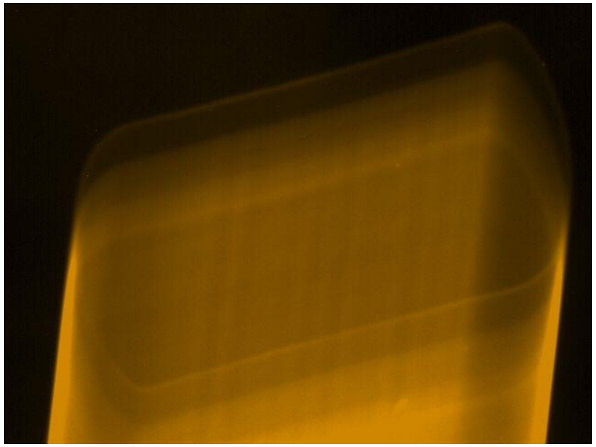
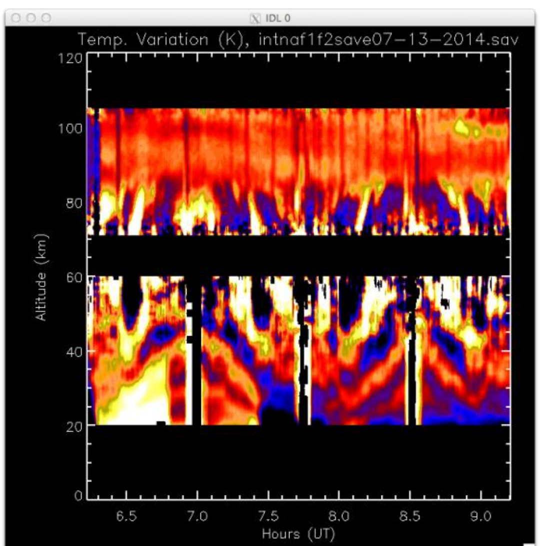


DEEPWAVE Rayleigh and Sodium Lidar Overview
DEEPWAVE Workshop, Boulder



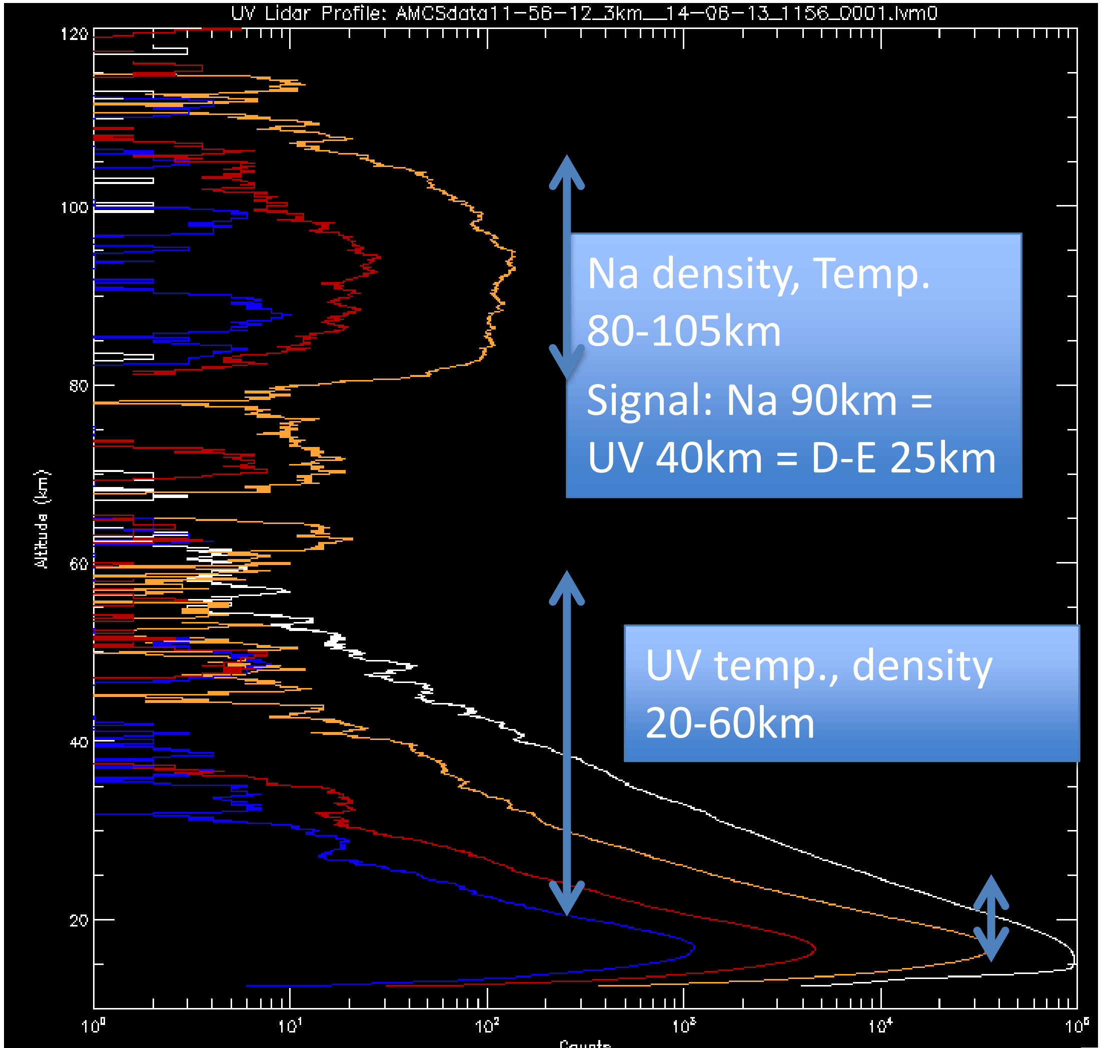
Biff Williams

GATS, Inc.

