From the Troposphere to the Thermosphere: Tracking Upward Atmospheric Wave Propagation

ASU School of Earth and Space Exploration, Arizona State University

Sophie R Phillips [1], Katrina Bossert [1], Mark Conde [2], Jintai Li [2], Lars Hoffman [3], Rich Collins [2], Denise Thorsen [2]

(1) School of Earth and Space Exploration - Arizona State University, (2) University of Alaska, Fairbanks, (3) Jülich Supercomputing Centre, Forschungszentrum Jülich, Jülich, Germany

Introduction

Atmospheric gravity waves (GWs) dictate the dynamics of Earth's atmosphere. These dynamics include perturbing background winds, temperatures and densities, and the deposition of momentum, which results in drag on background mean winds. This project seeks to observe GW coupling upwards into the thermosphere using wind and temperature perturbations. Secondary and higher order GW's, commonly seen in the Thermosphere, have been shown to arise from body forces due to primary gravity wave breaking (Vadas 2003). Therefore, GW observations over a range of altitudes allows for more insight into coupling from the lower atmosphere through secondary GW generation.

Data

Multiple instruments and reanalysis data were used to get data ranging from 5km up to 250-350km. In order to obtain a full altitude profile, data from multiple instruments were observed.

- **0-40km** - Modern-Era Retrospective Analysis for Research and Applications V2 (Merra-2)
- **30-40km** - 3D Atmospheric Infrared Sounder (AIRS)
- **40-60km** – Rayleigh Lidar
- **80-95km** – Meteor Radar Data
- **250-350km** – Scanning Doppler Imager (SDI) at 630nm

The SDI at Poker Flat, Alaska was passed through a smoothing process where background winds were subtracted and waves with periods between 20 and 90 minutes were extracted. AIRS and Rayleigh temperature perturbation values were obtained by subtracting average background temperatures.

Nightly Variances

Many nights with low auroral activity were originally observed using these instruments, but December 23rd stood out as a date of higher activity in the atmosphere, as seen from Table 1 AIRS and 630nm SDI variances.

	Nov 2, 2018	Nov 28, 2018	Dec 23, 2018	Jan 7, 2019	Jan 18, 2018
Temperatures AIRS (K)	0.73	0.60	1.3	0.39	0.026
Temperatures SDI (K)	128.4	67.1	107.0	85.1	84.4
Zonal Wind SDI (m/s)	59.9	37.8	76.6	64.0	97.7

Table 1. Background subtracted temperature and zonal variances from AIRS and SDI for nights with low auroral activity.

Planetary Waves Presence

Merra-2 shows a global view of Meridional and Zonal winds. On the night of interest, polar night jet disruption and evidence of planetary waves was observed in both the zonal and meridional winds.

