The Mid-Latitude Lower-Stratospheric Mountain Wave "Valve Layer"

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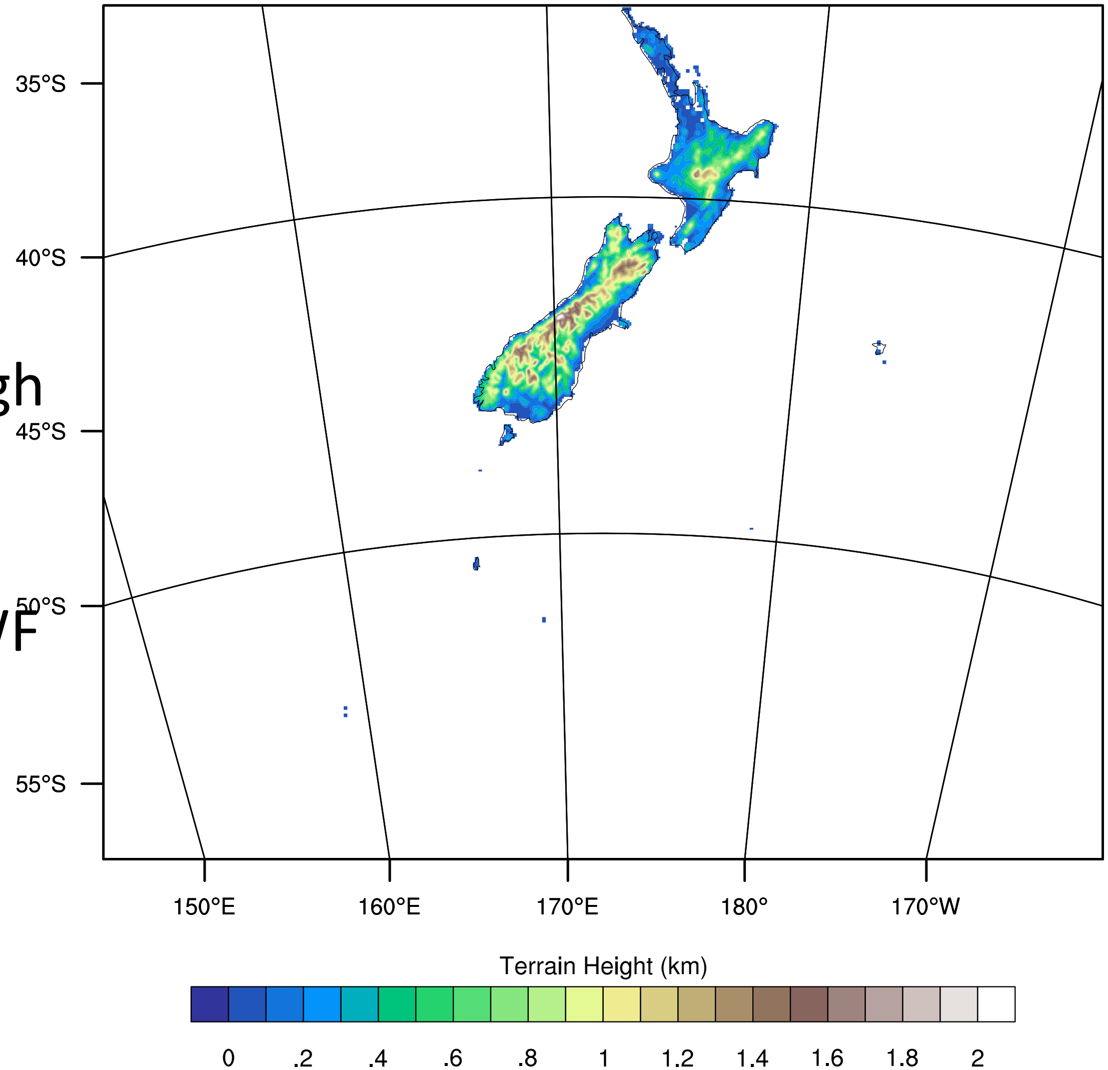
NCAR's Computational Resources (CISL, Yellowstone)

WRF Setup

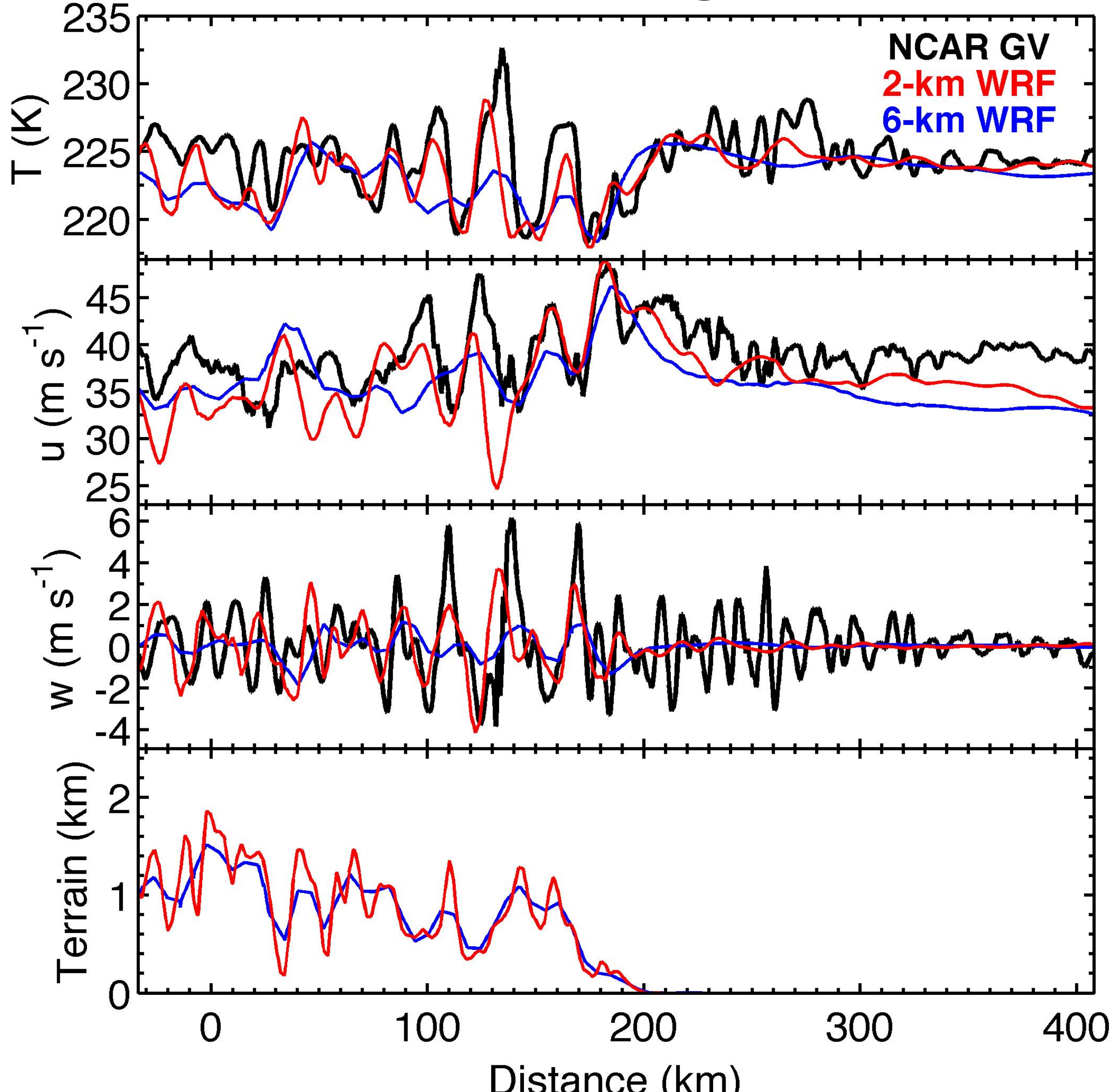
- The "Long Run"
  - 6km resolution
  - Initialized 24 May 2014
  - Run continuously through 1 Aug 2014 (DEEPWAVE period)
  - Forced by ~16km ECMWF
  - Top @ 100Pa, ~45 km
  - Δz = ~50 m – 600 m



