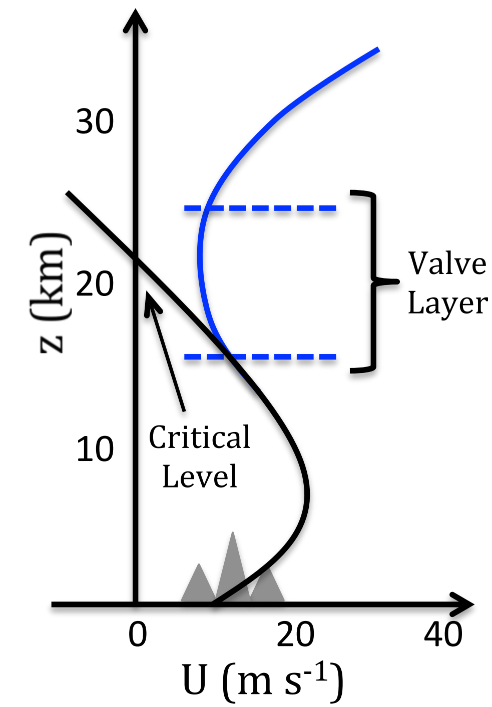
- Minimum wind speed
- Nearly a **cubic** relation between transmitted $MF_x$ and minimum wind speed
  - Cubic relation consistent with parameterization predictions (e.g. Palmer et al. 1986, McFarlane 1987)



# Global Context

- The valve layer is a climatological feature in the wintertime mid-latitude lower stratosphere

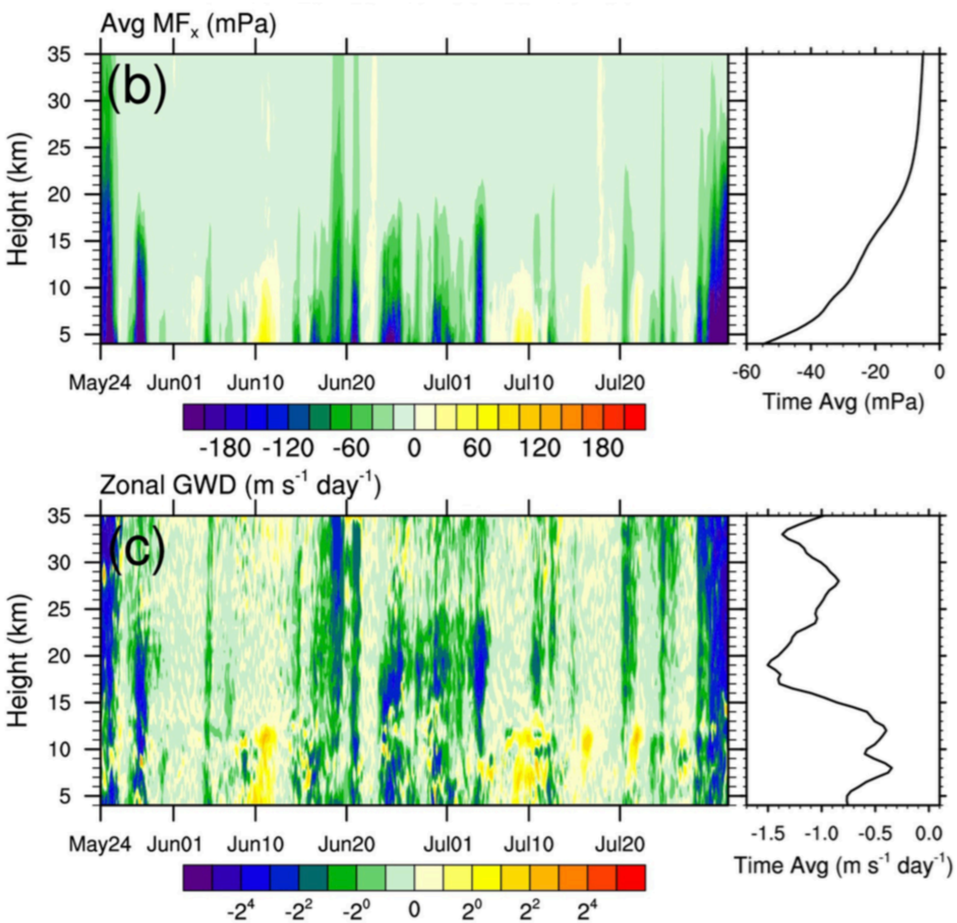


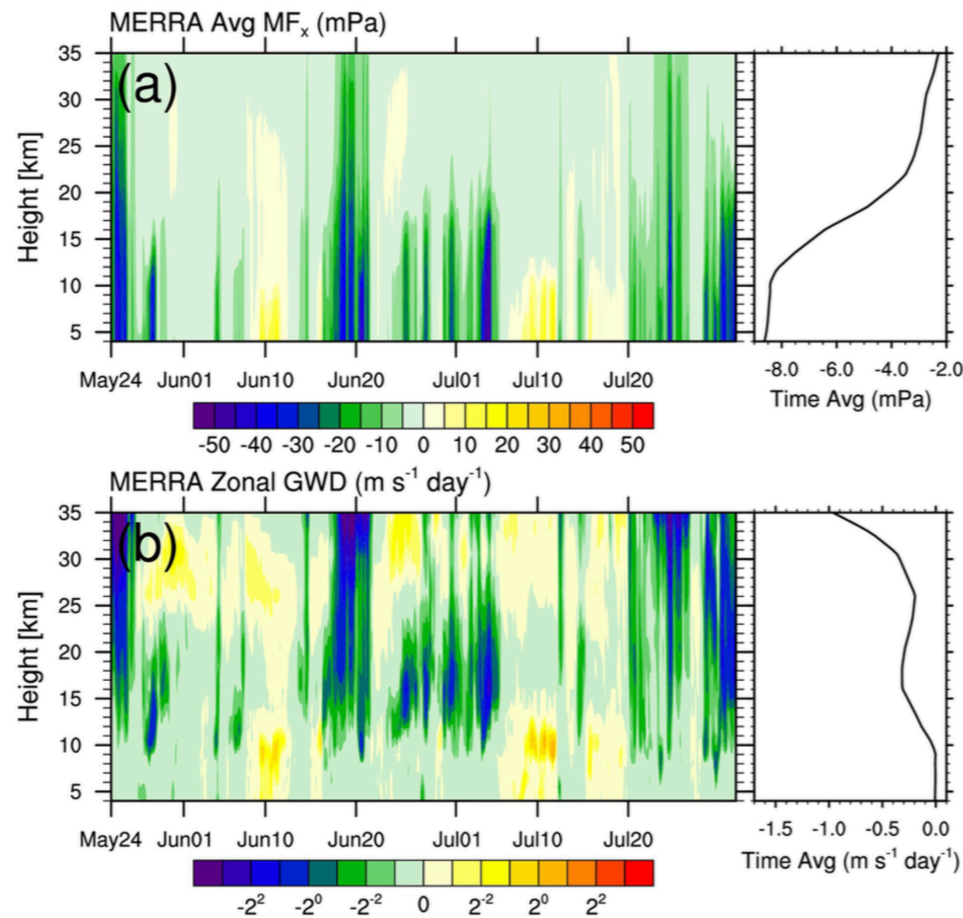
# WRF/MERRA Comparison

- Area averaged $MF_x$ (top) and $GWD_x$ (bottom)

