Mountain Wave Evolution in Response to Rapidly Decreasing Cross-Mountain Flow Observed by FF9, FF10, and RF22

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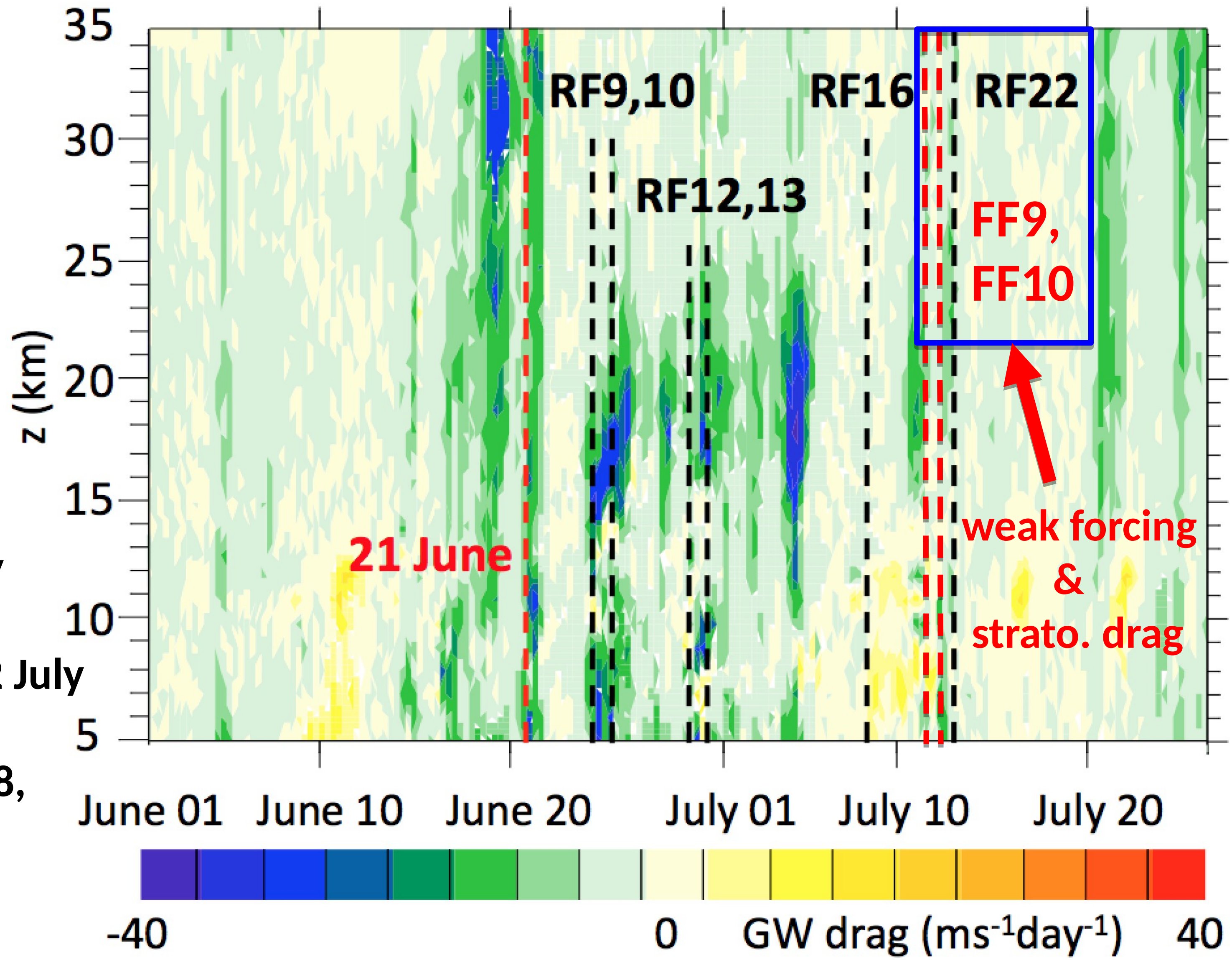
Focus on MW event spanning ~2 days; 12-13 July

- cross-mountain flow decreased strongly over the event
- stratospheric winds yielded a strong propagation channel into the mesosphere

GW drag
from WRF 6-km
continuous run



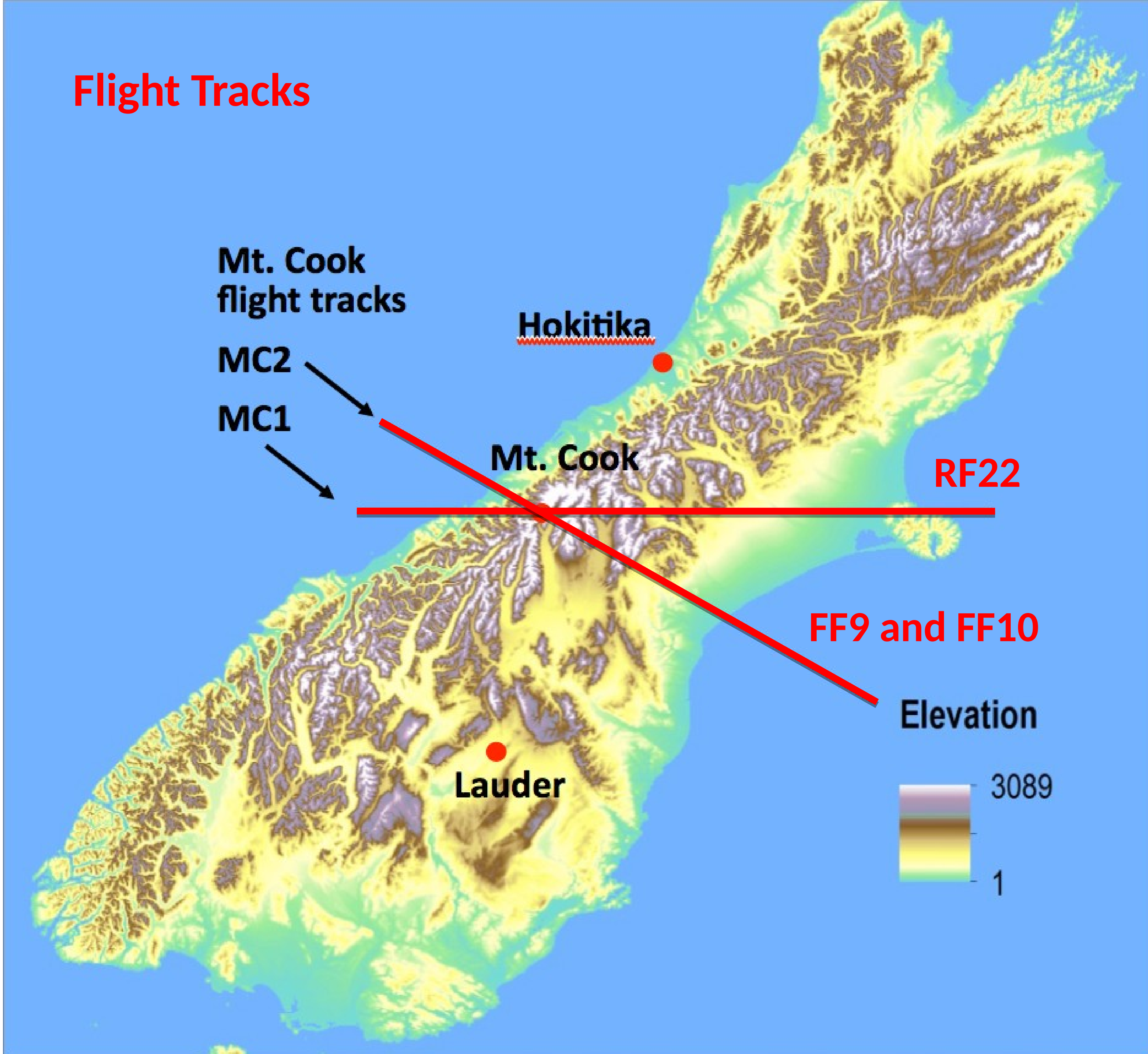
Flights included:

FF9 ~19 UT 12 July

FF10 ~23:75 UT 12 July

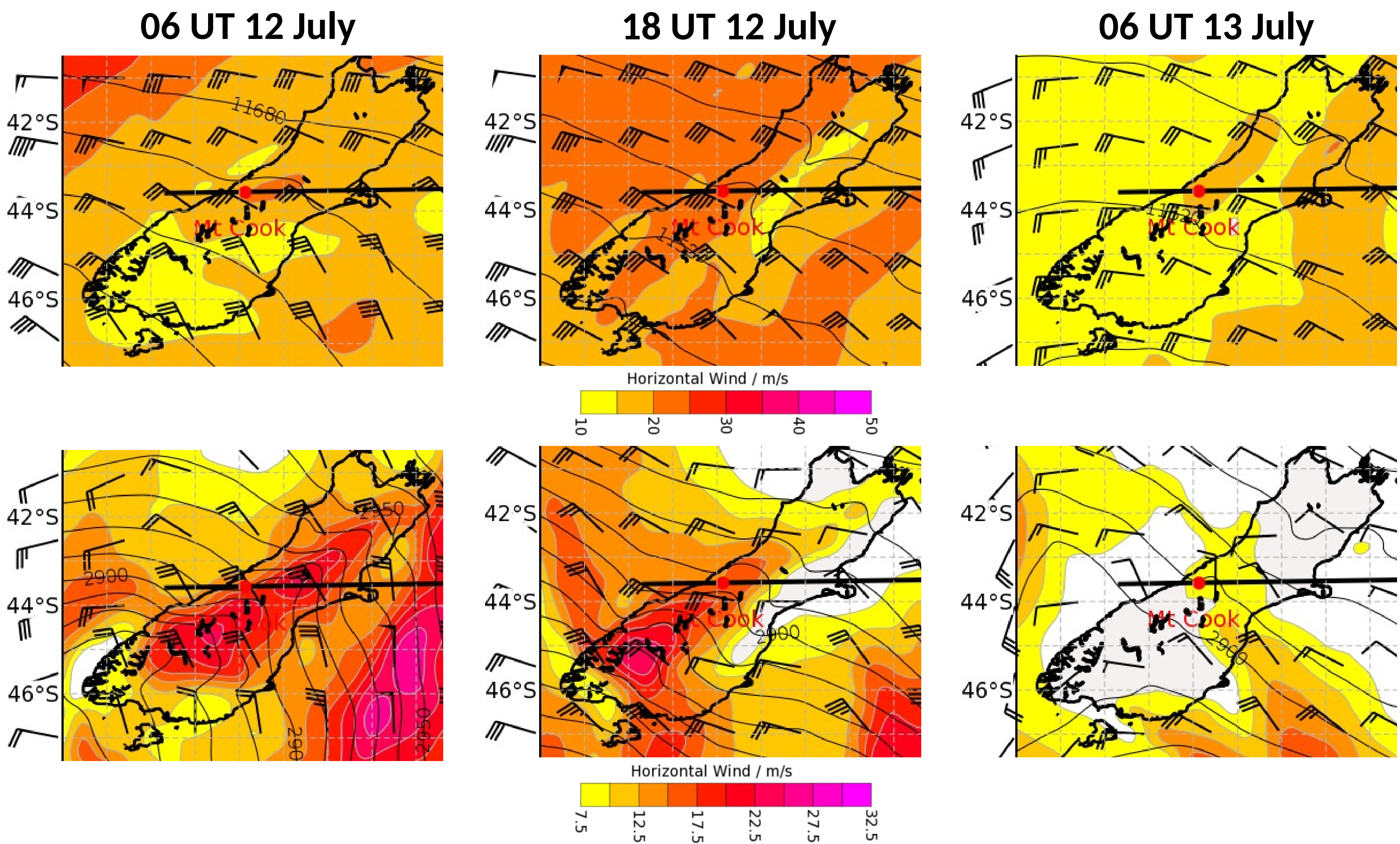
RF12 ~6:20, 7:10, 8, and 8:50 13 July

Flight Tracks



ECMWF 700 and 200 hPa geopotential height winds

- frontal passage, accel. cross-mtn. flow up to ~15 UT at ~200-700 hPa on 12 July
- decreasing cross-mtn. flow ~15 UT 12 July to ~03 UT 13 July

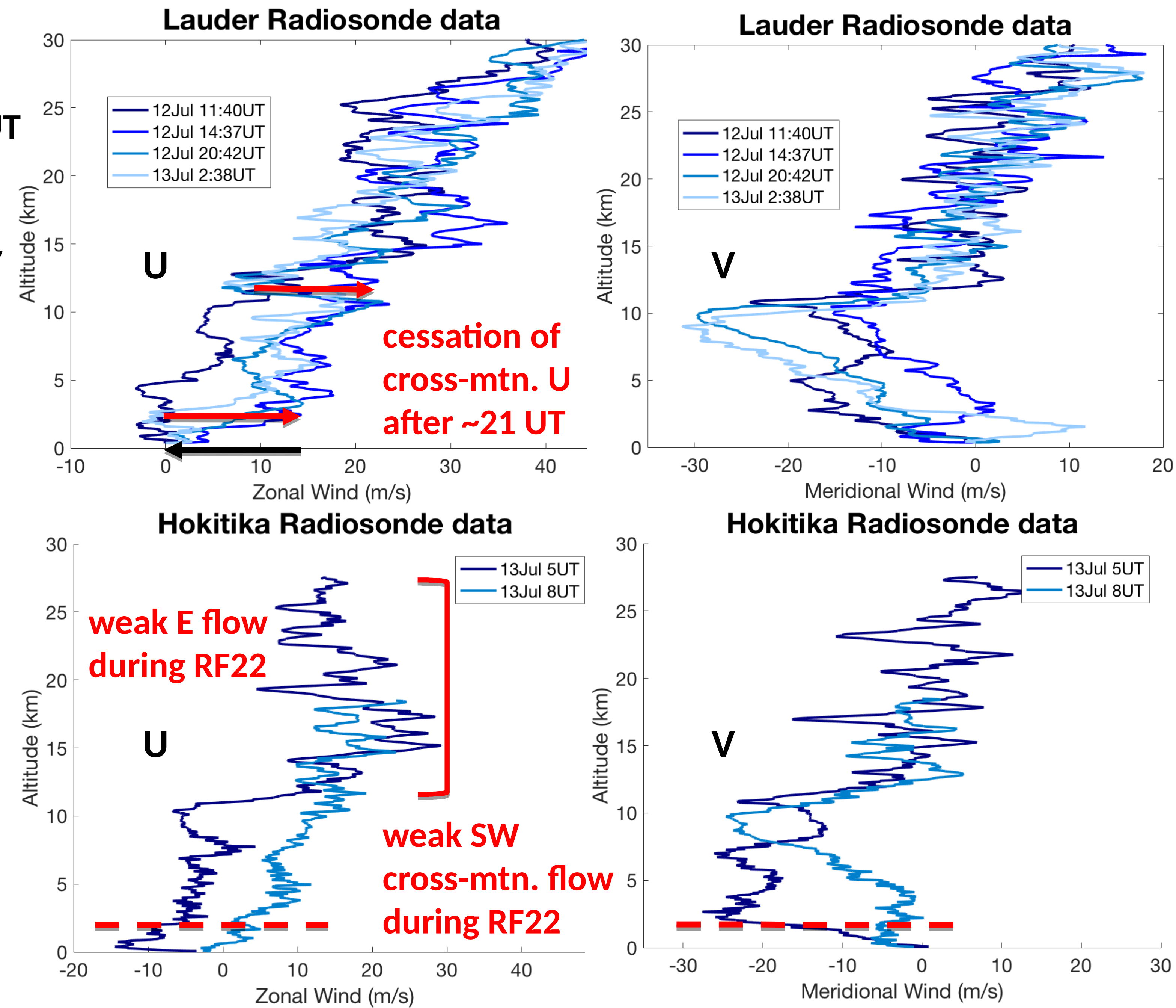


Radiosondes at Lauder and Hokitika

Lauder: 11:40, 14:37, & 20:42 UT on 12 July;