23 Oct 2014

UV, Na, and Double-Edge Profiles

120km



Na density, Temp. 80-105km

Signal: Na 90km = UV 40km = D-E 25km

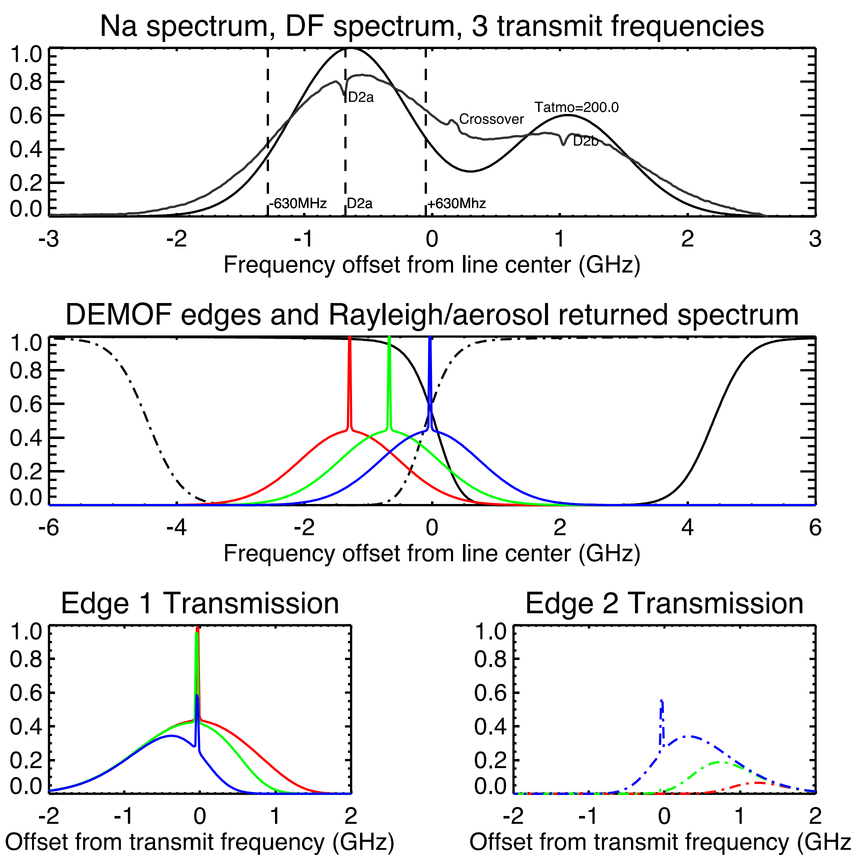
UV temp., density 20-60km

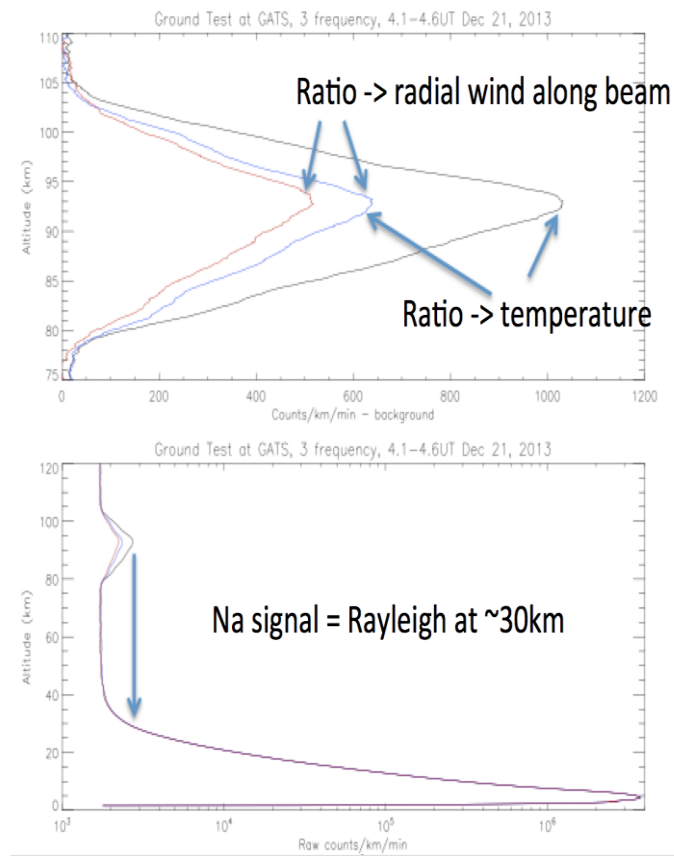
Double-Edge w’, BSR, 15-25km

10km

Log scale

Na lidar: high-resolution spectroscopy



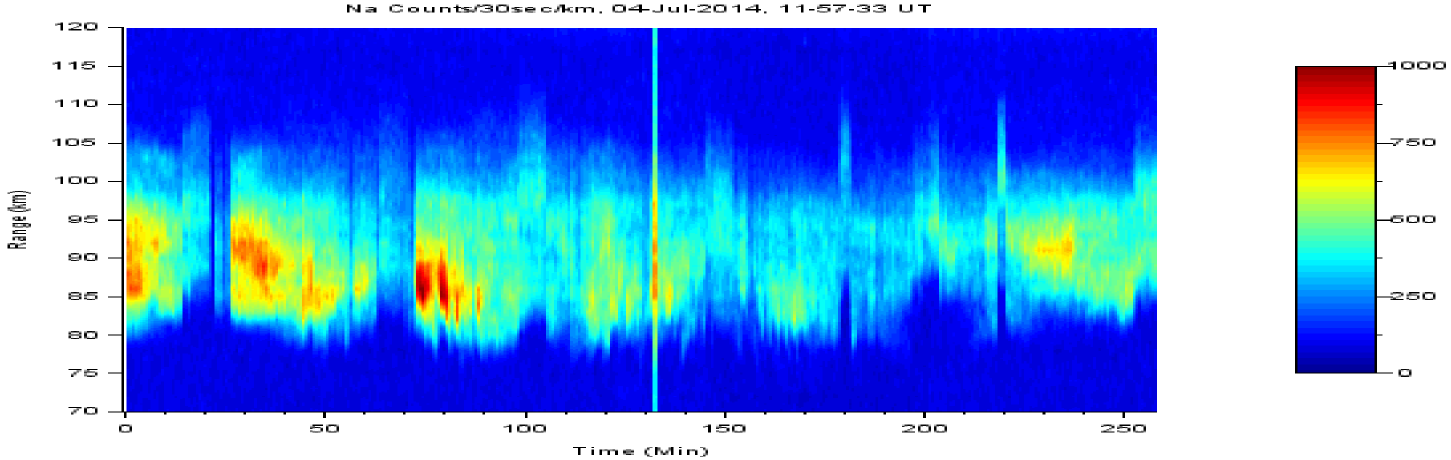


Rayleigh lidar data products

- Temperatures and densities in upper stratosphere/mesosphere
  - Measure relative density with UV beam, integrate density to get temperature from assumed temperature start point at top of profile
  - Start point affects top 1-2 scale heights until integration converges
  - Density is relative measurement, use radiosondes to calibrate?
  - Temperature profile needs good start temperature at ~70km
  - Aerosols cause issues from 20-30km, luckily NZ has low aerosol loading
  - 20-75km coverage integrating whole flight (~5 hours)
  - 20-65km coverage with 30 min integration
  - 20-55km coverage for larger waves (1K error at 45km) with 5 min integration
  - Can look at signal variations (density/aerosol layers/high cirrus/PSC) at high resolution (200m hor., 37m vert.) from 15-25km
  - Good data all flights except rf01 (no viewport), rf02 (bad connection in UV receiver), rf15 (daytime)

Na lidar data products

- Na density:
  - Layer from 80-105km with sharp bottom side gradient
  - Good tracer of short period GW activity
  - Shows GW presence and vertical structure
  - Difficult to quantify due to Na chemistry
  - Useful data all flights except rf01 (no viewport), rf15 (daytime)
  - Real time plots in data catalog starting rf16
    - Turns produce a vertical shift in real-time plots
    - Star, moon, laser issues produce vertical stripes in plots