**WRF**




**MERRA**



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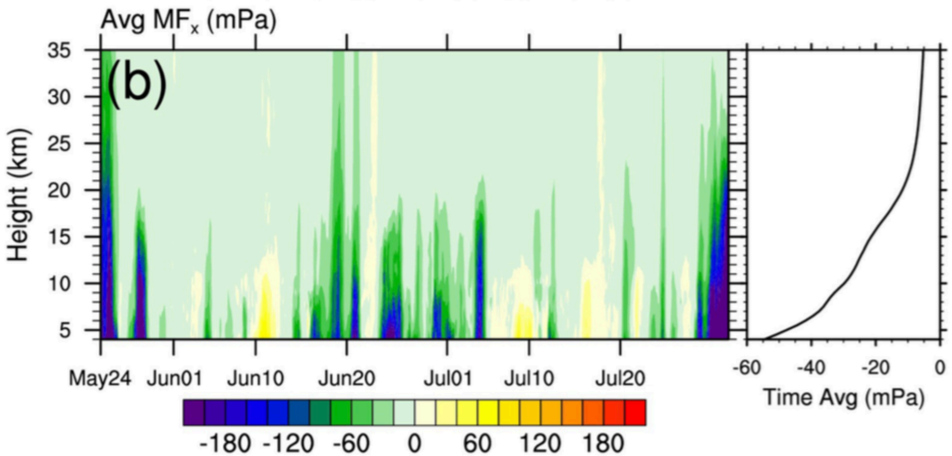
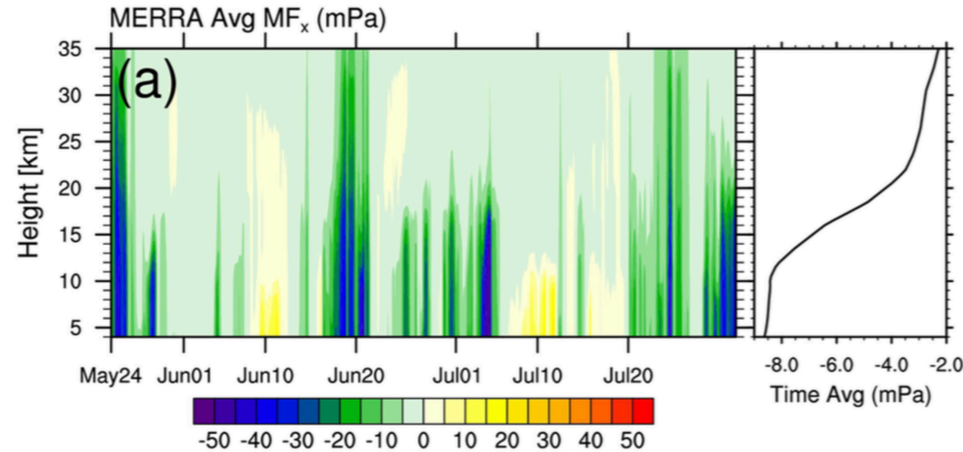
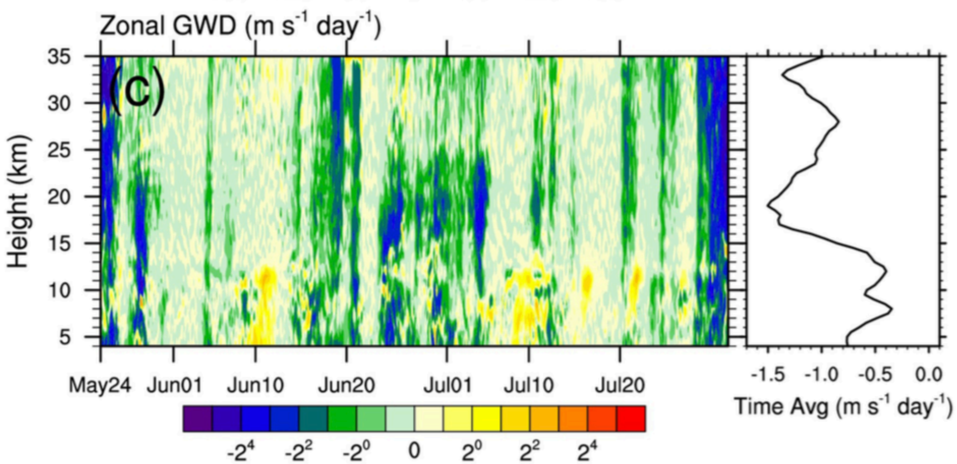
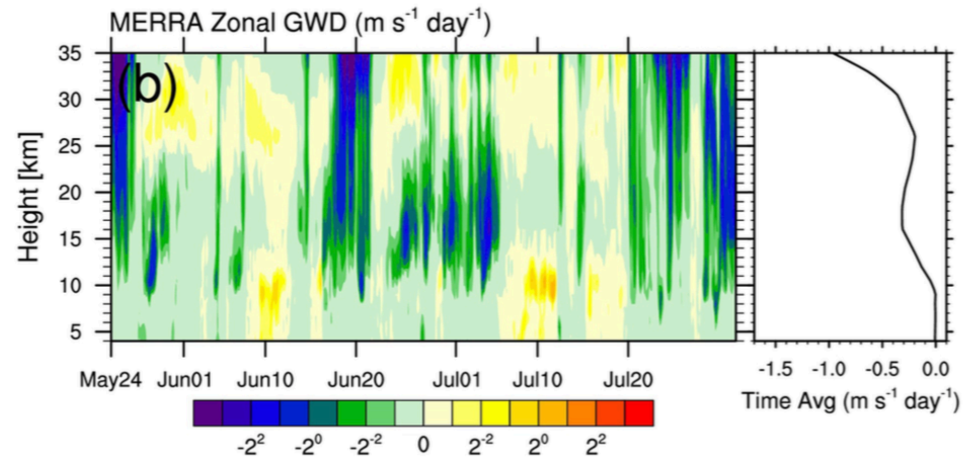
**WRF** | **MERRA**



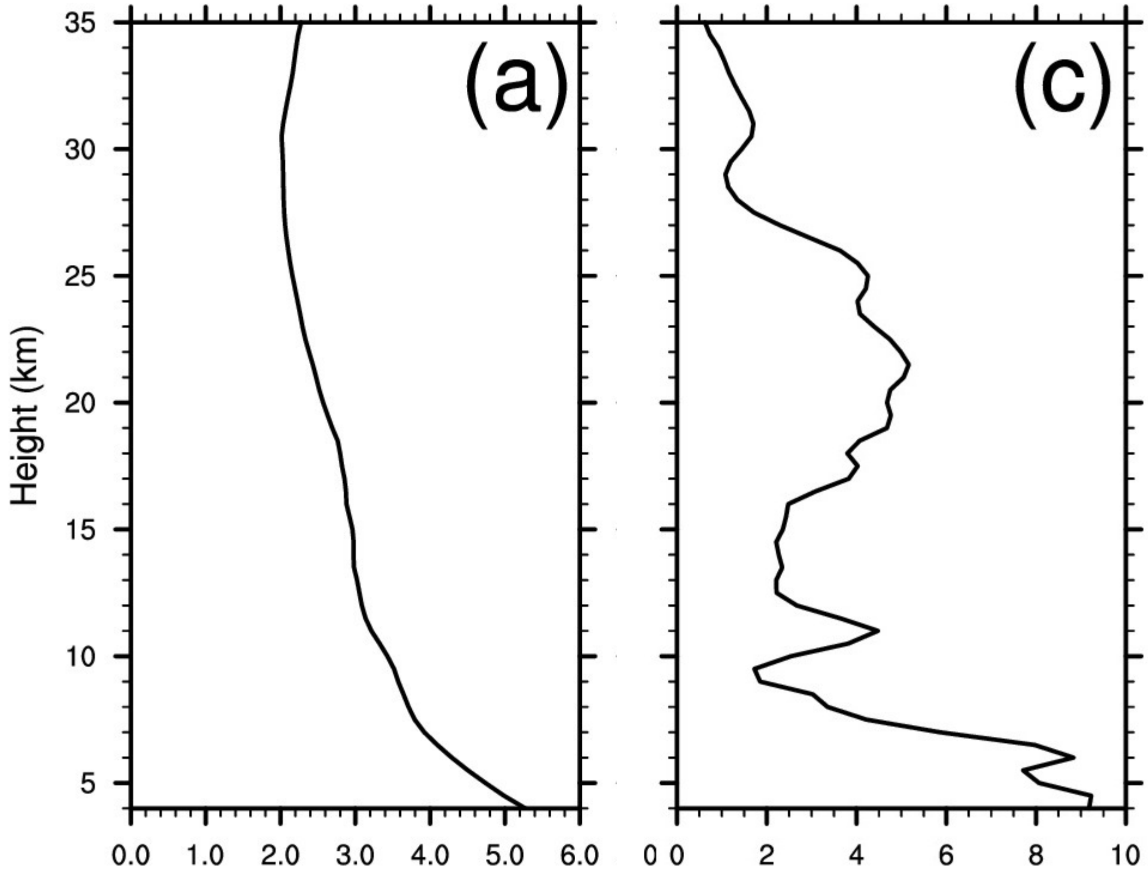




**NOTE: MERRA Contours ¼ of WRF!**

# WRF/MERRA Comparison

- Area averaged $MF_x$ (left) and $GWD_x$ (right)