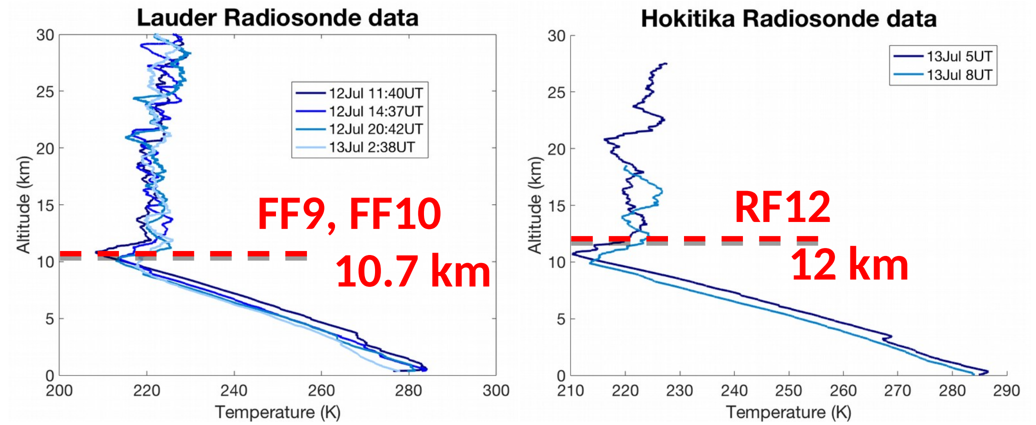
02:38 on 13 July

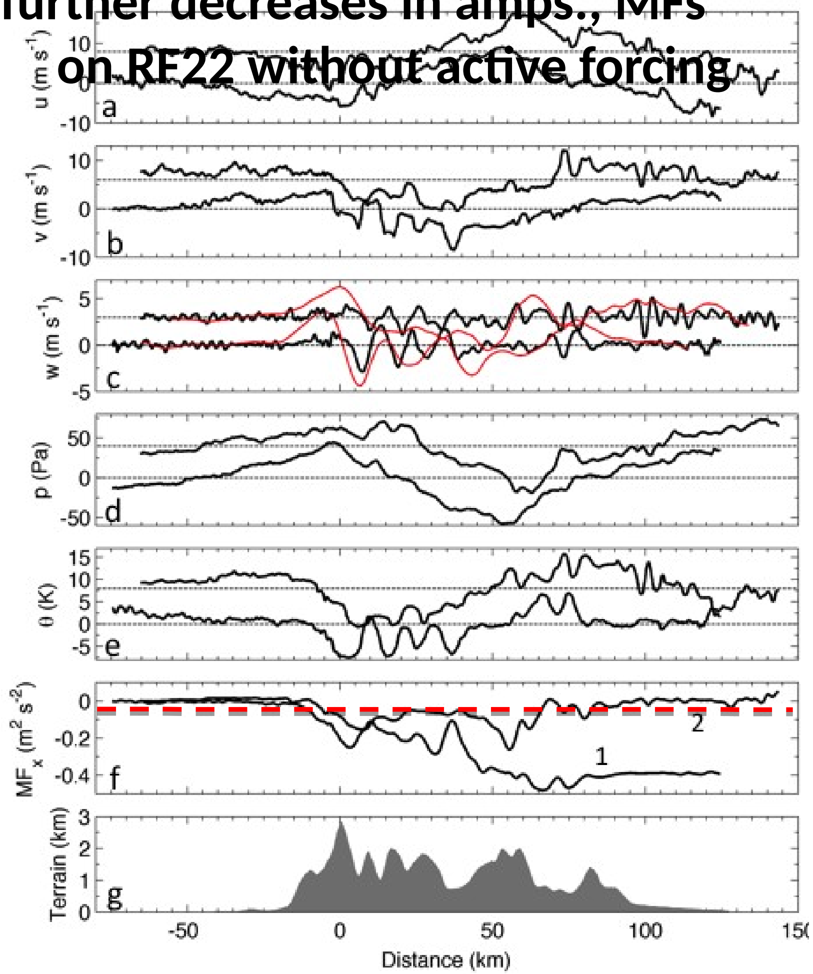
Hokitika: 05 and 08 UT on 13 July

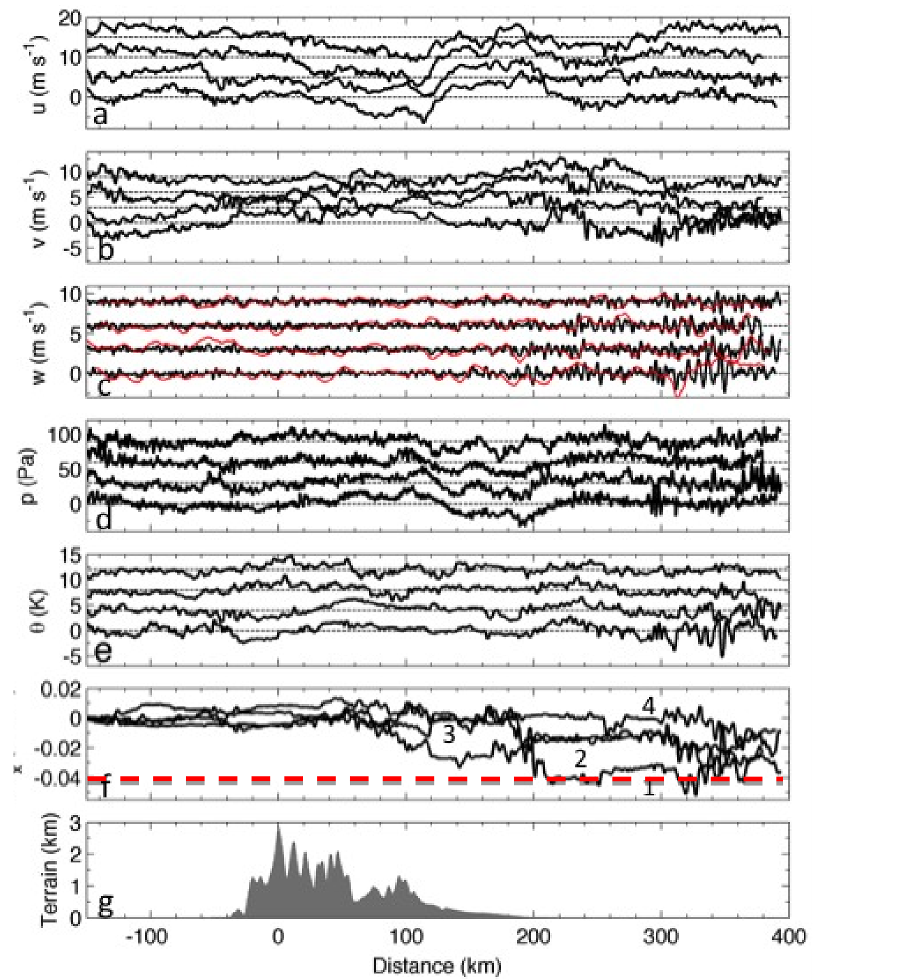


Flight-level observations

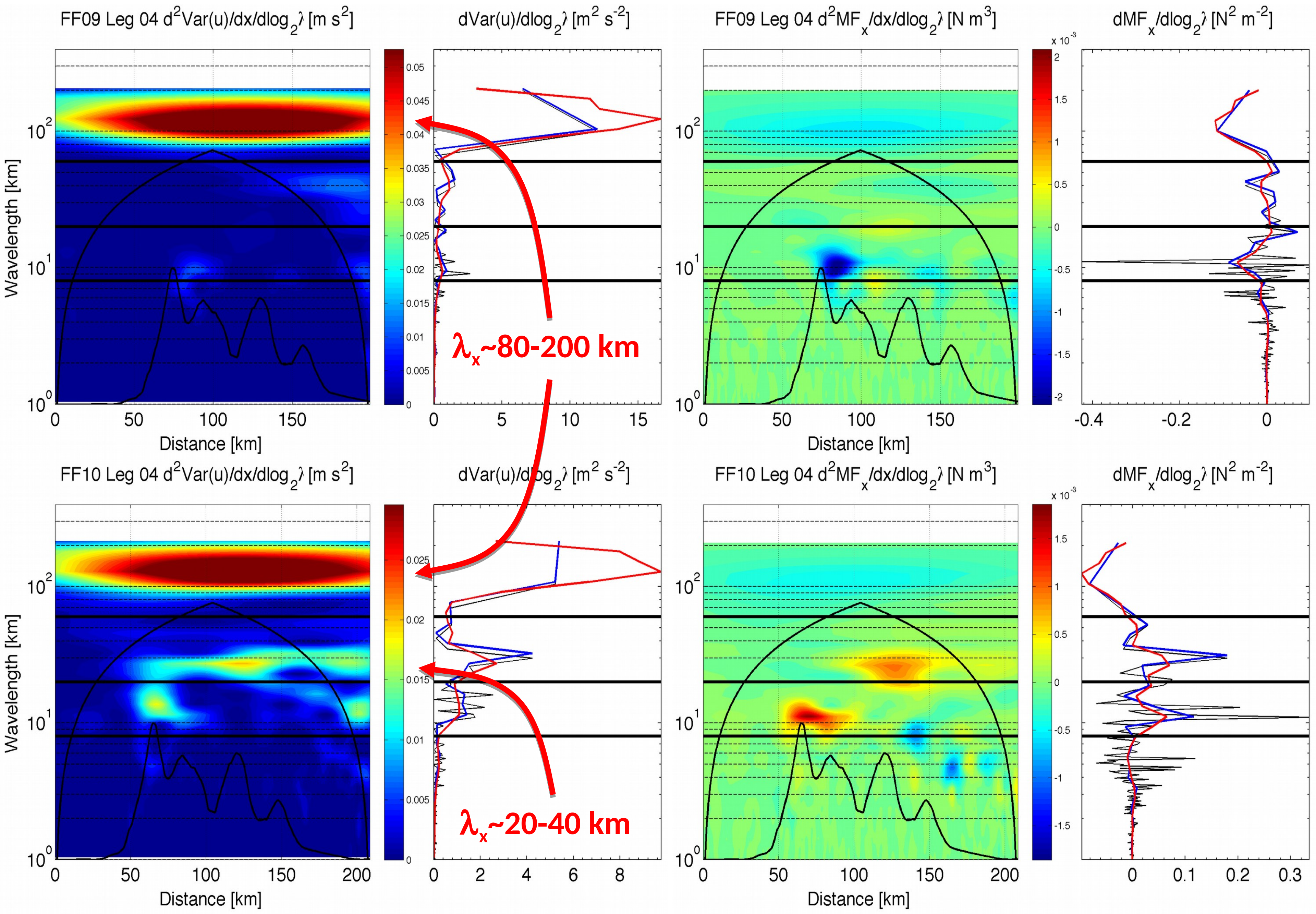
- very strong FF9 responses in strong
  cross-mountain flow
- smaller-scale MFs ~10 times
  smaller on FF10
- further decreases in amps., MFs
  on RF22 without active forcing



