RAYLEIGH AND RESONANCE LIDAR STUDIES OF THE MIDDLE AND UPPER ATMOSPHERE

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ABSTRACT :

The activity, propagation, and vertical coupling of gravity waves in the Arctic stratosphere, mesosphere and thermosphere are investigated in this study. We use a Poker Flat Rayleigh Density and Temperature Lidar (PFRDTL) and a Sodium Resonance Wind Temperature Lidar (SRWTL) installed at Poker Flat Research Range (PFRR), Chatanika, Alaska (65°N, 147°W) based on three altitude regions. These are the: Upper Stratosphere and Lower Mesosphere (USLM, 40-50 km), Middle Mesosphere (50-60 km), and Upper Mesosphere and Lower Thermosphere (UMLT, 80-100 km). The current observations extend the scope of previous studies at PFRR and focusses on winters 2018-19, 2019-20, 2020-21 and 2021-22. In 2018-19 and 2020-21, there were major Sudden Stratosphere Warming (SSW) with the splitting of polar vortex. In 2019-20 and 2021-22 no SSW occurred. Previous studies at PFRR have shown decreased level of wave activity in the USLM in winters that are disturbed by SSWs. Furthermore, these studies have indicated that reduced levels of wave activity coincide with low levels of turbulence in the UMLT. These results have implications for understanding wave- and turbulent-transport in the middle atmosphere. The current Rayleigh lidar system employs a larger telescope and a three-channel receiver system to achieve high fidelity and higher signal-to-noise ratio and thereby extend the altitude range of the gravity wave measurements to the middle mesospheric region. The addition of the SRWTL provides measurements of gravity waves in the UMLT region. With lidar measurements of the temperature and density fluctuations over these altitude ranges, we explore the gravity wave activity, propagation, breaking, and coupling over altitude. By analyzing the gravity waves during disturbed winters with SSWs and undisturbed winters, we explore variations in the wave activity to determine if there are systematic variations in the wave activity and coupling associated with these disturbances. We investigate recently developed lidar retrievals to reduce the instrumental biases in the lidar estimates of gravity wave activity. The use of these retrieval methods allows us compare the gravity wave activity in the Arctic with the wave activity in Antarctic where SSWs are rare, and thus determine if there are significant wave-driven asymmetries that influence the structure and circulation of the middle and upper atmosphere polar regions.

INSTRUMENTS :

