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# Mountain wave propagation into the stratosphere and mesosphere forced by moderate wind speeds both perpendicular and parallel to the New Zealand mountains during the DEEPWAVE campaign

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Lidar data: Biff Williams, Dave Fritts, Katrina Bossert, GATS
AMTM data: Mike Taylor, Dominique Pautet, Utah State U.
WRF model run: Chris Kruse, Ron Smith, Yale U.
ECMWF data: Andreas Dornbrack, DLR

# Outline

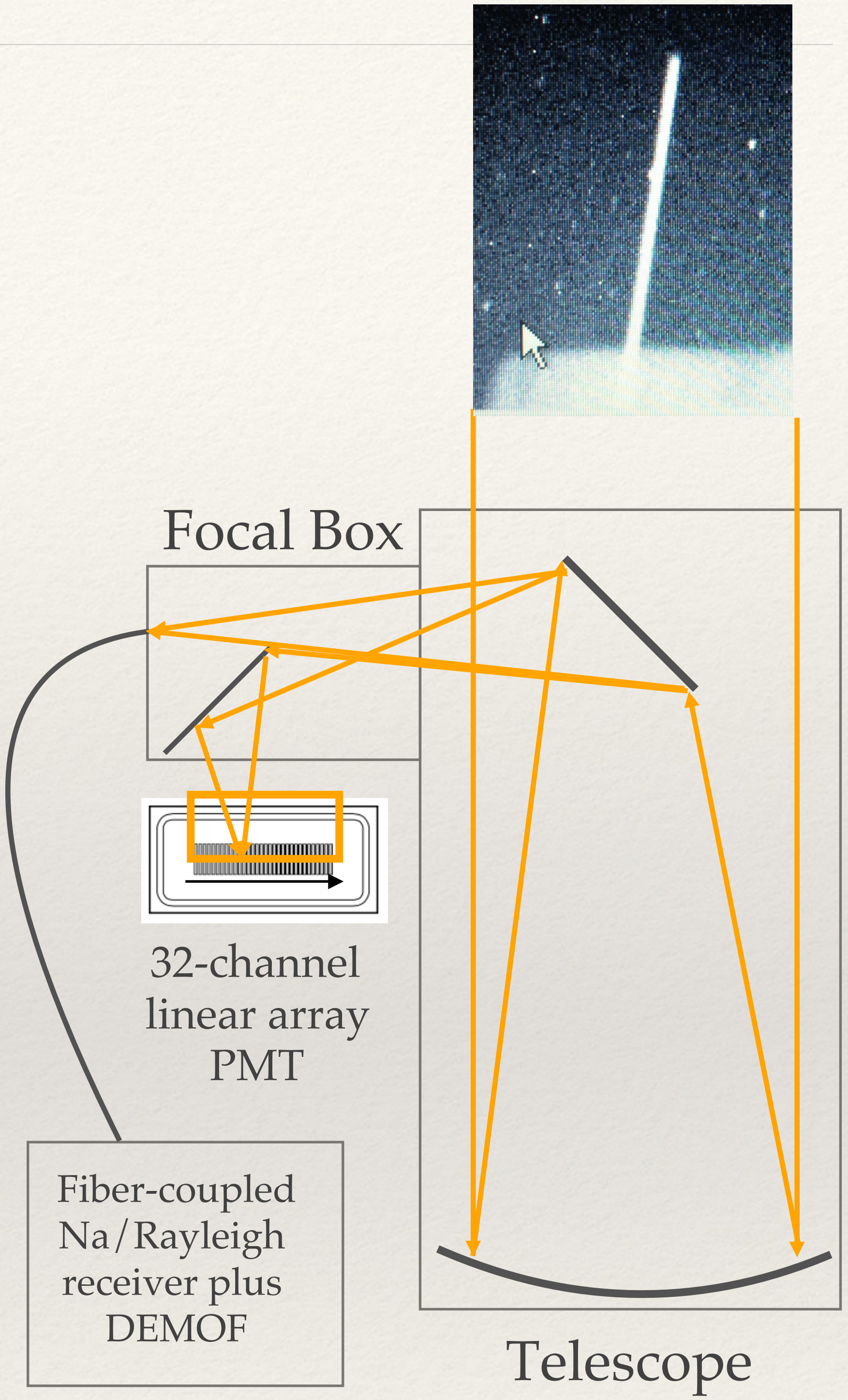
1. Rayleigh Lidar description
2. Flight Timing and Tracks
3. Rayleigh Lidar - ECMWF comparison
4. Transverse mountain waves: RF22, RF13
5. Parallel mountain waves: RF26
6. Conclusions

# Rayleigh Lidar Instrument Description

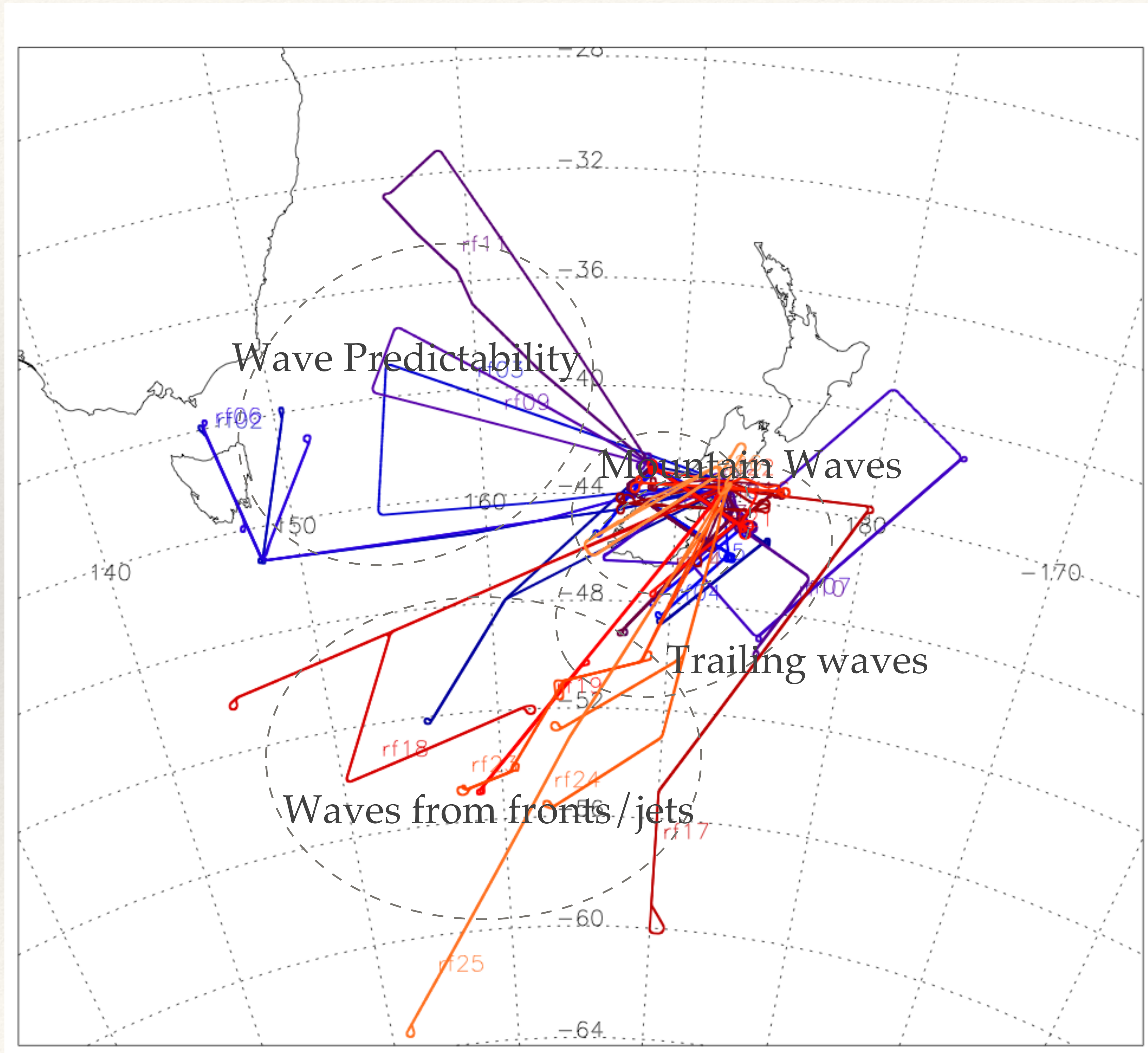
- New facility instrument built at GATS, Inc. for the GV
- Shares two standard GV instrument racks with the Na lidar
- **Laser:** diode-pumped Nd:YLF Photonics DS20-351
  - 5W at a 351nm wavelength, stronger Rayleigh scatter in UV
  - Small, robust and power efficient, no laser issues during the 6-week campaign.
- **Transmitted beam:** expanded to 20mm diameter, 0.4mrad
  - eye-safe at the aircraft exit for overflying aircraft
- **Telescope:** 30cm diameter f/4 Newtonian
- **Fiber-coupled receiver:** 50% efficiency photomultiplier tube
- **Returned signal profiles:**
  - **Raw:** 1 sec time and 37.5m altitude resolution
  - **Temperatures from 30-60km:** Bin to 1-5min, 3km

# Receiver

- 30cm diameter f/4 Newtonian telescope
- Pulsed beam uses exact same fiber coupled receiver (40% PMT, filter) as some of the current Na lidars
- Resolution: Raw data: 1 sec hor., 37m vert. binned to 20 sec, 3km
- Scanned beam: the forward scan edge is aligned with a new 32 channel PMT with an integrated 32 channel counter board
- Each of the 32 PMT channels sees a pulsed 150mW profile staggered in time
- On airplane: Add 32 profiles to get better SNR and time resolution