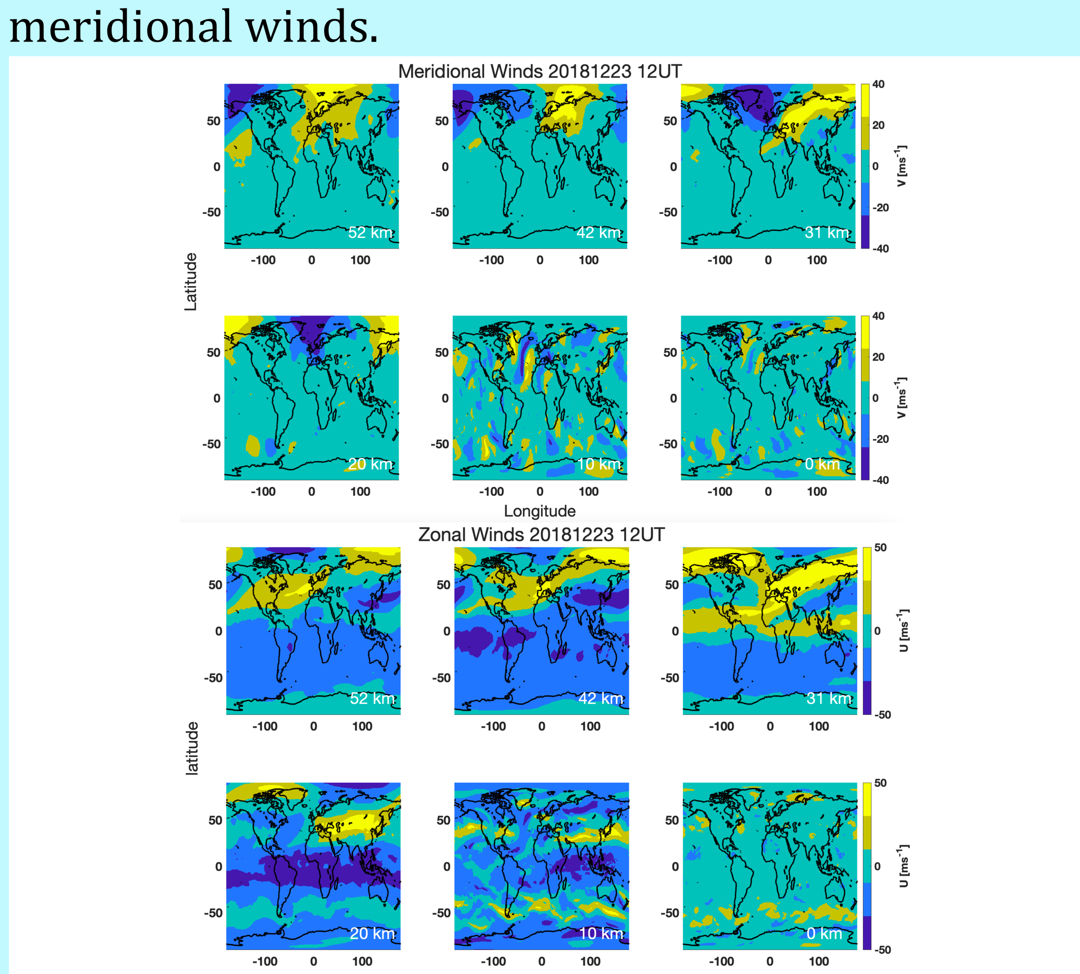

Figure 1. Global Merra-2 Meridional and Zonal Wind map. Each box shows 10km height intervals from 0-50km.

Sodium Lidar (80-110km)

The sodium lidar takes meridional wind measurements up to 110km, a bit higher in altitude than the meteor radar. It shows evidence of a semidiurnal tide. This can create strong winds for GW to propagate through. For this day, zonal winds are not available, which is why the 24 hour radar is helpful.