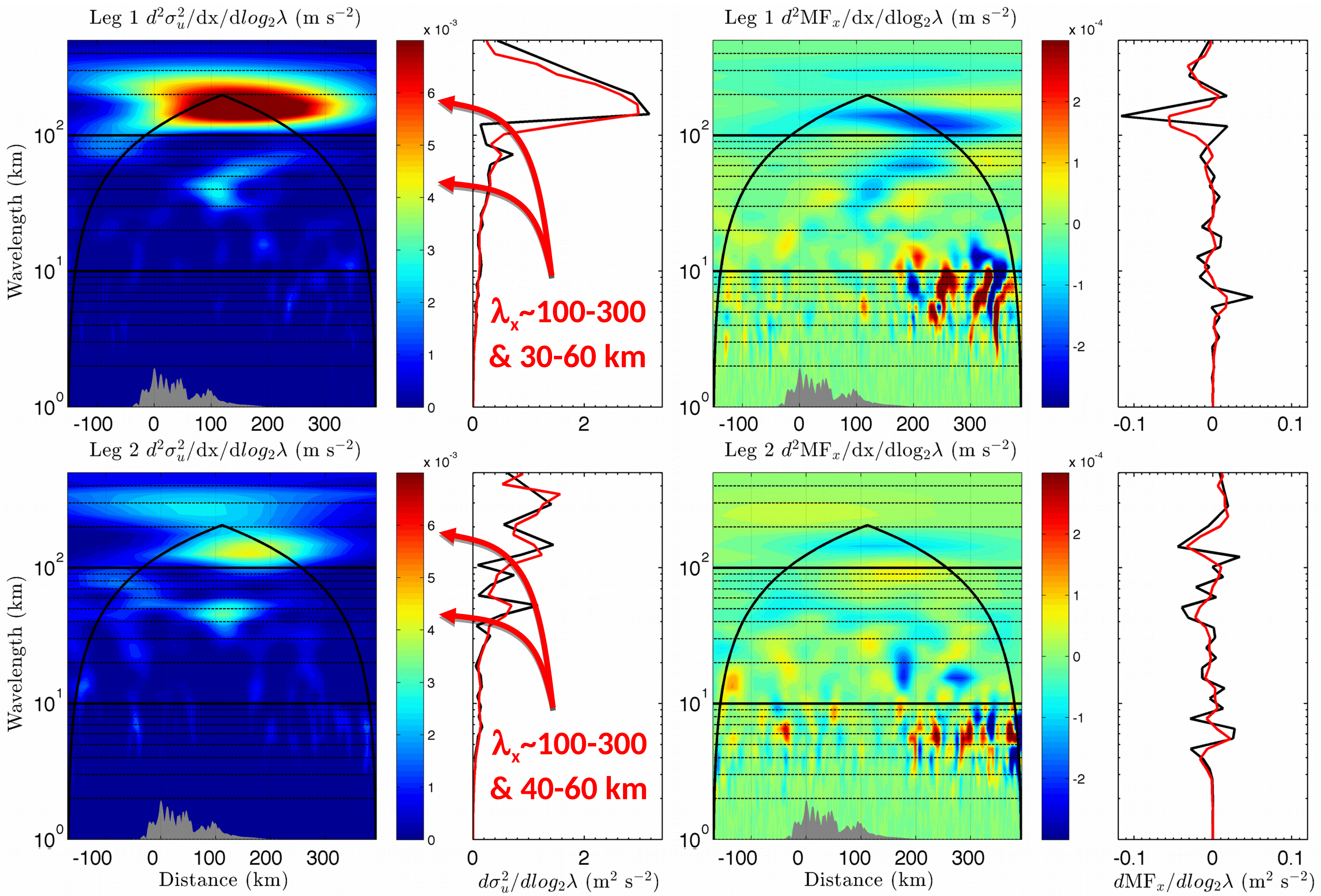




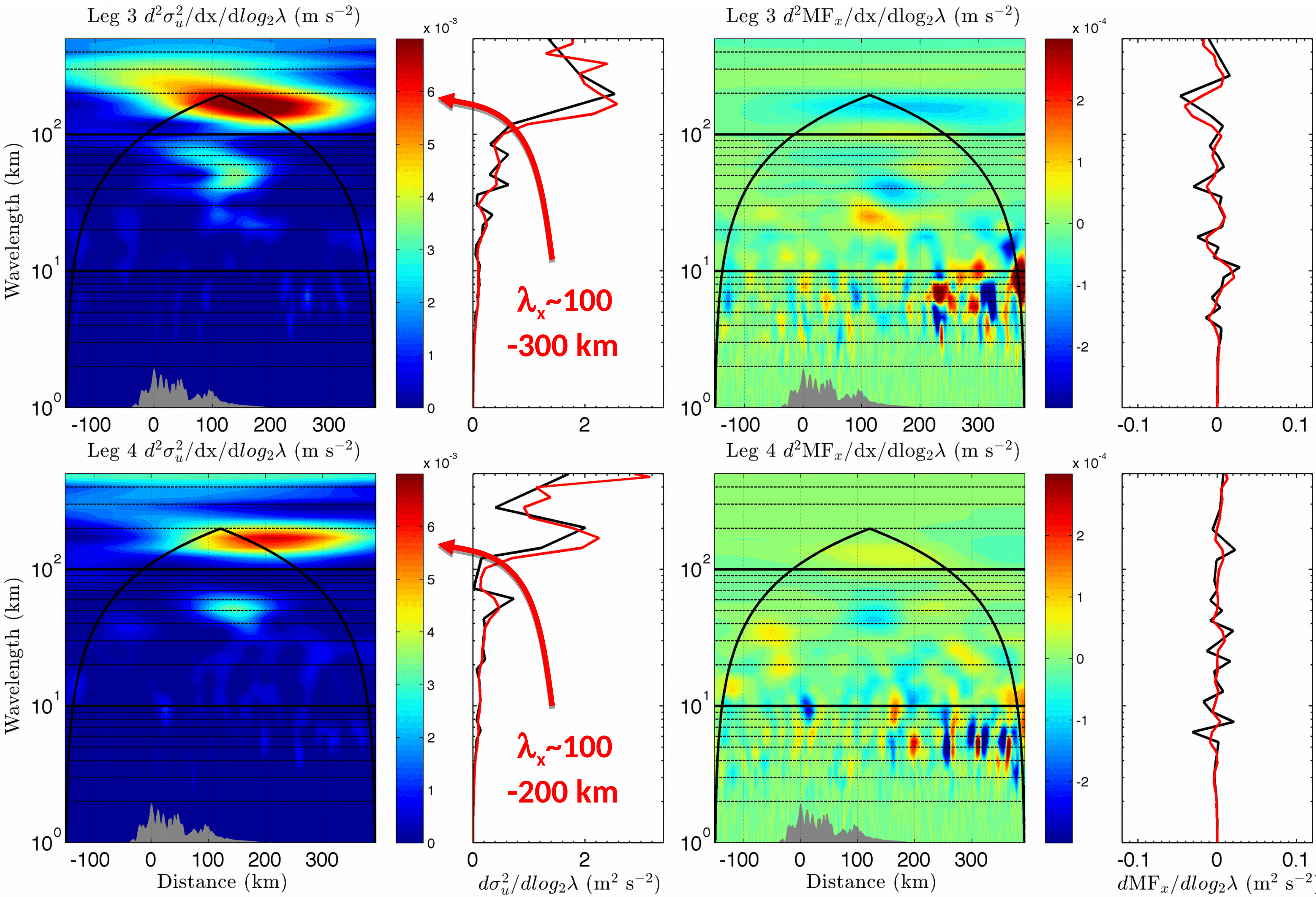
FF9 and FF10 MW Energy and Momentum Flux Spectra



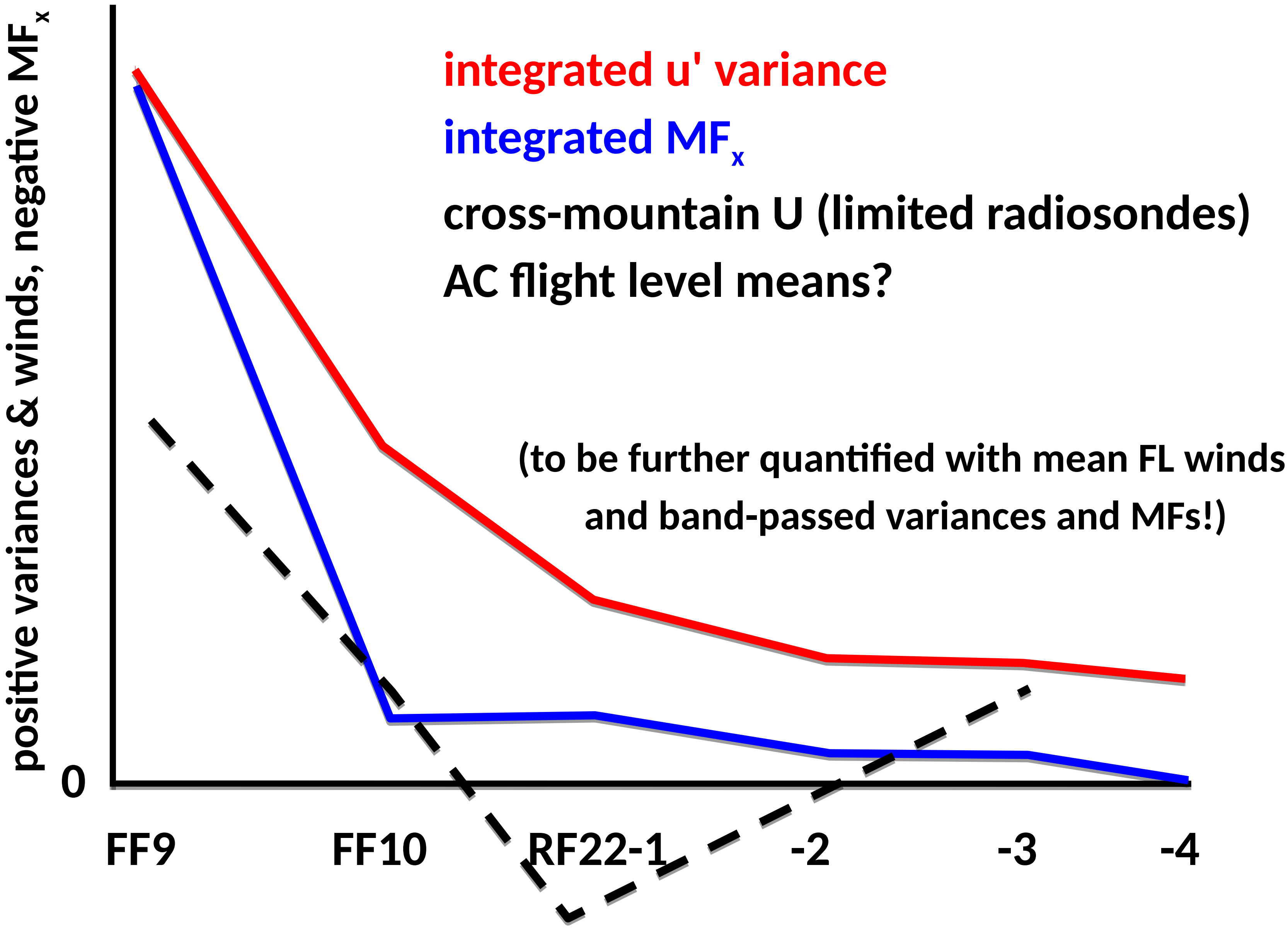
RF22 MW Energy and Momentum Flux Spectra – Legs 1 & 2