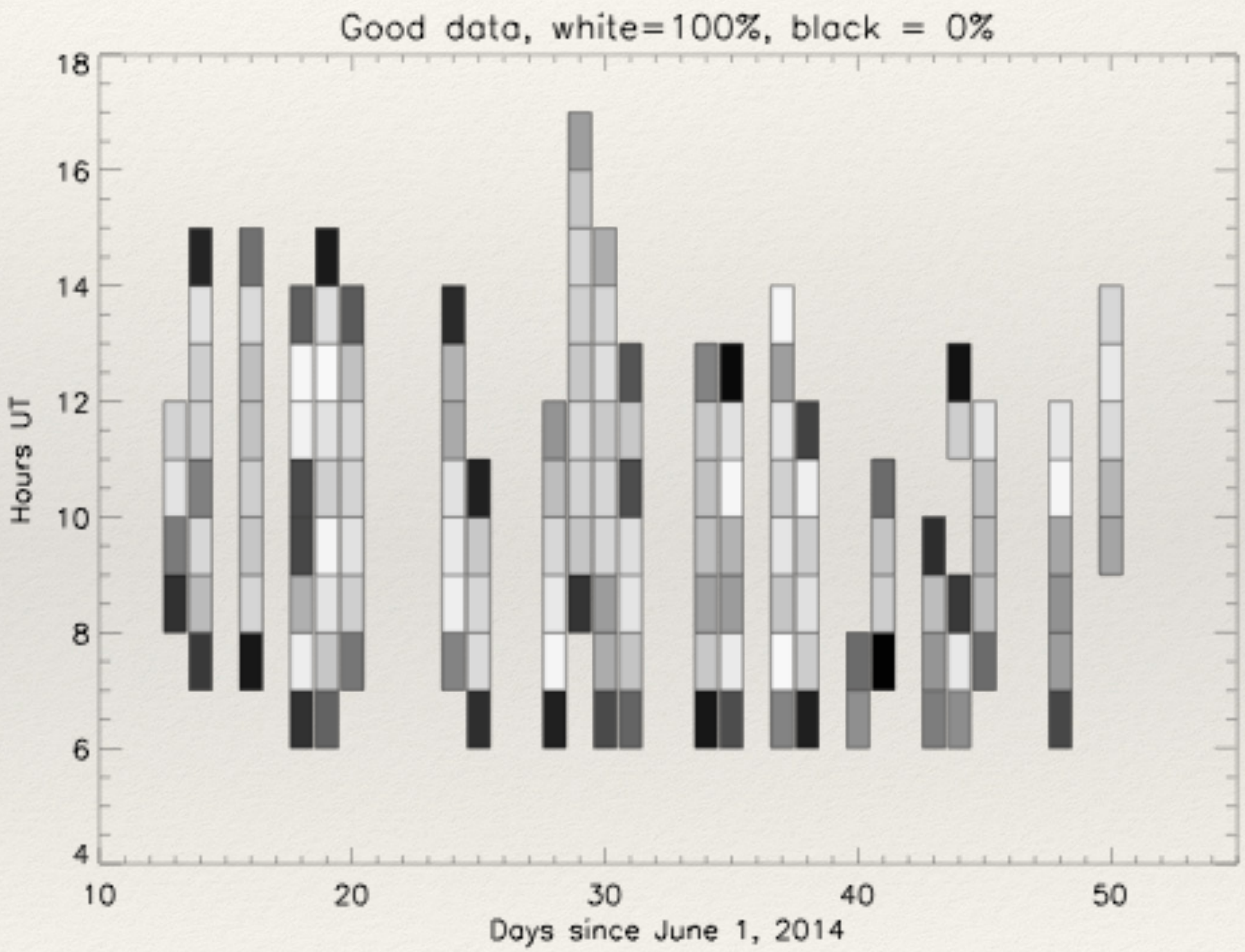


# DEEPWAVE Geographic Coverage: Flight Paths



# Seasonal/Time (UT) Coverage

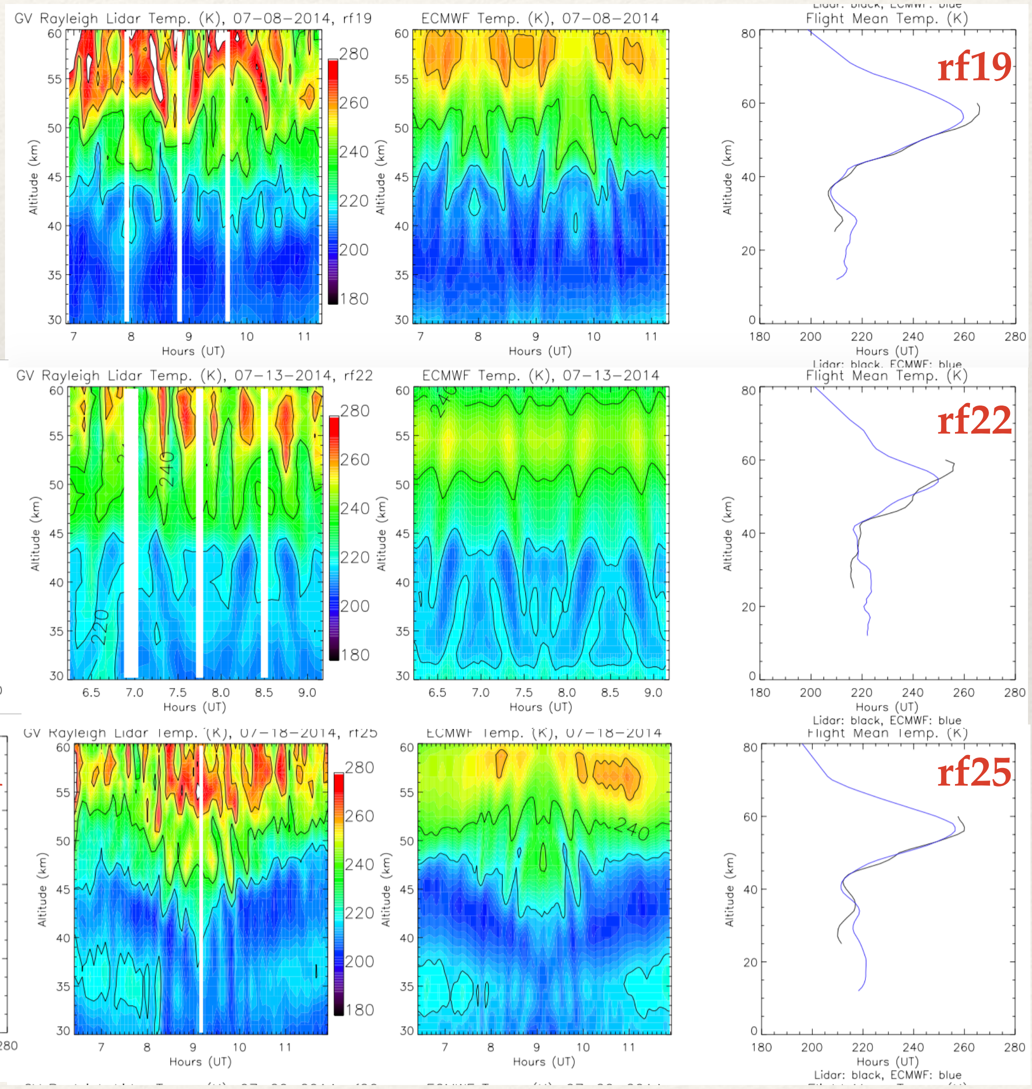
- 144 total hours
- 130 hours with >40 profiles/hr,
- typical flight lasted from 6-13 UT
- About half the flight hours over the New Zealand mountains



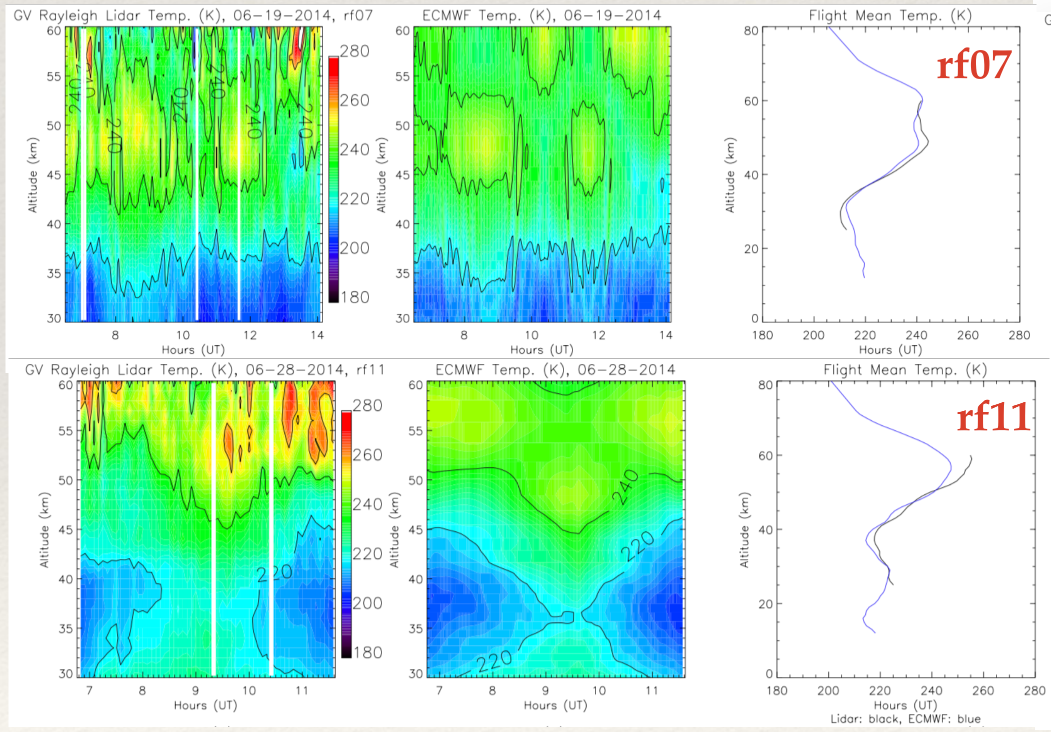
# Validation: ECMWF vs. Lidar

- ECMWF temperatures interpolated to GV time, latitude, longitude
- Mean temperatures very similar from 35-55km
- ECMWF sometimes warmer at 30km and cooler at 60km
- Medium scale waves (HWL > 50km) predicted well, both over the mountain and southern ocean
- Horizontal temperature changes also well predicted