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!**

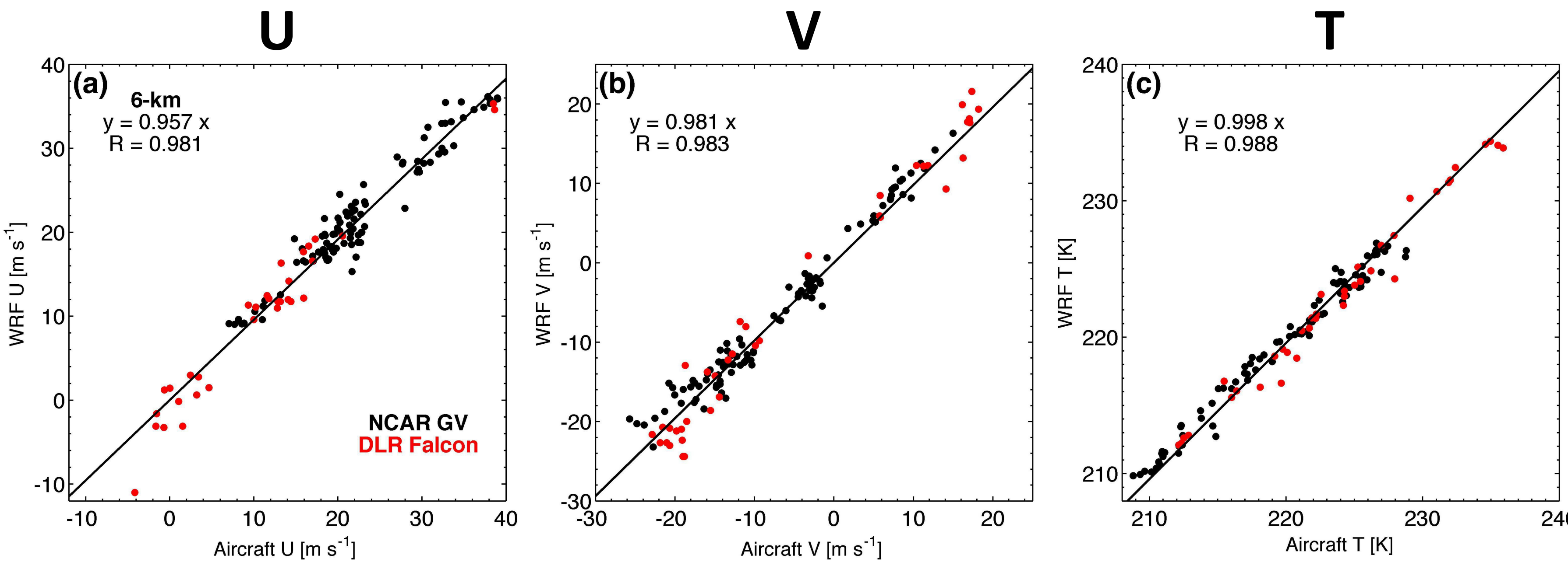
RF16 Leg 1



Ambient Atmosphere Validation: Aircraft

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

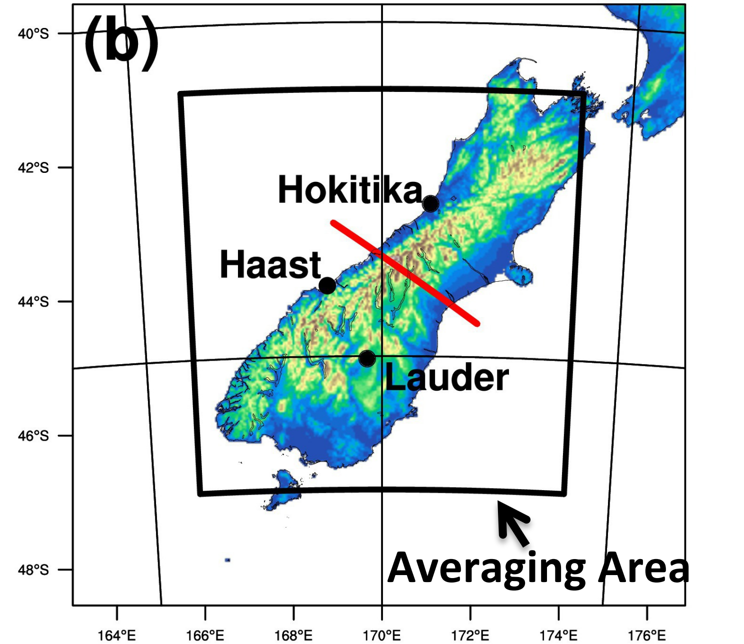
6-km Long Run

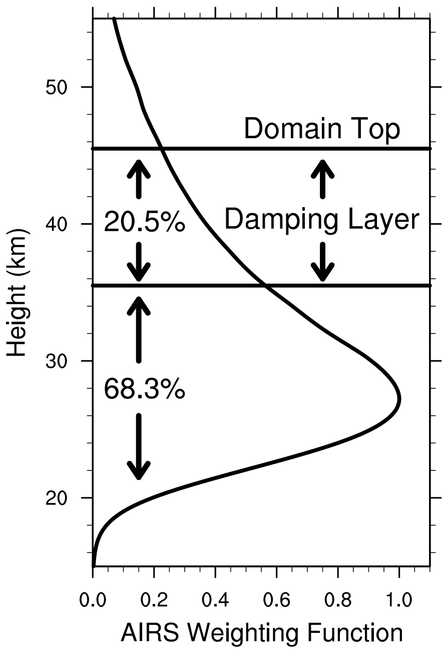


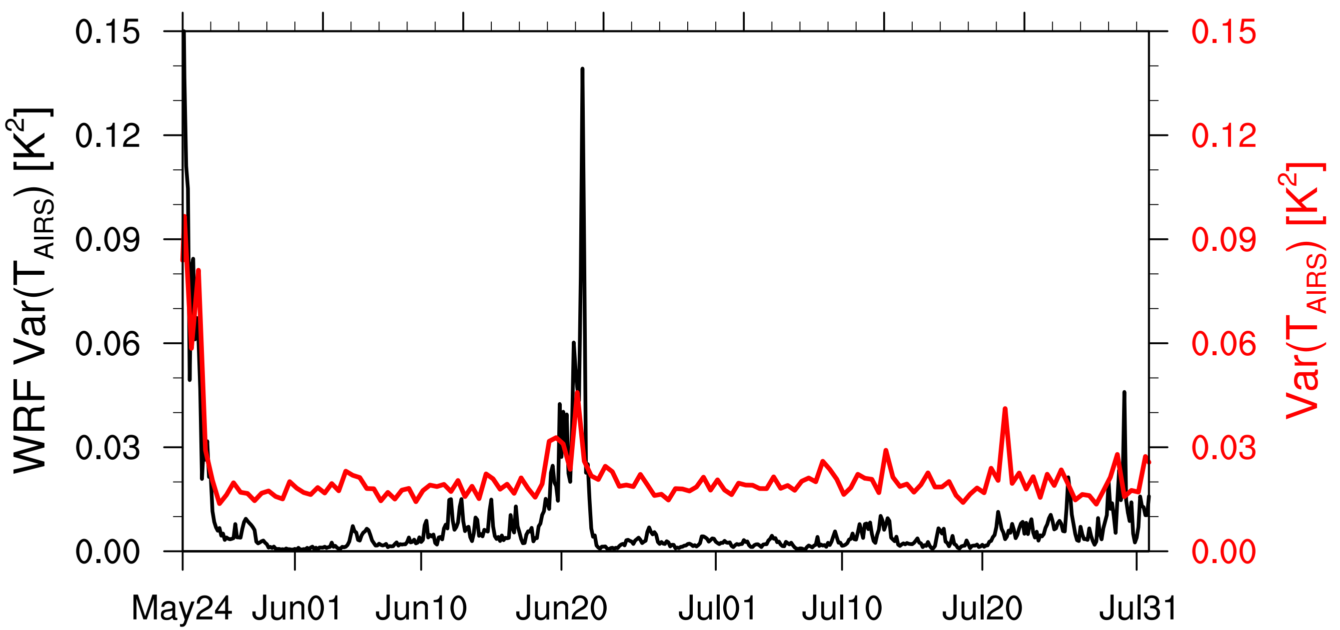
Mean Error = -0.80 m s^{-1}	ME = 0.60 m s^{-1}	ME = -0.44 K
Mean Absolute Error = 1.81 m s^{-1}	MAE = 1.73 m s^{-1}	MAE = 0.77 K

AIRS Validation (Courtesy of Steve Eckermann)

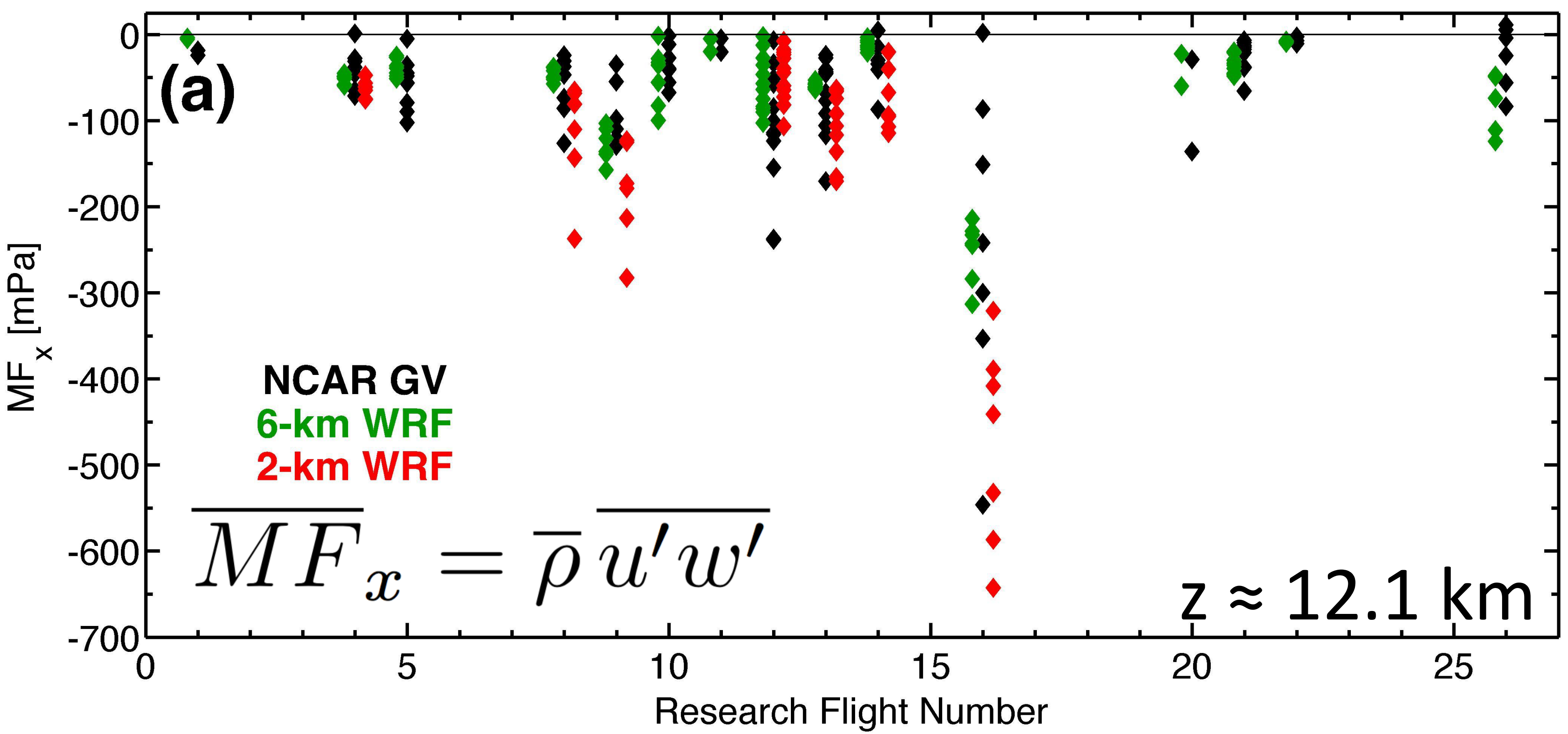
- Applied AIRS weighting functions to 3-D WRF fields to produce 2-D forward modeled AIRS temperatures within WRF
- Computed temperature variance over the box at right
- 20 mb, λ = 14.9381 μm, channel