RF22 MW Energy and Momentum Flux Spectra – Legs 3 & 4



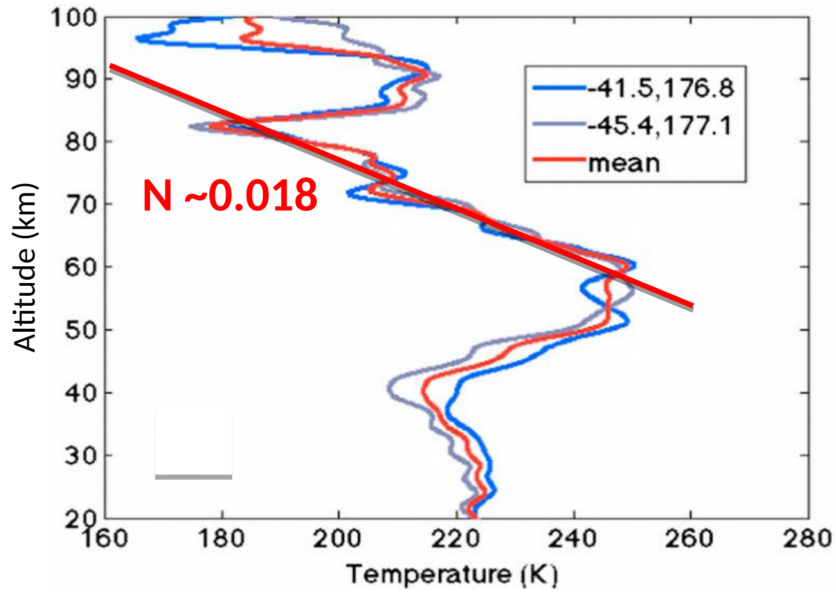
FF9, FF10, and RF22 Cumulative Variances and MFs

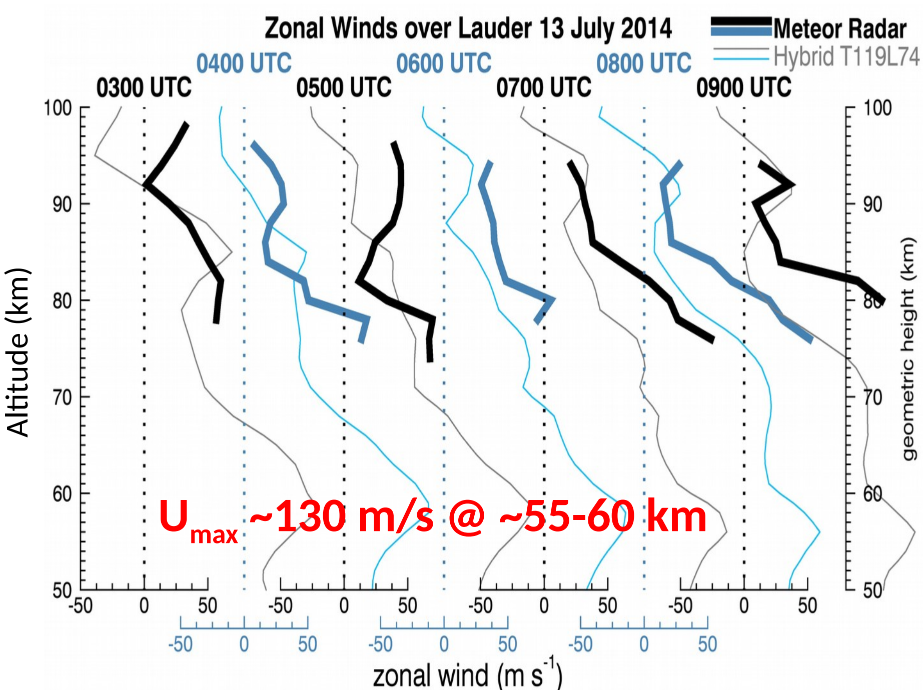


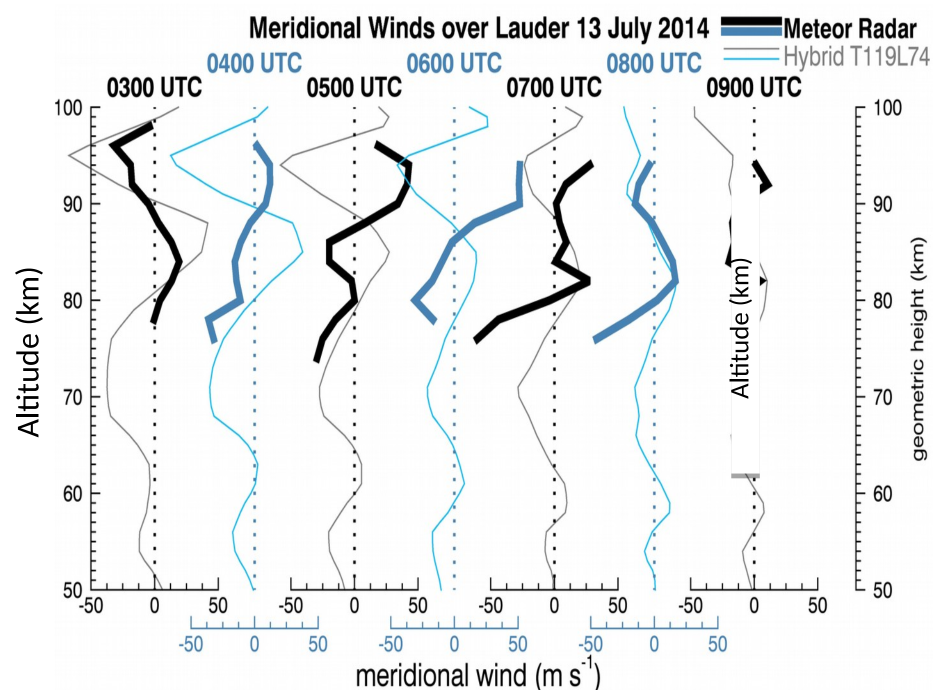
Stratospheric and Mesospheric Profiles

- SABER T(z) on 13 July is very different from Rayleigh lidar T(z) on 12 July
- possible indication of large-amp. MW in SABER T(z) above~ 70 km
- NAVGEM => U~130 m/s at ~58 km
- suggests reflection of small λ_x<25 km

SABER temperatures – 12:39 UT on 13 July







GV Rayleigh Lidar T(z)

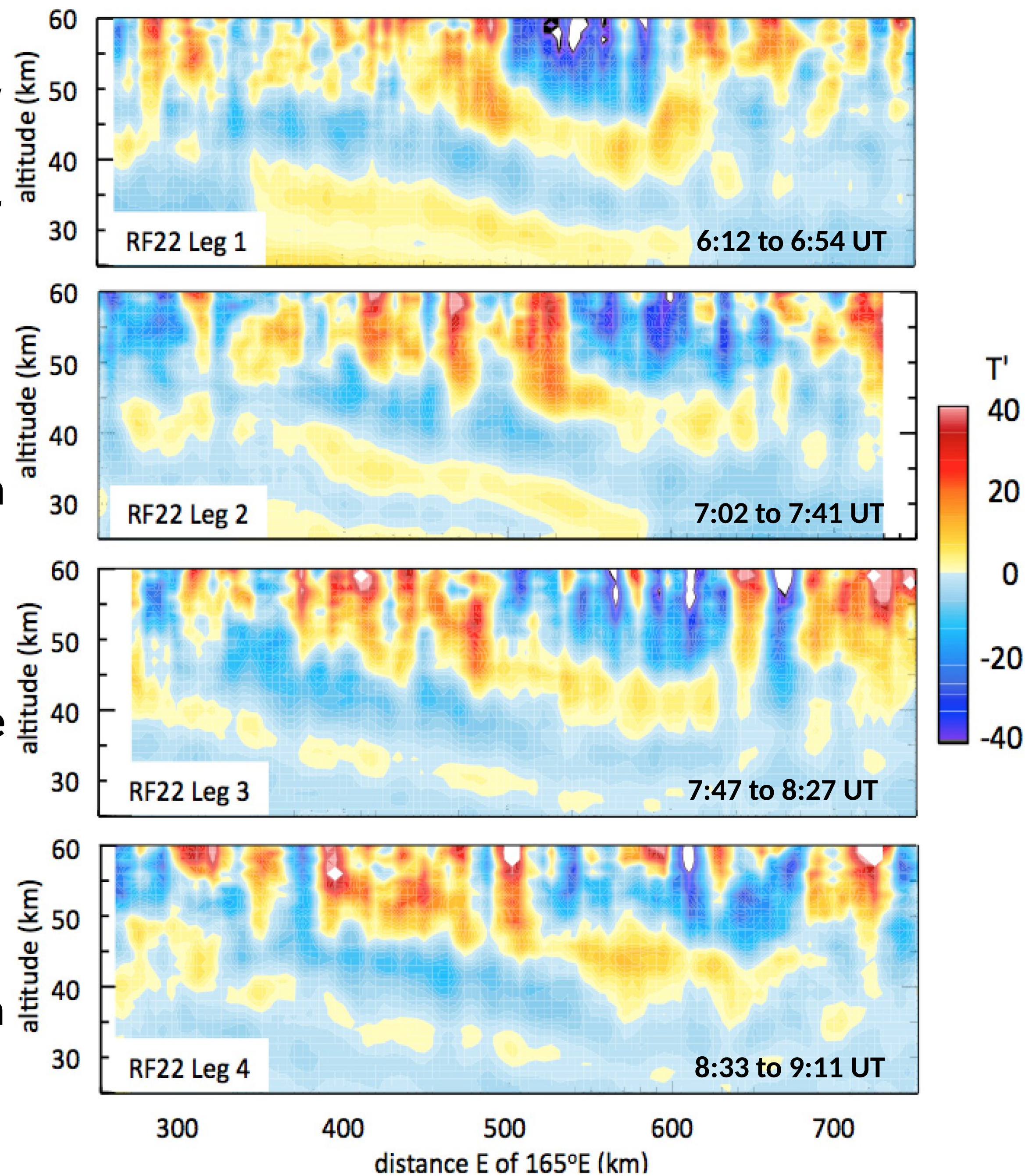
~250 km MW is strongest below 40 km at the earliest time, ~5 K, decreases strongly over the 4-hr flight, ampl. at 55-60 km?

long MW field exhibits ~50 km horizontal phase variability between segments above 40 km

MWs having λ_x~20-60 km occur at higher altitudes throughout RF22, but decrease in amplitude at lower altitudes throughout

MWs at the smallest λ_x have near-vertical phase slopes at ~55-60 km where U is maximum