Figure 1

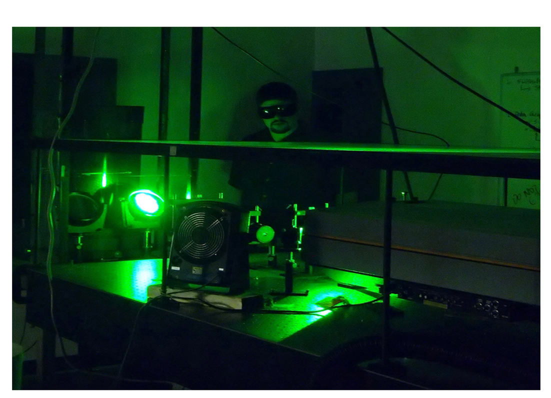

Figure 2

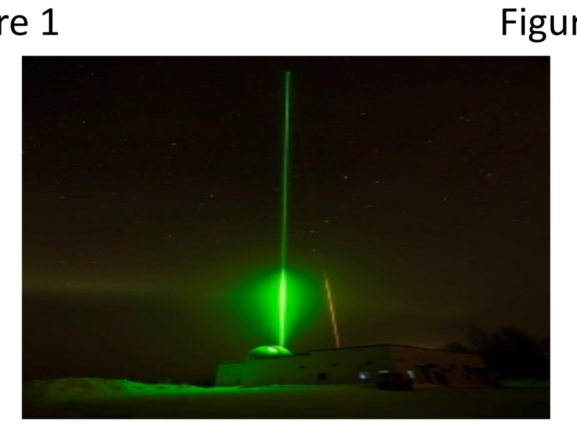

Figure 3

The two instruments that are used for the study are 1) Poker Flat Rayleigh Density and Temperature Lidar (PFRDTL) and 2) Sodium Resonance Wind Temperature Lidar (SRWTL). Figures 1 and 2 show the SRWTL and PFRDTL, respectively. Figure 3 shows a view of the lidar building at Poker Flat research range, Alaska with both the above mentioned lidars being operated. The yellow beam is from the SRWTL which helps to analyze Waves in the Upper Mesosphere and Lower Thermosphere region (UMLT, 80-100 km). The green beam comes out from the PFRDTL and this lidar helps to know about the waves in the Upper Stratosphere and Lower Mesosphere (USLM, 40-50 km) and Middle Mesosphere (50-60 km).

POLAR VORTEX :

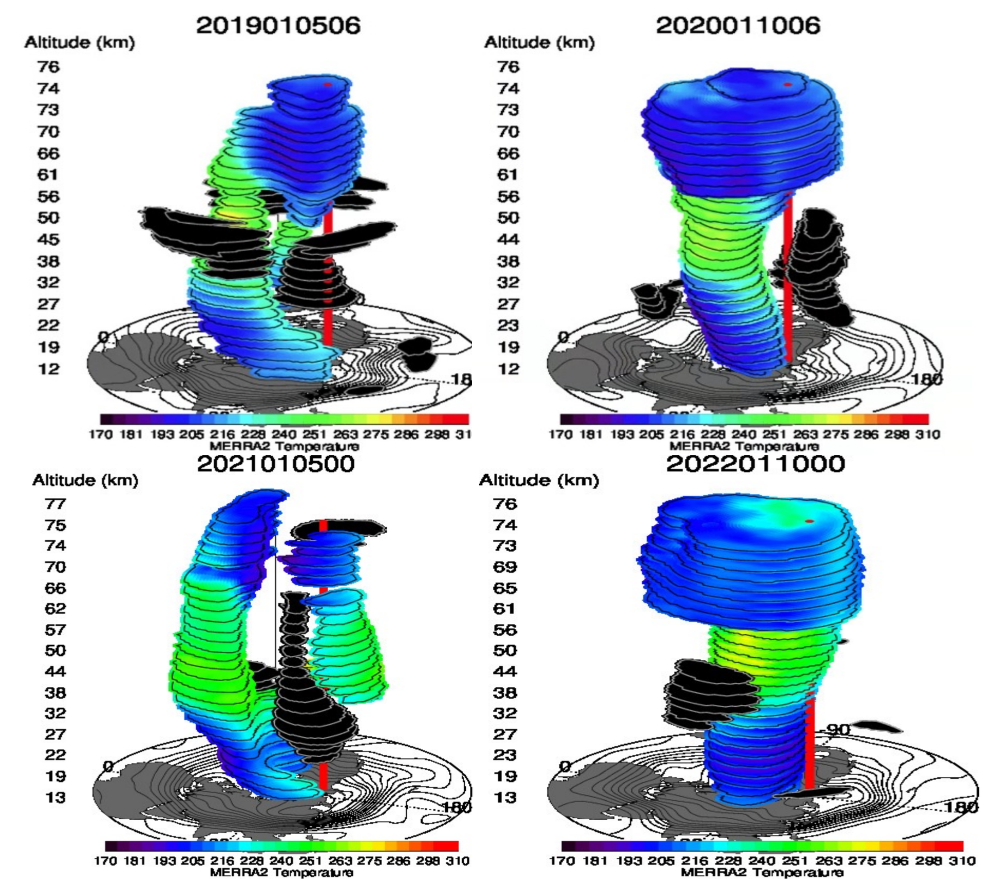

Figure 4

Figure 4 shows the polar vortices on chosen nights in winters 2018-19 (Top left), 2019-20 (Top right), 2020-21 (Bottom left), 2021-22 (Bottom right) in the middle atmosphere at Chatanika, Alaska. In the winters of Sudden Stratosphere Warming (SSW) there is a split vortex or vortex displacement around the period of SSW whereas the vortex remains intact in the quiet winters of 2019-20 and 2021-22.