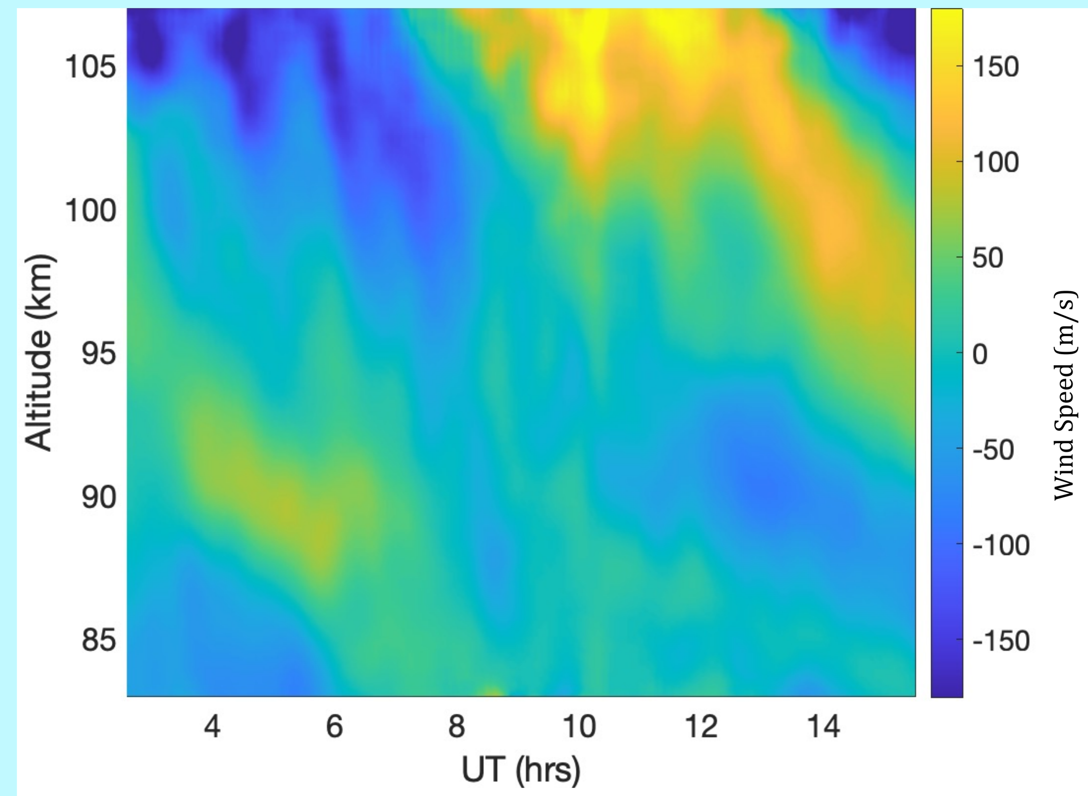

Figure 6. Averaged lidar measurements of showing meridional winds against altitude throughout the night of December 23, 2018.

Meteor Radar (80-95km)

The meteor radar takes wind measurements at Poker Flat, Alaska.

Figure 4 panel b shows extremely strong zonal winds at both 82-88km at 10UT, and then again at 94-98km at 20UT. A similar, weaker, wind pattern can be seen in meridional winds from 82-88km at 5UT and 92-98km at 15UT. We note that stronger winds are observed above these altitudes in the lidar.

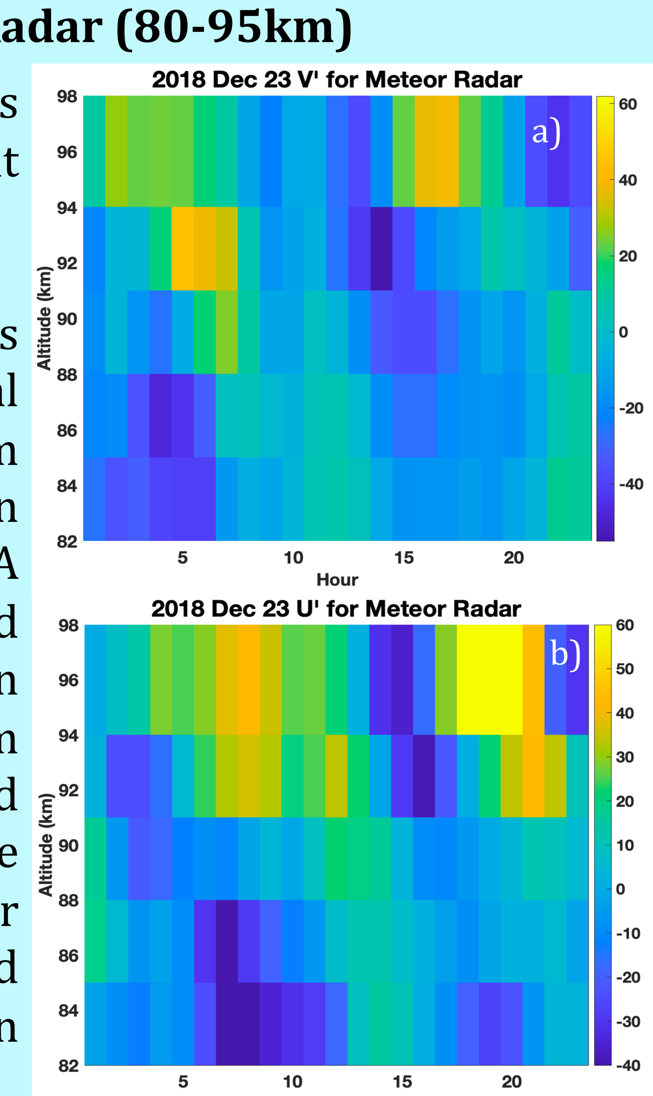

Figure 4. Meridional (a) and Zonal (b) Wind Perturbations measured by meteor radar at -147.5W, 65N.