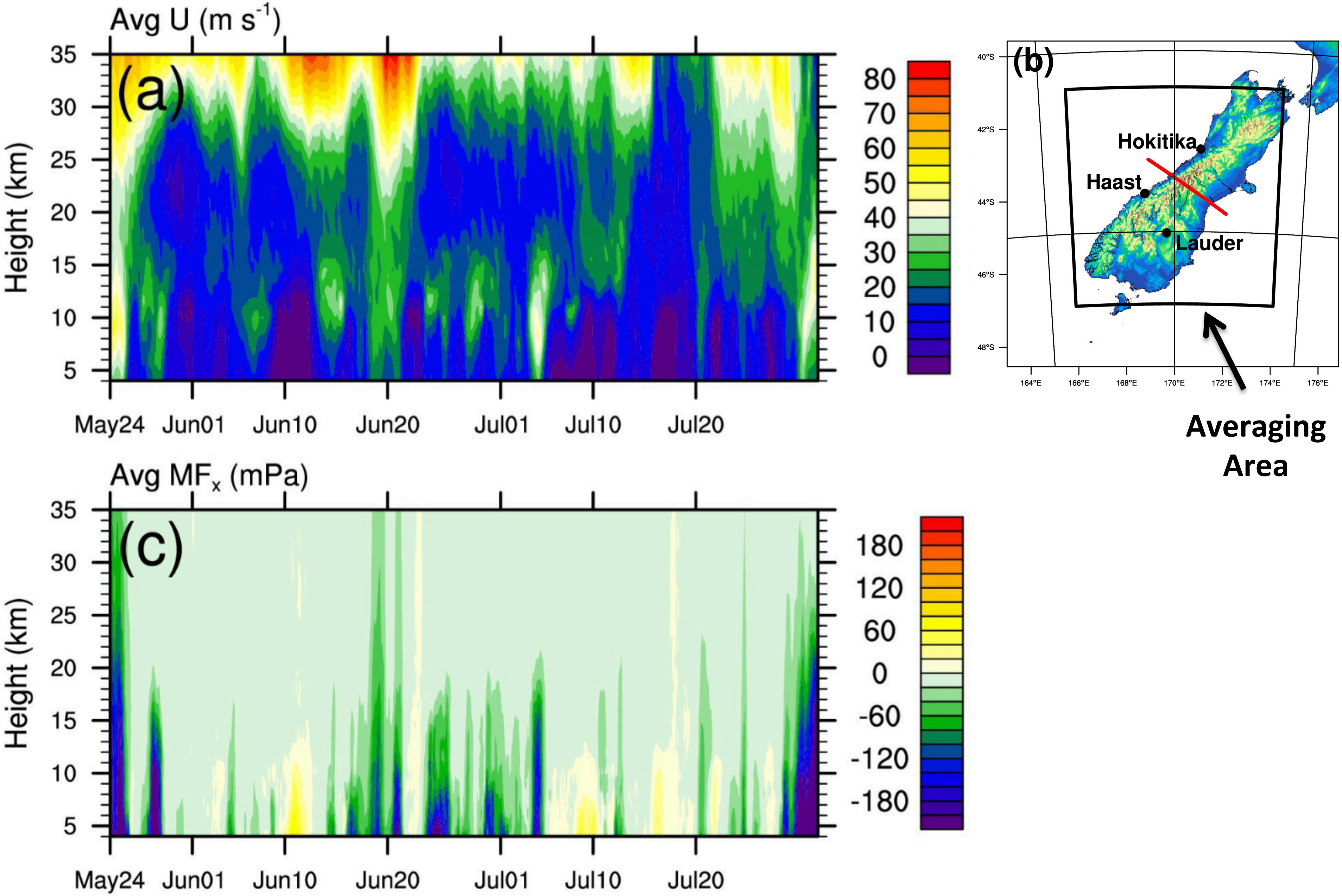


Momentum Flux Validation

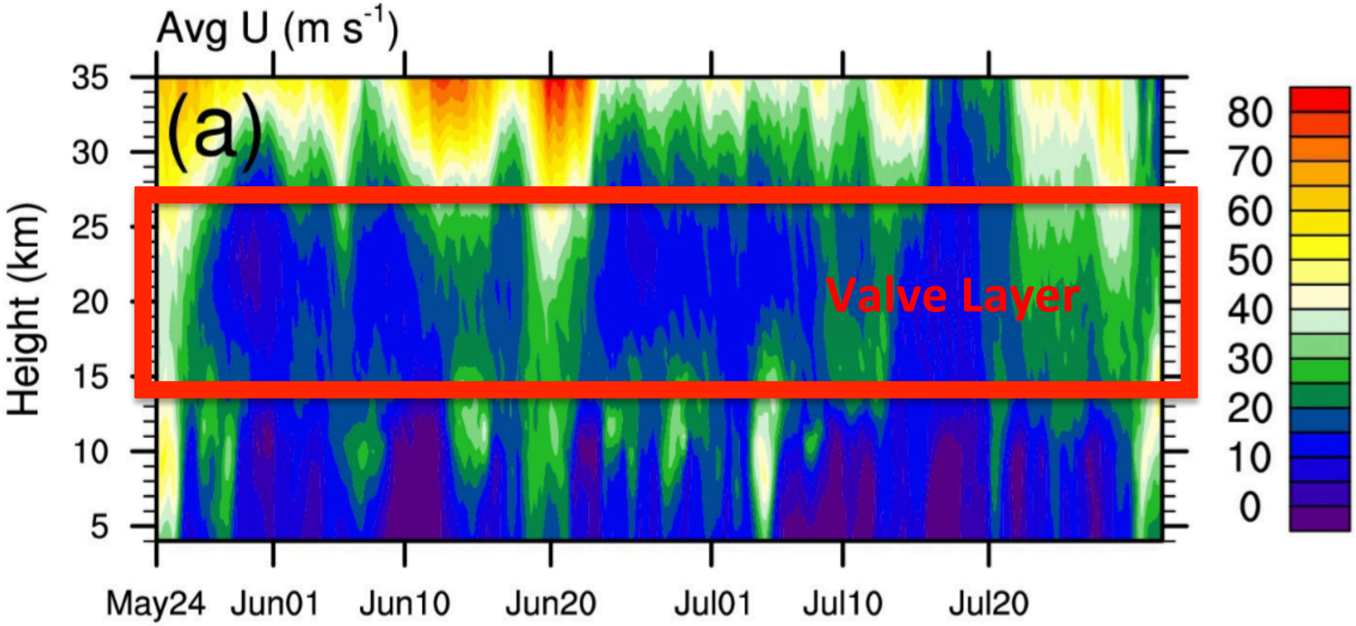


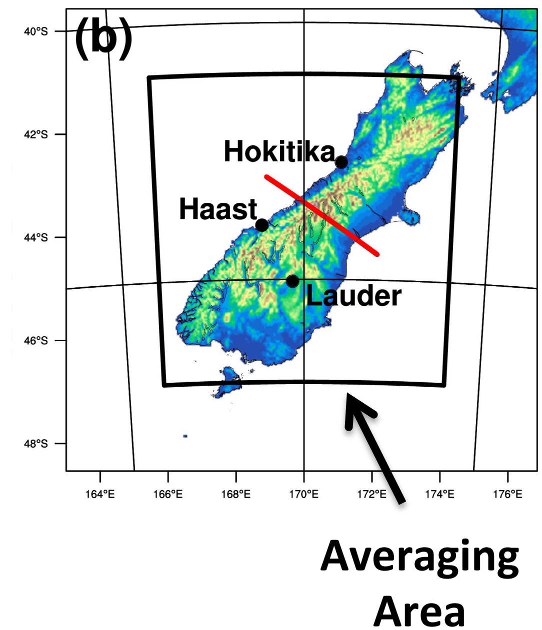
- Leg/Distance Averaged Quantities
- Long Run doesn't reproduce MF_x variability, **but reproduces event averages**
- Long Run Mean Error = +3.838 mPa, -5.56%

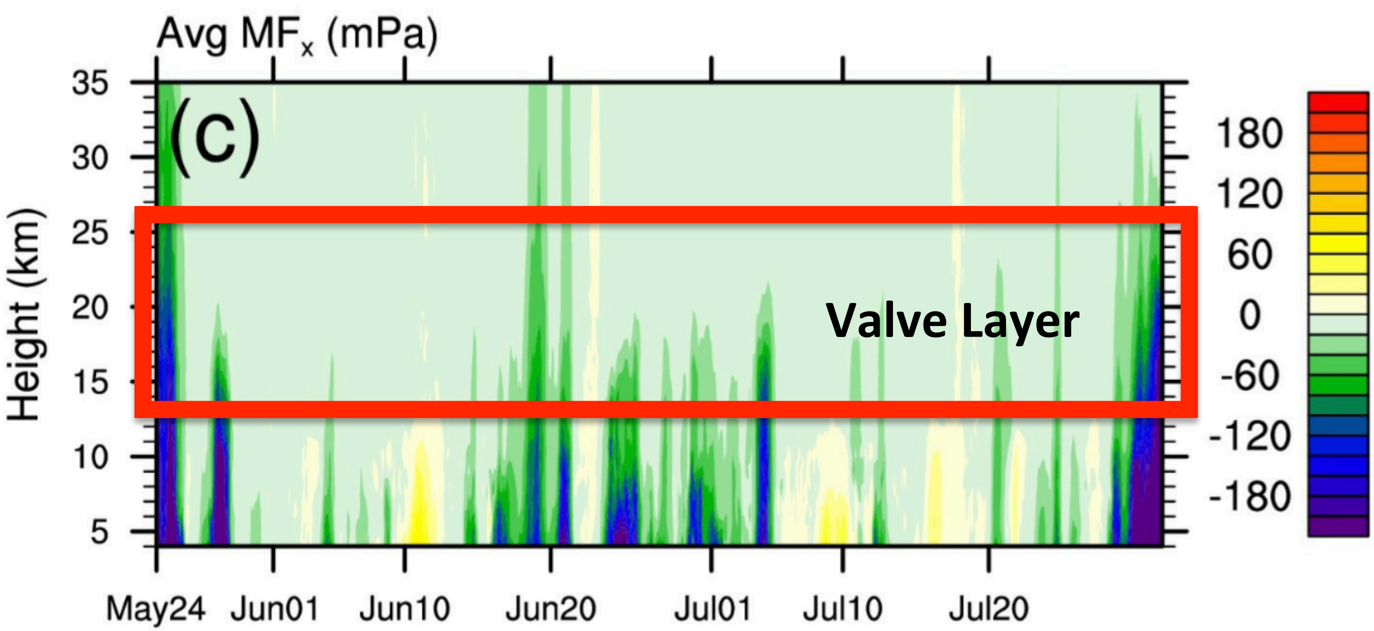
Mountain Wave Propagation over NZ



Mountain Wave Propagation over NZ



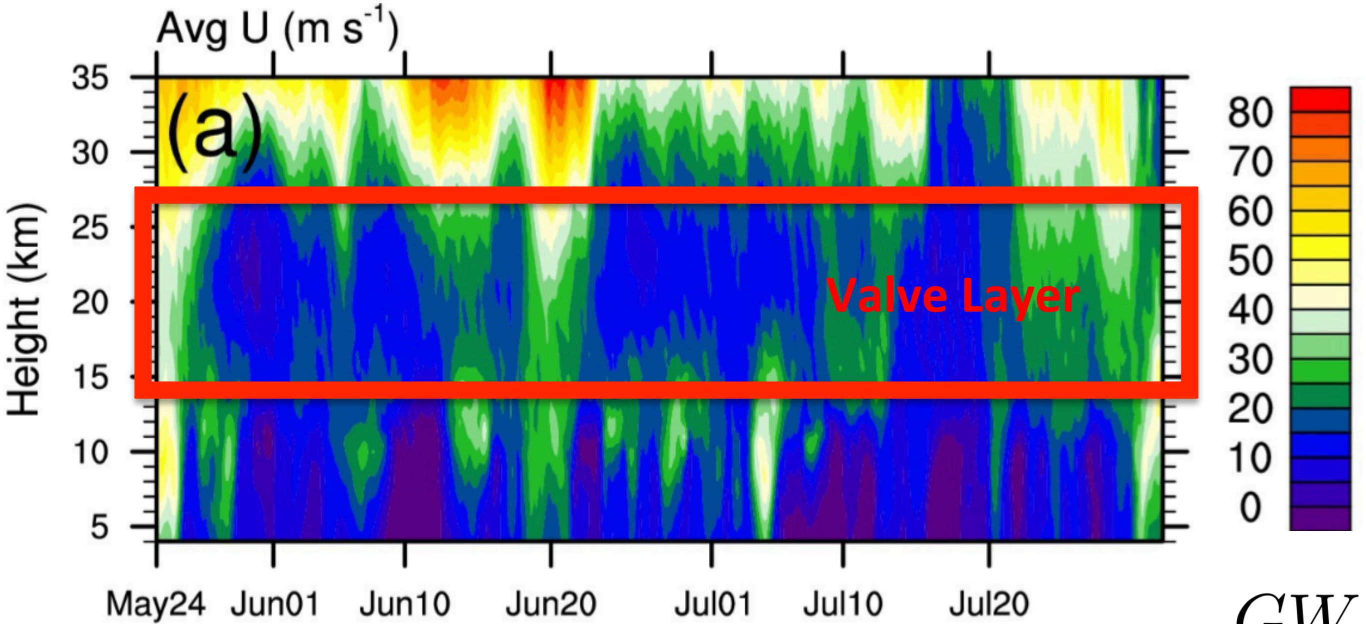




Little mountain wave MF_x gets through a weak wind Mountain Wave "Valve Layer"