Na lidar data products

- Mesopause-region temperatures from Na beams
  - More quantitative but doesn't resolve all the waves
    - Tmapper has better time resolution integrated over 87km +-5km altitude
    - Na lidar has vertical resolution (3km from 80-105km)
  - Spectral measurement, does not assume hydrostatic equilibrium
  - Pulsed Na beam has better altitude but worse time resolution
  - Scanned beam has more signal but lower altitude resolution
  - Cross talk between pulsed and scanned Na beam fixed between rf08 and rf09, temperatures more accurate after this
  - Useful data rf09-rf14, rf16-rf20
  - Measured crosstalk signal, so data from rf02-rf08 may be correctable
  - Still working on temperature calibration

Na Lidar: Double-Edge Strat. Receiver

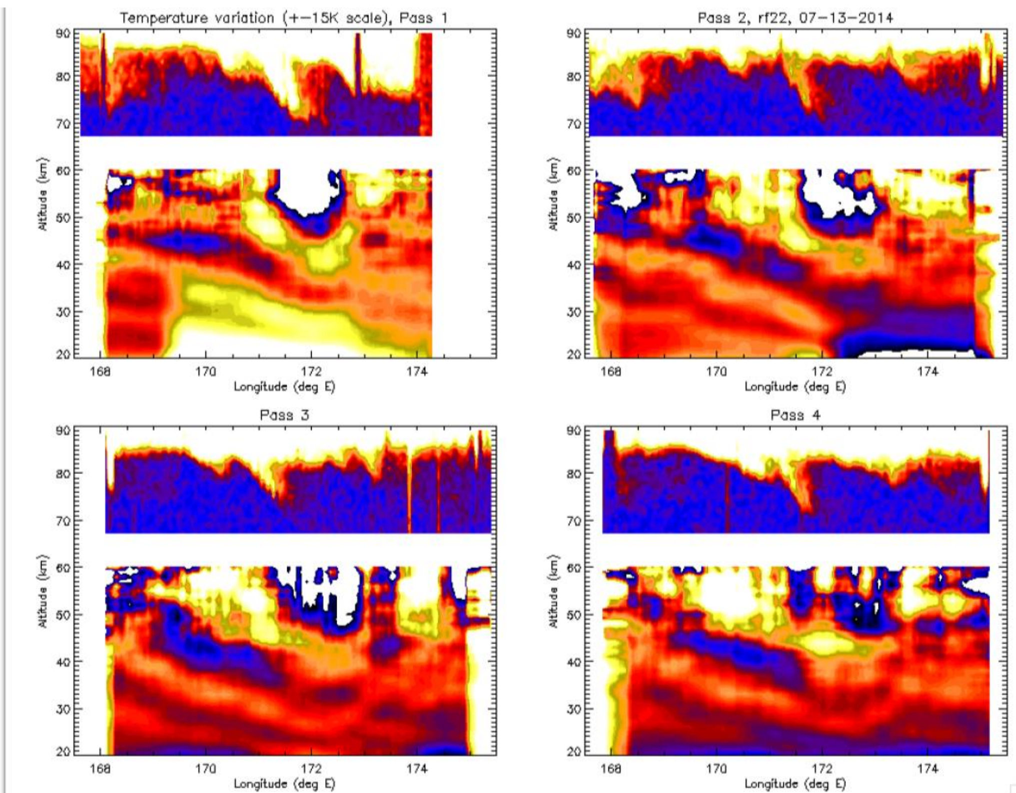
- Vertical winds 15-25km from Double-Edge filter
  - Filter has taken data rf02-rf14, rf16-20 with expected signal levels
  - First deployment of this technique
  - Laser frequency control not as good on the airplane as on the ground (vibration, turbulence) or during test flights (hanger)
  - Will likely only see large wave events (>+-3 m/s)
  - Careful analysis needed

rf22: Strong MW 20 to 85km

- Katrina will discuss Na data in more detail for rf22 and rf24
- Mountain wave growing strongly from 20 to 85km, 25K amplitude at 55km
- Visible in Rayleigh, Na and Tmapper for 4 passes over the mountains

Na Density

$T\text{-}T_0$

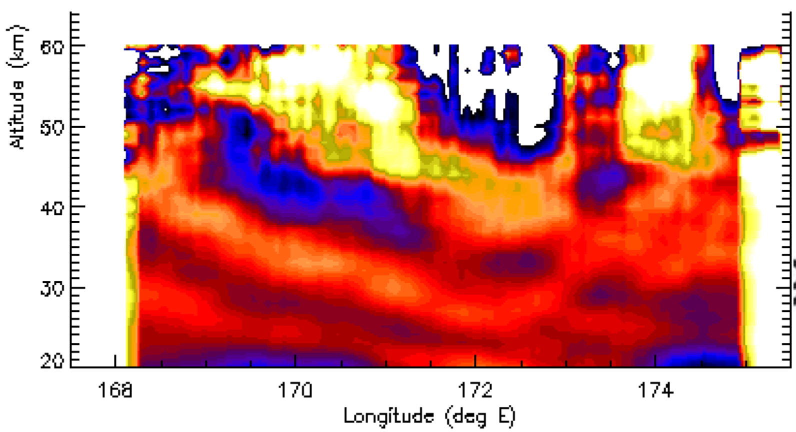


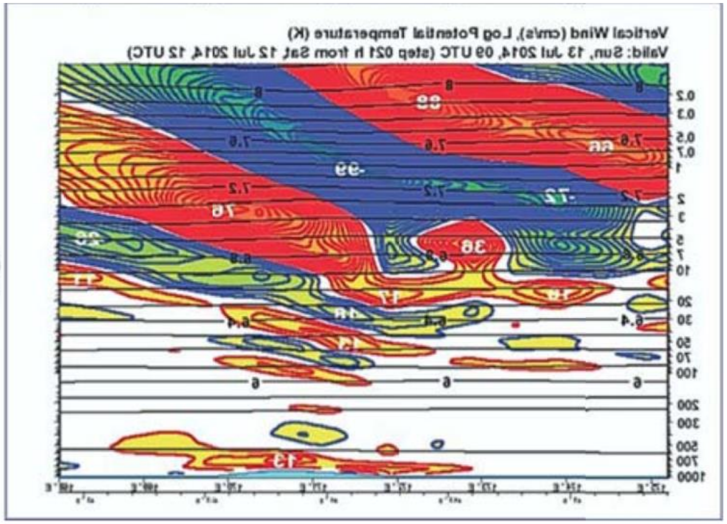
90km

20km

rf22: Strong MW to 85km (cont.)