TEMPERATURE PROFILE :

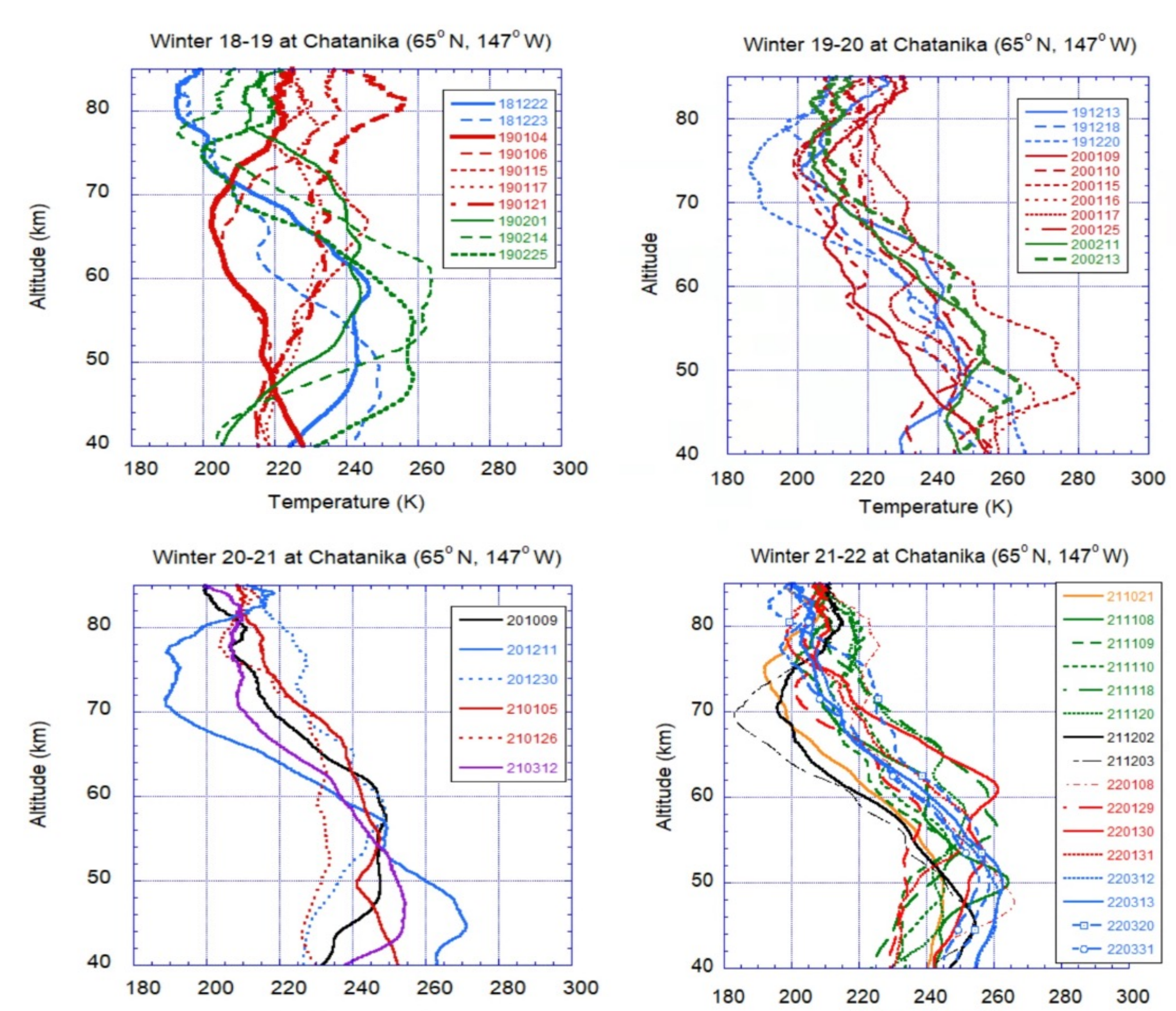

Figure 5

Temperature profiles at Chatanika, Ak are shown in figure 5. These temperatures are nightly averaged and are retrieved from the PFRDTL. In winters 2018-19 (Top left) and 2020-21 (Bottom left) the stratopause disappears during the SSW period around first week of January and then reappears at an elevated altitude. The stratopause comes back to its normal position at the end of the SSW in both these winters. During the non-SSW winters of 2019-20 (Top right) and 2021-22 (Bottom right), the stratopause always remains in its normal position.

GRAVITY WAVE ACTIVITY IN THE USLM AND MIDDLE MESOSPHERE :

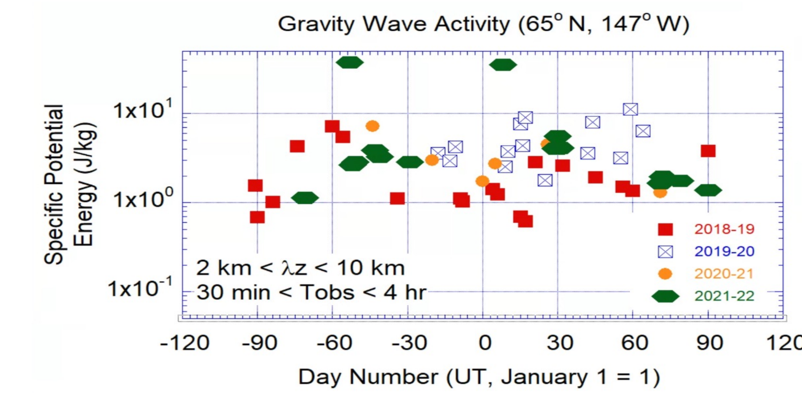

Figure 6