Lidar ECMWF Mean

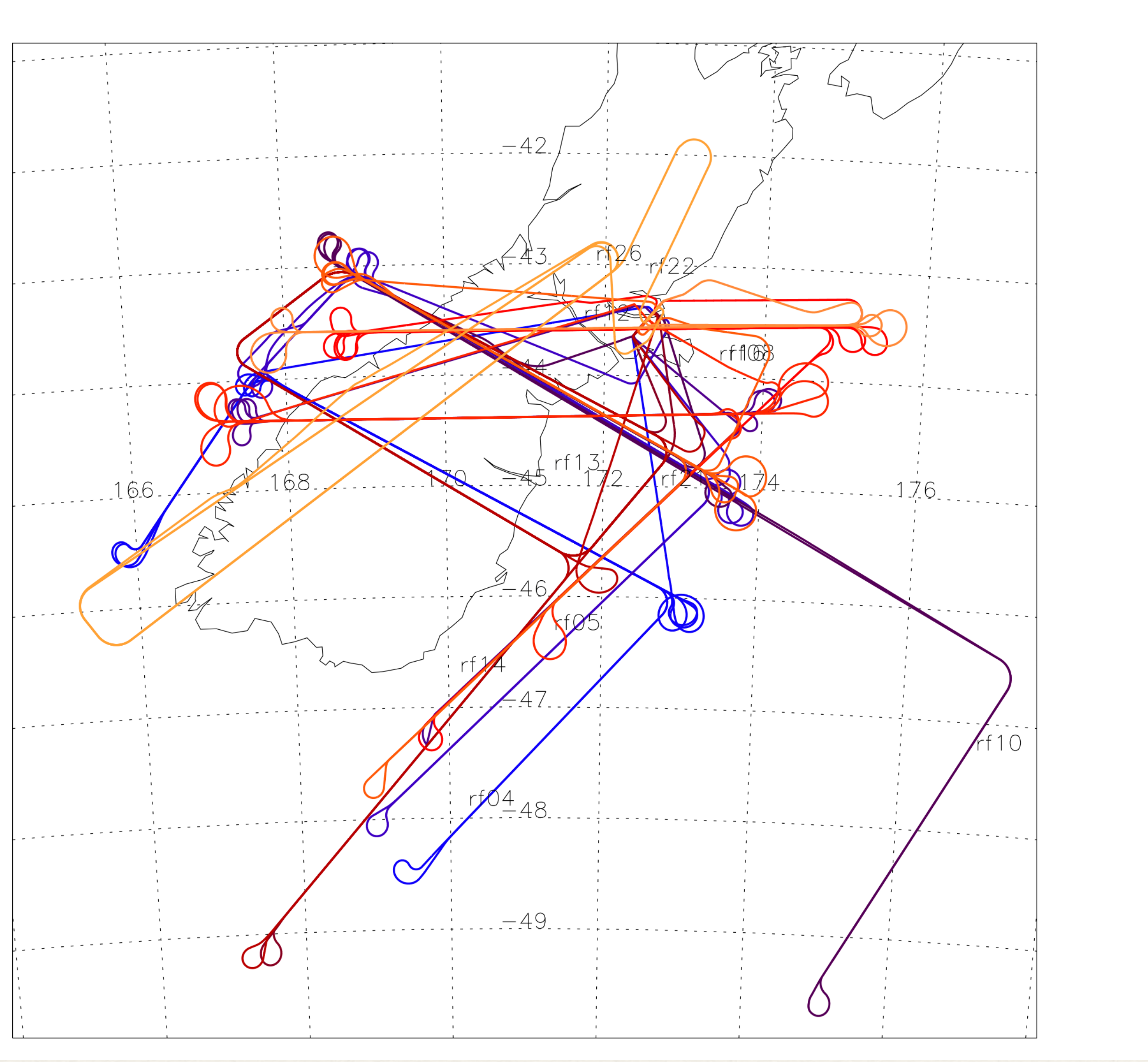



Lidar ECMWF Mean



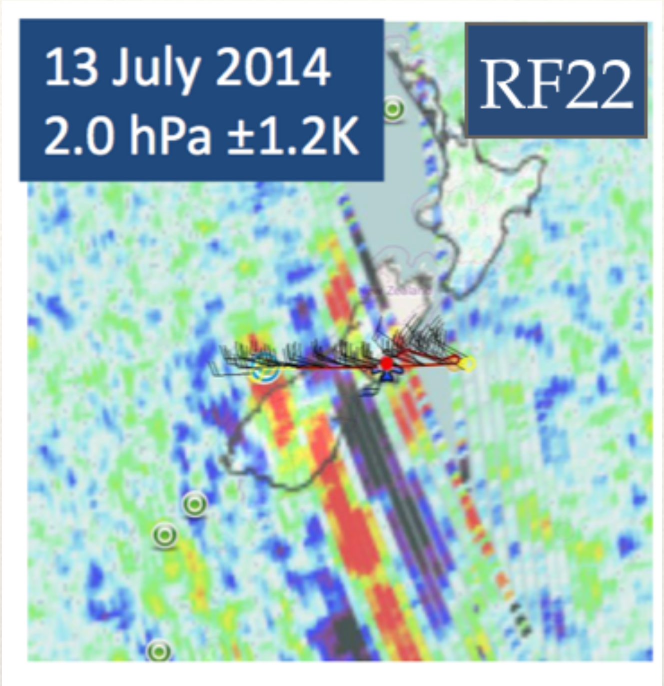
# South Island Mountain Flights

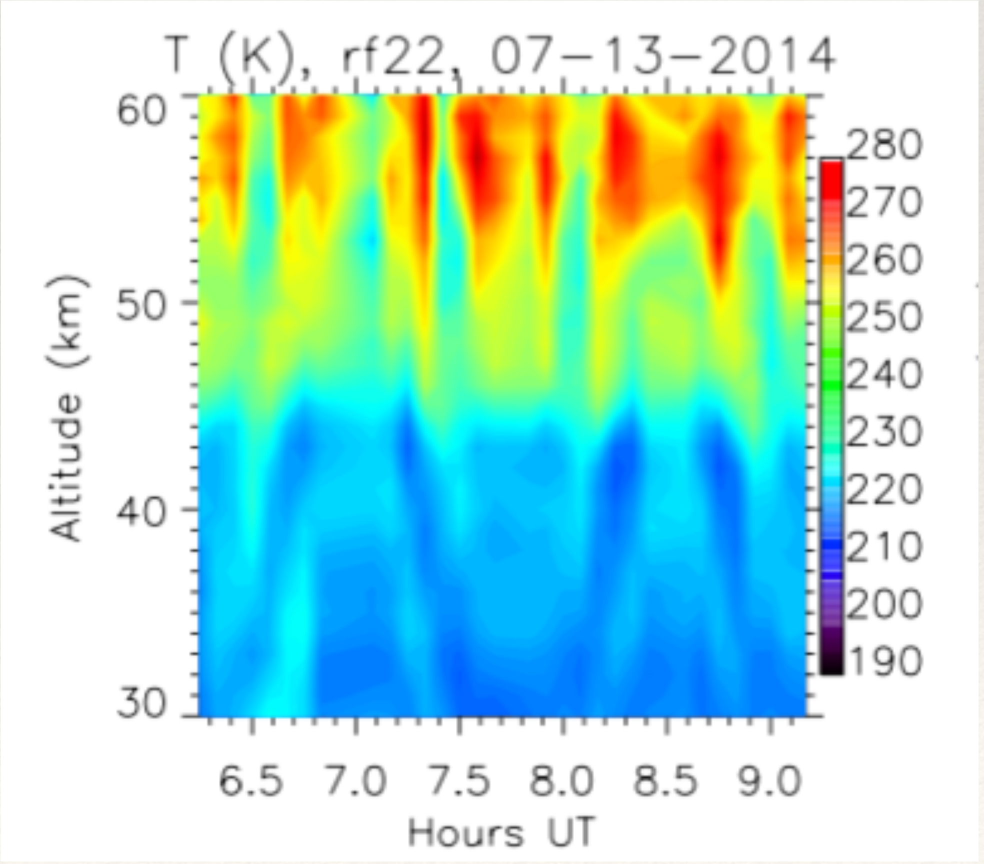
1. East-West flights
   1. RF08
   2. RF14
   3. RF16
   4. **RF22**
2. Perpendicular to mountains
   1. RF04
   2. RF05
   3. RF10
   4. RF12
   5. **RF13**
   6. RF21
3. Along mountain range:
   1. **RF26**



# Mountain Waves - RF22

- East-West flights over Mount Cook
- Weak westerly forcing in troposphere
- Westerly winds at flight level
- Large response (5-25K amplitude) in stratosphere and mesosphere predicted by the models and observed by lidar, AMTM, and AIRS
- ~240km horizontal wavelength
- Wave turns relative to forcing direction (W-WNW)