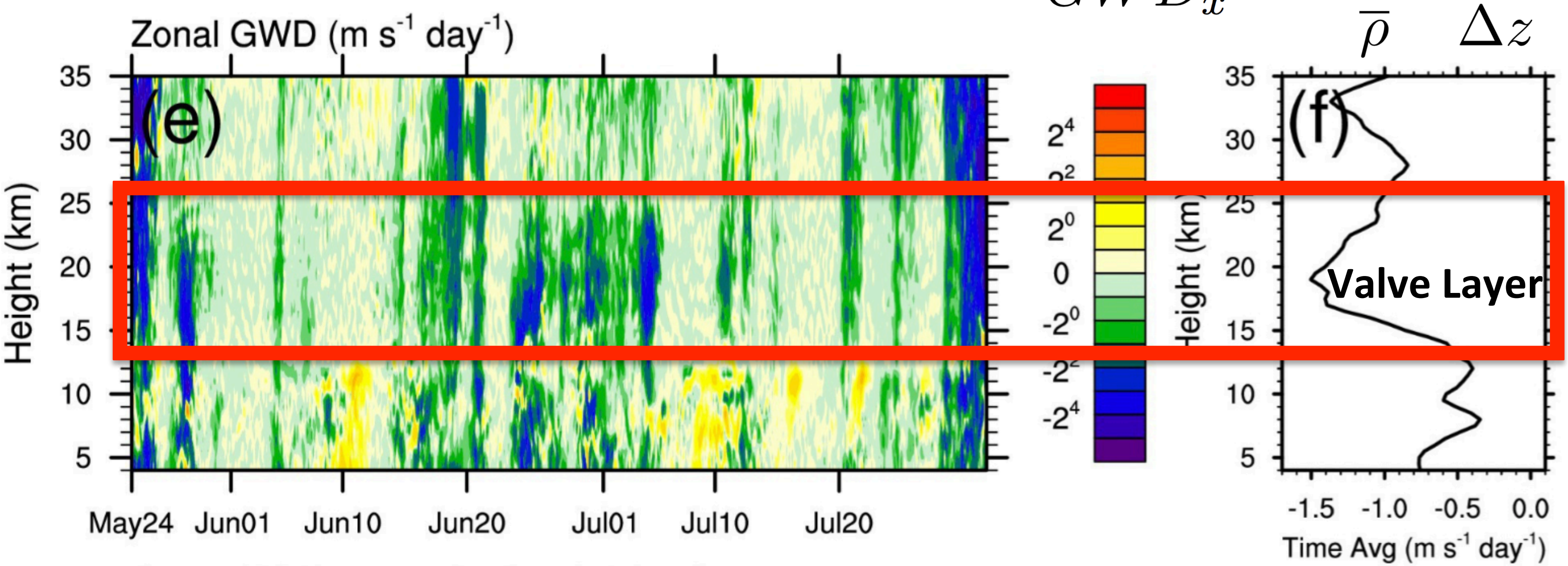
The Valve Layer restricts momentum flux analogous to a valve restricting mass flux through a pipe

Mountain Wave Propagation over NZ



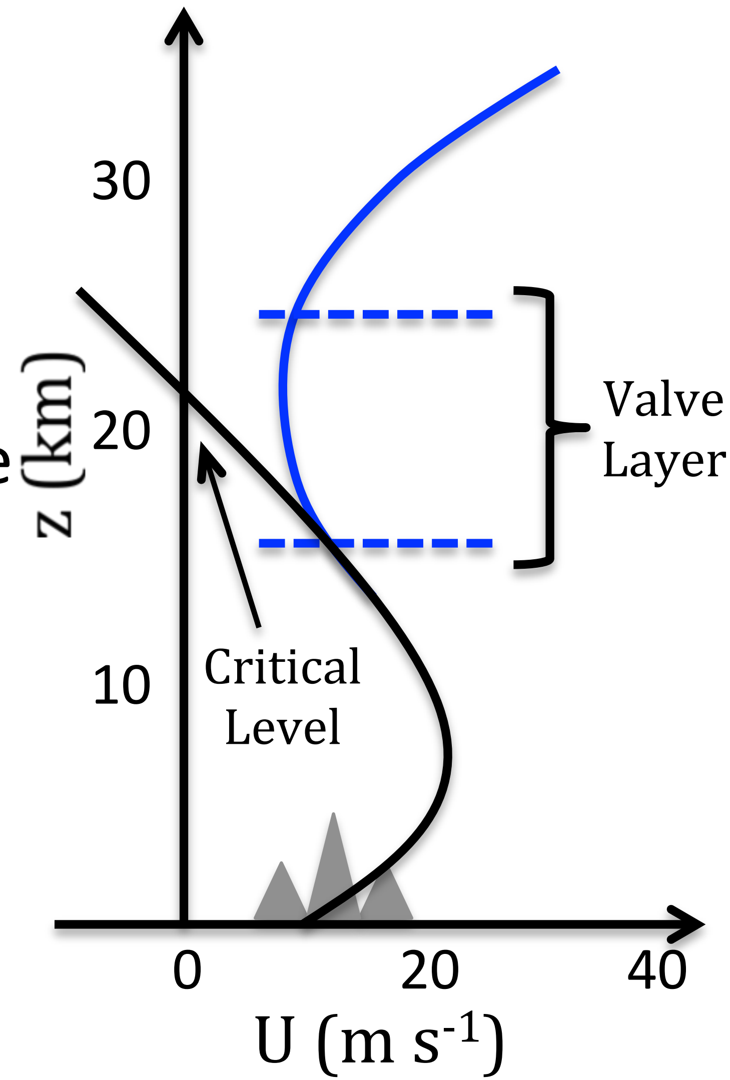
Zonal GWD peaked in Valve Layer

$$GWD_x = -\frac{1}{\overline{\rho}} \frac{\Delta \overline{MF_x}}{\Delta z}$$

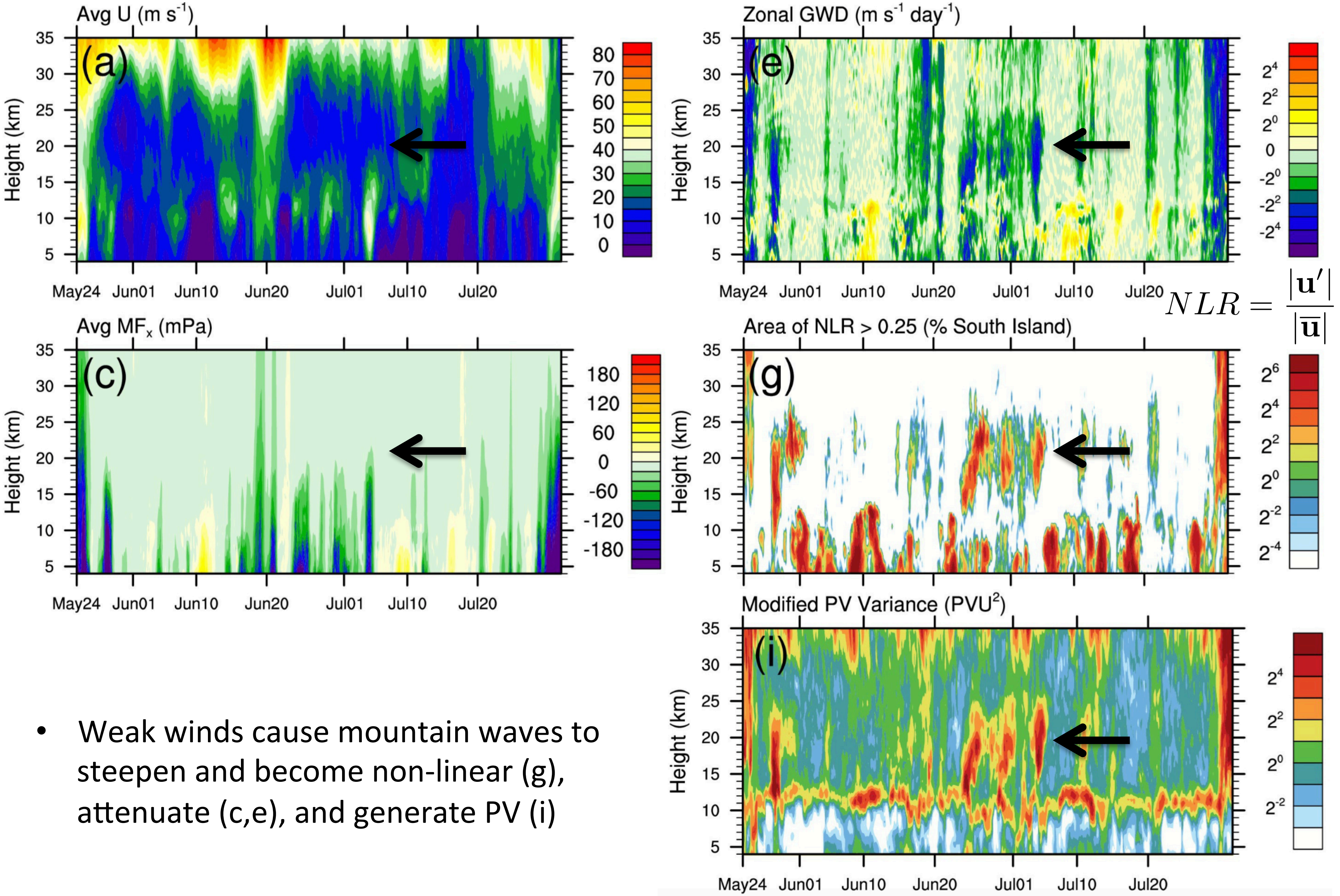


Valve Layer Definition

- Valve Layer: layer with weak winds, but no critical level
  - Waves sometimes transmitted, sometimes attenuated, depending on incident amplitude and layer conditions
  - Momentum fluxed through controlled by minimum wind speed
  - Typical during DEEPWAVE!!



Attenuation Characteristics

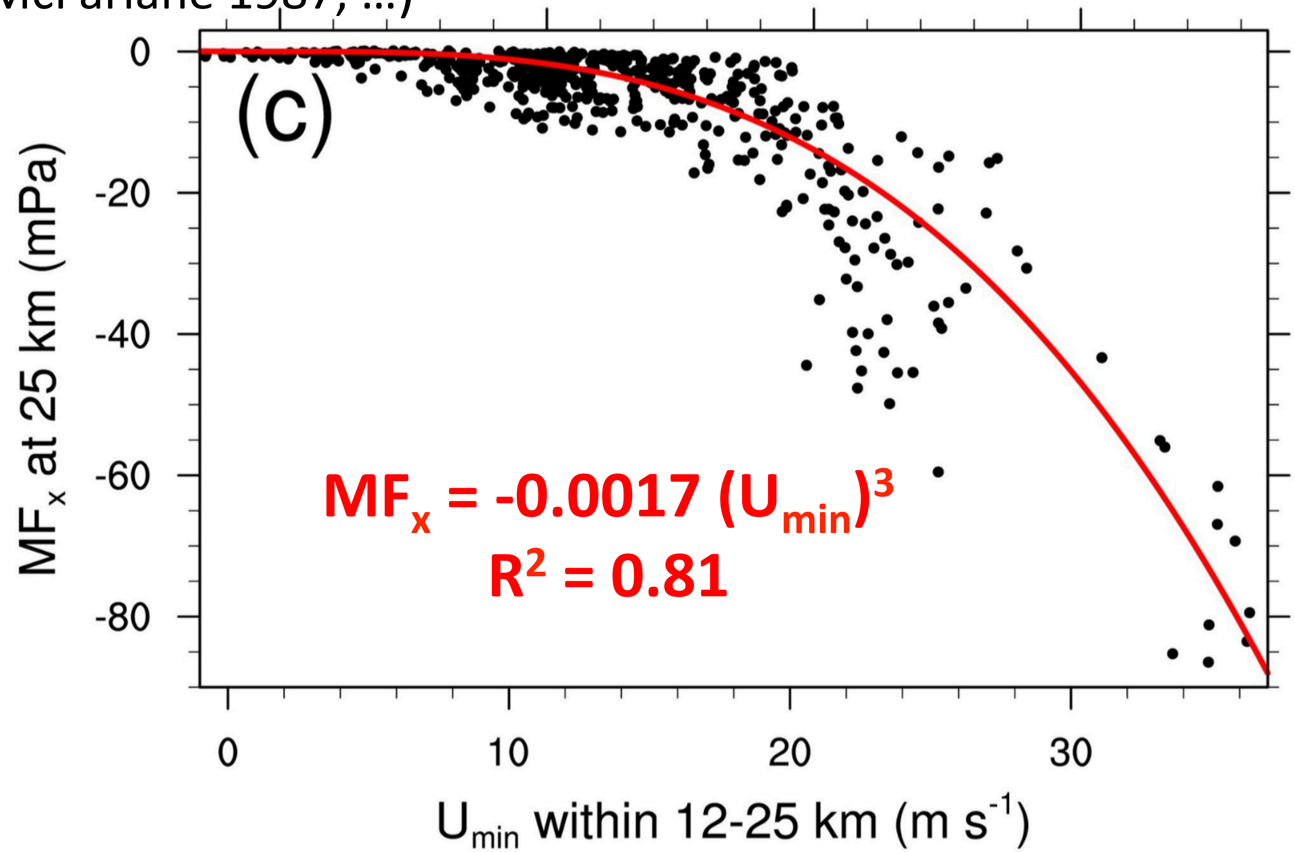


$$NLR = \frac{|\mathbf{u}'|}{|\overline{\mathbf{u}}|}$$

- Weak winds cause mountain waves to steepen and become non-linear (g), attenuate (c,e), and generate PV (i)

What Controls MF_x Transmission?