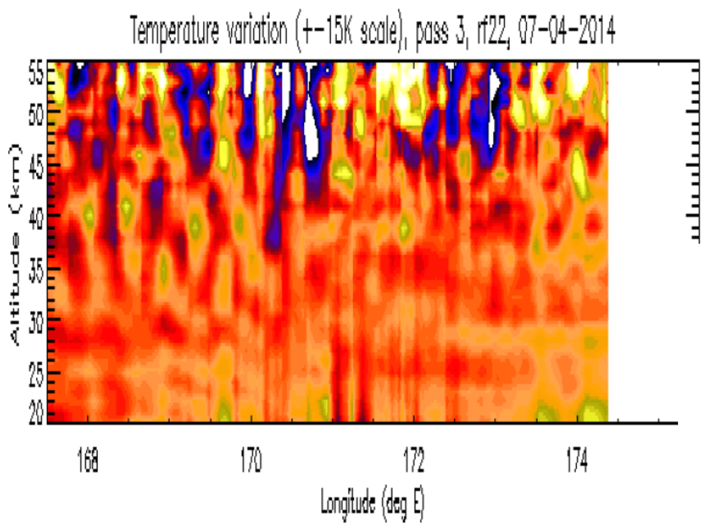
- Good agreement with ECMWF 9Zmodel forecast
- Wave fronts move upwards to the west with increasing vertical wavelength
- Smaller scale wave structures at 172-173E at 30km
- Flatter wave structures downstream to east

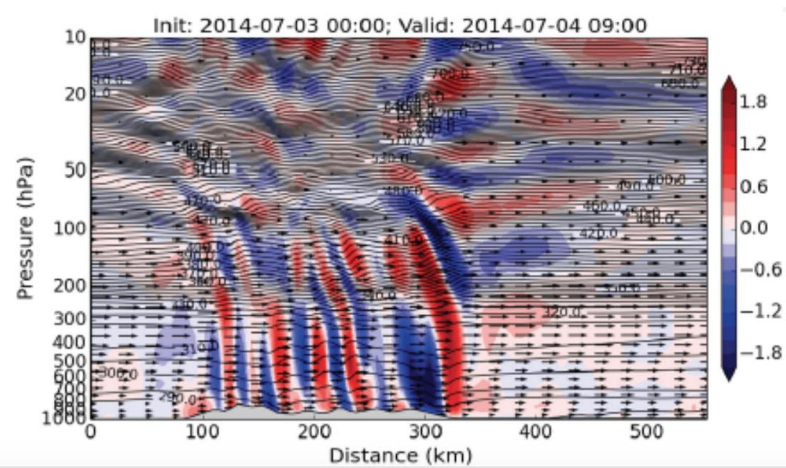




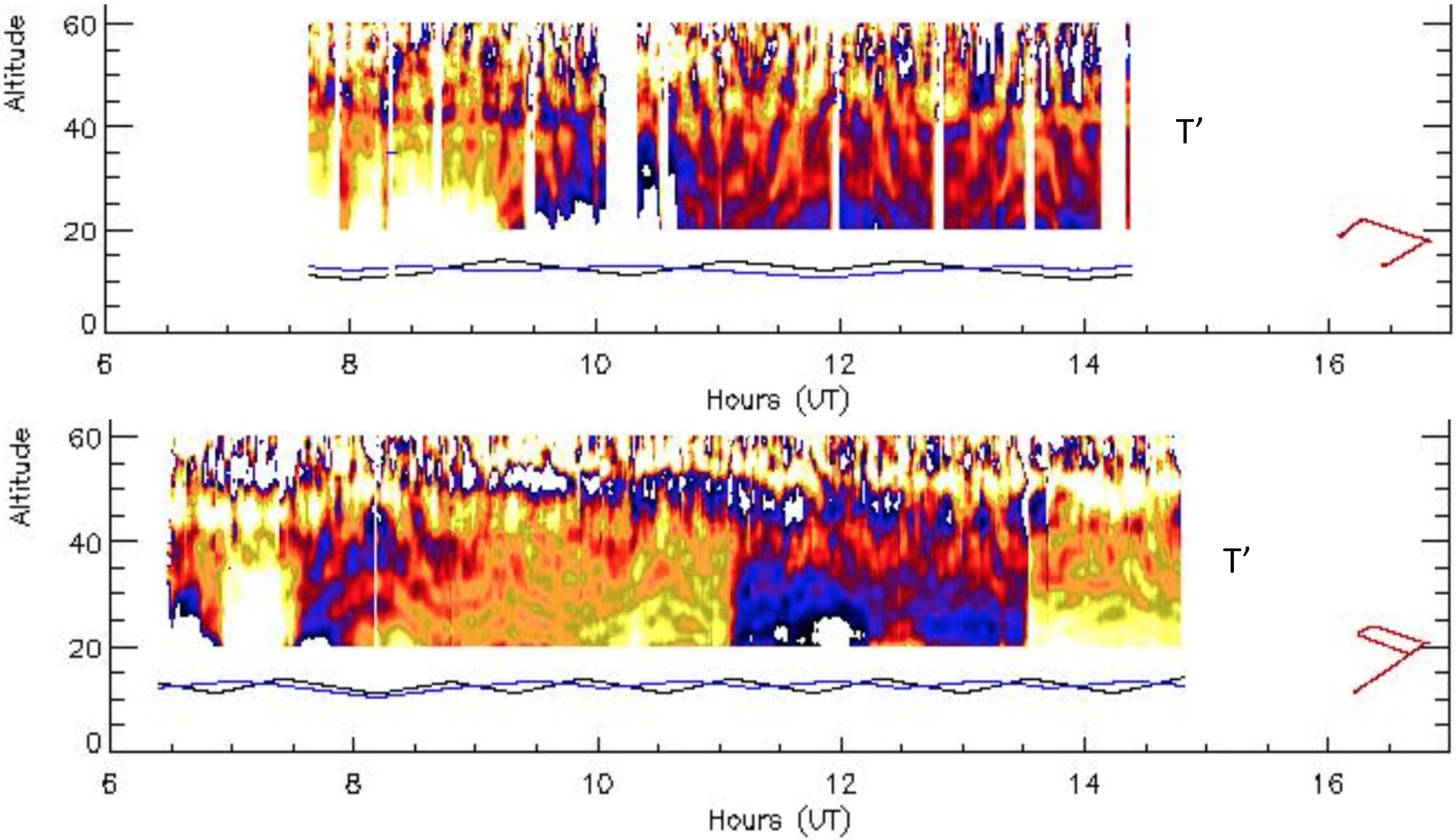
rf16: MW breaking
secondary wave generation

- Strongest MW at flight level, likely breaking above
- Lidar data: crossing waves going east and west from 30-55km in lidar data on west side, flatter wave structures downstream to east
- WRF predicts crossing waves upstream, flatter structures downstream