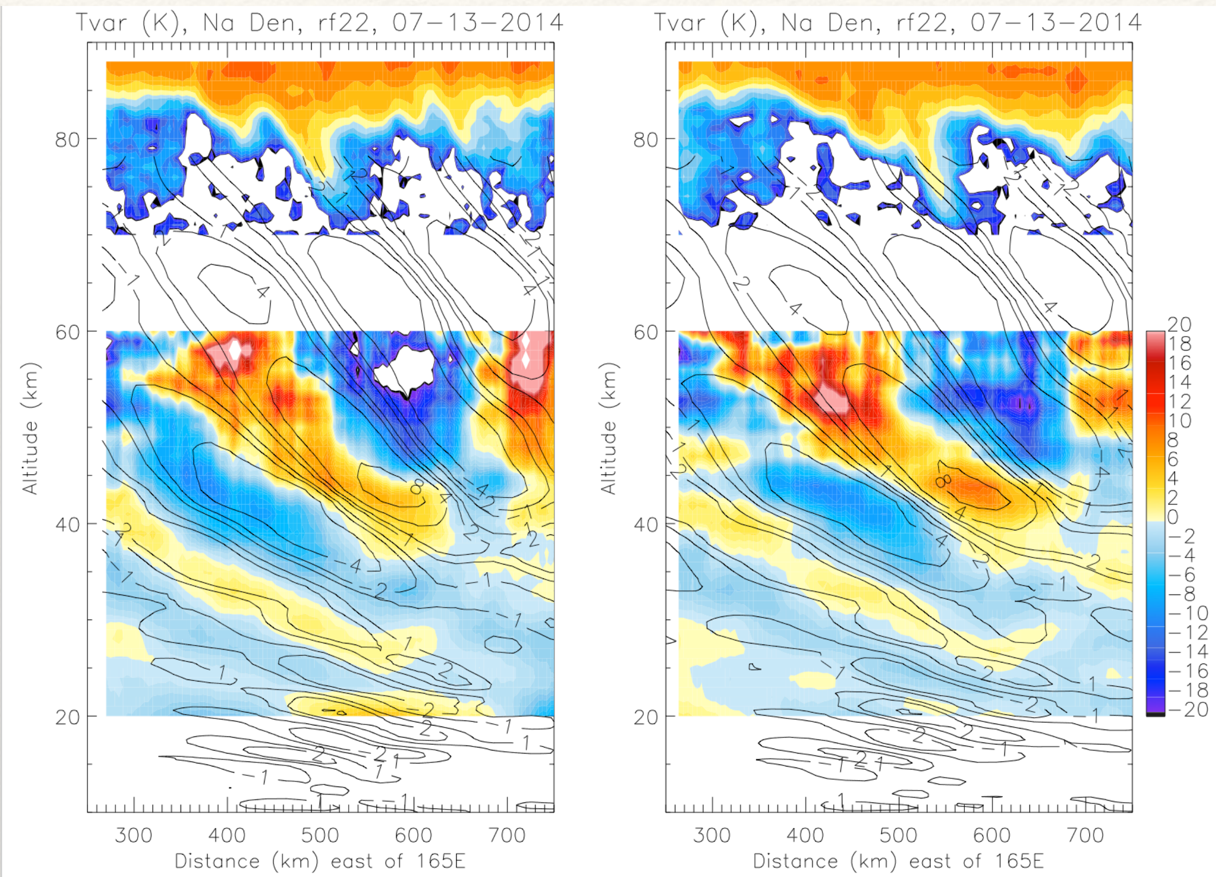


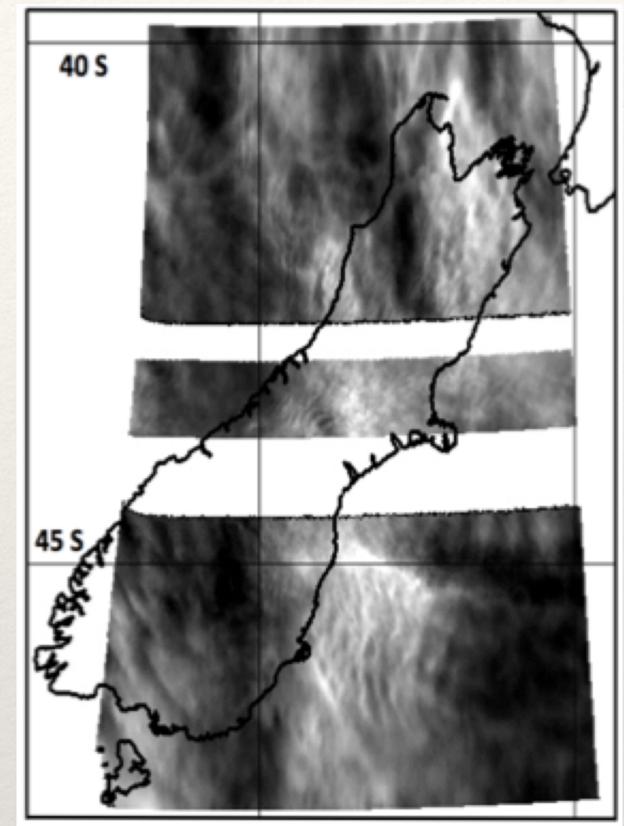
# RF22- Upper Atmosphere

Na density

T′



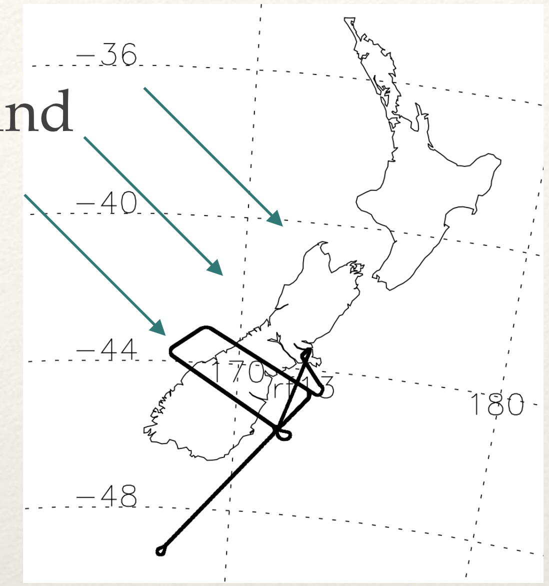

**AMTM - 87km**

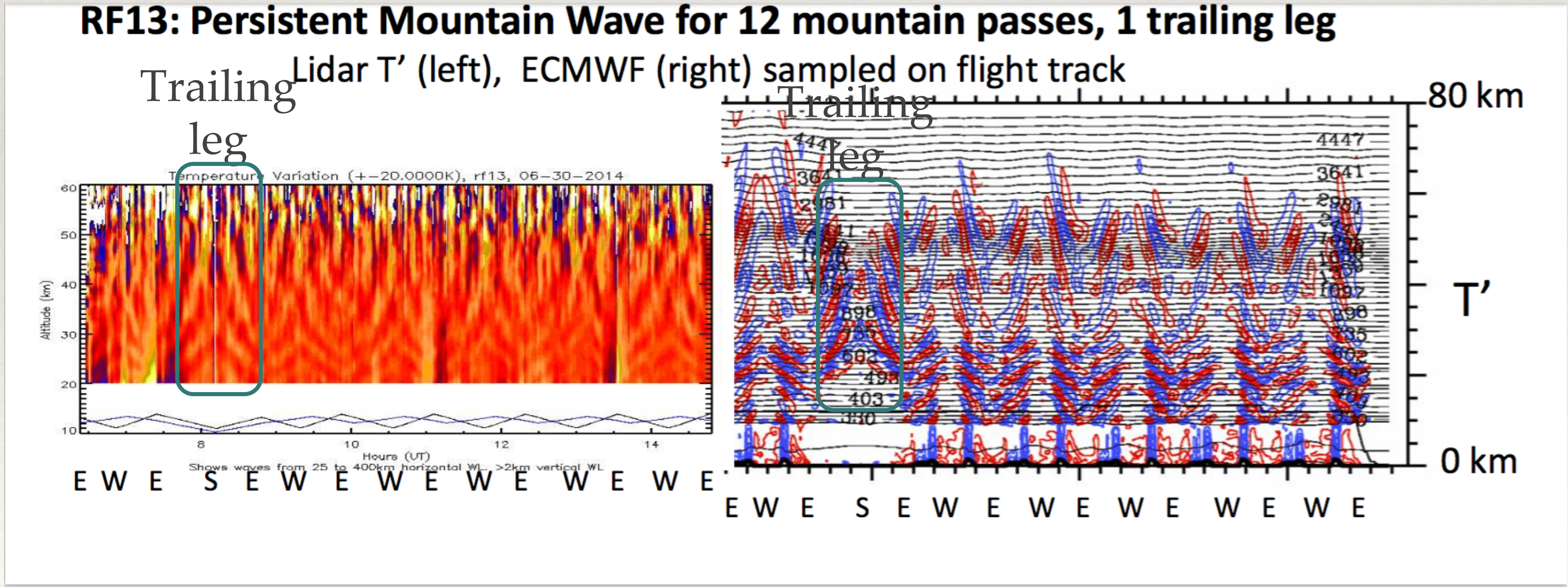



- ECMWF (contour lines) forecast the wave reaching 80km, although with somewhat lower amplitudes
- MW reached 85km with large amplitude followed by breaking and secondary wave generation at 85-90km [*Bossert et al.*, JGR, 2015]
- Large forcing the day before, delayed response or just good propagation conditions?
- Steve Eckermann doing ray tracing to study origin

# Mountain Waves - RF13

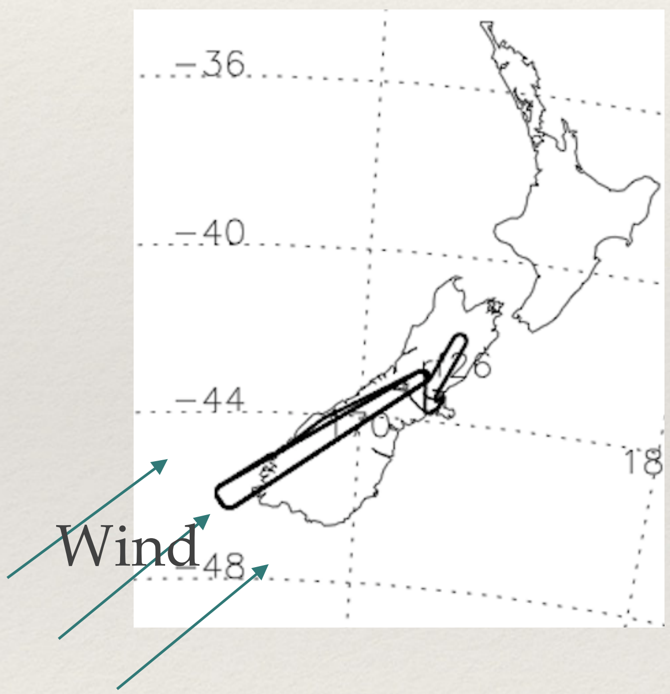
- Flight track and moderate tropospheric wind perpendicular to mountain range
- Persistent medium scale mountain waves for 8 hr
- ECMWF model predicted MW scale, amplitude, and increase in vertical wavelength with height, but does not extend as far upstream
- Trailing leg stronger waves at higher altitudes in both
- Waves do not reach mesopause