Specific potential energy (SPE) is a measure of gravity wave activity in the atmosphere. Figure 6 shows the SPE in four winters. In this case, only waves with 2 km to 10 km wavelength and periods in between 30 mins and 4 hours are taken into consideration. The mean SPE in 2018-19, 2019-20, 2020-21 and 2021-22 are 2.19, 5.15, 3.41 and 7.13 J/kg, respectively.

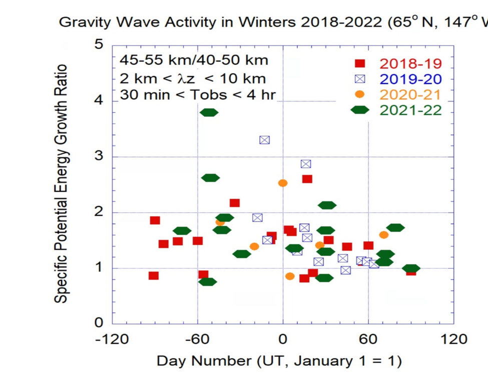

Figure 7

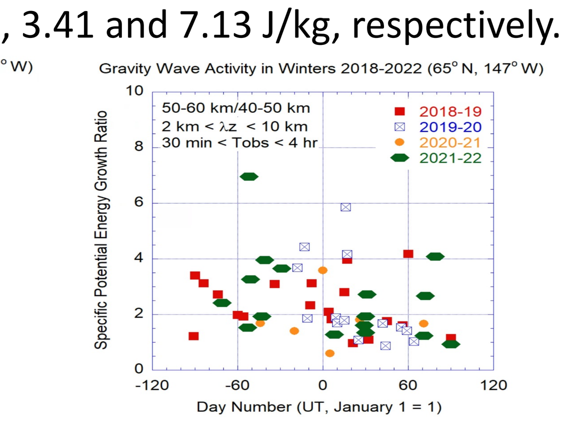

Figure 8

Figure 7 shows the growth ratio between 40-50 km and 45-55 km (GR1) and figure 8 shows the growth ratio between 40-50 km and 50-60 km (GR2). The mean GR1 in 2018-19, 2019-20, 2020-21 and 2021-22 are 1.44, 1.58, 1.60 and 1.63, respectively. The mean GR2 for the above-mentioned winters are 2.33, 2.35, 1.78, 2.60, respectively.