AIRS (30-40km)

AIRS shows a strong temperature perturbation at 65N and around -160W. This perturbation extends from around 42 to 55 km in altitude.

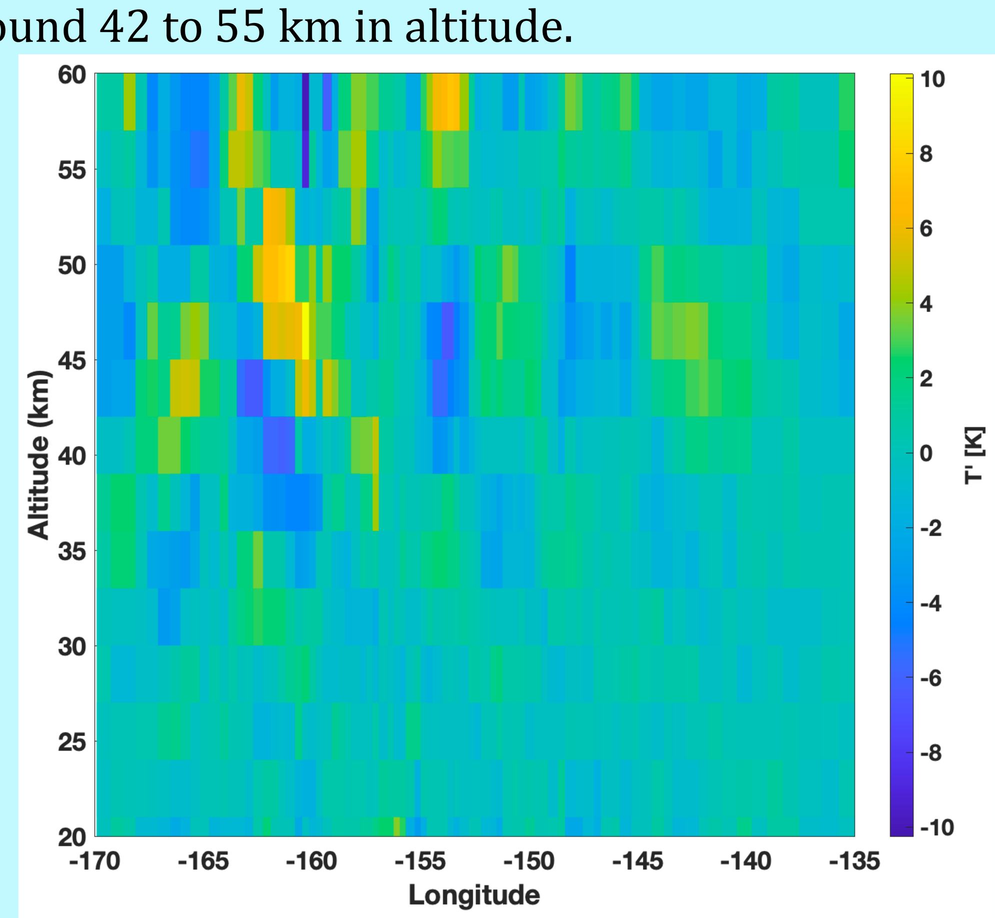

Figure 2. Dec 23, 2018 AIRS Temperature Perturbations at 65 Latitude, over -170 to -135W Longitude at 13 UT.

SDI (250-350 km)

The entire SDI FOV was split into 4 quadrants and averaged profiles from each quadrant were plotted over each other in order to identify the seen GW activity. Note that GWs take up to 24 hours to couple from the troposphere to the thermosphere, so these waves are not directly related to the ones observed in AIRS on Dec 23. However, the prior day also showed waves present in the Rayleigh lidar.