Regression: WRF = m*MERRA




**$MF_x$ Slope**

**$GWD_x$ Slope**

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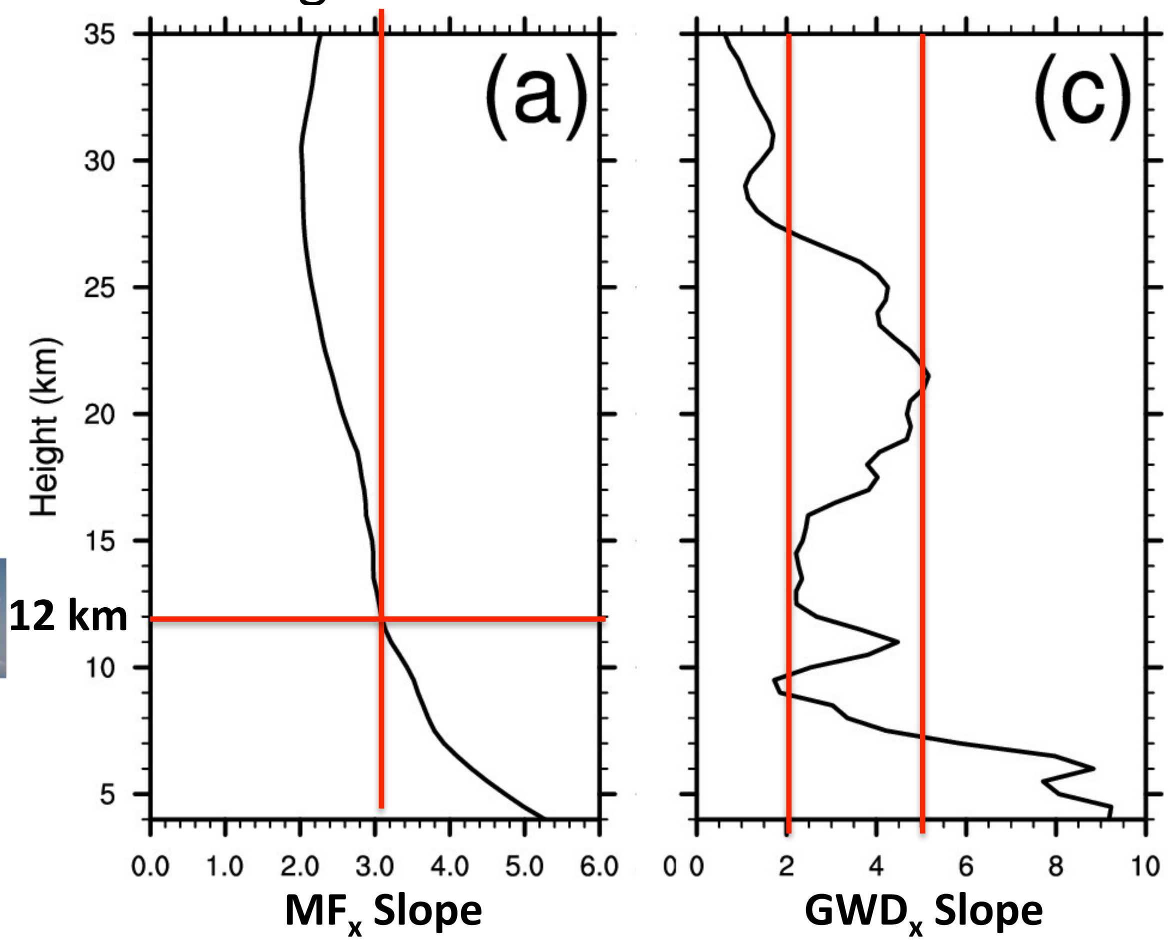
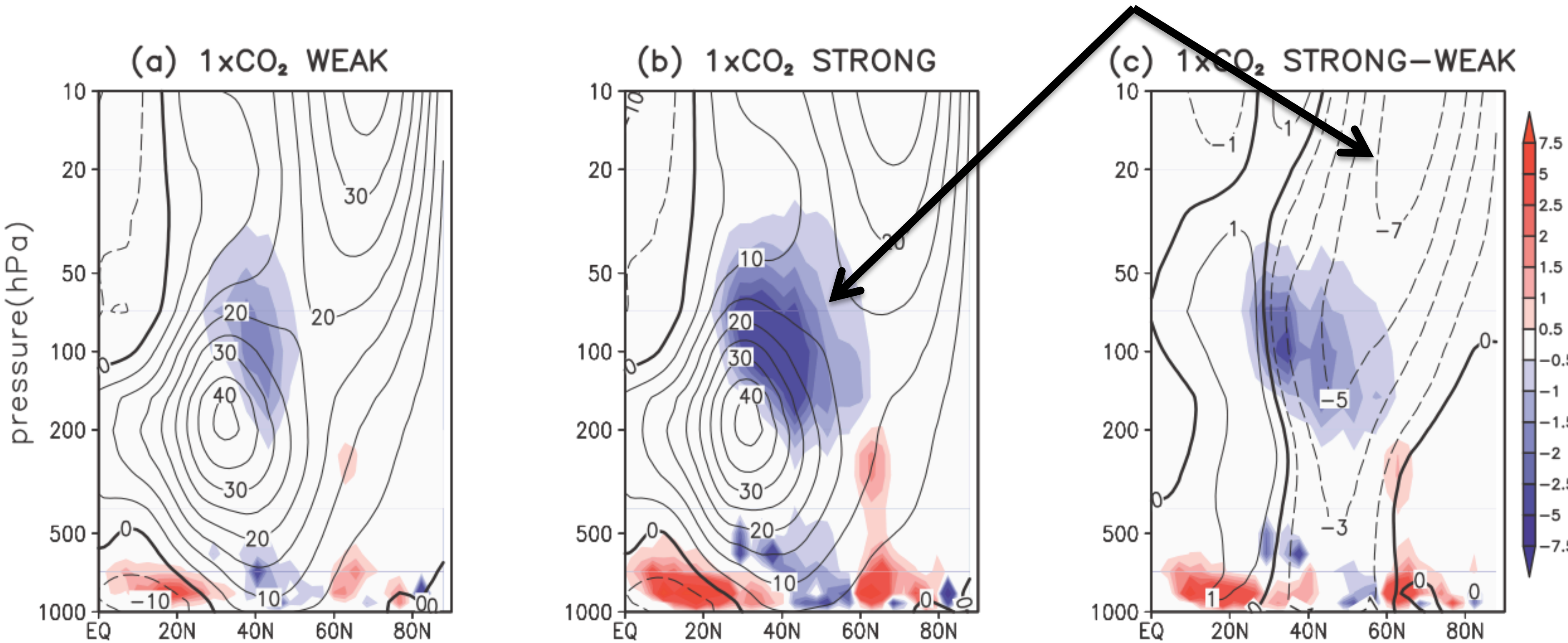



**Param. $MF_x$ into stratosphere ~3x smaller than well-validated WRF!**

**Param. GWD 2-5 times smaller than well-validated WRF in Valve Layer!**

# Implications of too little GWD




(Sigmond and Scinocca 2010)

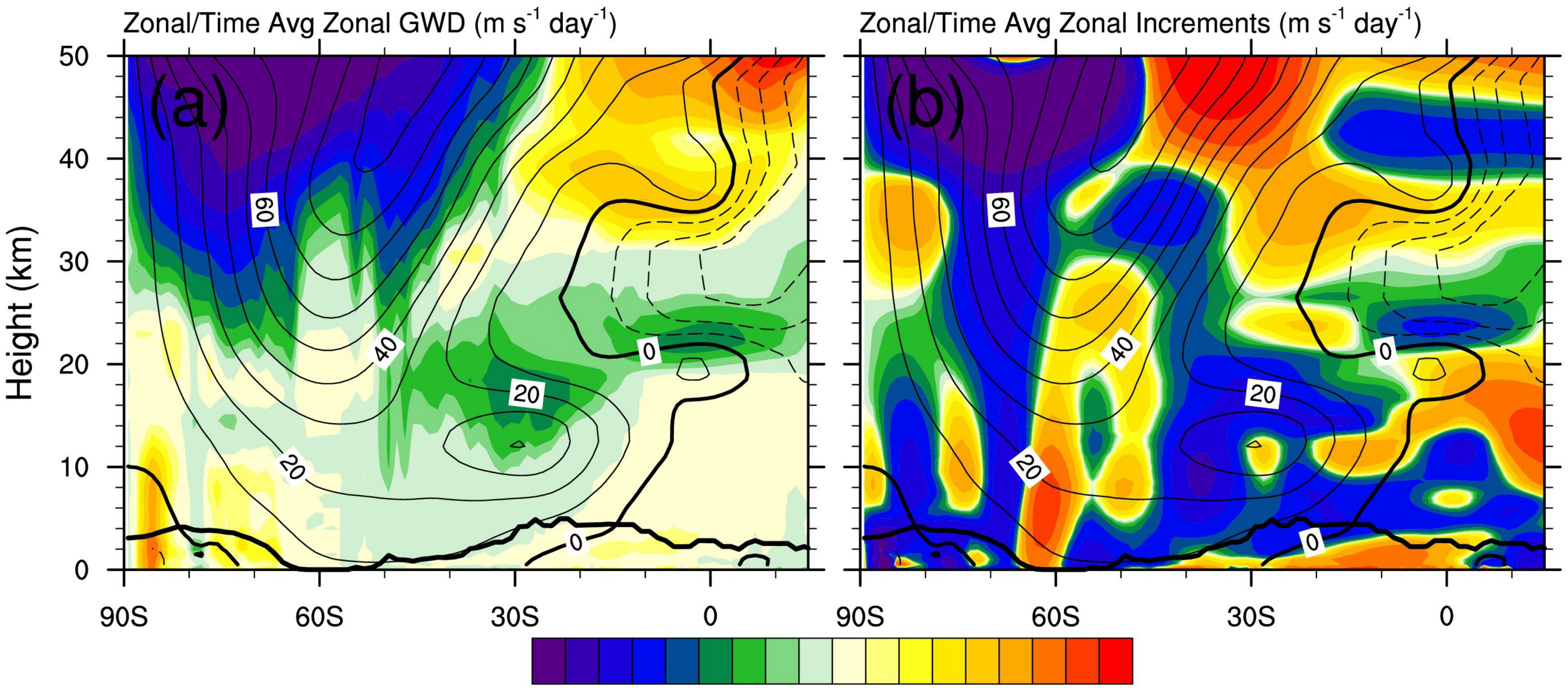
- Sigmond and Scinocca (2010) found that increased mid-latitude lower-stratospheric GWD slowed the polar stratospheric vortex (PSV) by altering planetary wave propagation and drag
- Under-representation of GWD may be a part of the cold-pole problem!