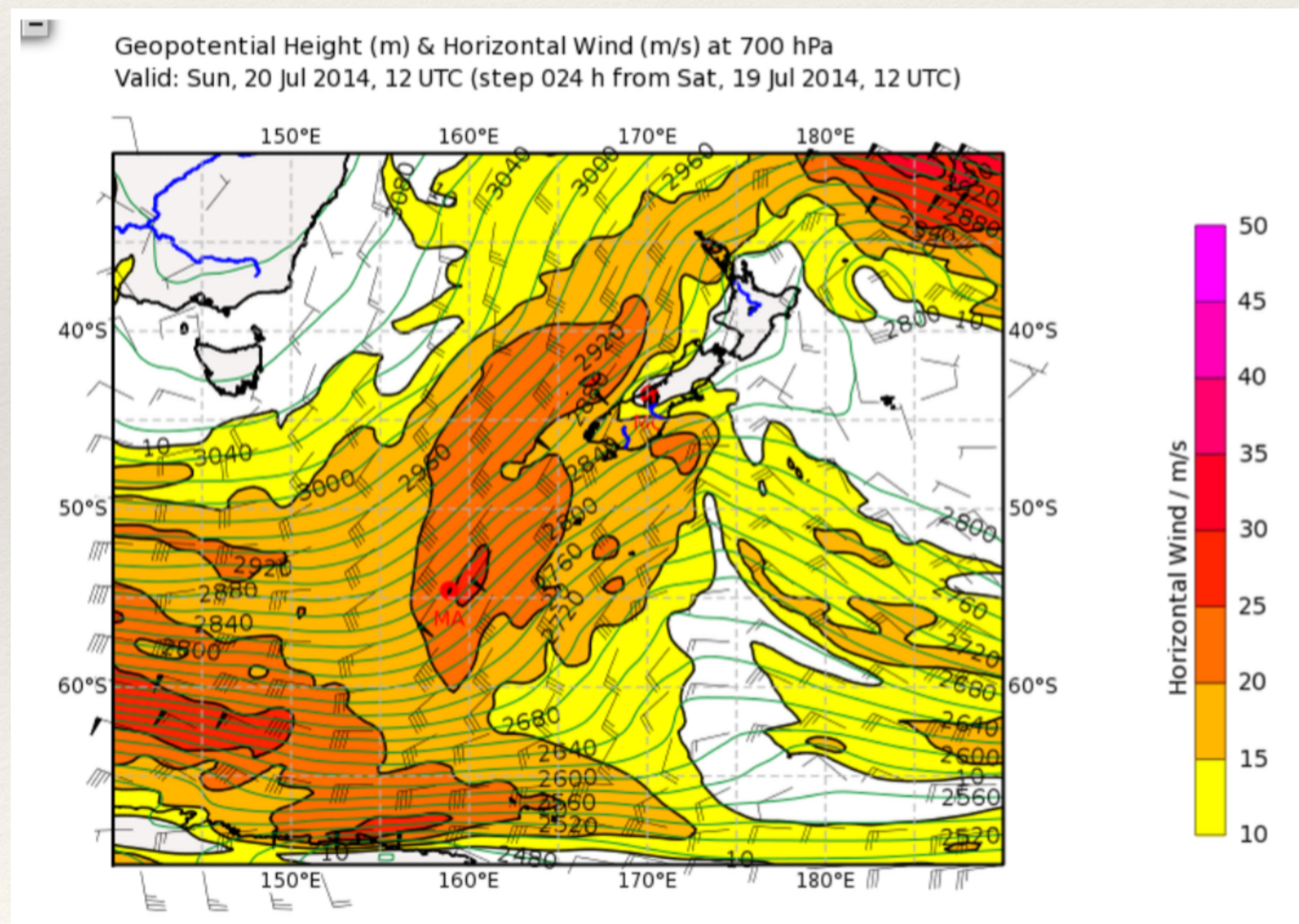


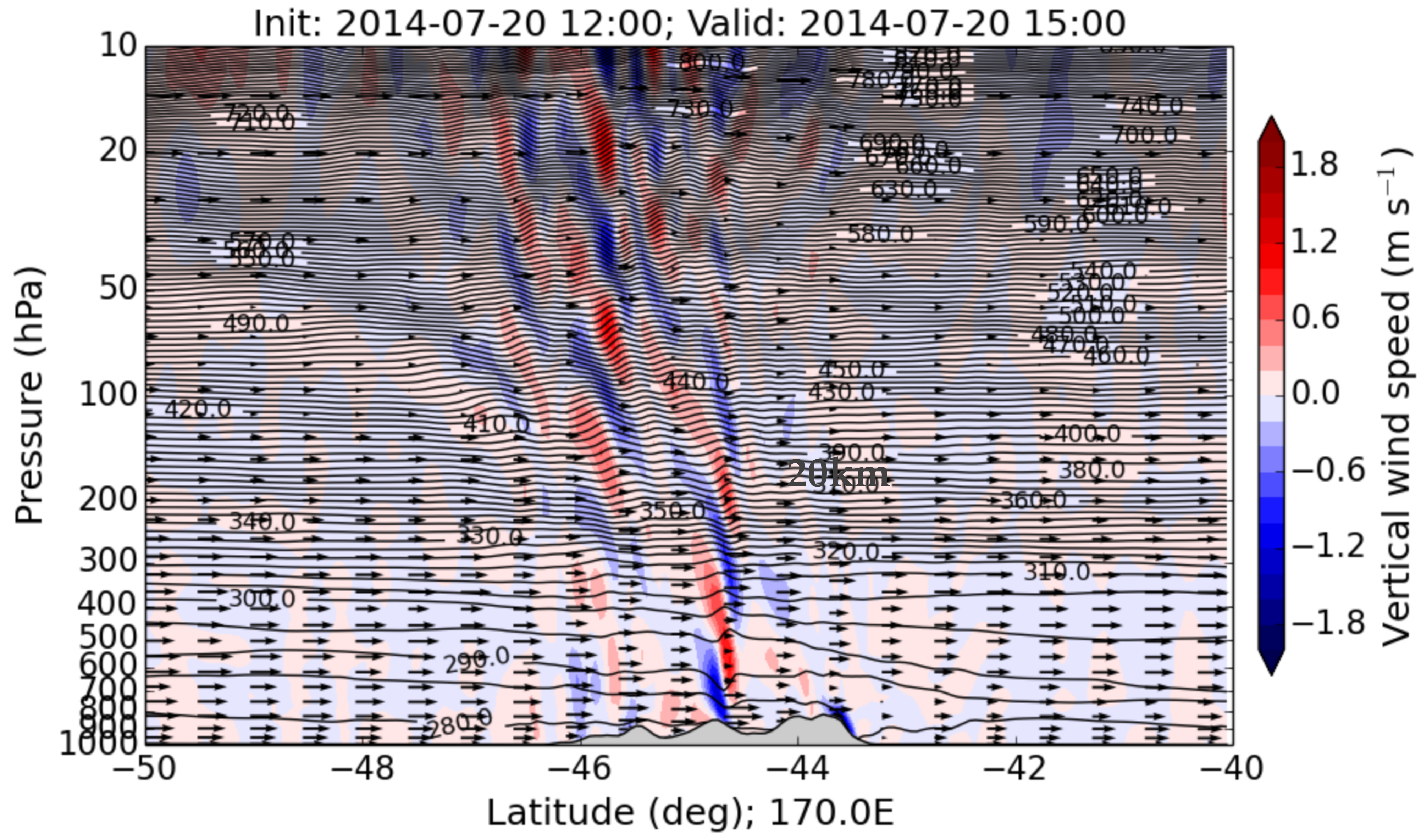
# Mountain Waves - RF26

- Moderate forcing from SW at ~20m/s
- Tropospheric winds parallel with mountain range
- Multiple loops along crest of mountain range