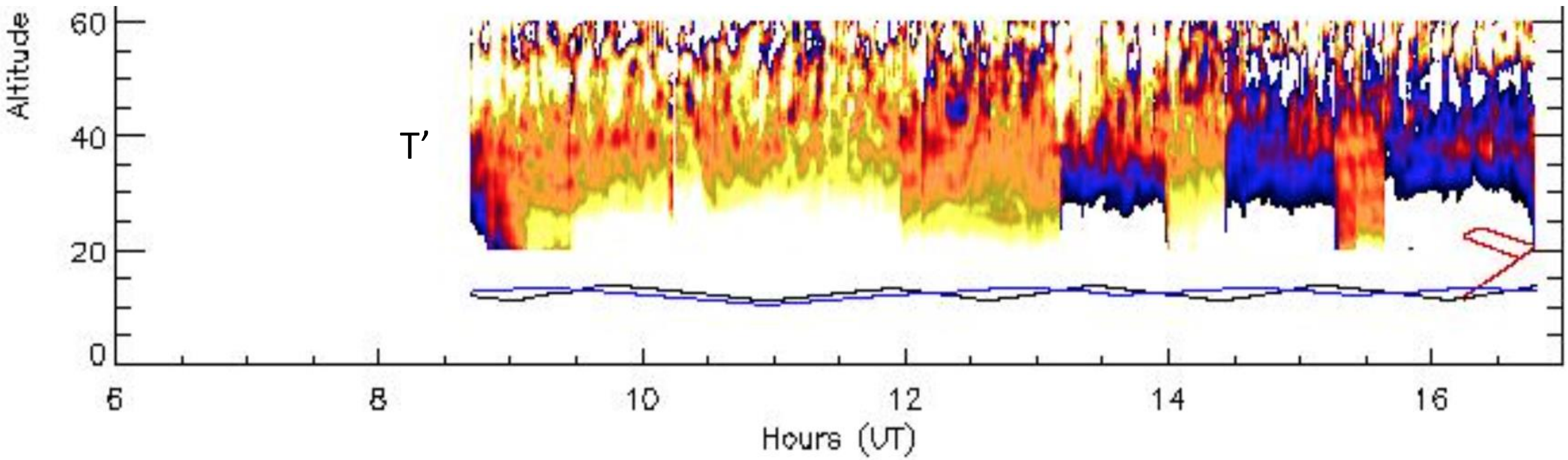


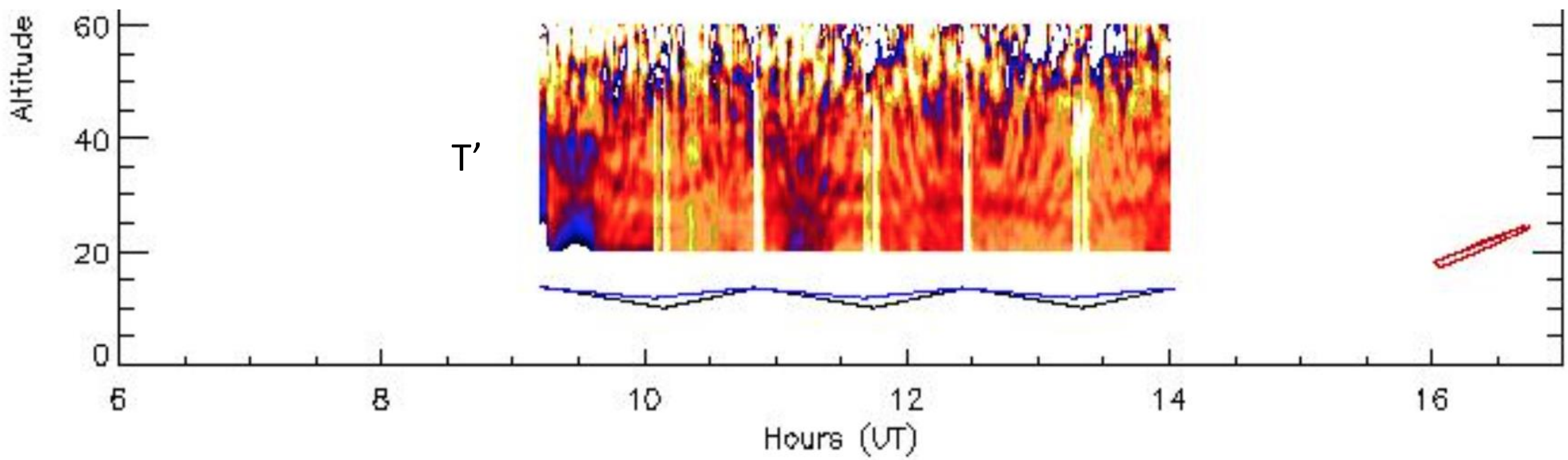


rf04, rf13: possible medium scale MW



rf12, rf26: possible small-scale MW



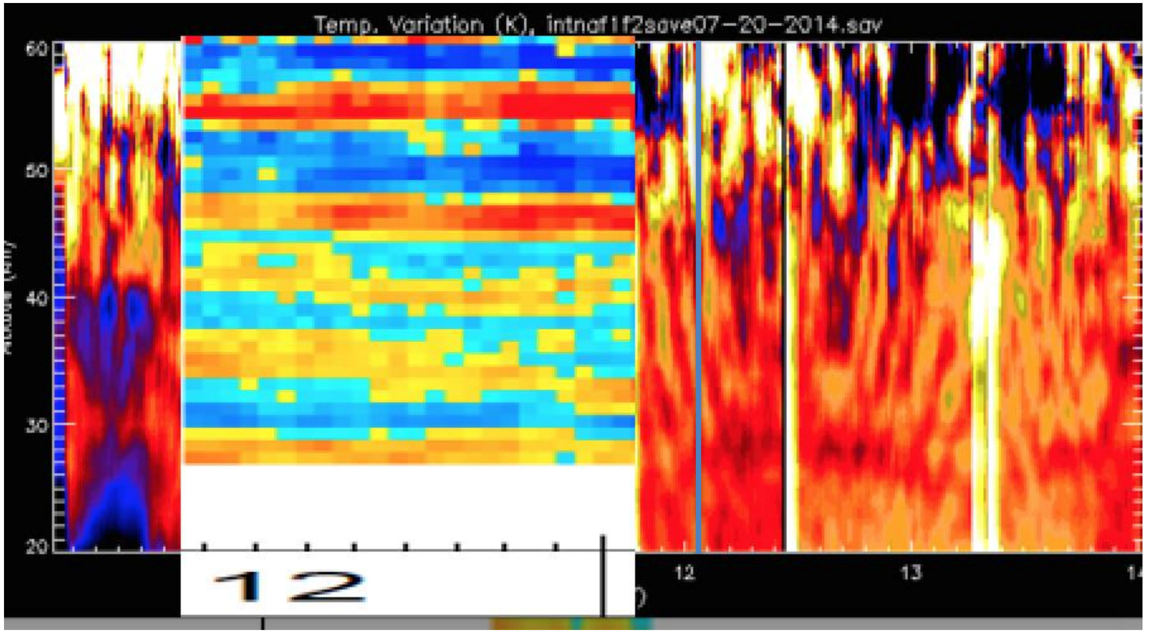


MW in Lauder lidar

- rf26: Bernd's Rayleigh system often sees persistent temperature layers with minimal movement in height
- GV lidar sees persistent highly inclined layers
- Likely GW's with zero horizontal phase speed