# Conclusions

- WRF reproduced observed ambient environment
- WRF reproduced event mean $MF_x$
- Mountain waves frequently attenuated in a climatological Valve Layer
- $MF_x$ and $GWD_x$ significantly under-represented in MERRA
  - MERRA increments consistent with this! (not shown)
  - May be part of the cause of the common cold-pole problem in Chemistry-Climate Models

# MERRA Winds, $GWD_x$, Increments

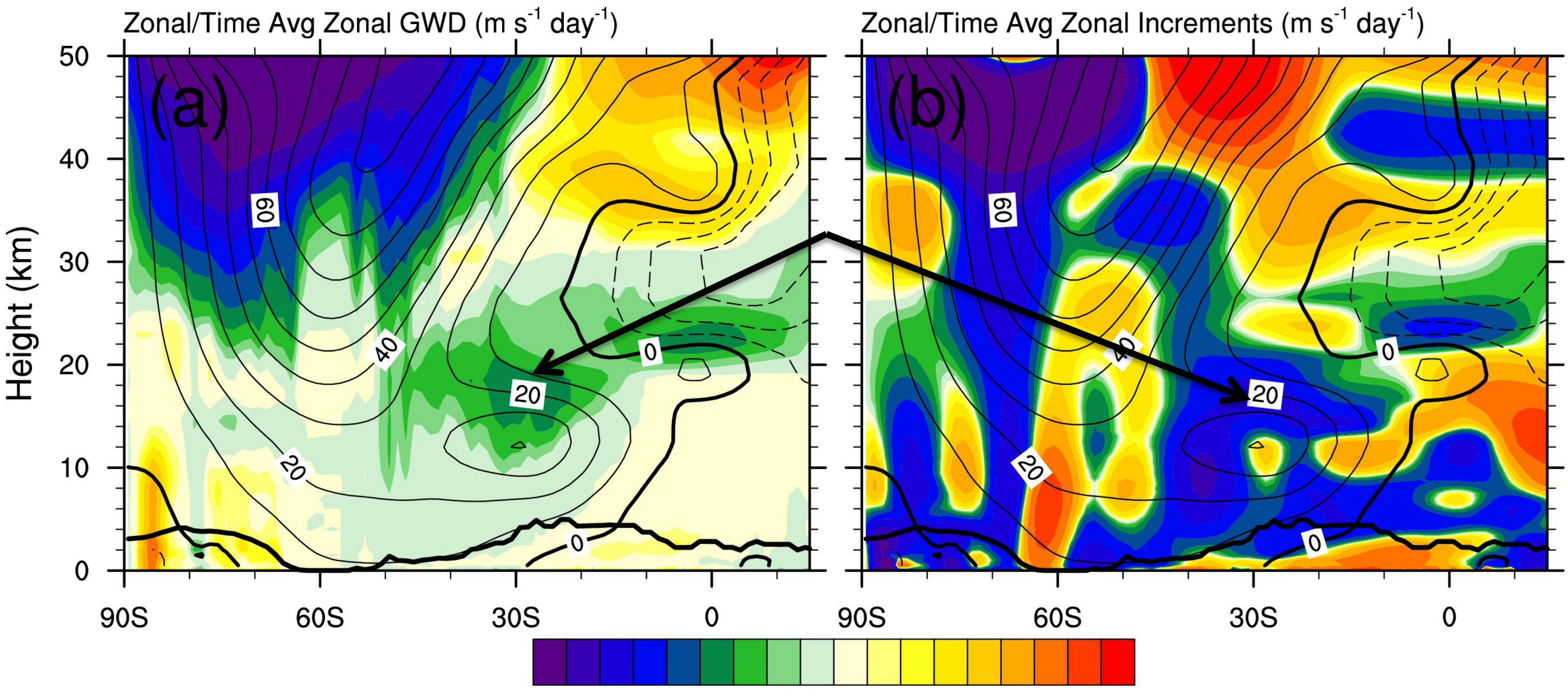
- Increments
  - Six hourly model errors, expressed as a tendency
  - Used to force model toward observations within governing equations
  - For u, has units of acceleration
  - Interpreted by McLandress et al. (2012) as a missing GWD in the model




Zonal, Time Avg

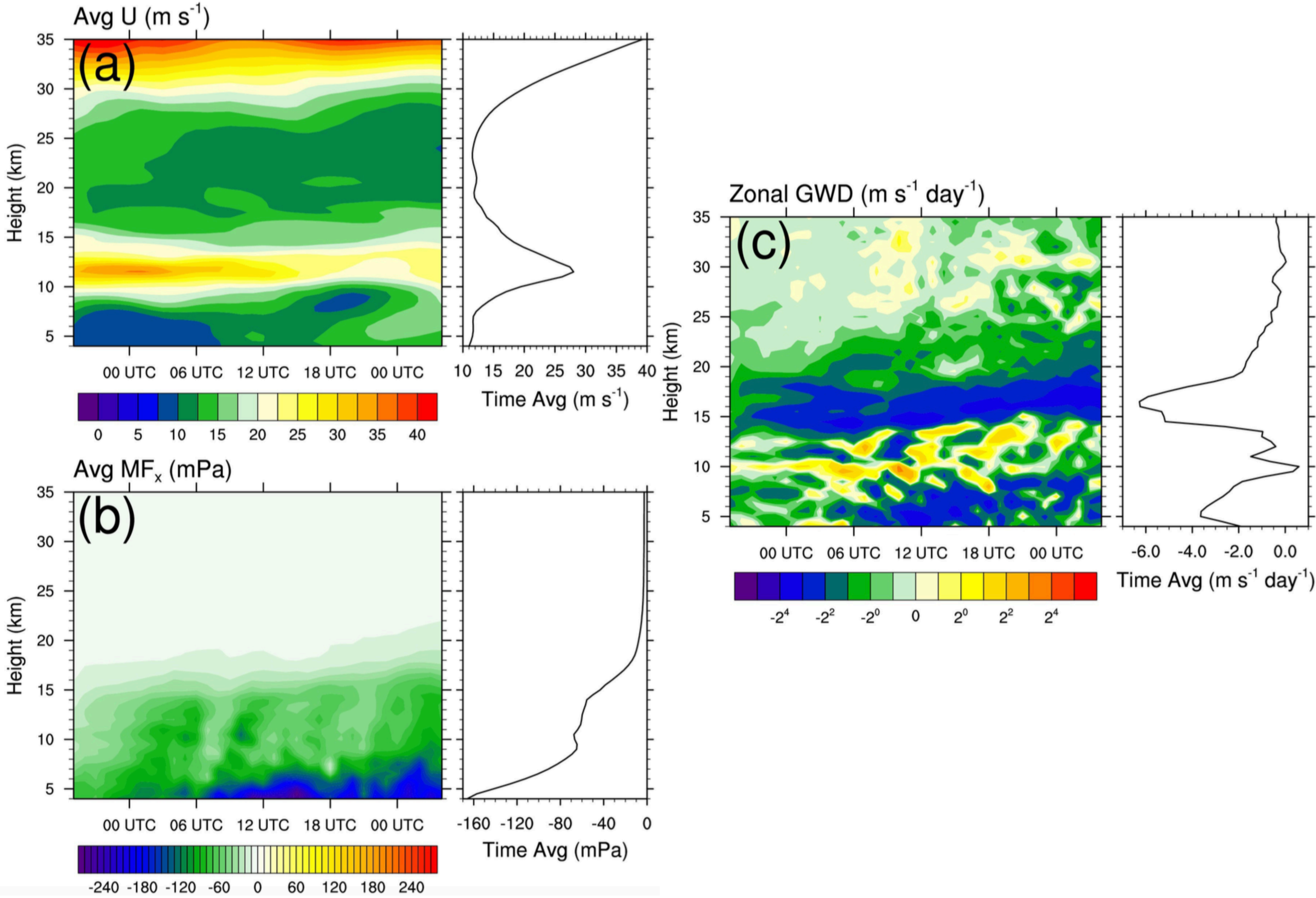
# MERRA Winds, $GWD_x$, Increments

- Increments collocated with and same sign as GWD
- **4-8 times larger than parameterized GWD**
  – Consistent with WRF comparison




Zonal, Time Avg

# Extra: Local Effects



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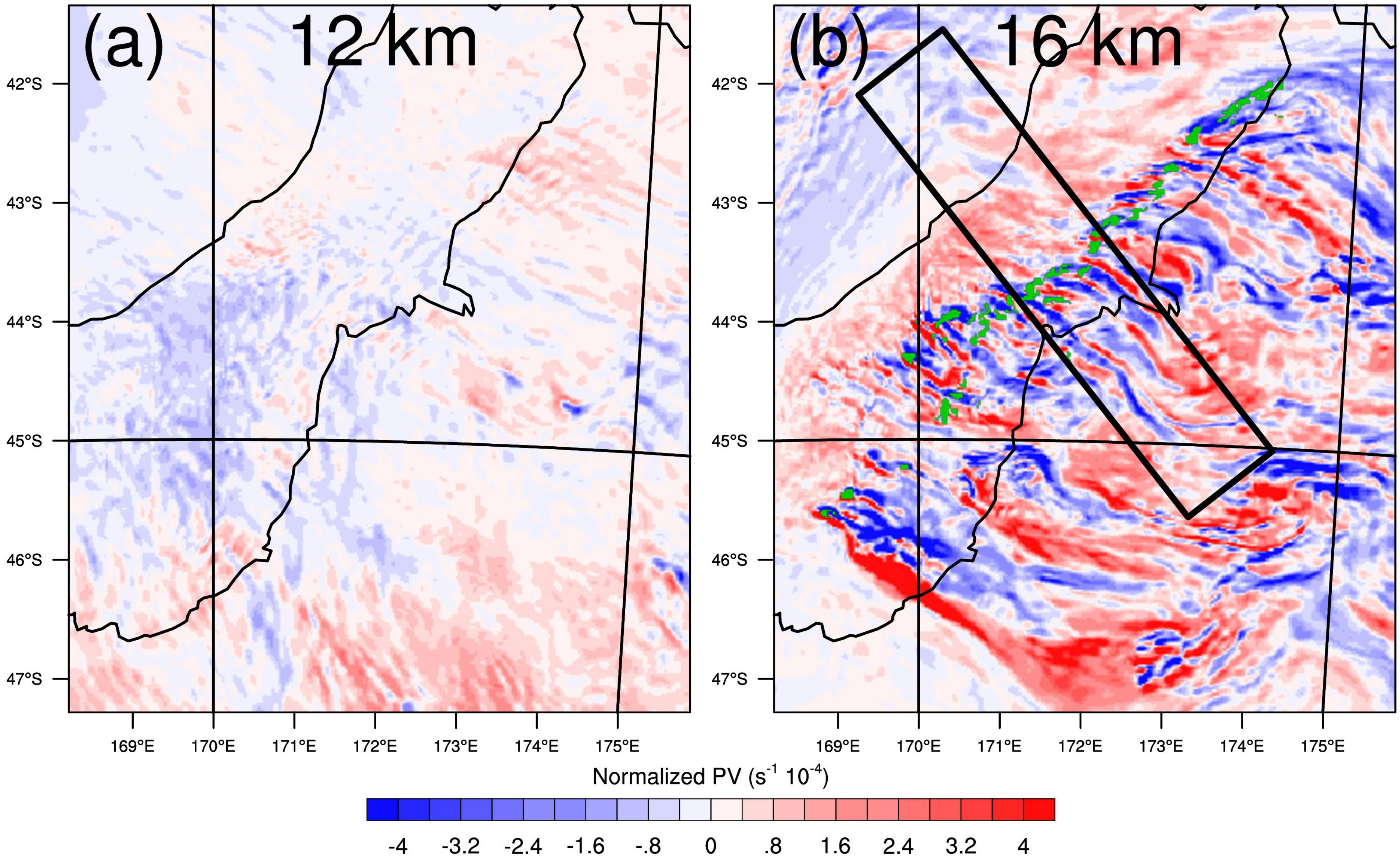