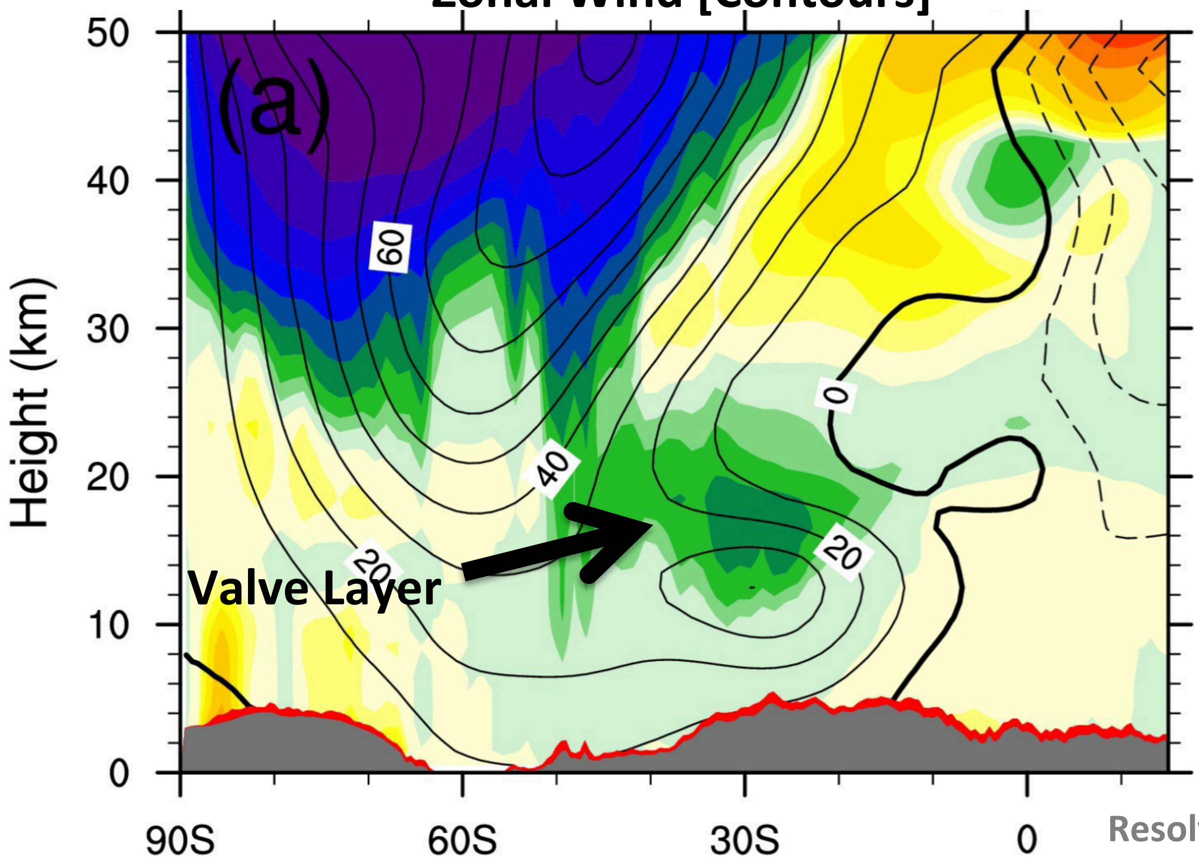
- Minimum wind speed primarily controls amount of MF_x transmitted
- Cubic fit well approximates relation between transmitted MF_x and minimum wind speed
  - Cubic relation consistent with linear saturation theory (Lindzen 1981, Palmer 1986, McFarlane 1987, …)



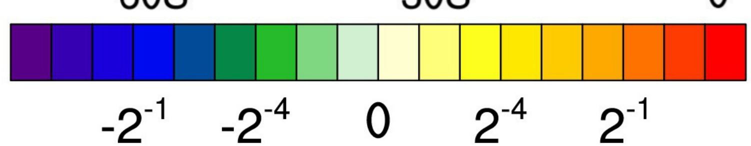
MERRA Zonal, Time Avg GWD, Wind

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

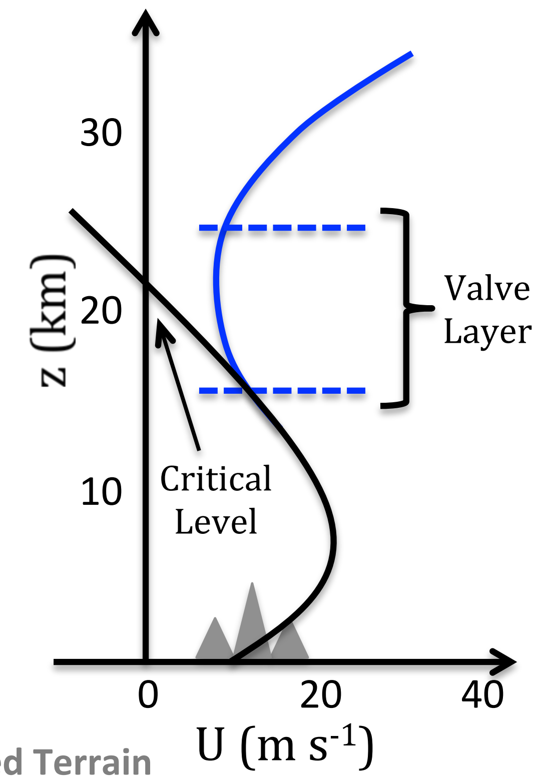
MERRA Zonal GWD ($m\ s^{-1}\ day^{-1}$) [Color]
Zonal Wind [Contours]



Zonal, Time Avg
June, July 2010-1015



Resolved Terrain
Subgrid-scale Terrain



GW Parameterization in MERRA, MERRA2

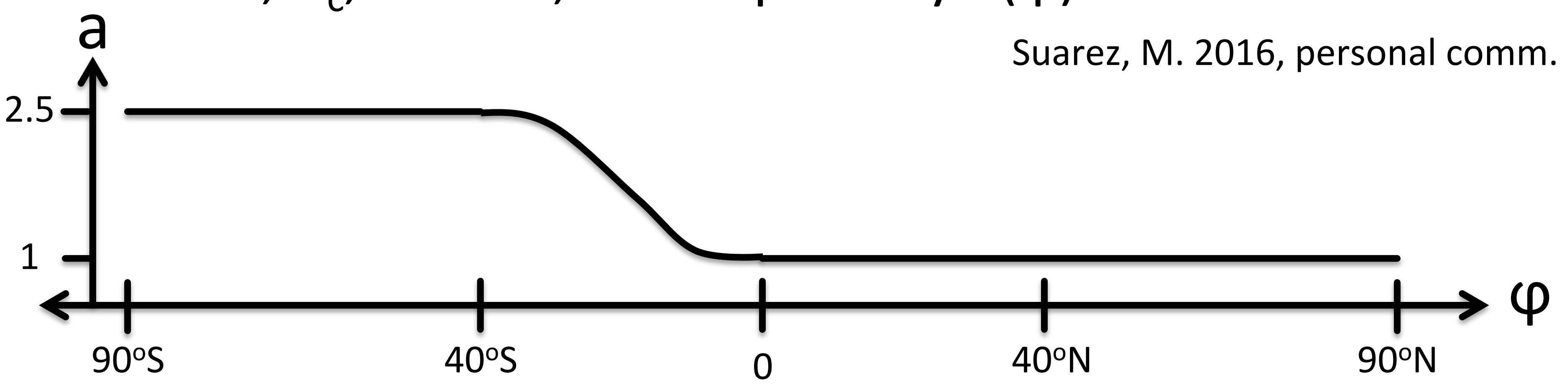
- Both use McFarlane 1987 GWD parameterization
- Saturated momentum flux relation:

$$MF_{x_{sat}} = -\frac{F_c^2 \epsilon k}{2} \frac{\overline{\rho}\,\overline{u}^3}{N}$$

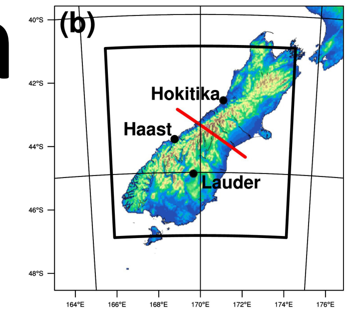
Tuning parameters: F_c-critical Froude number, ε-efficiency factor, k-wavenumber

- **MERRA**, $F_c = 0.5$, $\varepsilon = 0.125$, $\lambda = 2\pi/k = 100$ km
- **MERRA2**, F_c, λ same, ε multiplied by a(φ):

Suarez, M. 2016, personal comm.