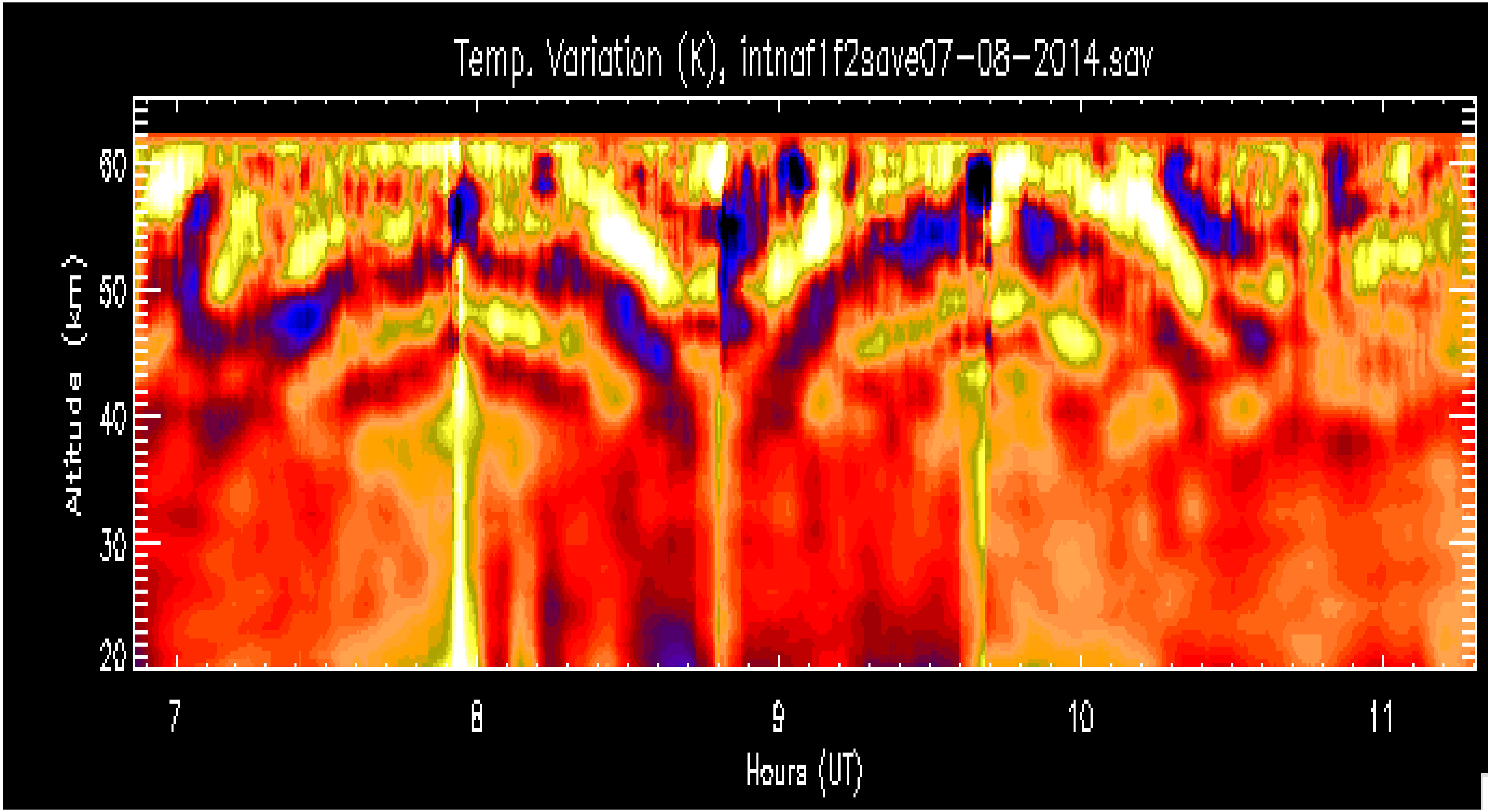
Lauder GV lidar

T'



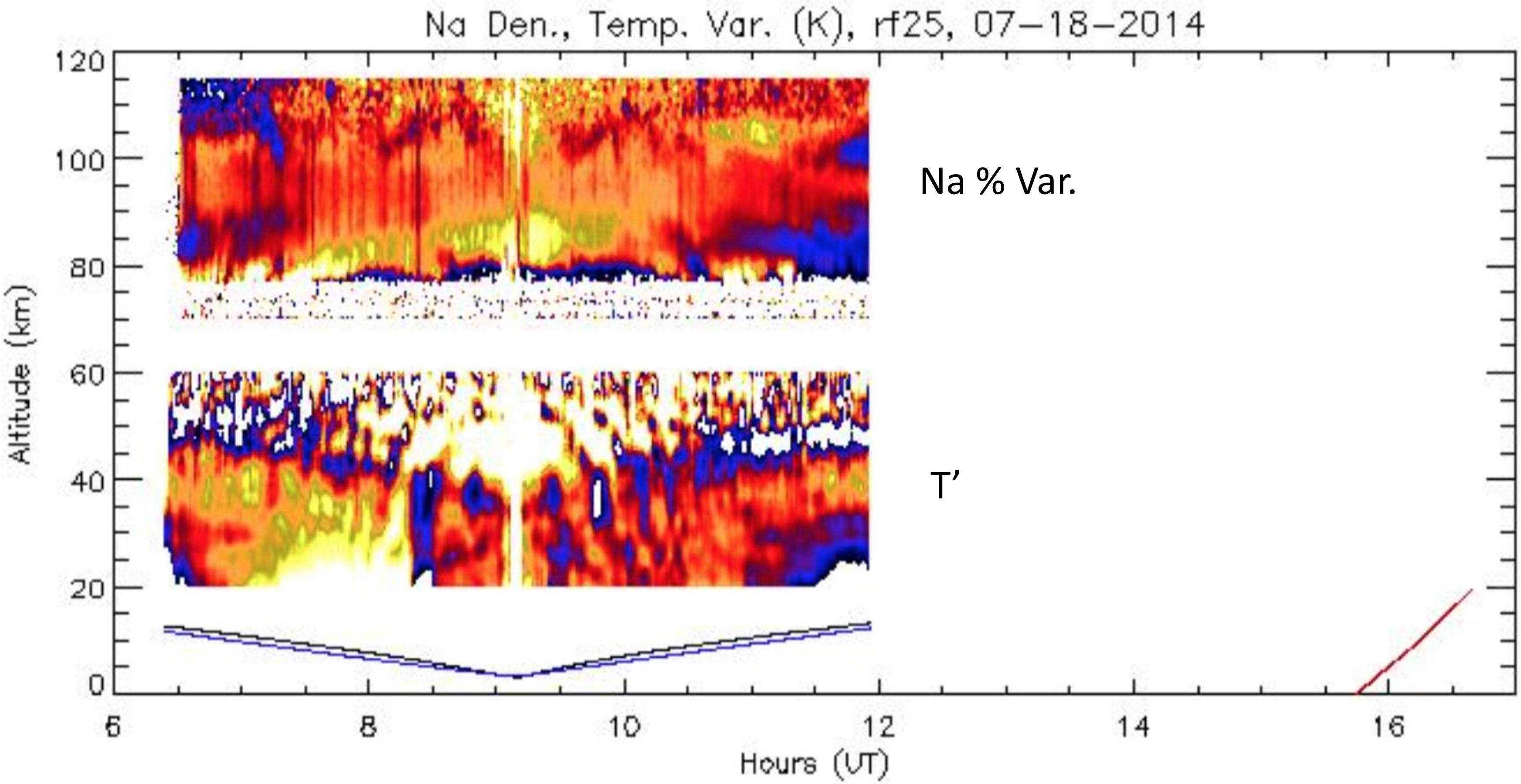
rf19: Non-orographic GW

- Southern Ocean, multiple passes
- Phase fronts flattening with height, +- 25K scale
- Rapid increase in amplitude from 35-60km