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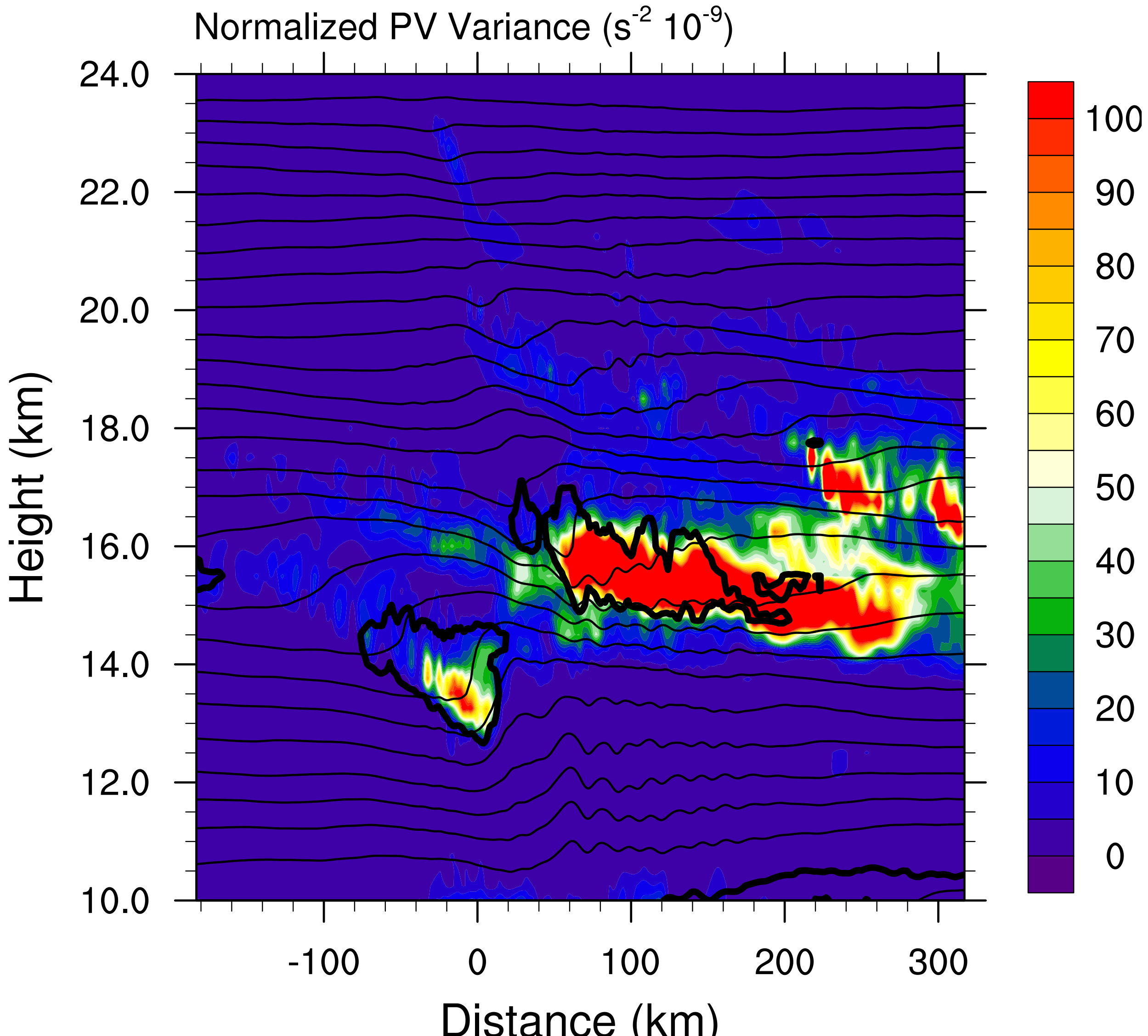
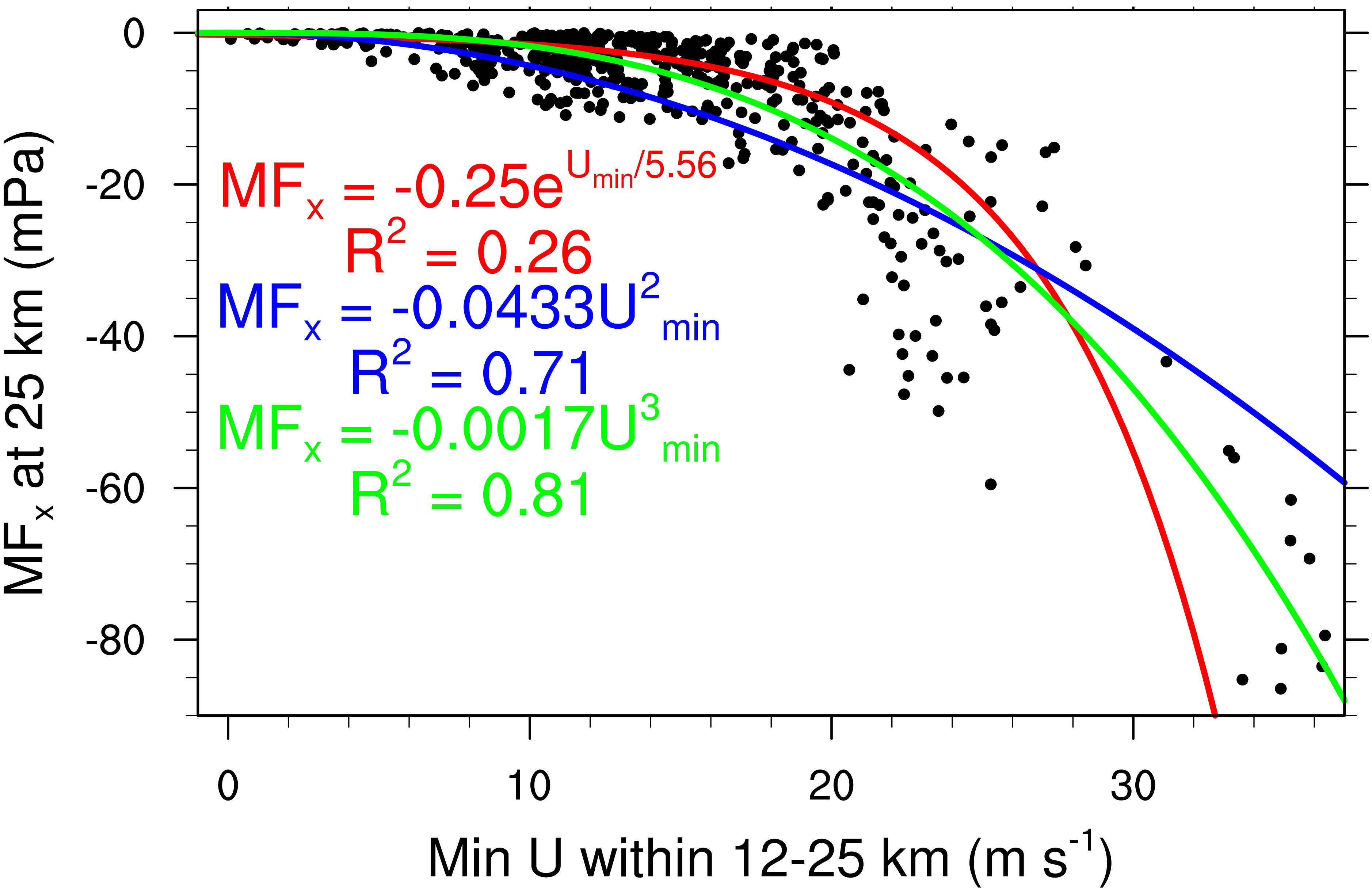