Intermediate λ_x ~100-150 km scales disappear at later times



GV Rayleigh Lidar T(x) for RF22 legs 1-4

z=50 km - blue

z=55 km - white

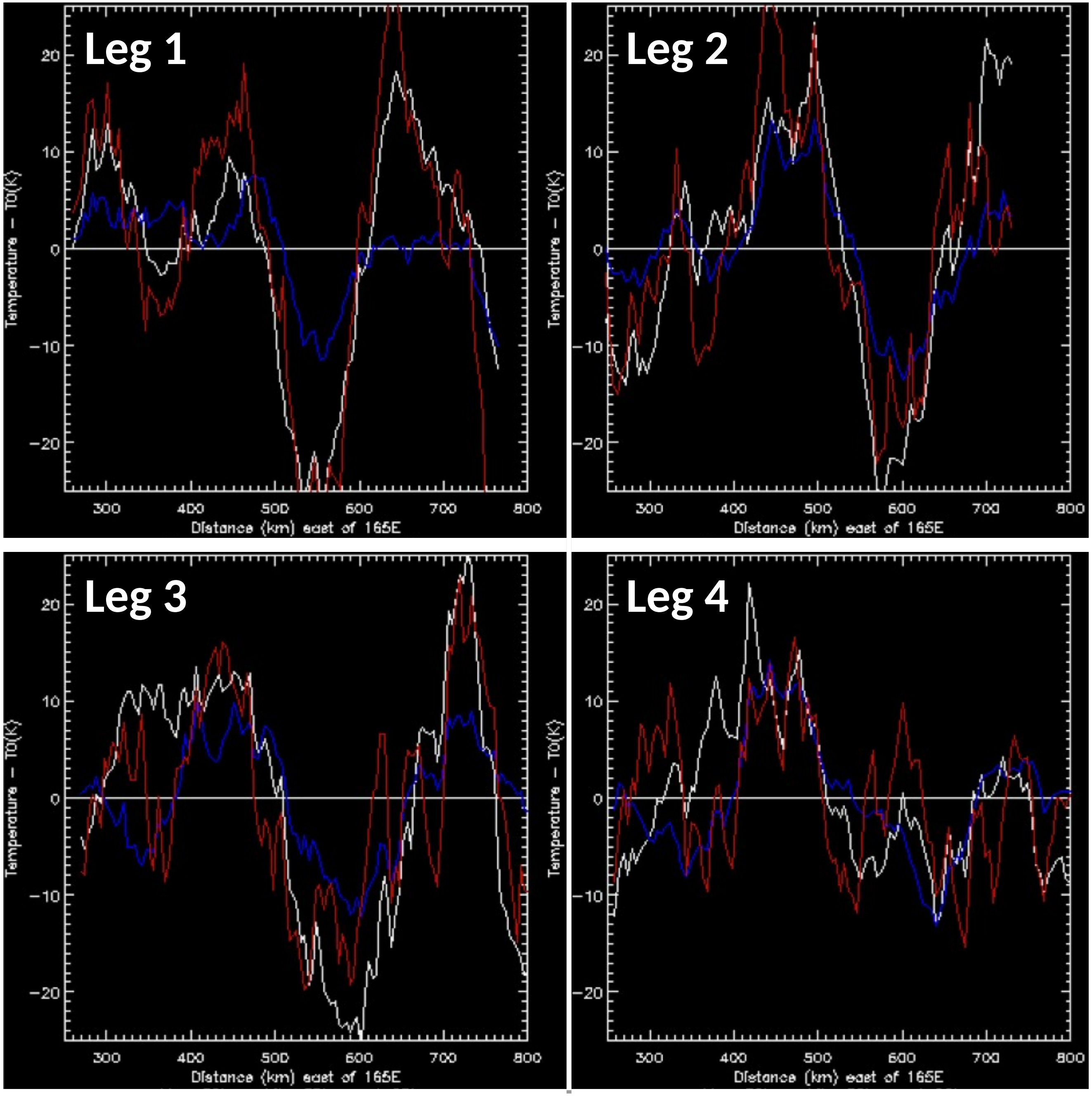
z=60 km - red

~250-300 km MW fits on legs 2 @ 3 yield

T' ~ 12 K @ 50 km

~ 18 K @ 55-60 km

T' much reduced on leg 4



GV AMTM and IR wing camera fields

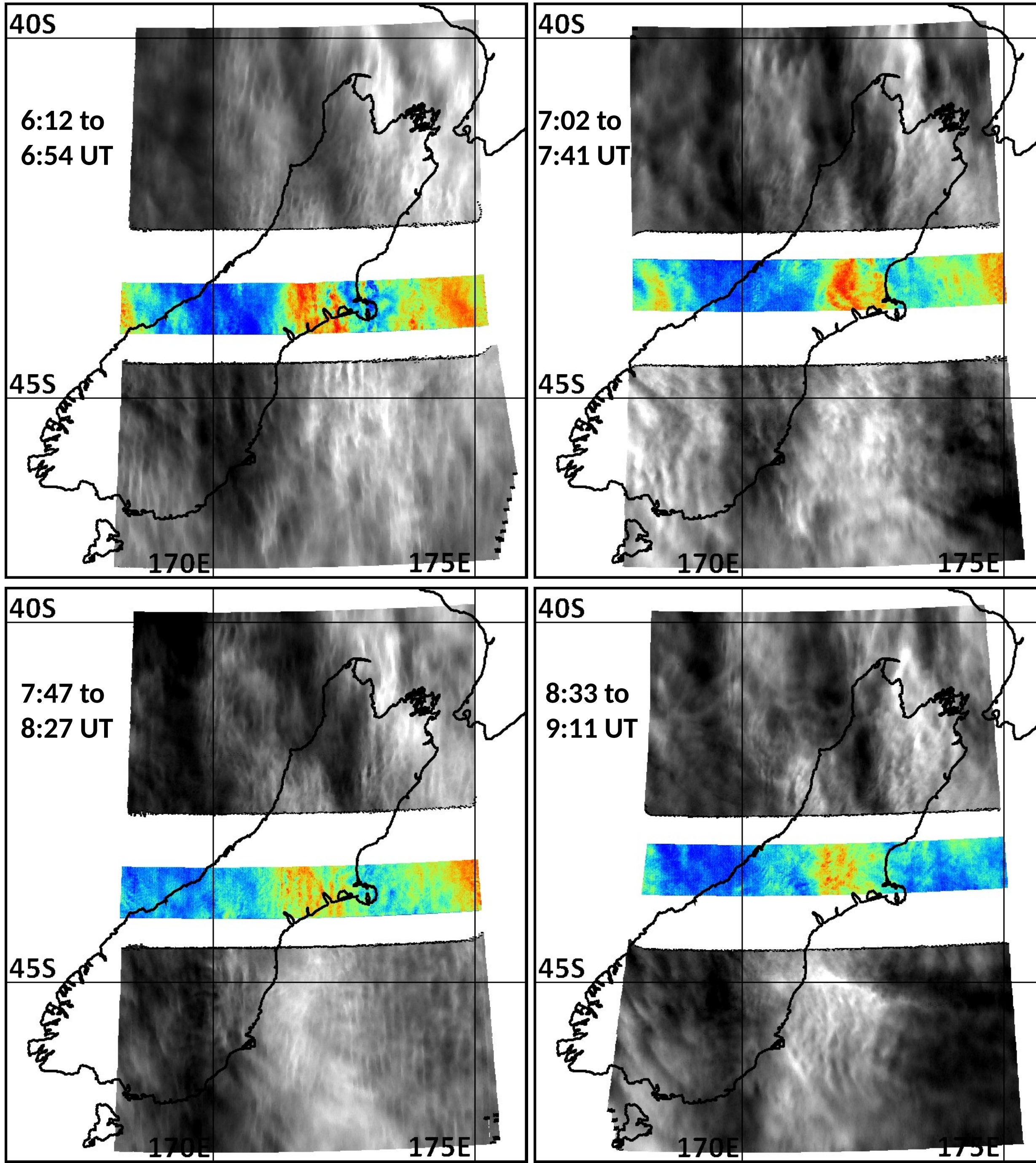
provide ~900-km cross-track FOVs

confirm largely ~N-S MW phase alignments

confirm superposed larger and smaller-scale MWs