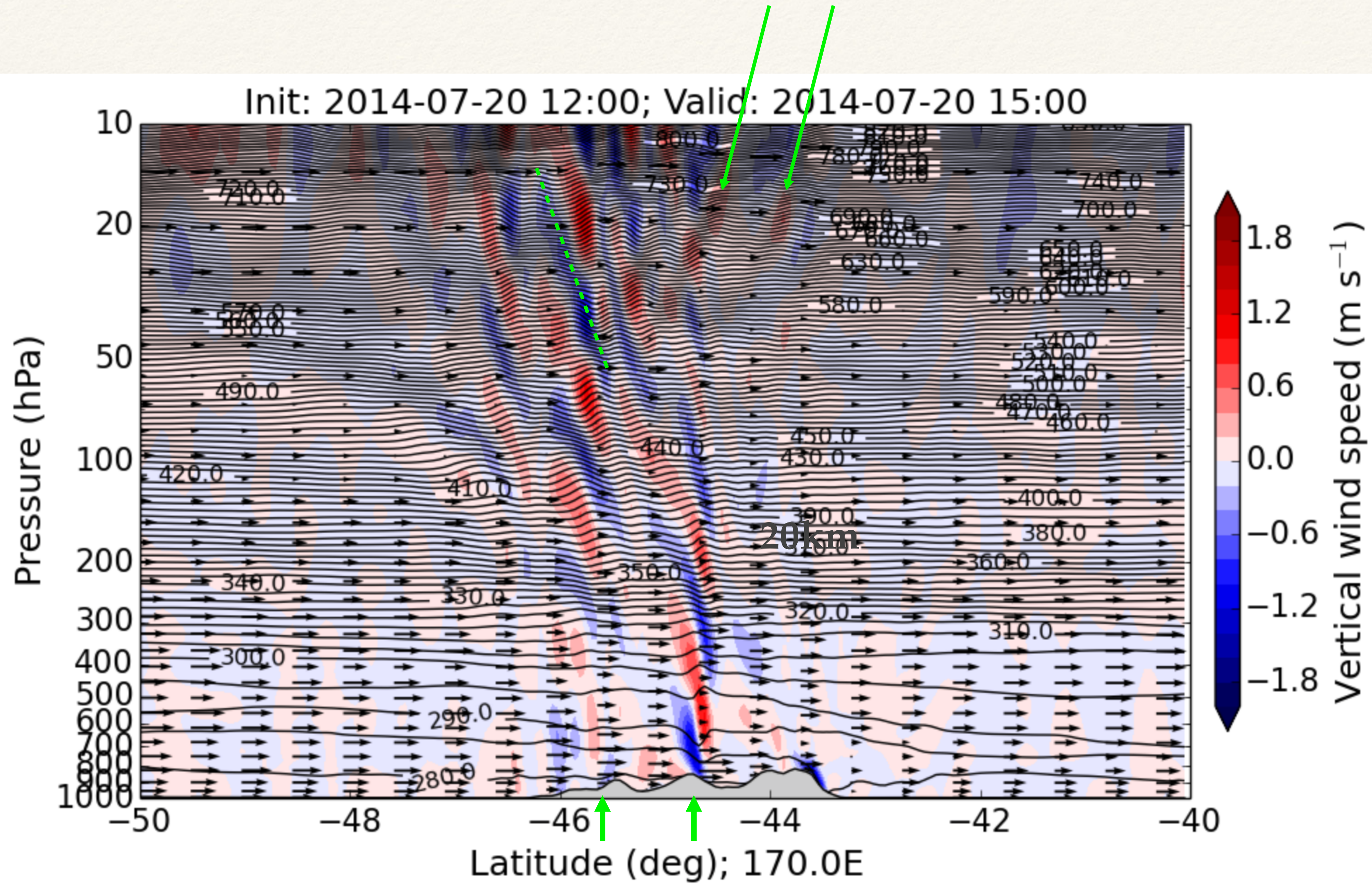



# RF26: WRF prediction at 170E




Download model.WRF_UIBK_6km.201407201200.003_cross170_0E_vert.png

# RF26: WRF prediction at 170E



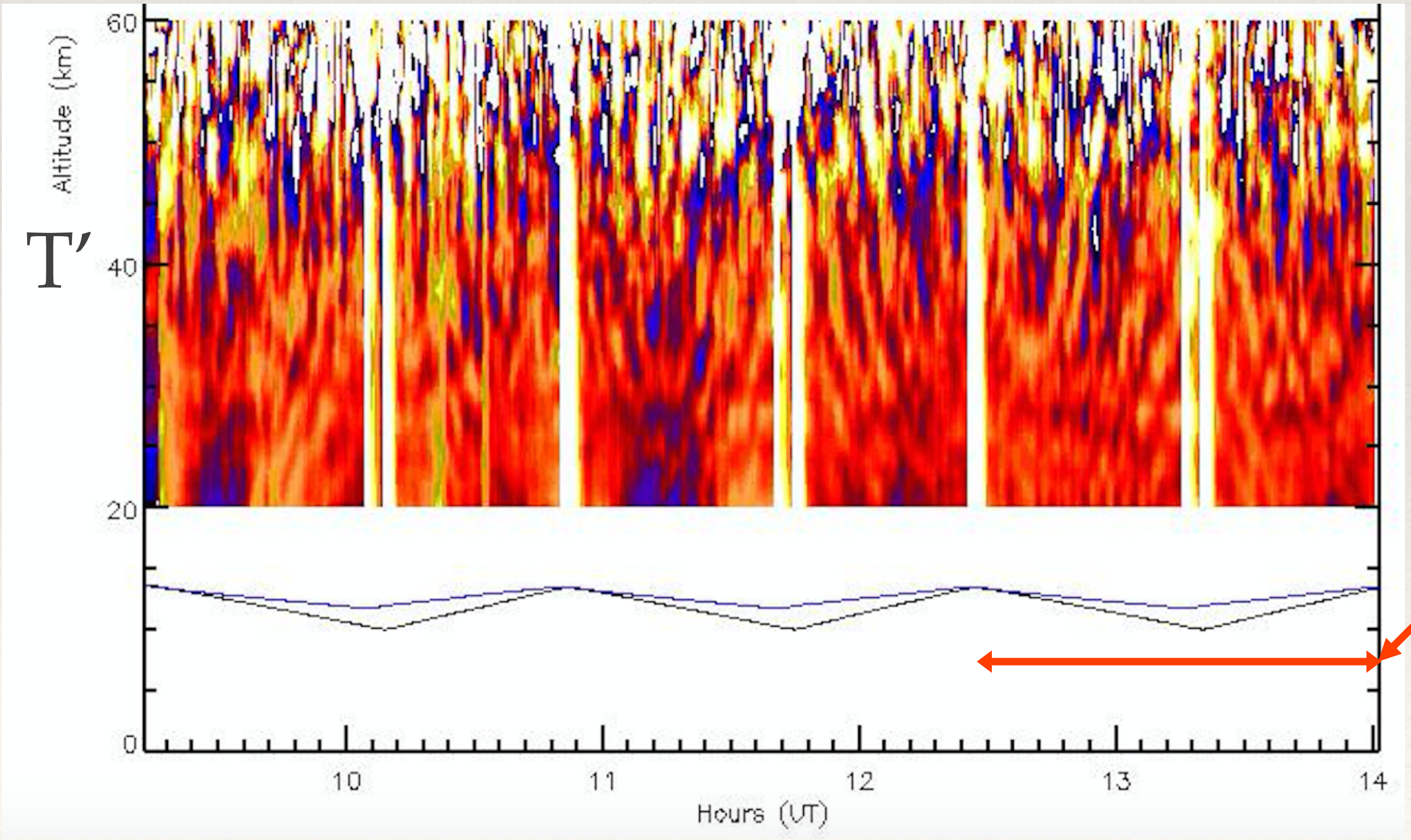

Download model.WRF_UIBK_6km.201407201200.003_cross170_0E_vert.png

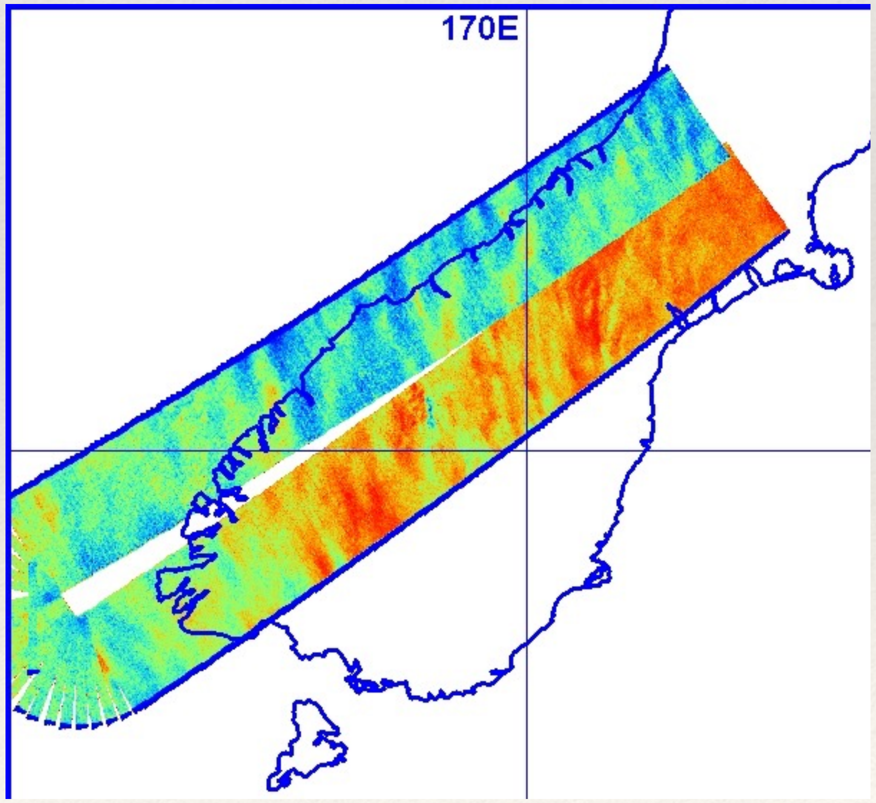
# Mountain Waves - RF26

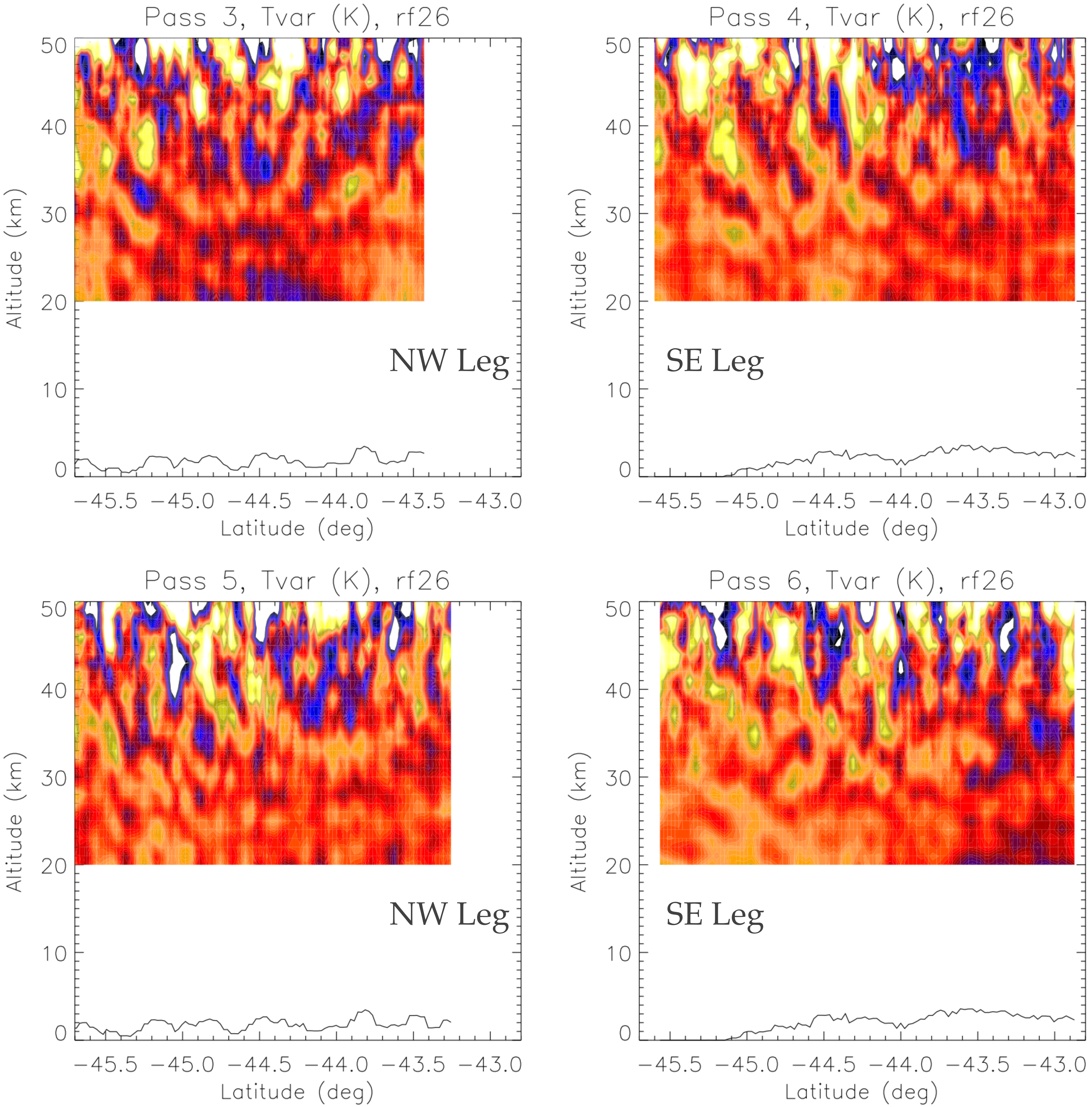
- Waves aligned perpendicular from NW to SE
- Persistent medium-scale waves in stratosphere and MLT
- Horizontal wavelength ~50 km, at edge of lidar resolution