# 25-km $MF_x$ vs. Stratospheric $U_{min}$



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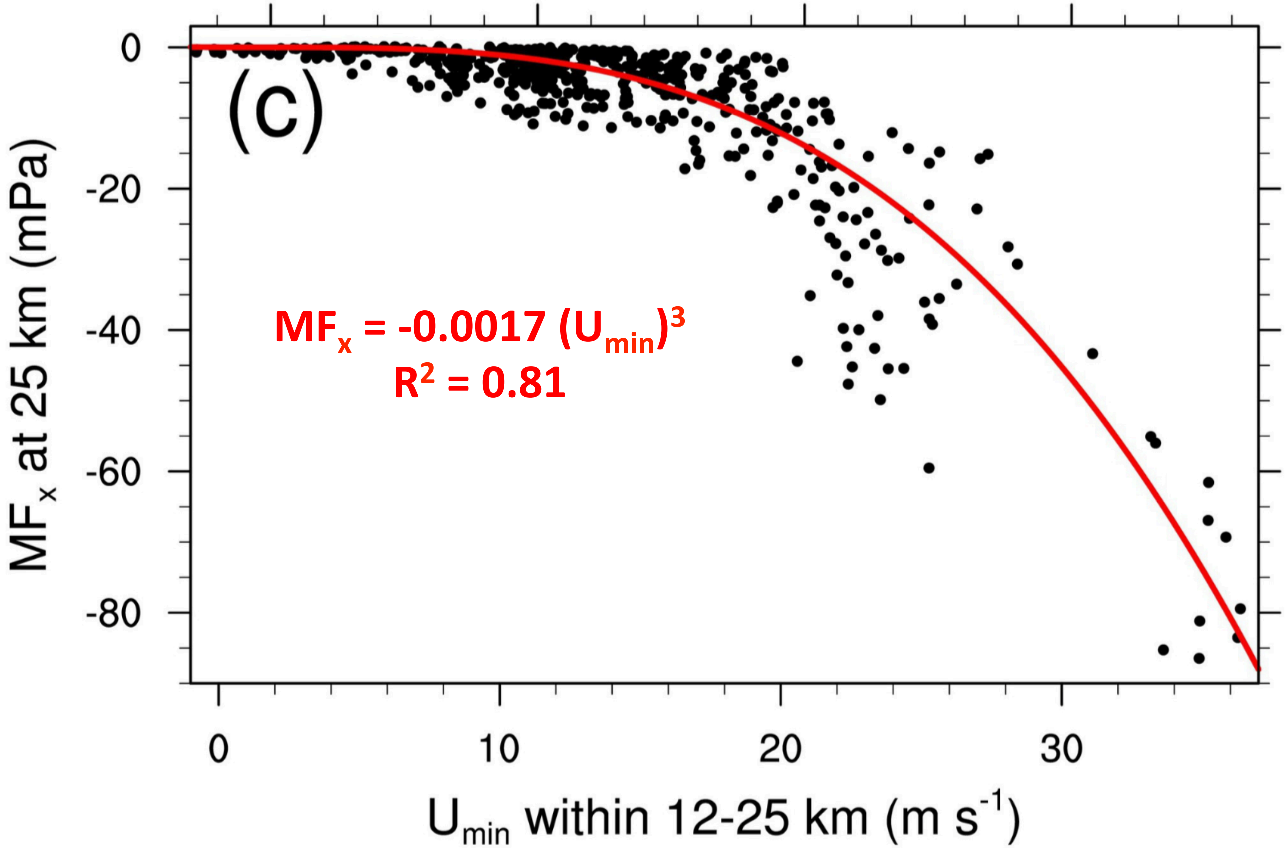


# Saturated (i.e. max) $MF_x$ Given ρ, N, U

- From Palmer 1986

$$\tau_{sat} = \varepsilon^2 \kappa \rho U^3 / N$$

Wavenumber

- From McFarlane 1987

$$\tau = \tau(0)/F^2 = -\frac{1}{2}(\bar{\rho}\mu\bar{U}^3/N).$$

- Max $MF_x$ (τ) most strongly constrained by U
  - Proportional to the cube

# McFarlane Parameterization

- From McFarlane 1987

$$MF_{x_{sat}}\,[N\,m^2] = -\frac{F_c^2}{2}\frac{\overline{\rho}k}{N}U^3$$

- $F_c$ and k are tuning parameters
- $F_c$, the local Froude number, is the saturation criterion
  - For a monochromatic wave, should be 1
  - Set to 0.5 in McFarlane 1987
- k computed assuming horiz. wavelength of 393 km
- This $MF_x$ only applicable over mountainous terrain

# Cubic Fit Comparison

- To compare predicted and best fit cubic relations, need to compute area integrated, not averaged, quantities
- Multiplied the Long Run Fit by the averaging area (426,414 $km^2$)
- Multiplied the param. relation by area of Southern Alps (approximated by 1/3 times South Island area, 50,146 $km^2$)

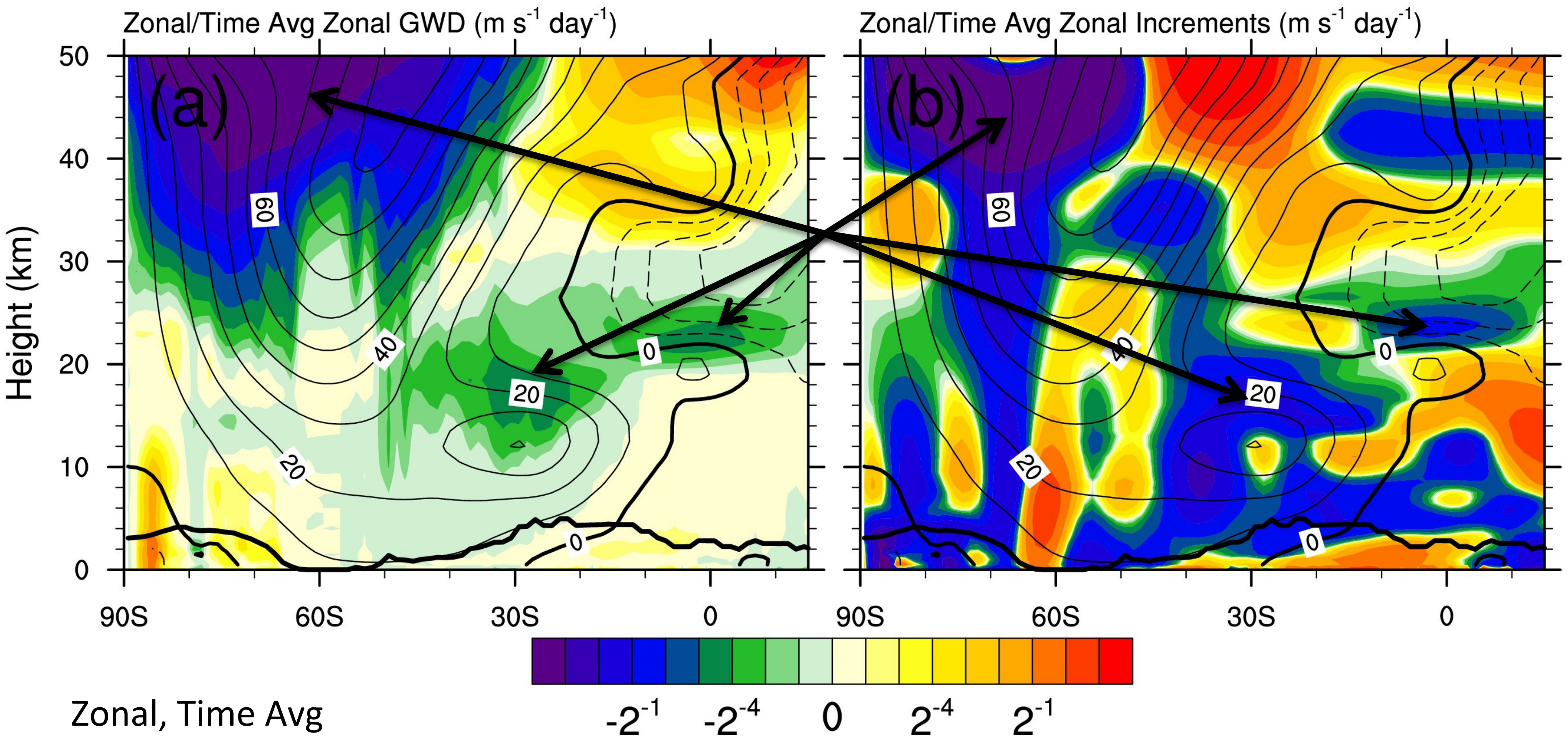
$$C_{int_{WRF}} = -741,960\,\frac{kg\,s}{m^2}$$