confirm variable large-scale MW phases along x between flight legs

suggest that the dominant λ_x varies on less than a 45-min time scale



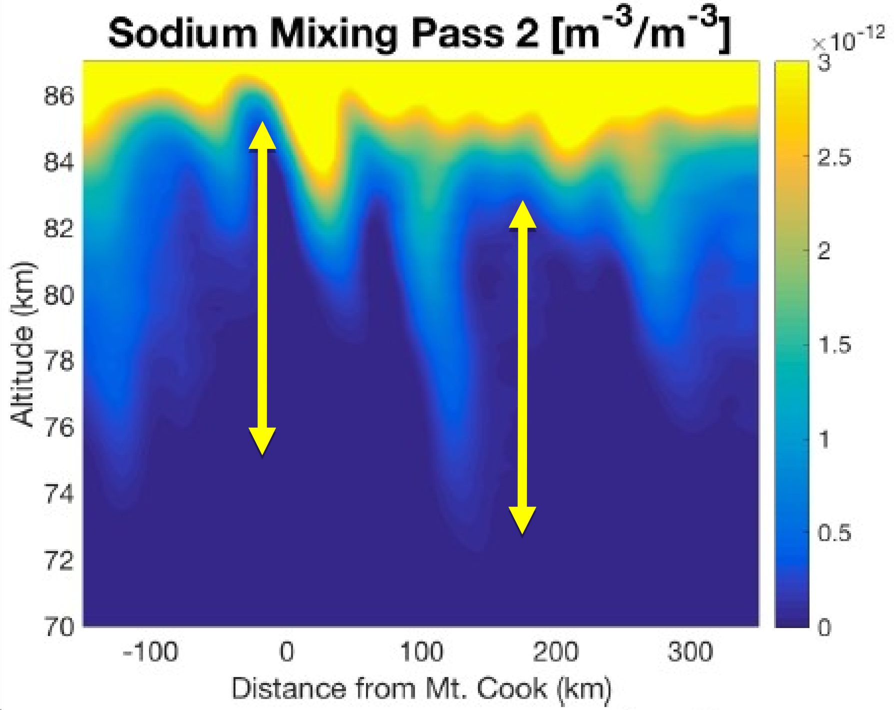
GV Na Lidar Na mixing ratios

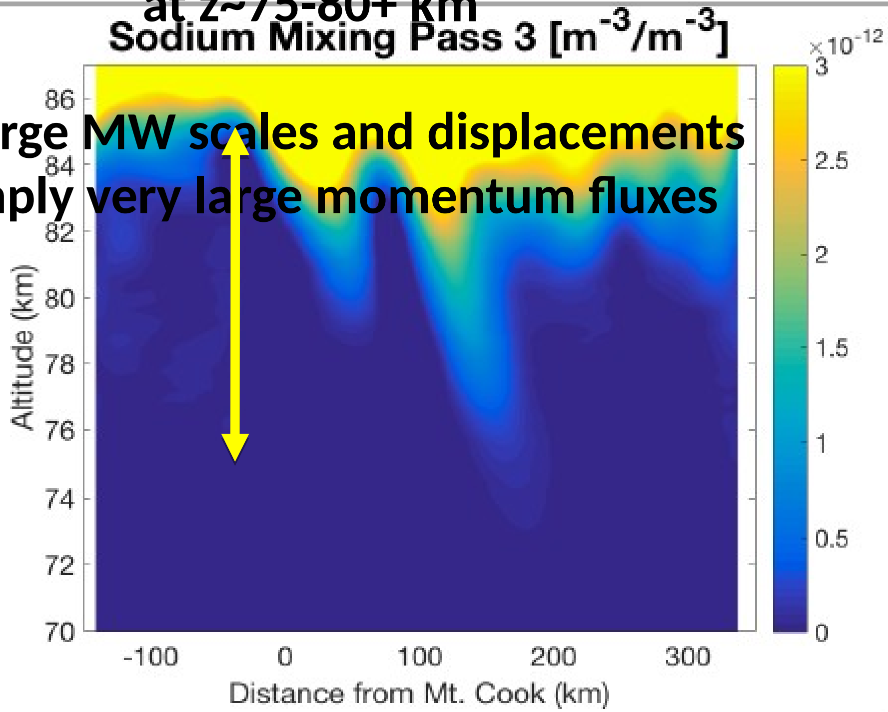
Na mixing ratios (NMRs) are good tracers of advection over short intervals

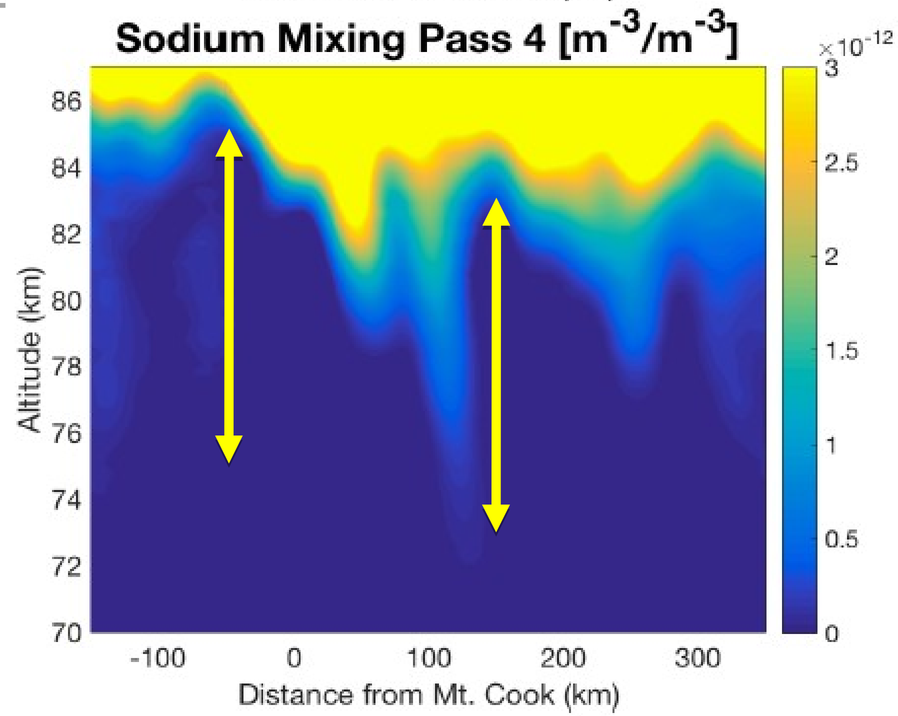
RF22 NMRs reveal:

- **multiple regions with peak-to-peak displacements ~10 km or larger**
- **clear overturning and MW breaking at z~75-80+ km**