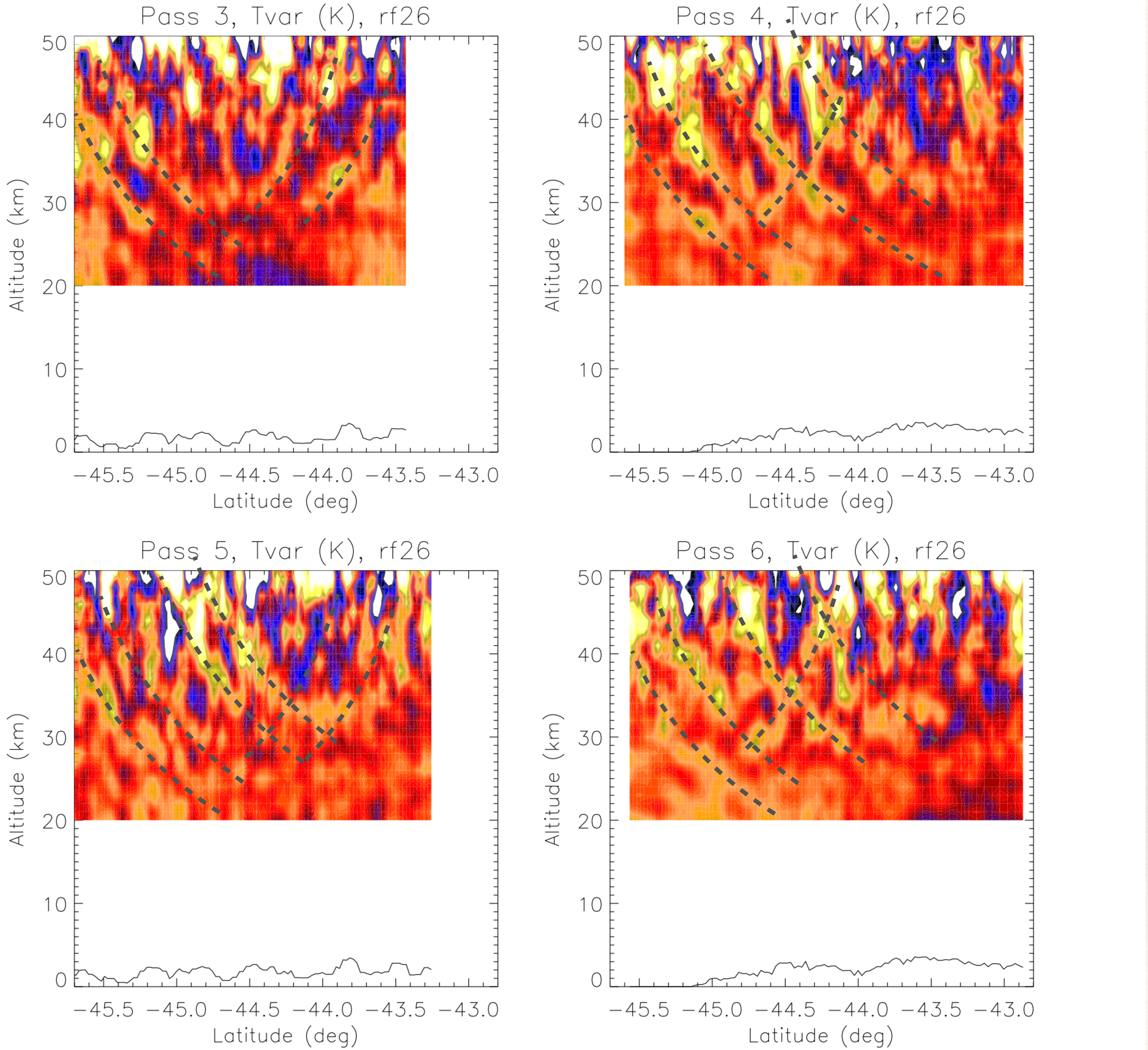
AMTM: 12:28-13:59

T′

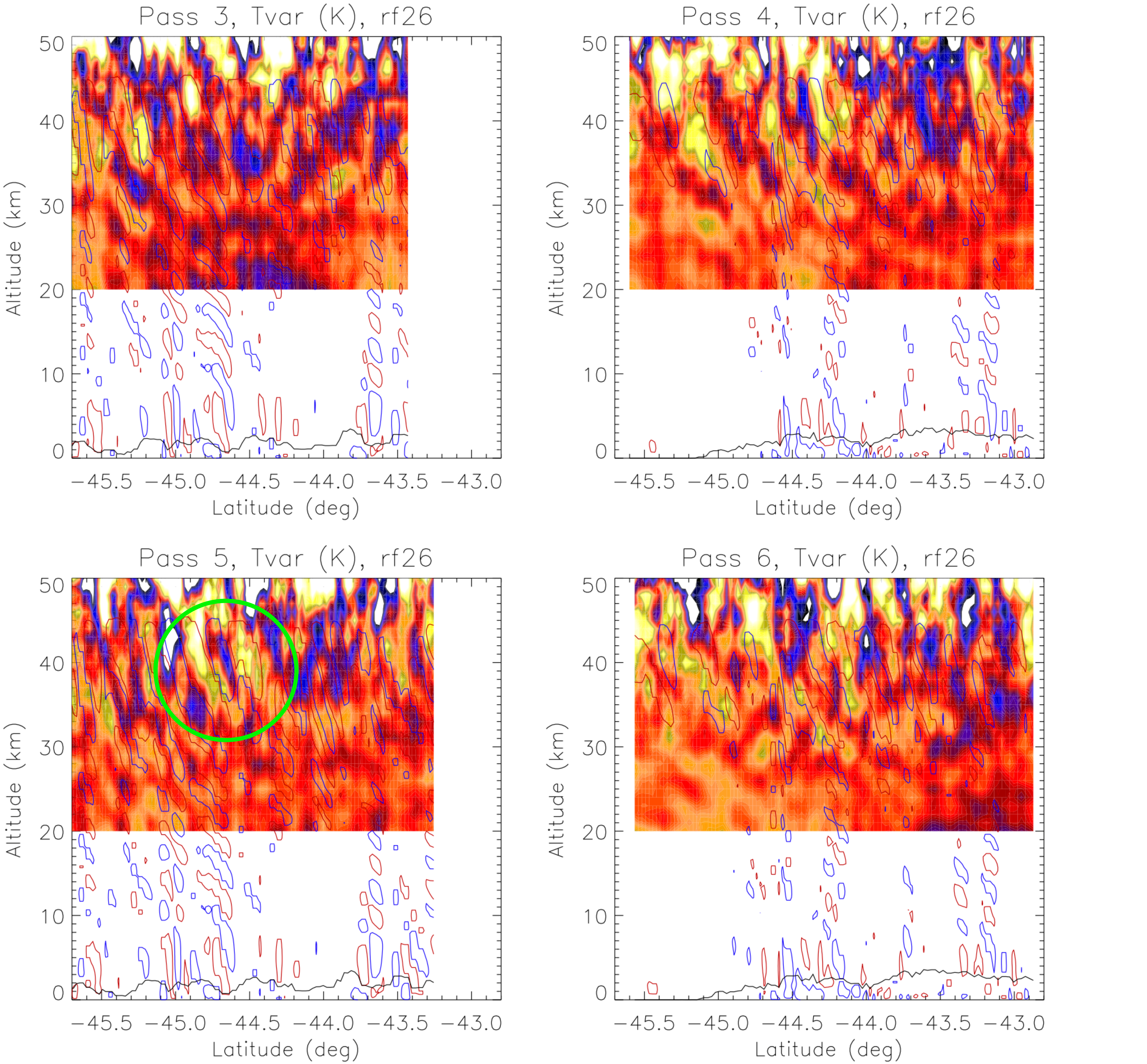


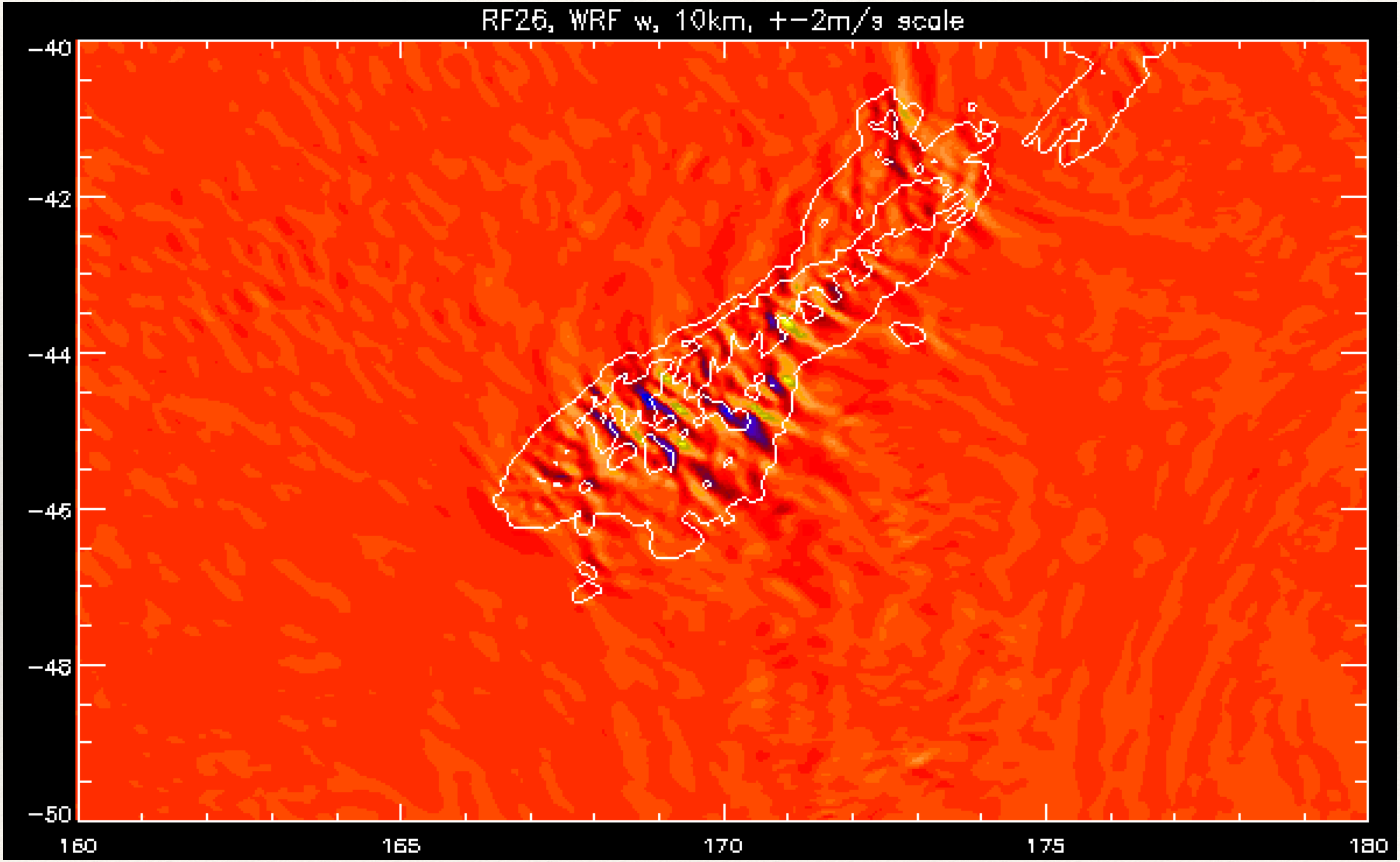

Pass 3, Tvar (K), rf26
Altitude (km)
Latitude (deg)
NW Leg
Pass 4, Tvar (K), rf26
Altitude (km)
Latitude (deg)
SE Leg
Pass 5, Tvar (K), rf26
Altitude (km)
Latitude (deg)
NW Leg
Pass 6, Tvar (K), rf26
Altitude (km)
Latitude (deg)
SE Leg



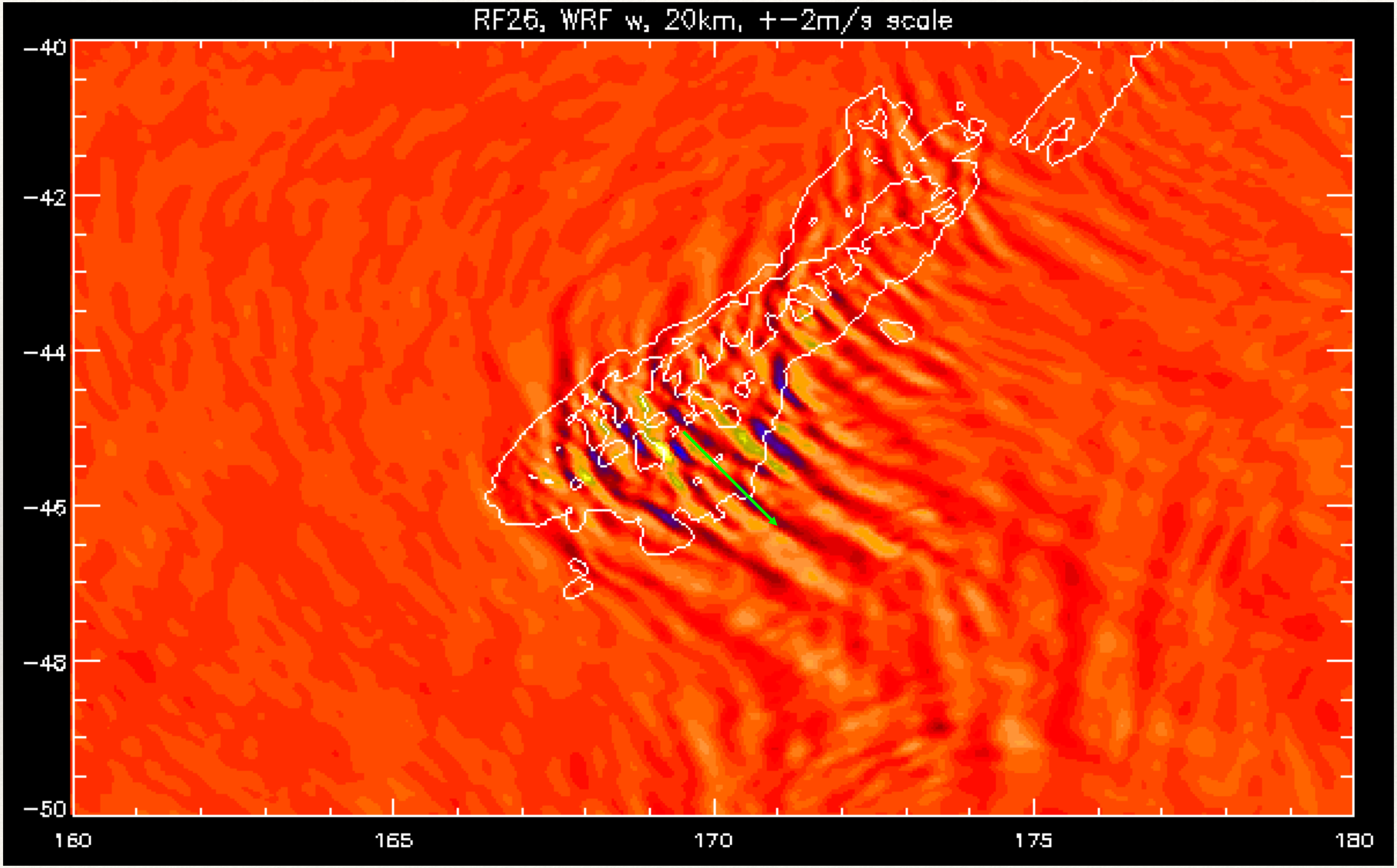
Pass 3, Tvar (K), rf26
Pass 4, Tvar (K), rf26
Pass 5, Tvar (K), rf26
Pass 6, Tvar (K), rf26
Altitude (km)
Latitude (deg)
0
10
20
30
40
50
−45.5
−45.0
−44.5
−44.0
−43.5
−43.0