$$C_{int_{sat}} = -501,072\,\frac{kg\,s}{m^2}$$

67.5% of WRF

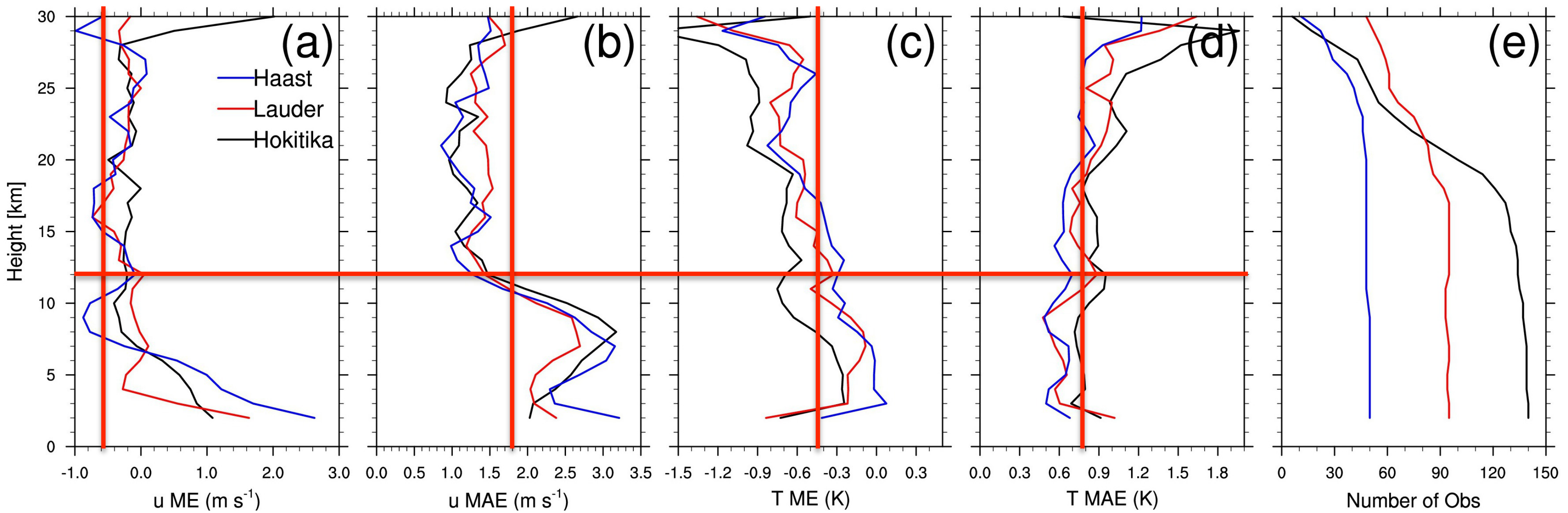
# MERRA Winds, $GWD_x$, Increments

- A number of other regions where GWD may be under-represented

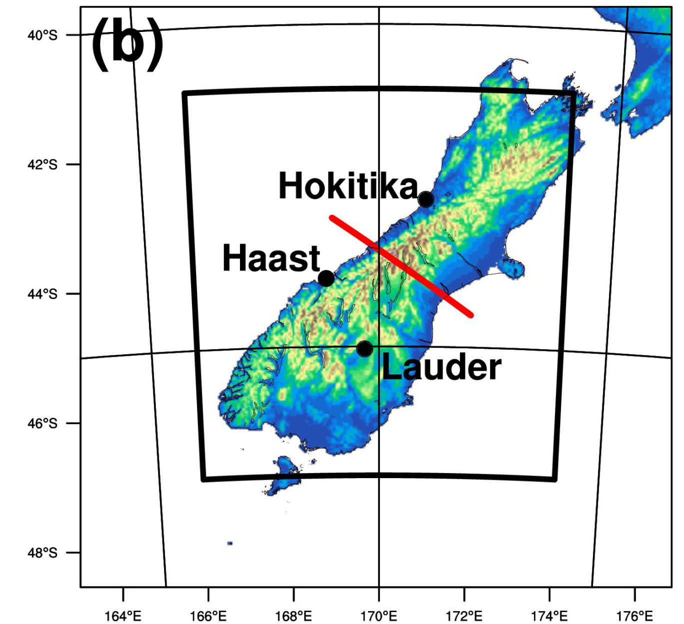



Zonal, Time Avg

# Ambient Atmosphere Validation: Radiosondes

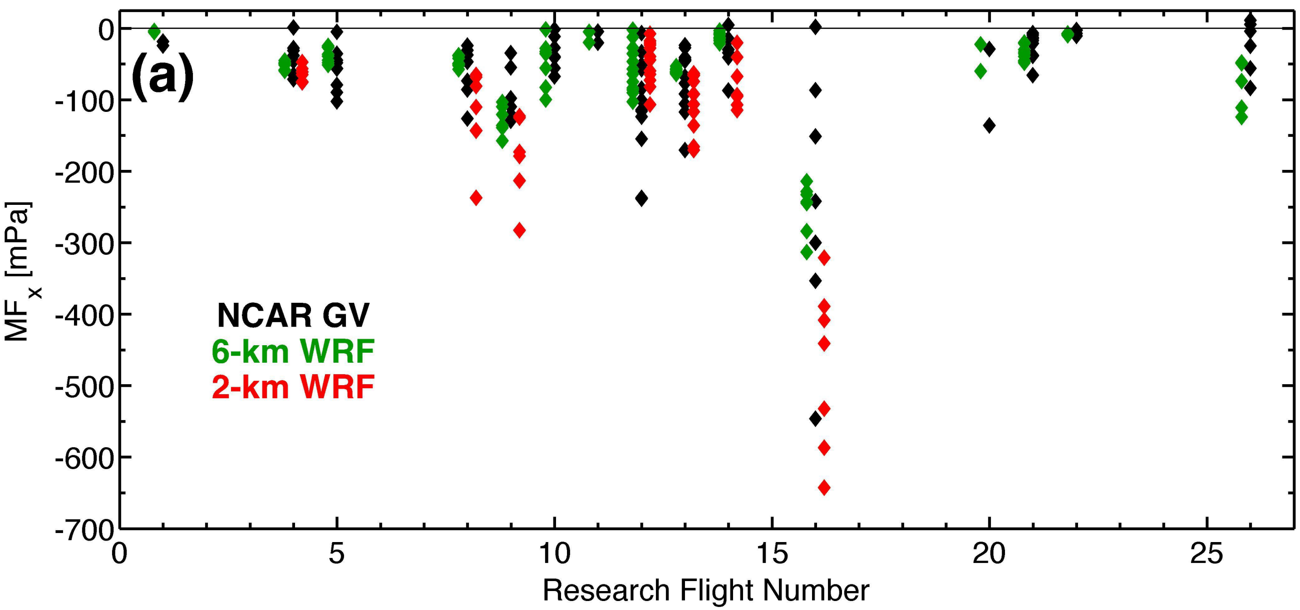



**Aircraft Validation Statistics**




- ME = Mean Error
- MAE = Mean Absolute Error
- Validation best in stratosphere

# Momentum Flux Validation




| | 6-km $\overline{MF}_x$ | 2-km $\overline{MF}_x$ |
|---|---|---|
| # of Legs | 97 | 58 |
| Slope | 0.667 | 1.236 |
| R | 0.463 | 0.610 |
| Bias | 3.838 | -46.584 |
| % Bias | 5.56 | 50.7 |
| MAE | 40.554 | 78.735 |
| % MAE | 58.76 | 85.69 |

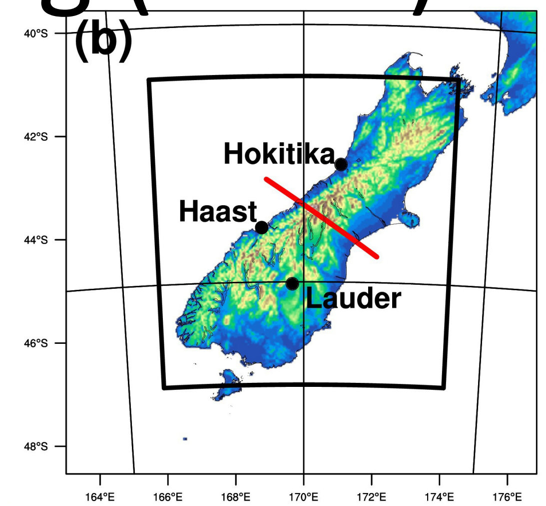
- Significant intra-event $MF_x$ variability
- Long Run doesn't reproduce $MF_x$ variability, **but gets averages correct**

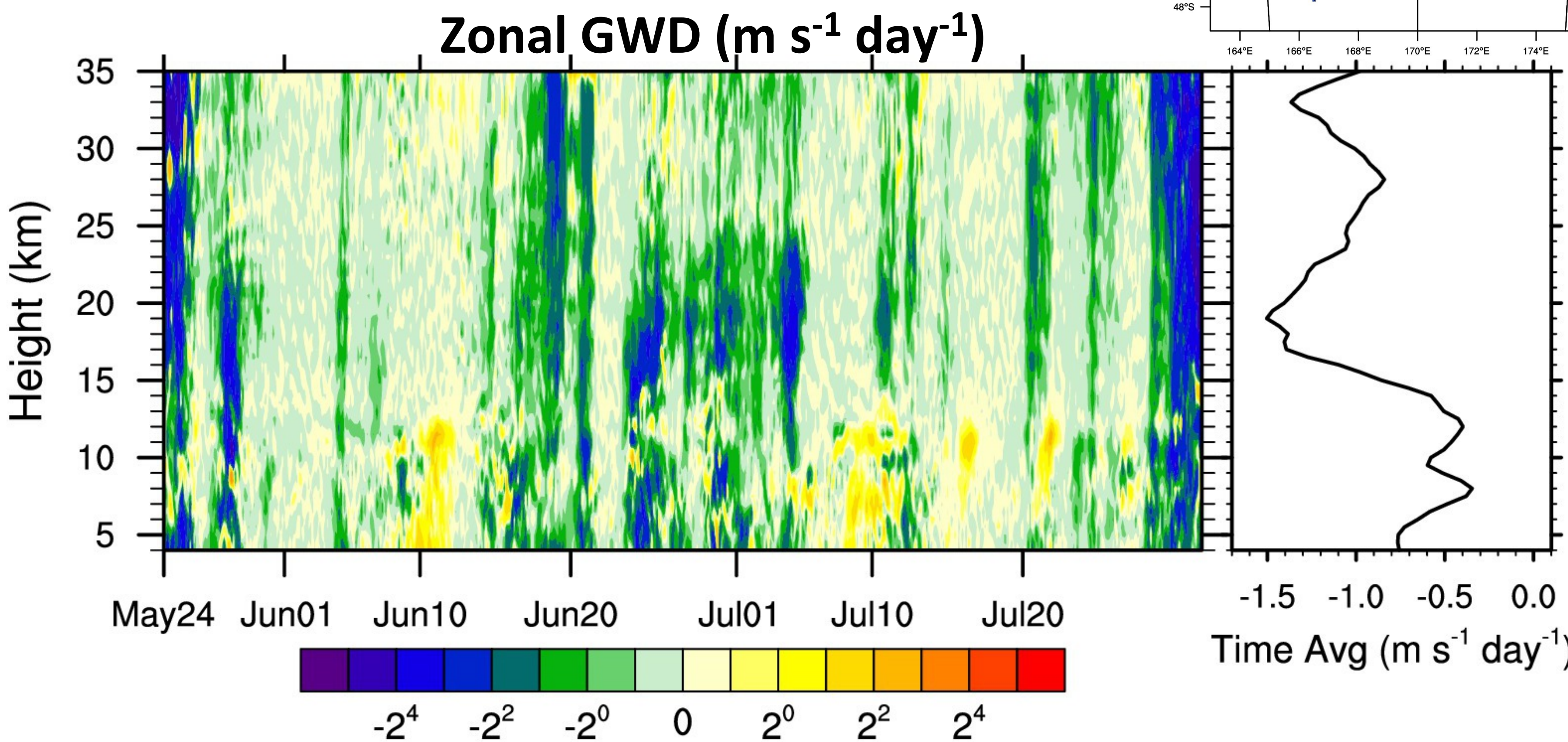
# Long Run Gravity Wave Drag (GWD)