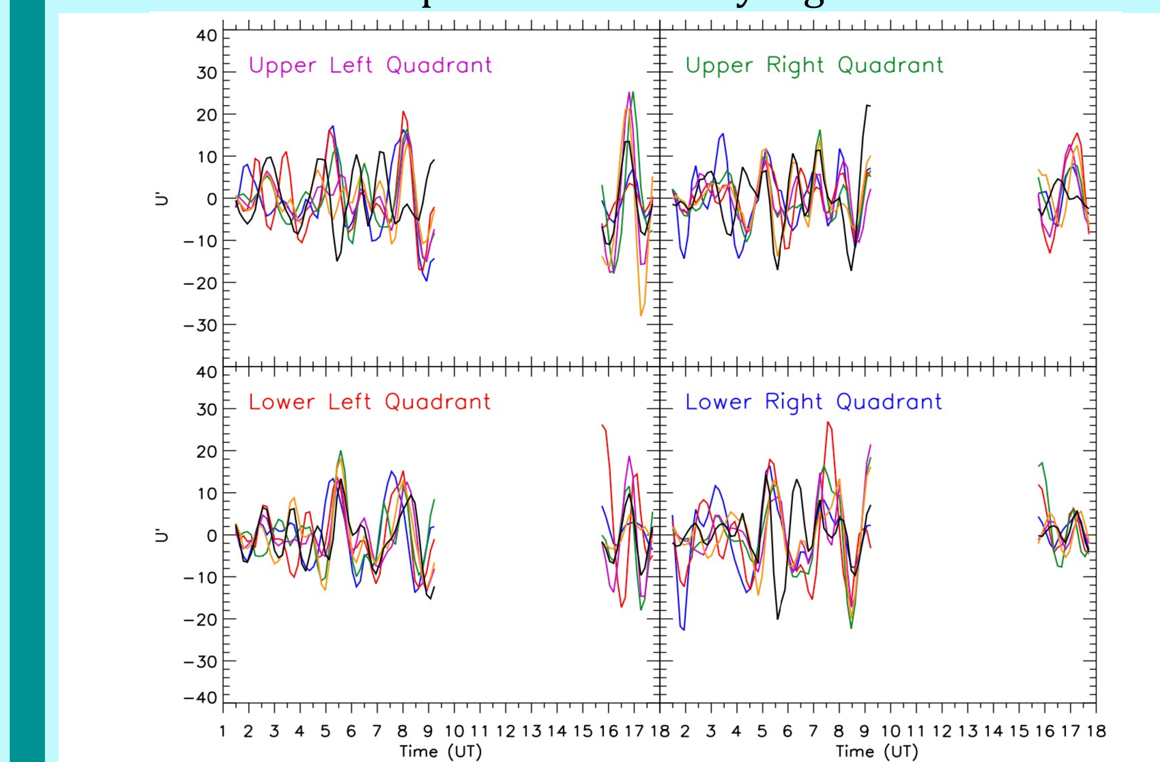

Figure 7. Averaged grouped directions showing zonal perturbations split up into their general geographic location on PKR SDI field of view. There was a 2 hour lapse in measurements from 12-14UT, which was replaced with /NAN data when conducting interpolation.

Rayleigh Lidar (40-60km)

Lidar shows temperature perturbations over the night for increasing altitudes at -147W, 65N. There are waves present over the period of measurements. There are also traces of a stronger, larger wave at 55km at the same time.