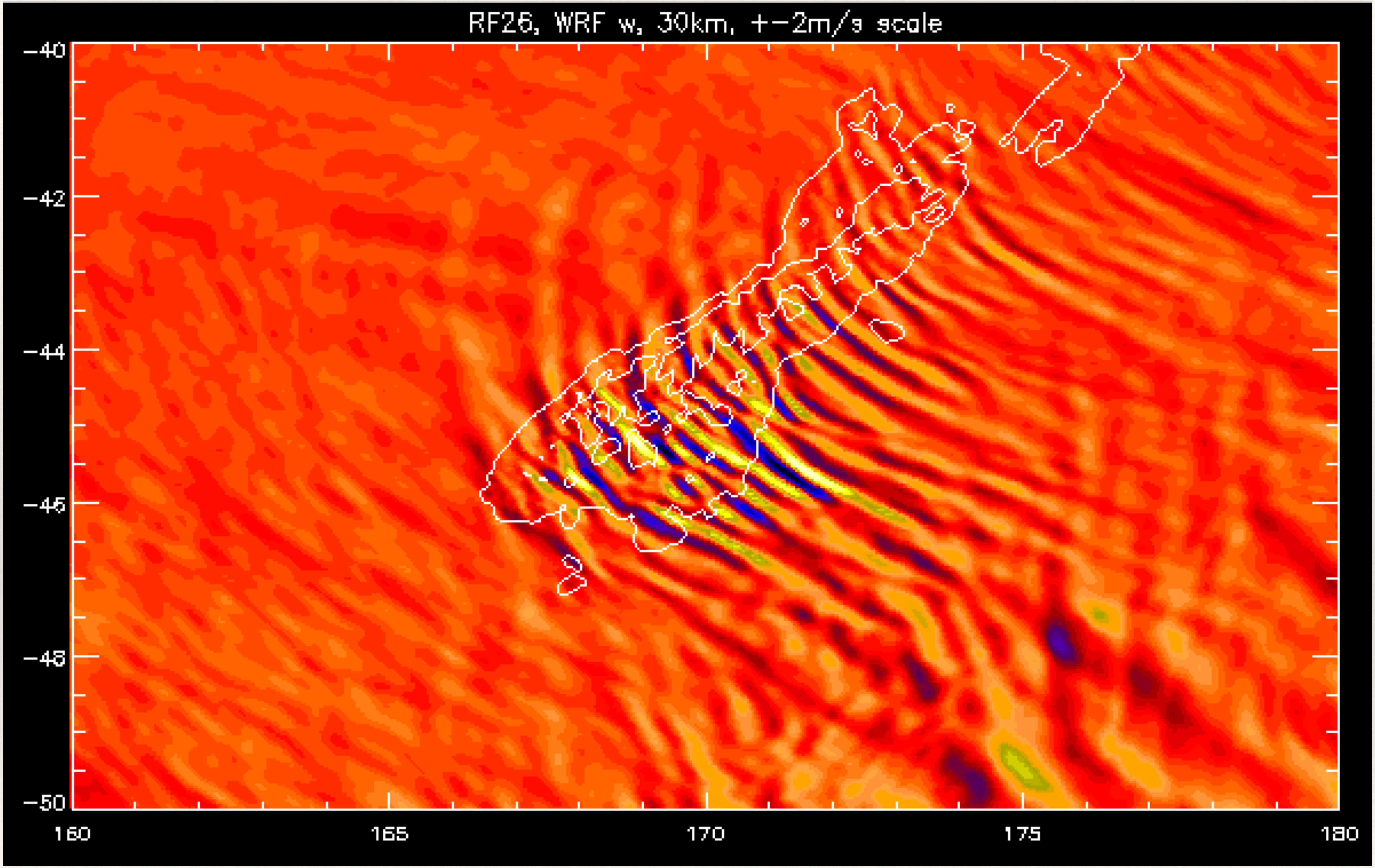


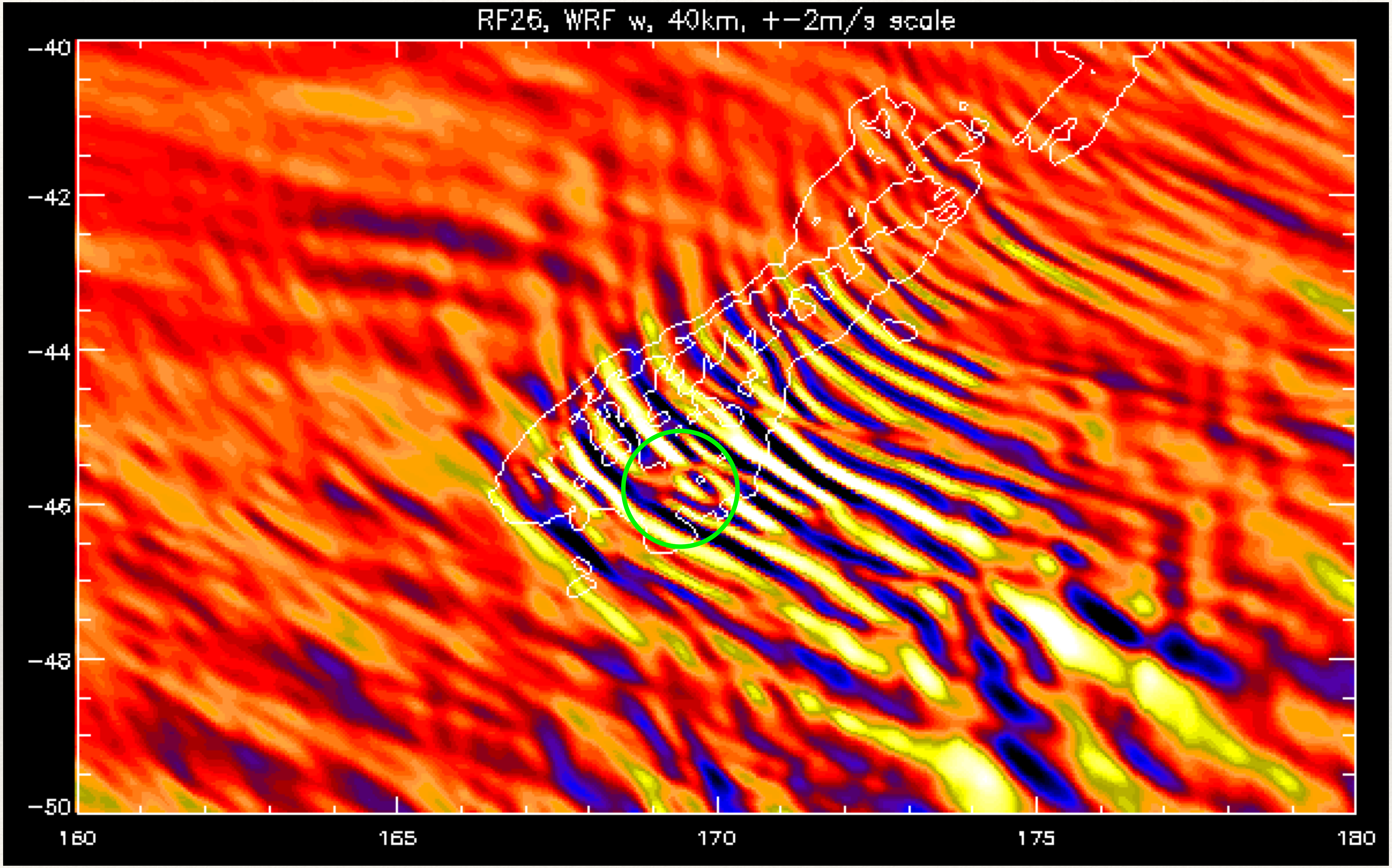
Pass 3, Tvar (K), rf26
Pass 4, Tvar (K), rf26
Pass 5, Tvar (K), rf26
Pass 6, Tvar (K), rf26
Altitude (km)
Latitude (deg)
0
10
20
30
40
50
−45.5
−45.0
−44.5
−44.0
−43.5
−43.0

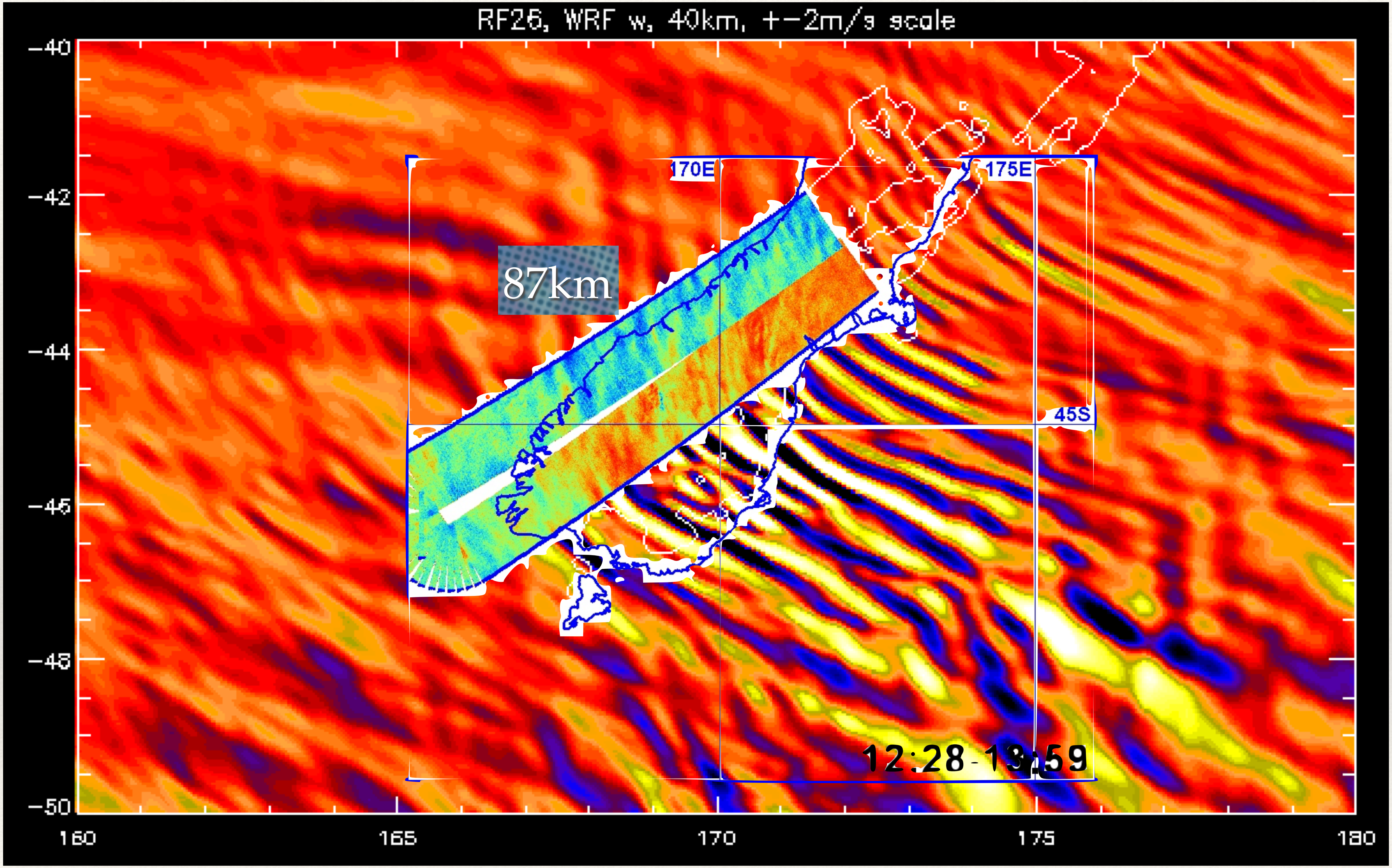


RF26, WRF w, 10km, +-2m/s scale
-40
-42
-44
-46
-48
-50
160
165
170
175
180


RF26, WRF w, 20km, +-2m/s scale
-40
-42
-44
-46
-48
-50
160
165
170
175
180


RF26, WRF w, 30km, +-2m/s scale
-40
-42
-44
-46
-48
-50
160
165
170
175
180


RF26, WRF w, 40km, +-2m/s scale
-40
-42
-44
-46
-48
-50
160
165
170
175
180


RF26, WRF w, 40km, +-2m/s scale
87km
170E
175E
45S
12:28-13:59
-40
-42
-44
-46
-48
-50
160
165
170
175
180

# Conclusions

1. The airborne Rayleigh lidar provides high-resolution mesoscale temperature measurements of the the middle atmosphere
   a. better horizontal resolution than satellites, up to 10 repeated legs over the same terrain
   b. better horizontal coverage than ground-based observations
2. Forcing perpendicular to mountains
   a. RF22: Weak forcing but strong, large horizontal wavelength waves in mesosphere
      1. Slow vertical propagation from strong forcing previous day?
      2. weak forcing + good propagation conditions?
   b. Strong forcing: Waves break in stratosphere?
3. Forcing parallel to mountains
   1. Multiple small horizontal wavelength waves excited in troposphere by different peaks in mountain range
   2. Interference, secondary wave generation in stratosphere?
   3. Use more detailed/higher altitude models: WRF 2km runs, NAVGEM 0-100km