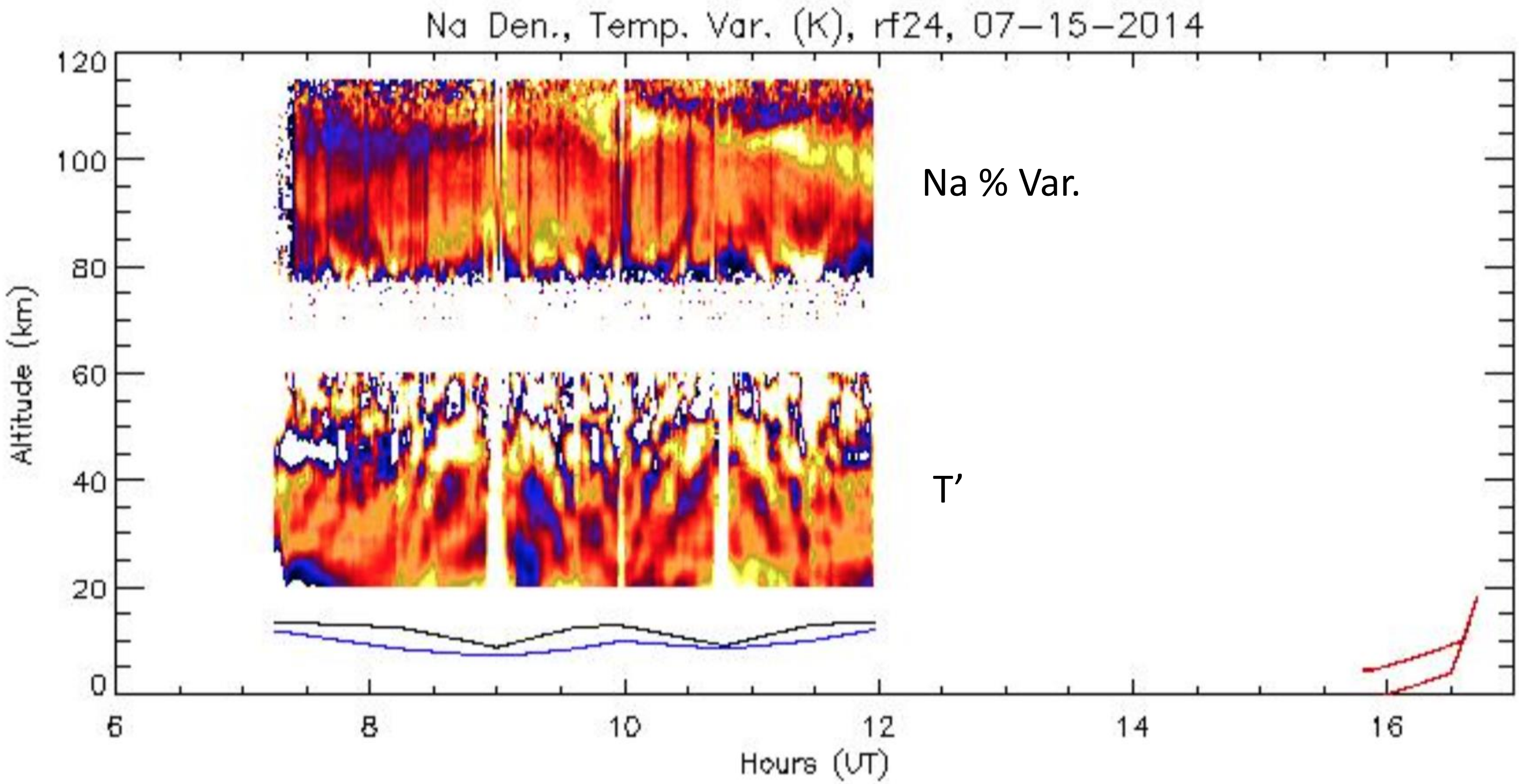
rf25: Non-orographic GW

- Southern Ocean, one long down-and-back
- Medium scale wave: phase fronts flattening with height
- Na layer bottom side rises as we went south
- Long horizontal wavelength wave inclined downward as we go south