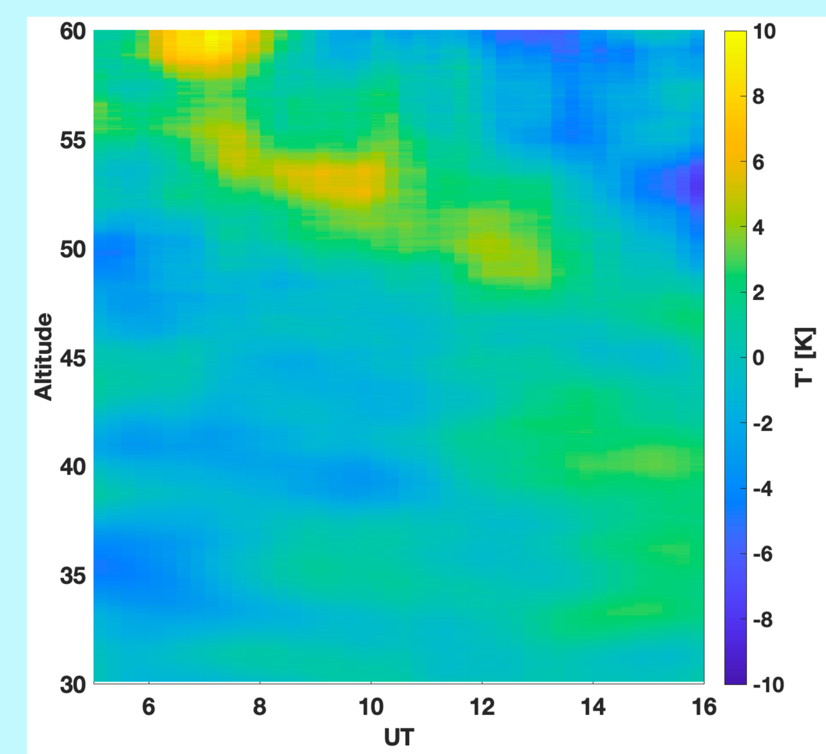

Figure 5. Averaged Rayleigh Lidar measurements showing temperature perturbations against altitude over the night of December 23, 2018.

Merra-2 (0-40km)

From 0-70km, the wind changes direction between the surface and lower stratosphere. GWs cannot propagate when winds change directions as such; they would have broken at this direction change. This indicates that GWs observed in the stratosphere and higher altitudes likely have a different source than mountain waves.

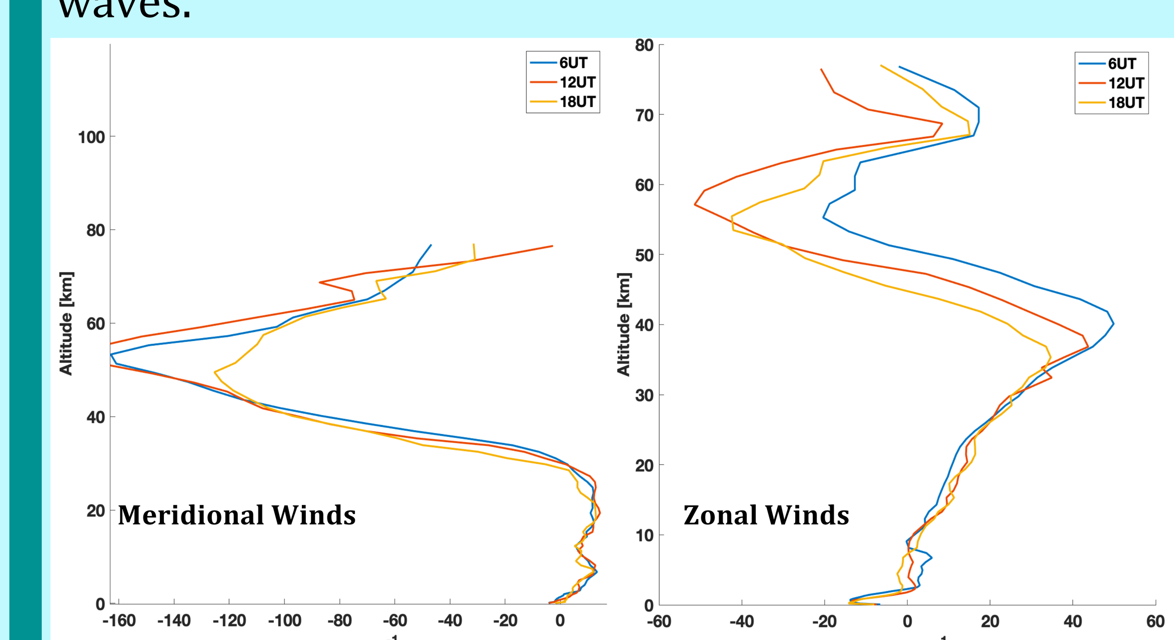

Figure 3. Merra-2 data showing Meridional (Left) and Zonal (Right) wind perturbations at -159W 65N, at 6, 12, and 18 UT. Background wind has been subtracted off.

Rayleigh Lidar and AIRS Comparison

The Rayleigh Lidar was box car averaged for every 10 km, so it can be compared with AIRS resolution. When compared to each other, Figure 8 shows that AIRS is not necessarily resolving the waves with smaller vertical wavelengths that the lidar observes. Lidar shows smaller waves occurring between 30-40km that could have significant coupling effect at higher altitudes.