$$GWD_x = -\frac{1}{\bar{\rho}}\frac{\Delta\overline{MF}_x}{\Delta z}$$

$$\overline{MF}_x = \bar{\rho}\,\overline{u'w'}$$

$$\overline{(\,.\,)} = \frac{1}{A}\int_A (\,.\,)\, dA$$



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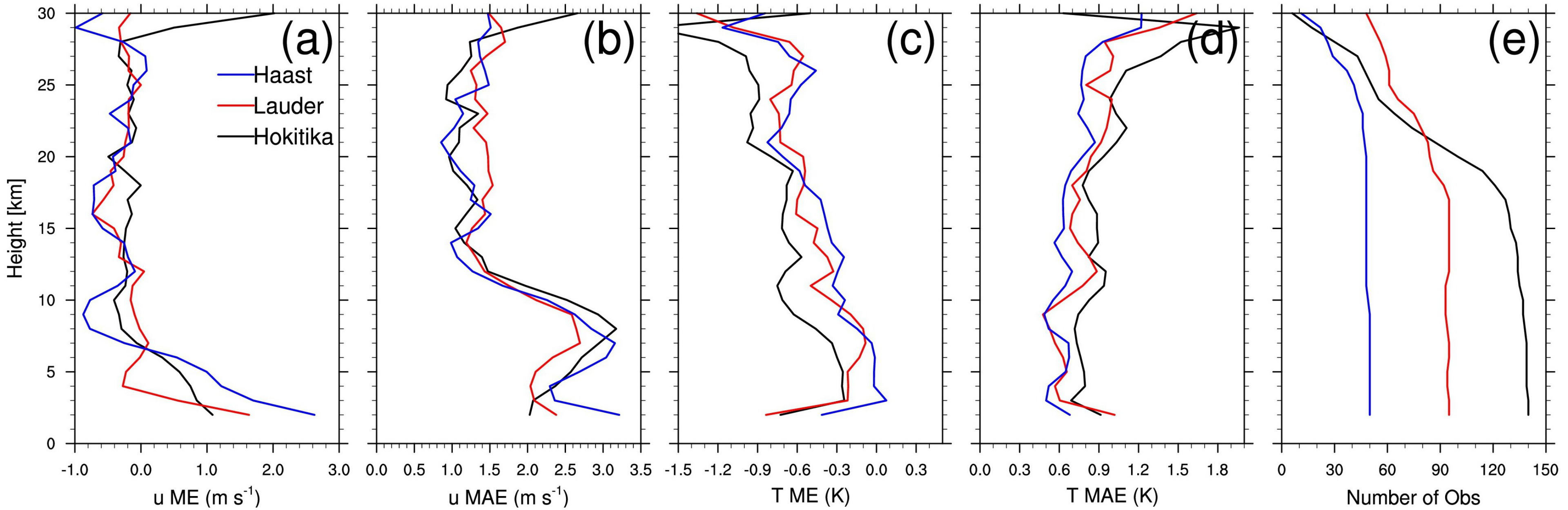
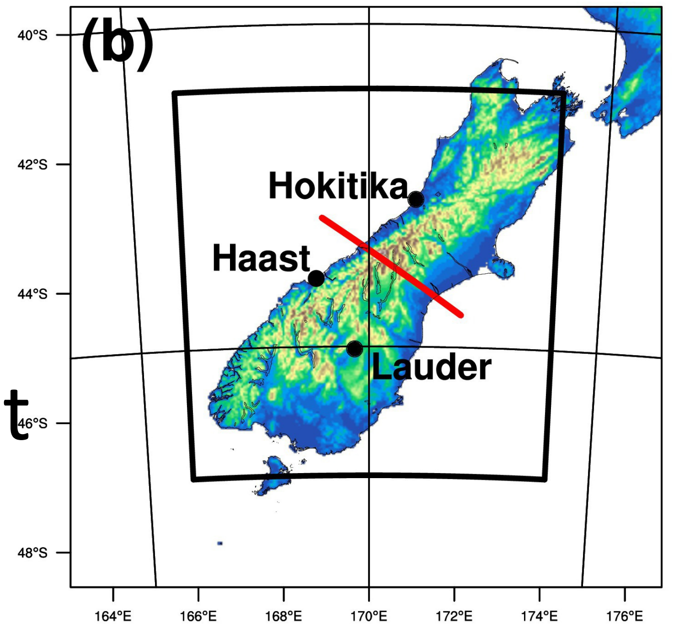



- ME = Mean Error
- MAE = Mean Absolute Error
- Validation good at all levels, best in stratosphere



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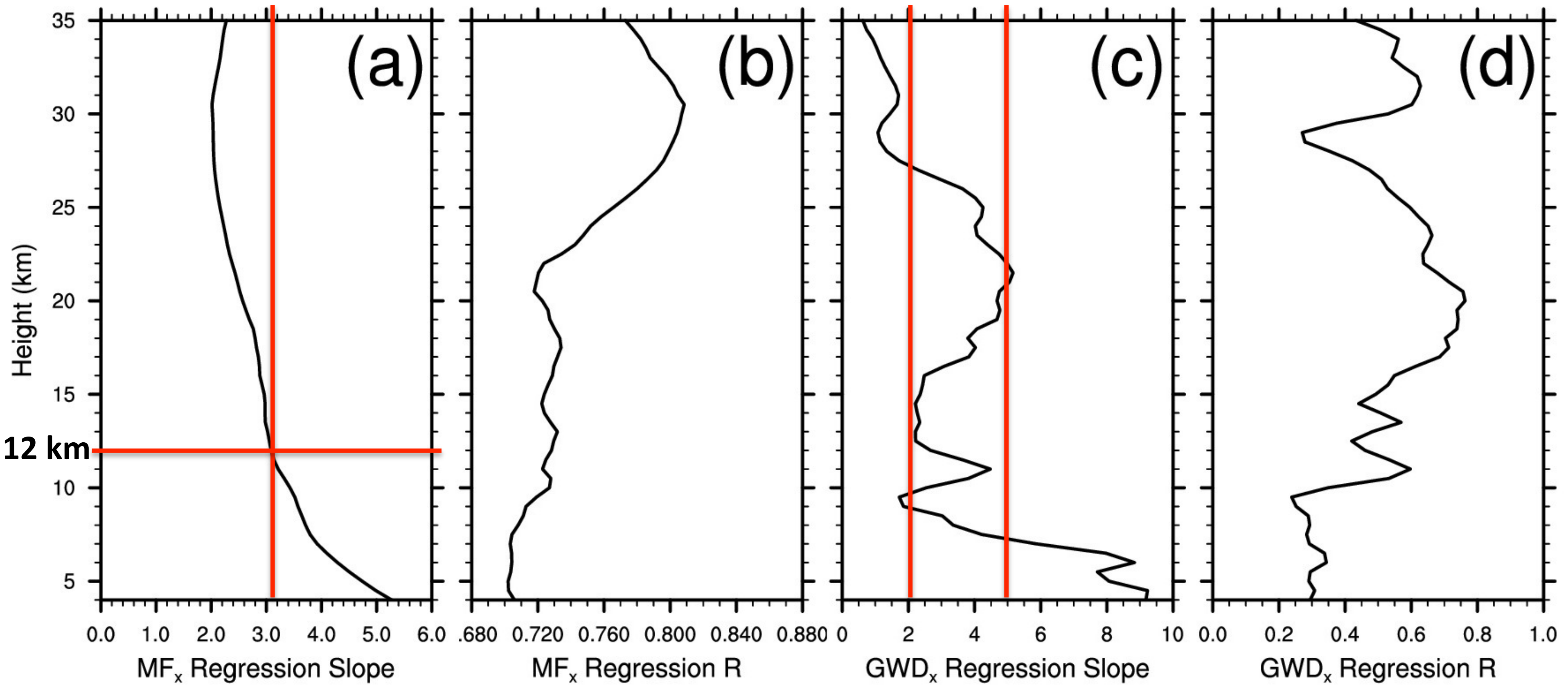


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**Param. GWD 2-5 times smaller than well-validated WRF in Valve Layer!**