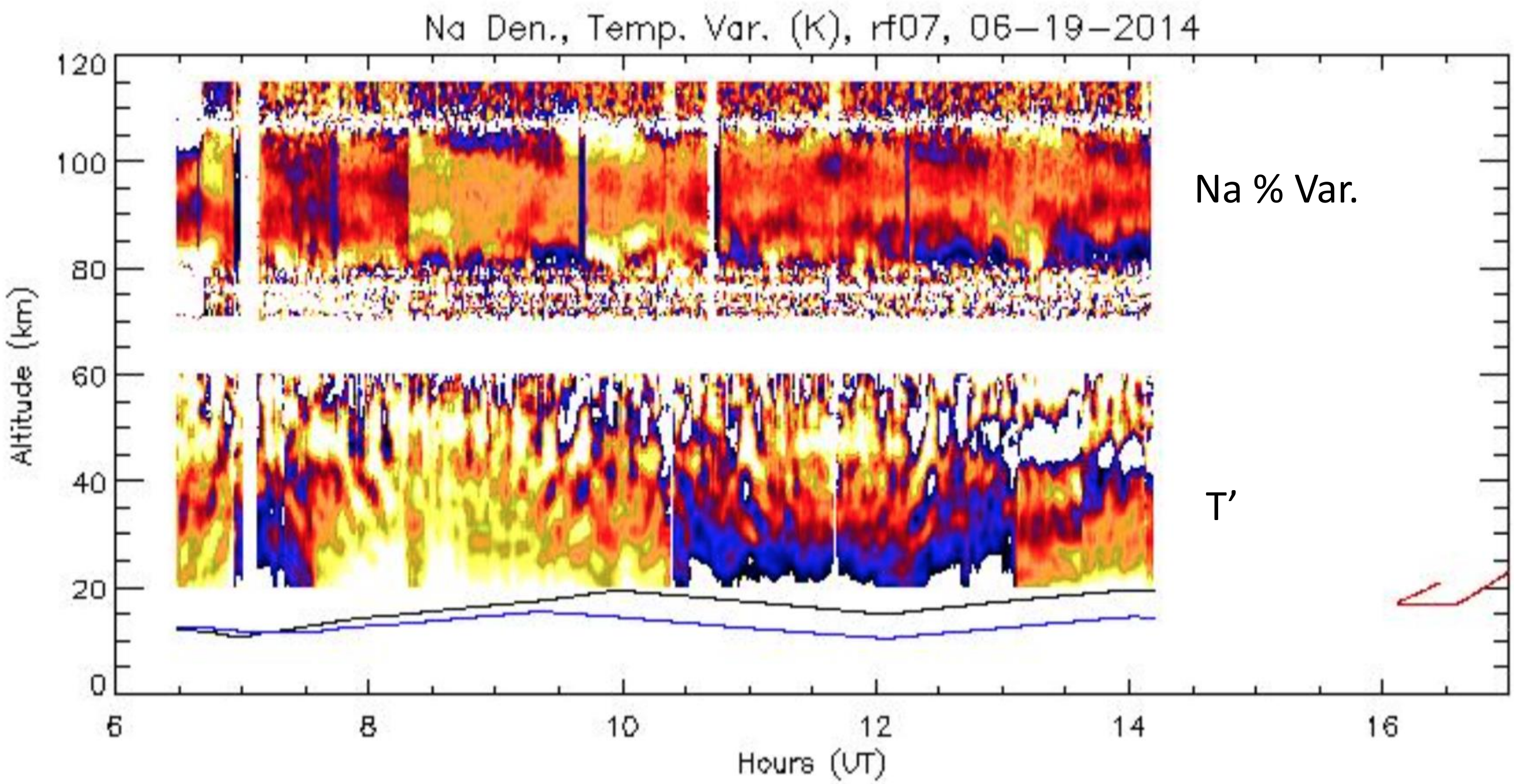
rf24: Non-orographic GW

- Southern Ocean, multiple offset passes
- Vertical wavelength increasing with altitude
- Possible Na layer response, phase tilt matches
- Jet produced?



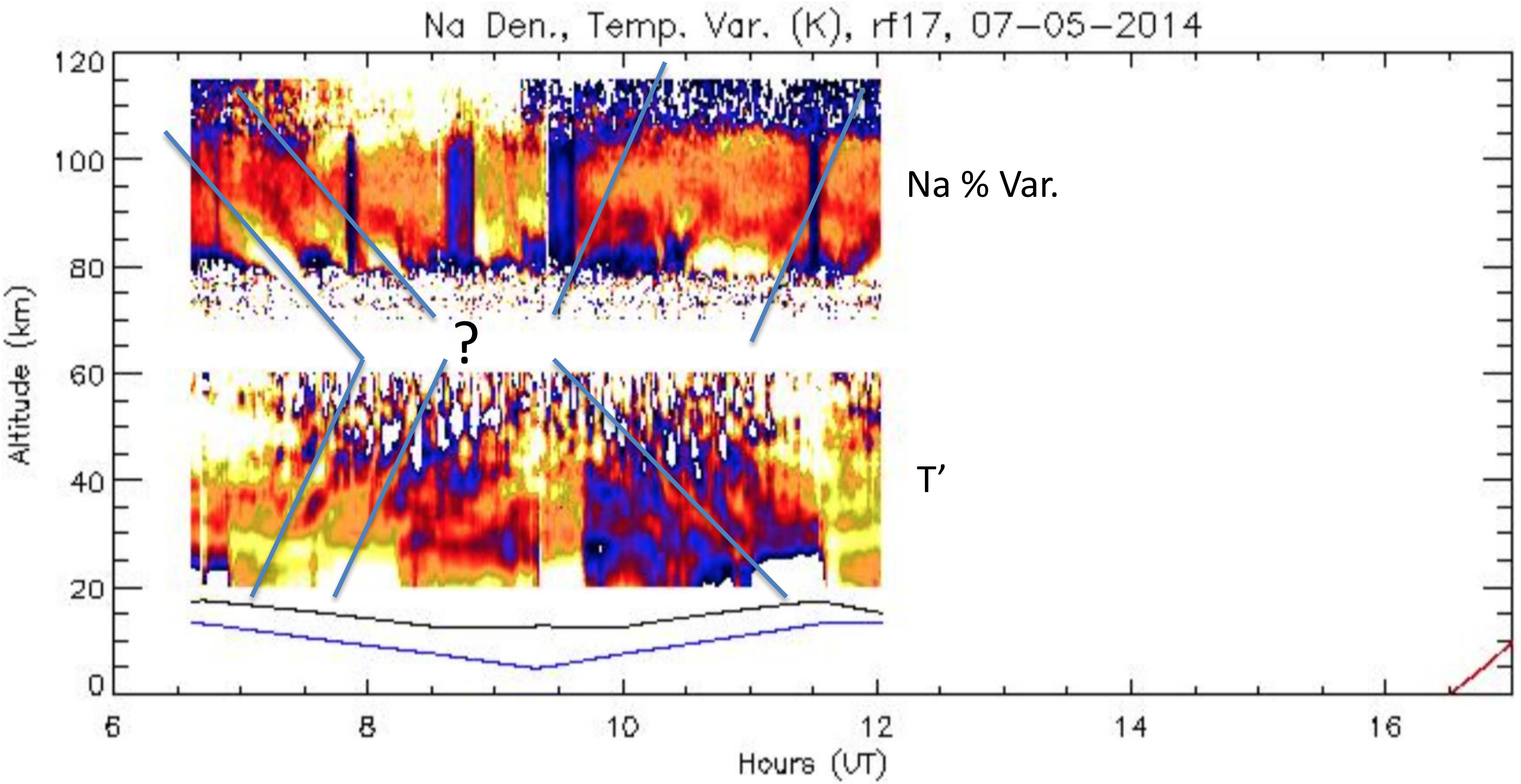
rf07: Non-orographic or lee GW

- Eastern Ocean, rectangular pattern
- Medium scale waves: phase tilts upward with altitude
- Na layer active, difficult to match wave fronts
- Storm produced?



rf17: southern ocean GW:

Southern ocean: opposite phase tilt at 40km and 80km



Science Results and Conclusion

- Significant waves in middle atmosphere (20-60km) on 13 out of 23 flights at 100km+ horizontal wavelengths
- Several nights with waves at smaller scales, working on re-analysis, may be more
- Deep mountain wave propagation: 6 flights
  - MW penetrate to 50km on rf04, rf12, rf13, rf16, rf22, rf26
  - rf23: Auckland island lee waves: airplane descended, no lidar data
- Ground-based Rayleigh lidar at Lauder sees fixed layers when MW present.
- Waves reach end of most legs at full strength, go farther upstream than I expected
  - Going farther upstream and downstream would have been better
- rf16: MW breaking -> secondary wave gen. at smaller scales
- Good comparison with model predictions on rf16 and rf22
- Non-orographic waves (southern, eastern, Tasman oceans)
  - Reach 50km on 7 flights: rf06, rf07, rf17, rf18, rf19, rf24, rf25
- Still need to look at models and AIRS data for most flights