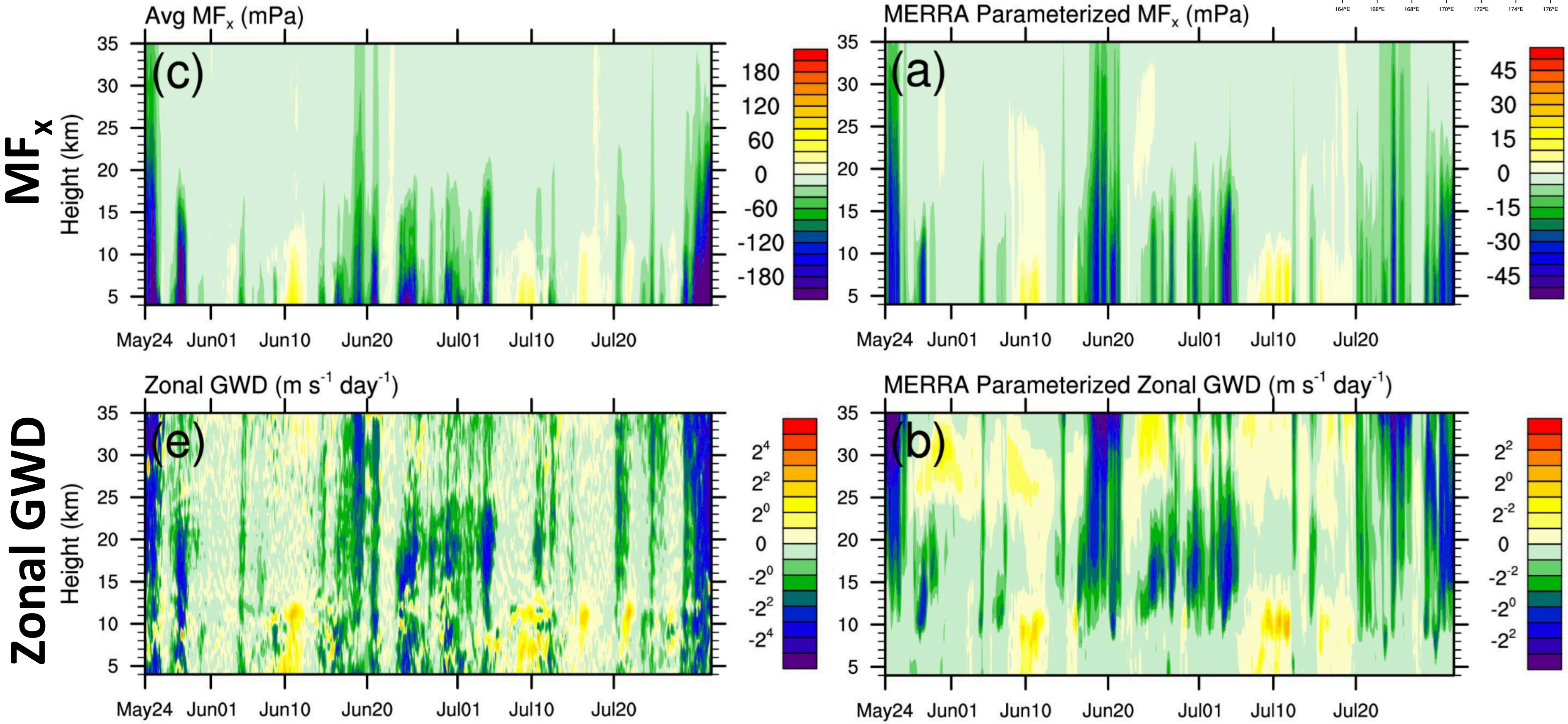


WRF, MERRA Comparison

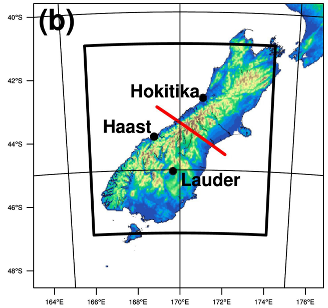


Over New Zealand

WRF **MERRA**



WRF, MERRA Comparison

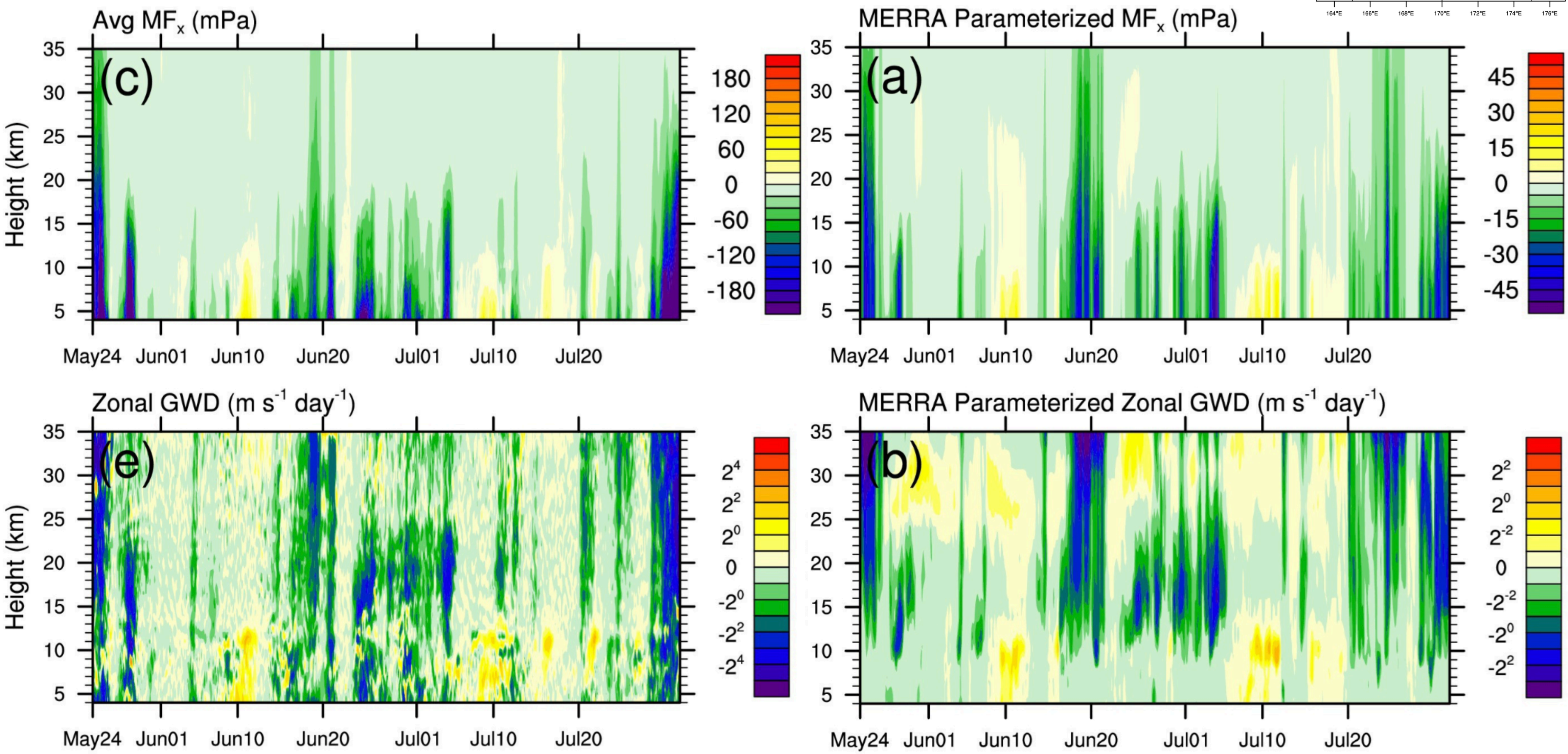


Over New Zealand

WRF | **MERRA**

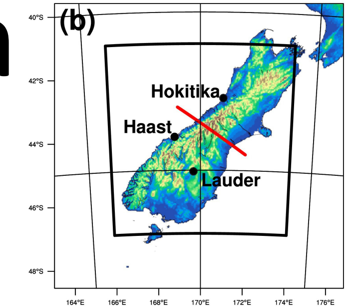
MF_x

Zonal GWD

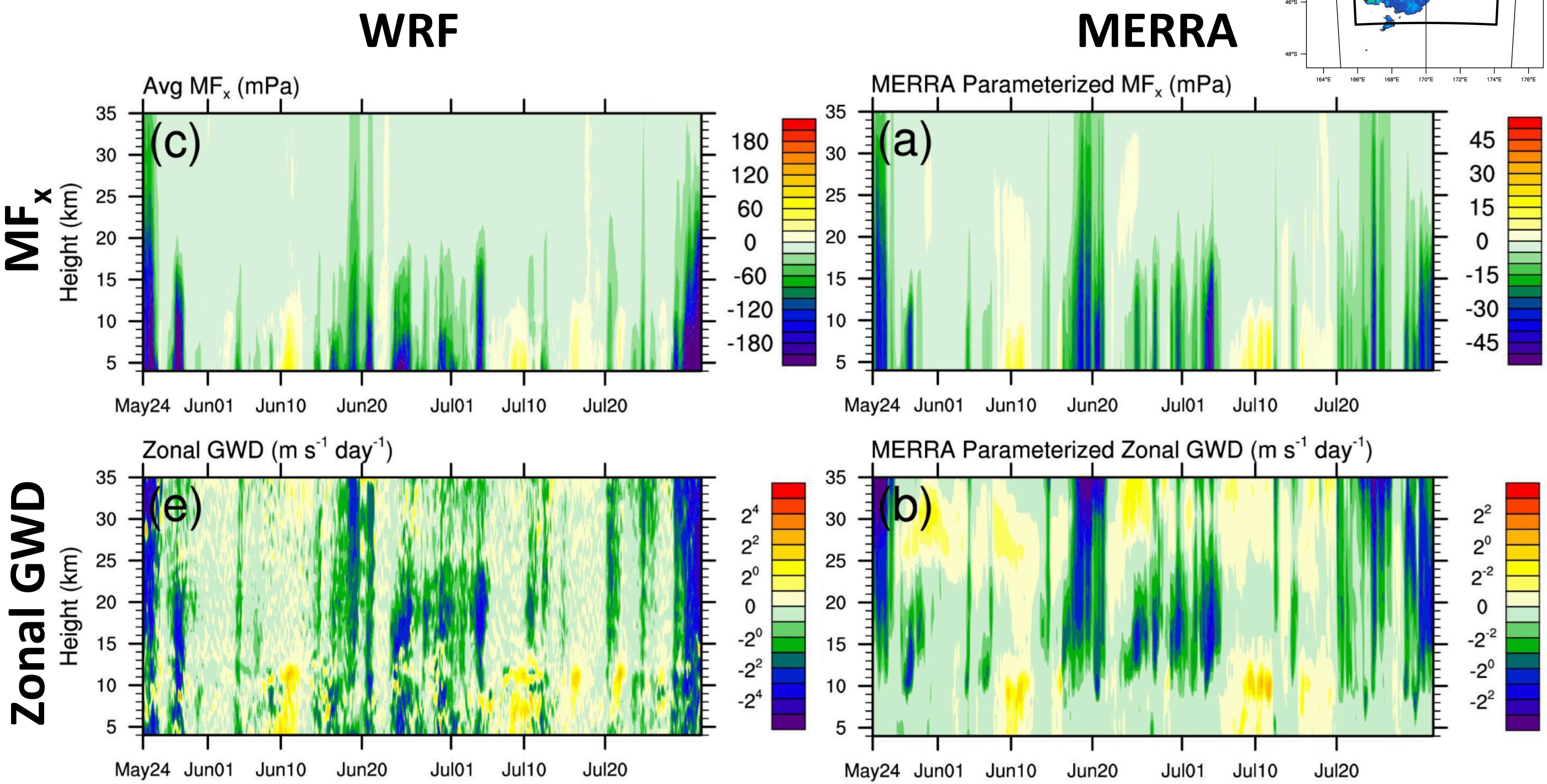


NOTE: MERRA Contours ¼ of WRF!