Large MW scales and displacements imply very large momentum fluxes

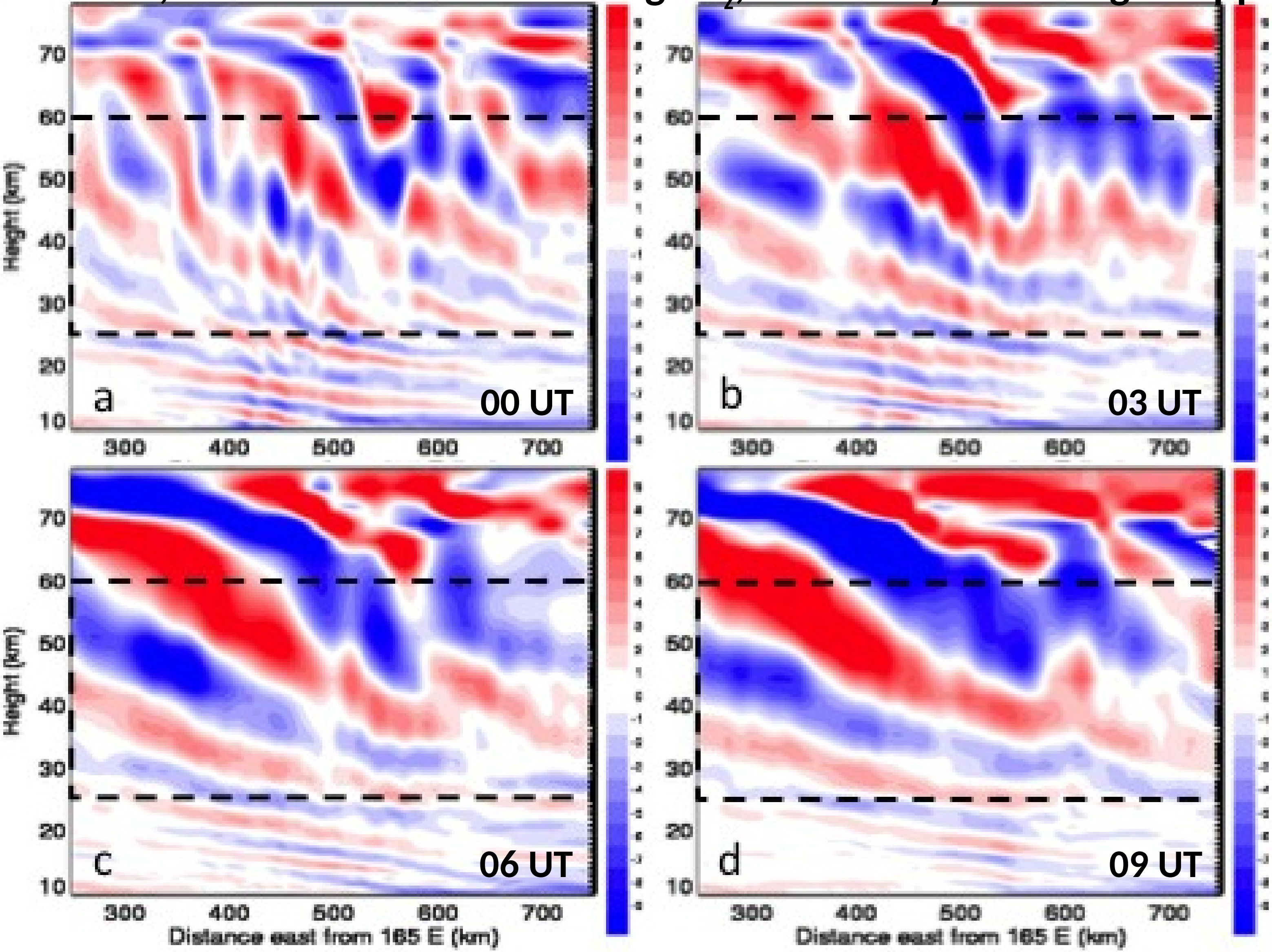






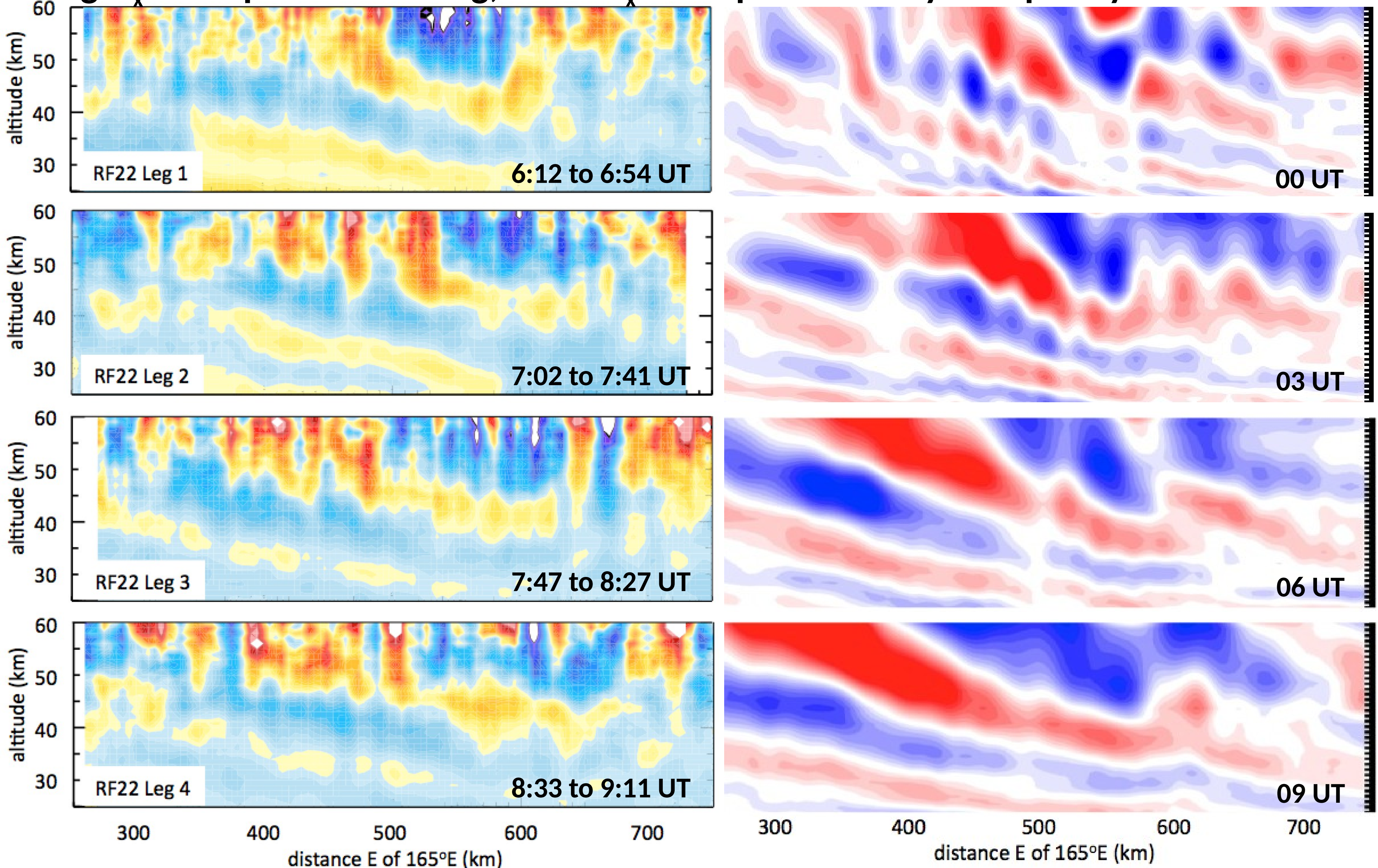
UKMO Unified Model simulation of RF22 at 2-km resolution

- init. 12 UT 12 July; BCs by global UM with UKMO analysis; top/sponge at 78/58 km
- captures many features seen at FL and in Rayleigh lidar: superpositions of long and short MWs; refraction to small and large λ_z; MW decay as forcing disappears



Rayleigh lidar – UKMO Unified Model (UM) comparison

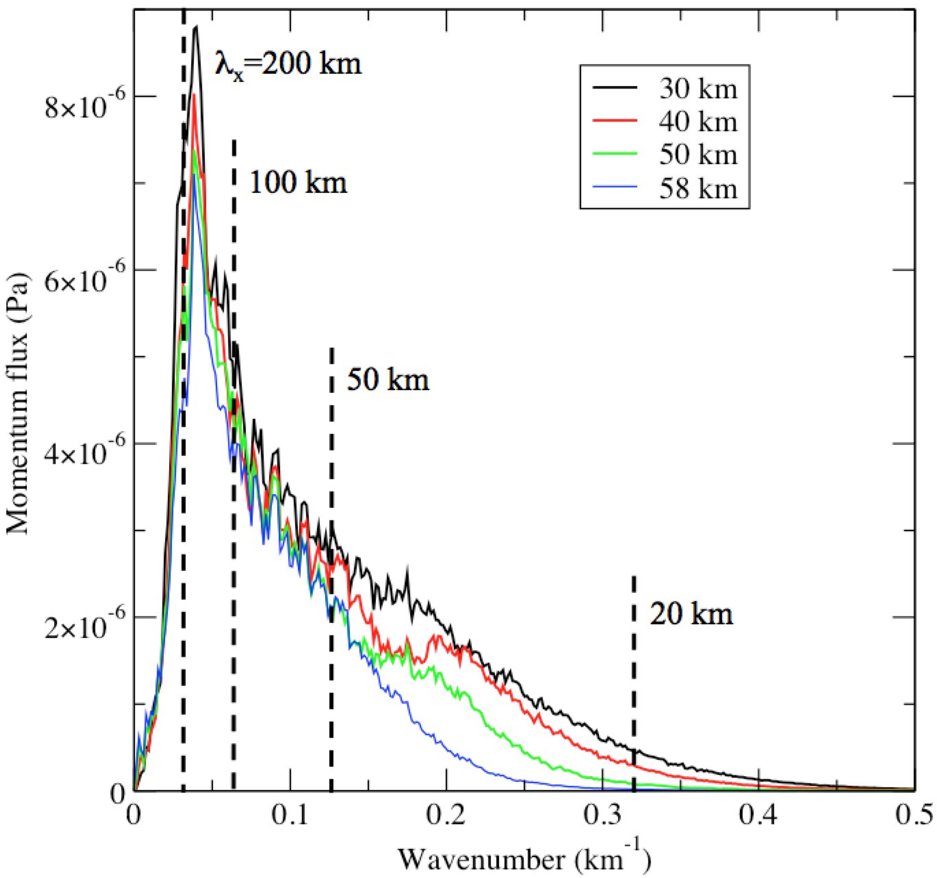
UM MW: describes approximate λ_x and superpositions; amplitudes ~2x too small; long-λ_x MWs persist too long; short-λ_x MWs persist decay too quickly

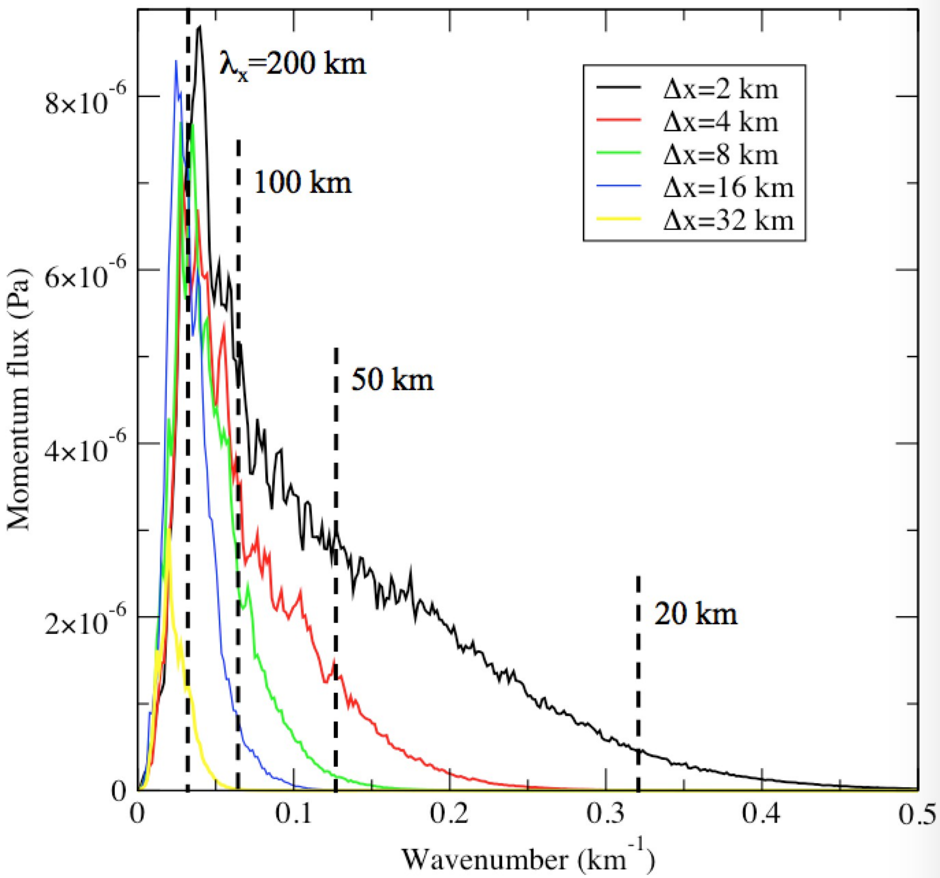


UM Mountain Wave Momentum Fluxes

- UM reveals that larger-λ_x MWs from the same source contribute more of the total MF at higher altitudes in the RF22 event

- UM RF22 simulations at 2, 4, 8, 16, and 32 km resolutions also reveal that coarse resolution strongly constrains the MW MF to ~50% or less for λ_x <12 Δx





Summary

- RF22 was flown specifically to sample MLT responses to weak MW forcing: a few hours at ~10 m/s, decreasing thereafter

- FF9 revealed transient large amplitudes and momentum fluxes at flight level, but FF10 and RF22 showed strong & sustained reductions after

- flight level analyses revealed the MW scales that were also seen at much higher altitudes

- increasing stratospheric zonal winds created a propagation channel that enabled MWs to propagate ~linearly ($u'<U$) into the mesosphere

- attainment of large amplitudes at z~70-80 km enabled very large vertical displacements, ~5 km or more, strong overturning, and expected strong instabilities and MW dissipation thereafter

- large responses in the MLT occurred long after cessation of forcing, especially for the larger-λ MWs having small vertical group velocities