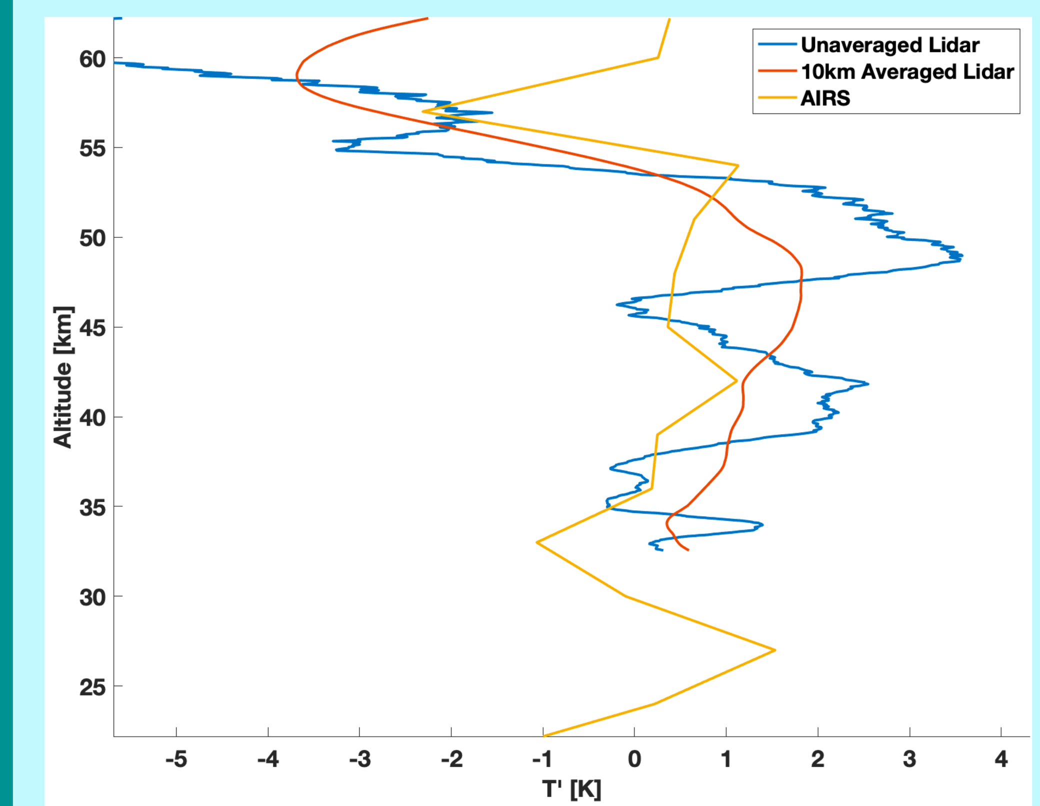

Figure 8. A comparison of AIRS, Rayleigh lidar, and 10km Rayleigh Lidar box car averaged lidar data. Both datasets were taken at 13 UT in the same location at -147W, 65N.

Conclusions

The Poker Flat SDI shows GW activity on our date of interest, December 23rd, 2018. This inspired a project observing different altitudes leading up to this thermosphere observation. Merra-2 shows a polar night jet disruption in the upper stratosphere during December 23, 2018, which could be a source of GW propagation. This instrument also shows a turn from positive to negative winds going into the stratosphere, indicating mountain waves are likely not a source. Both AIRS and Rayleigh Lidar show strong temperature perturbations, and Meteor Radar and lidar show strong winds that would allow GW propagation and coupling from the mesosphere to the thermosphere. These conditions could create the increased variances seen in the SDI.

Our group also plans to continue the comparison of Lidar to AIRS mesospheric measurements to look for evidence of small vertical wavelength waves likely generated in the stratosphere that may grow and attain high amplitudes in the lower thermosphere.

References

Vadas, S. L., Fritts, D. C., & Alexander, M. J. (2003). Mechanism for the generation of secondary waves in wave breaking regions. *Journal of the Atmospheric Sciences*, *60*(1), 194–214. https://doi.org/10.1175/1520-0469(2003)060<0194:mftgos>2.0.co;2

Acknowledgements

This work was funded under the AFOSR FA9550-21-1-0189 and NSF AGS2052993.