WRF, MERRA Comparison



Over New Zealand

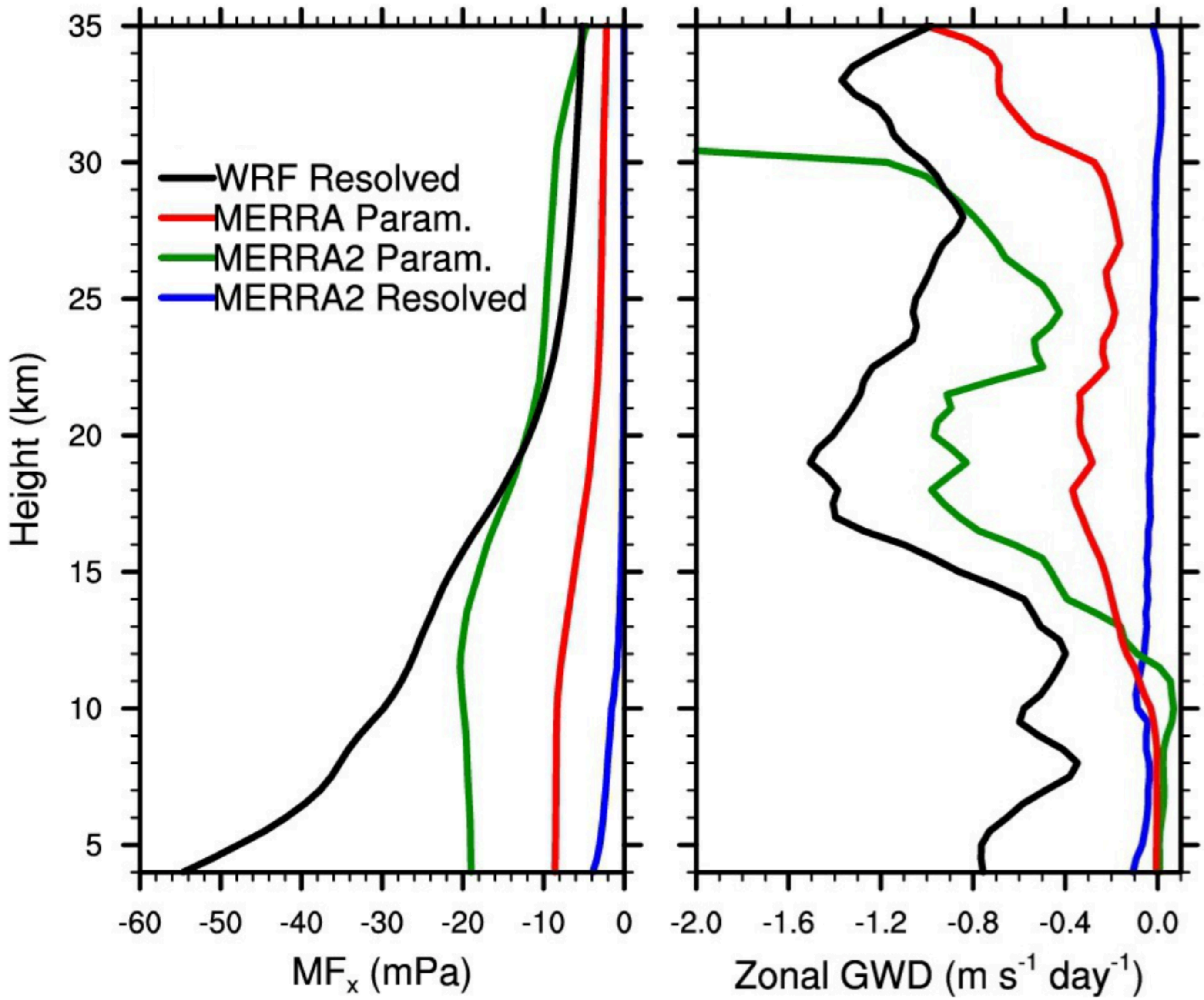


NOTE: MERRA Contours ¼ of WRF!

MERRA2 similar to, but larger than MERRA (not shown)

WRF, MERRA, MERRA2 Comparison

Area, Time (24 May-1 Aug) Average



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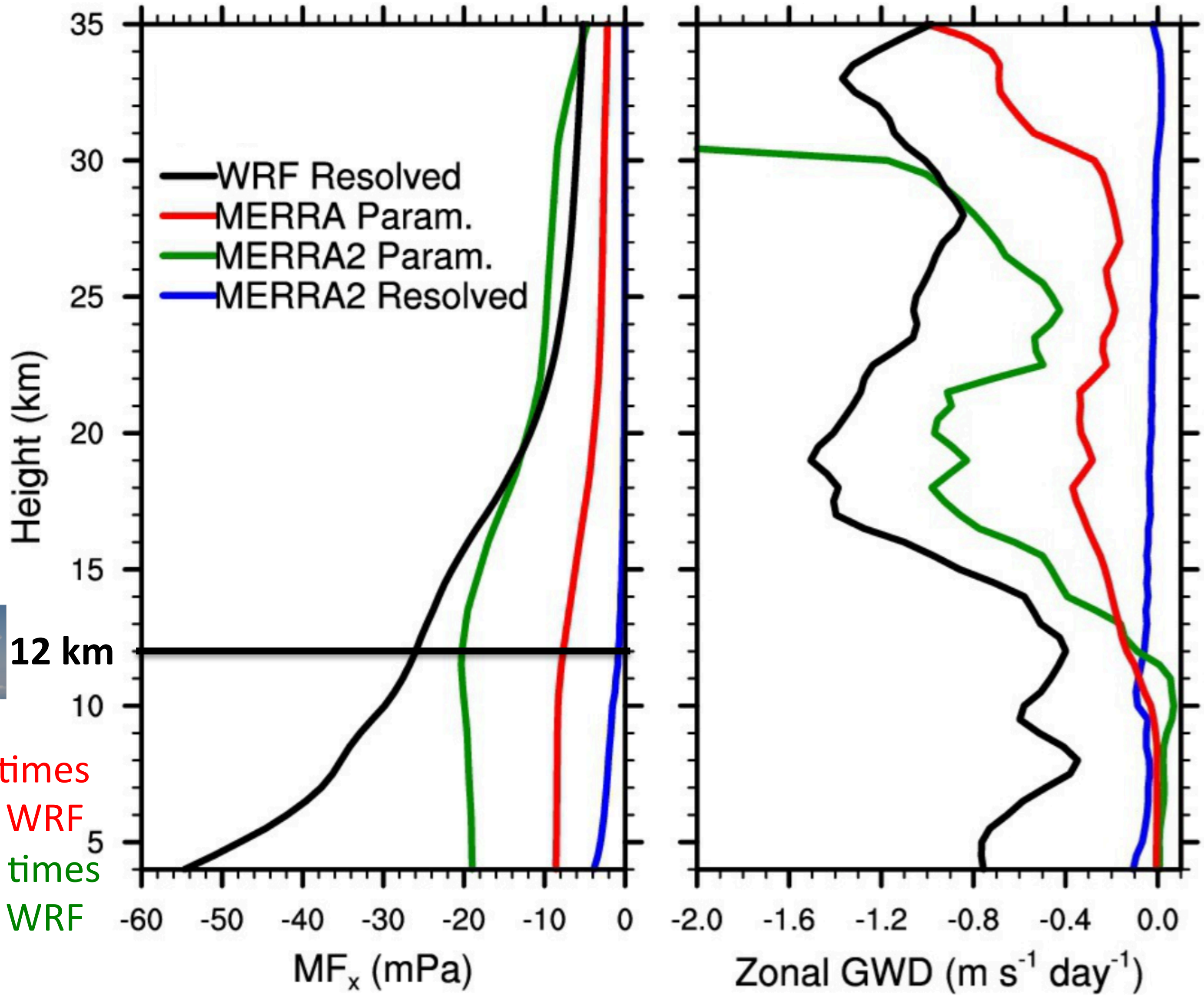
Area, Time (24 May-1 Aug) Average

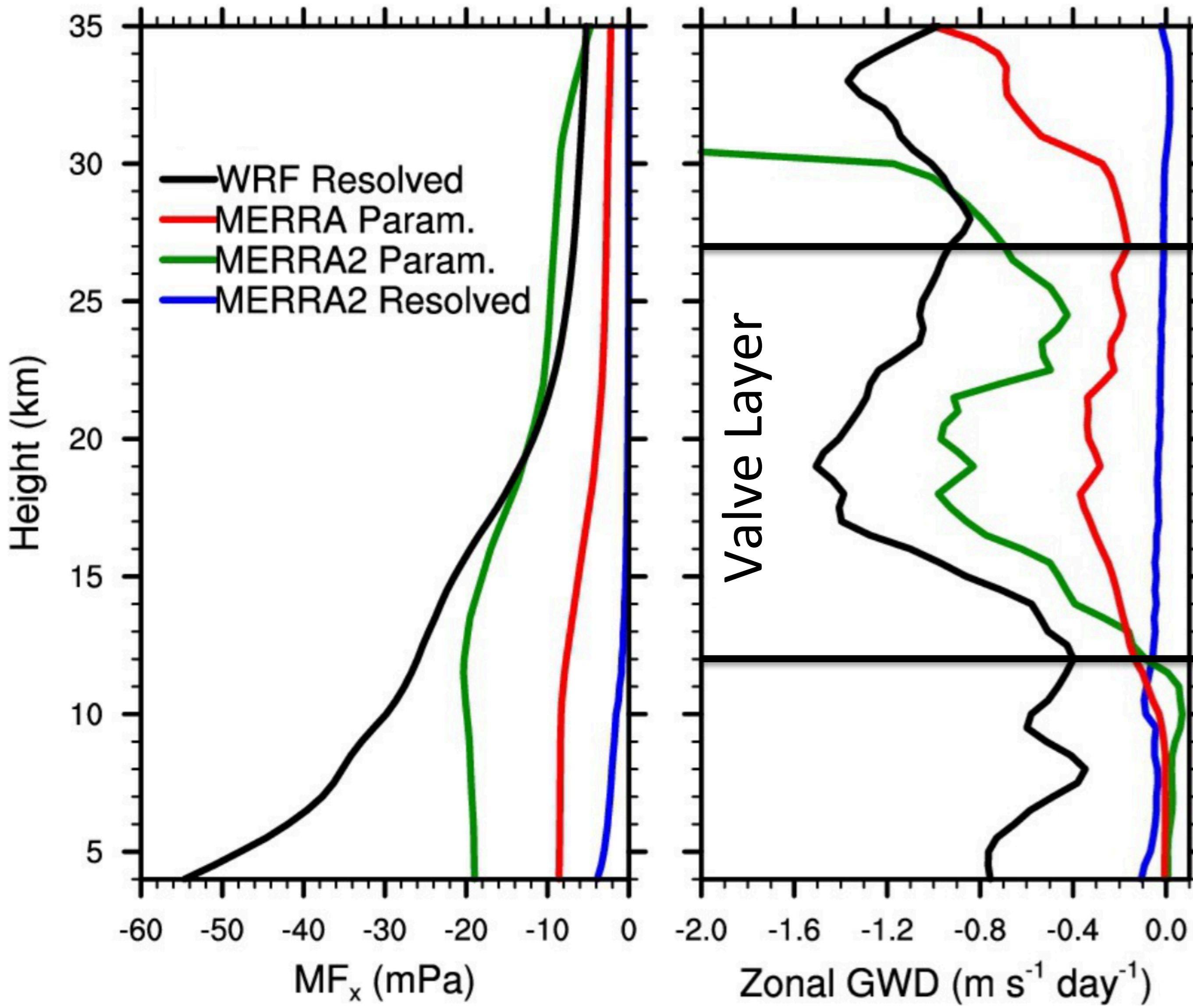


MERRA ≈3.5 times smaller than WRF

MERRA2 ≈1.3 times smaller than WRF

WRF, MERRA, MERRA2 Comparison

Area, Time (24 May-1 Aug) Average

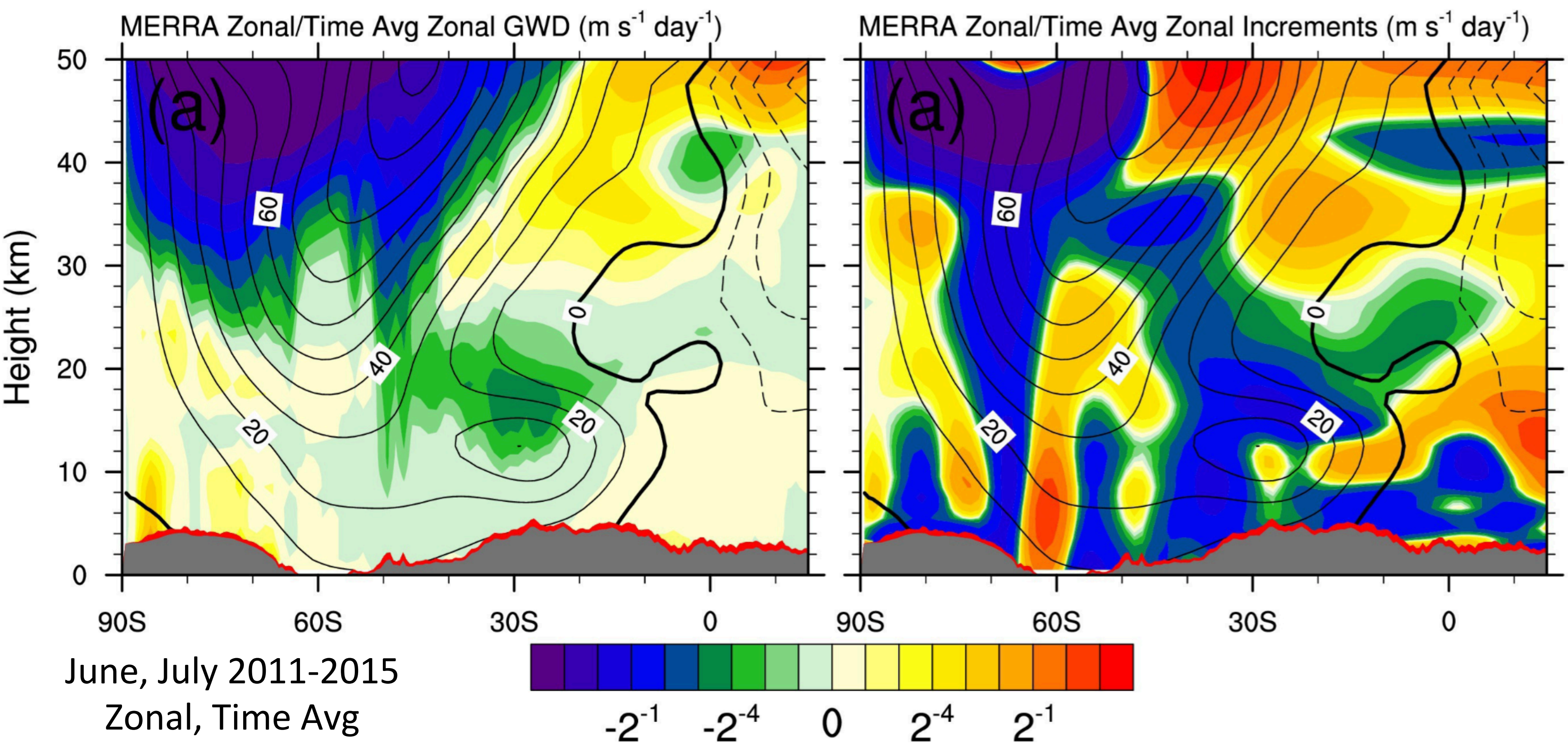


MERRA GWD ≈3-5 times smaller than WRF

MERRA2 GWD ≈1.5 times smaller than WRF

MERRA Winds, GWD_x, Increments

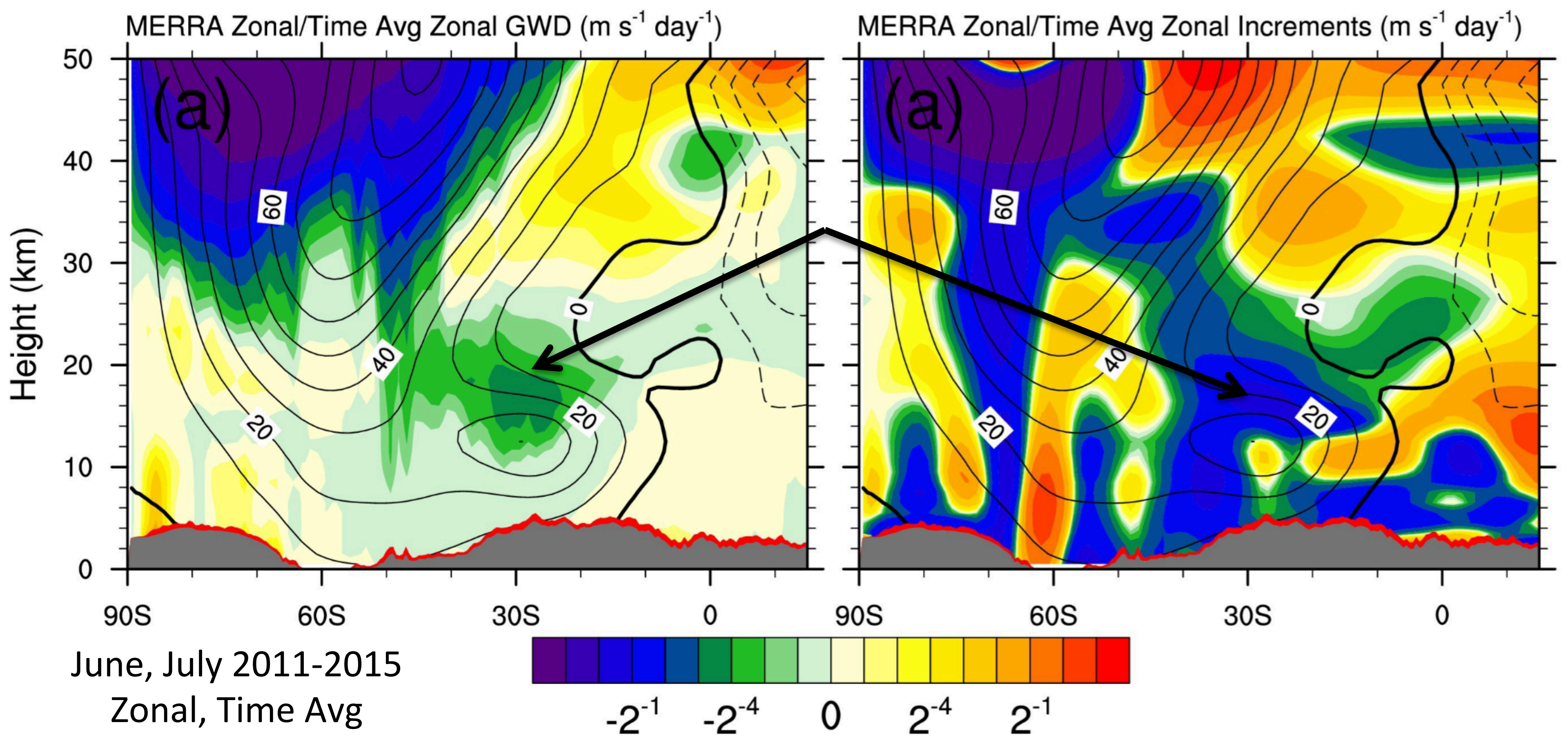
- Increments
  - Six hourly model errors, expressed as a tendency
  - Used to force model toward observations within governing equations
  - Interpreted by McLandress et al. (2012) as a missing GWD in the model



June, July 2011-2015
Zonal, Time Avg

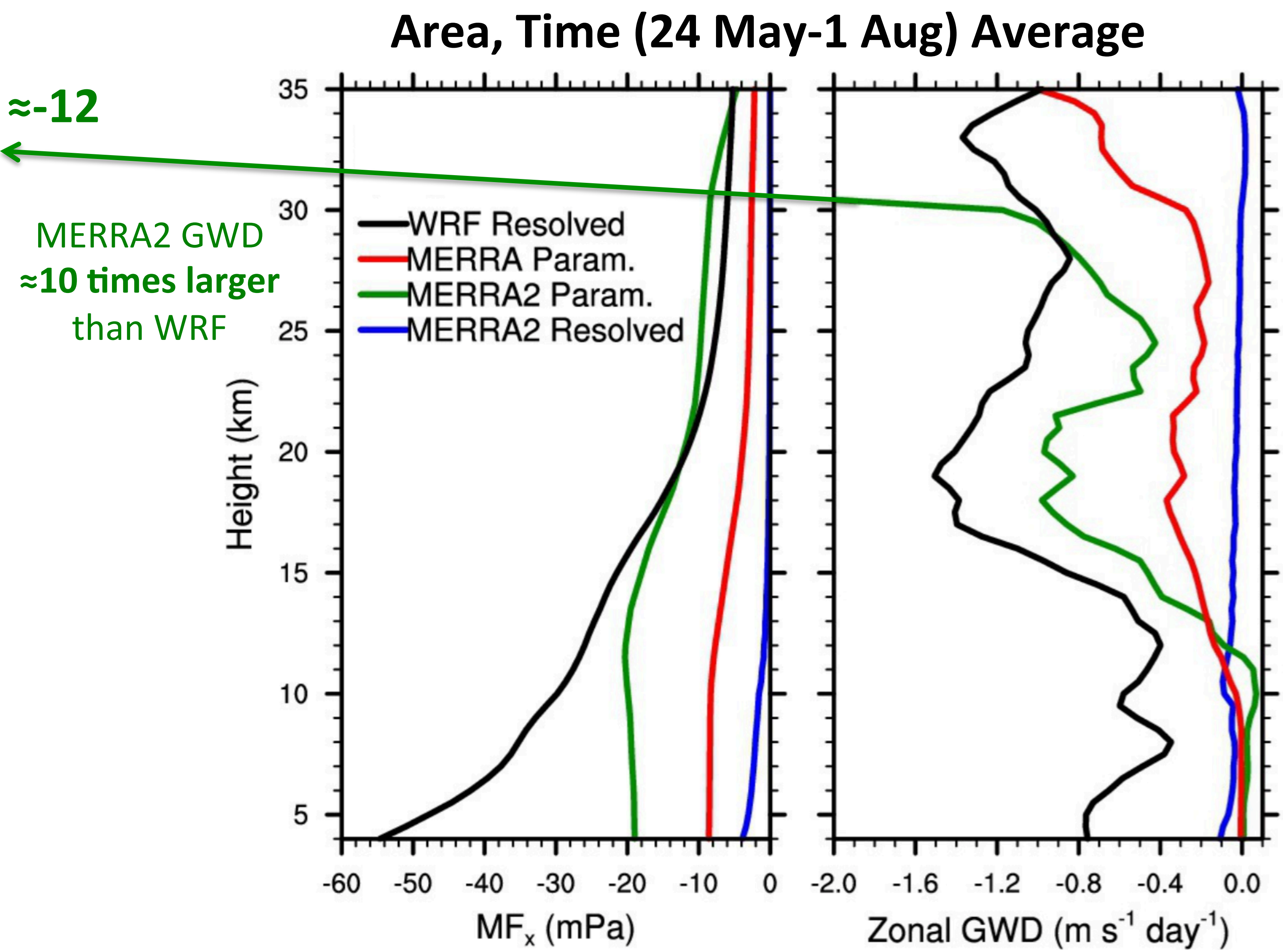
MERRA Winds, GWD_x, Increments

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



June, July 2011-2015
Zonal, Time Avg

WRF, MERRA, MERRA2 Comparison



MERR2 GWD Overrepresentation

$$MF_{x_{sat}} = -\frac{F_c^2 \epsilon k}{2} \frac{\overline{\rho}\,\overline{u}^3}{N}$$

- Over New Zealand, ε increased by 2.5

  => Increases source *and saturated* MF_x
- More MF_x into valve layer, more GWD there
  - Needed in MERRA GCM
- However, more MF_x is transmitted through the valve layer

  => More GWD aloft
- Changing the saturated MF_x inconsistent with WRF results!
  - Transmitted MF_x does not depend on MF_x below
- Suggest removing dependence on efficiency factor (ε) from saturated MF_x relation

Conclusions

- WRF reproduced observed ambient environment, event mean MF_x
- Mountain waves frequently attenuated in a climatological Valve Layer
- Valve Layer MF_x, GWD underrepresented in MERRA GCM by factor of 3-5
- This issue reduced in MERRA2, but GWD overrepresented above by factor of 10
- Careful modification of GWD parameterizations and their tuning parameters is warranted
  - Suggest increasing source MF_x without increasing saturated MF_x

Kruse, C. G., R. B. Smith, and S. D. Eckermann, 2016: The Mid-Latitude Lower-Stratospheric Mountain Wave “Valve Layer.” *JAS*, Accepted.