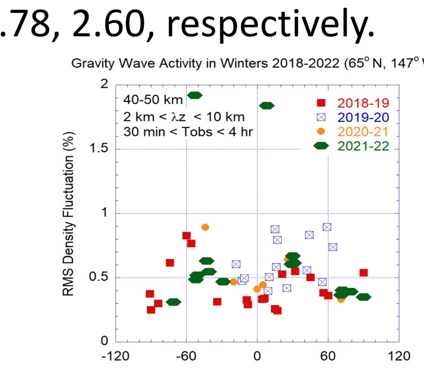

Figure 9

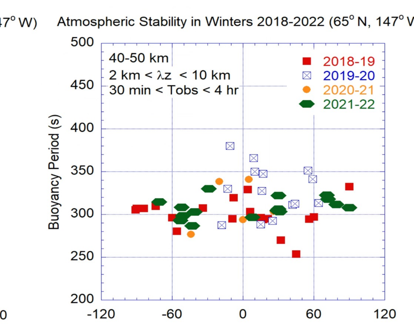

Figure 10

In the figure 9 the rms density fluctuation averaged over 40-50 km is shown as a function of day number. The mean values in 2018-19, 2019-20, 2020-21 and 2021-22 are 0.42, 0.62, 0.53 and 0.67, respectively. In figure 10 the buoyancy period averaged over 40-50 km is shown as a function of day number. The mean values in 2018-19, 2019-20, 2020-21 and 2021-22 are 300 s, 328 s, 312 s and 308 s, respectively.

GRAVITY WAVE ACTIVITY AND GROWTH RATIO IN THE UMLT :

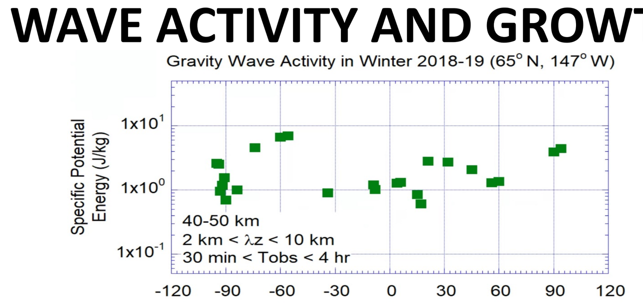

Figure 11

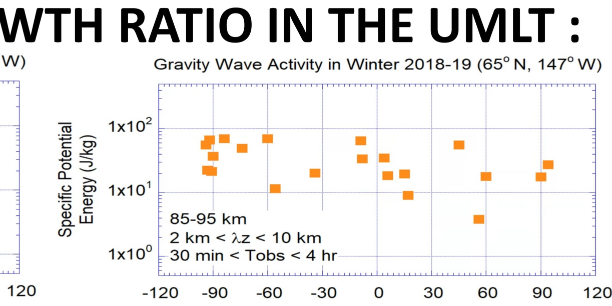

Figure 12

Figures 11 and 12 show the gravity wave activity in the USLM and UMLT, respectively. Even though there is weak correlation between the wave activities in the two regions, the SPE is very low in both the regions during the SSW (Early January) compared to the other days when there was no SSW.

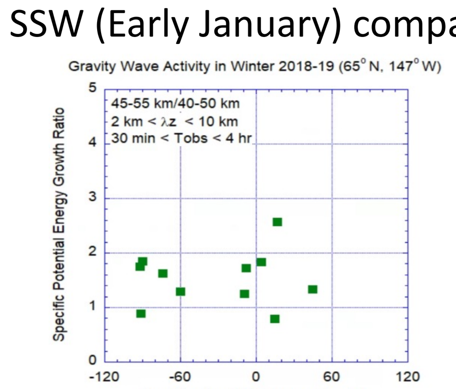

Figure 13

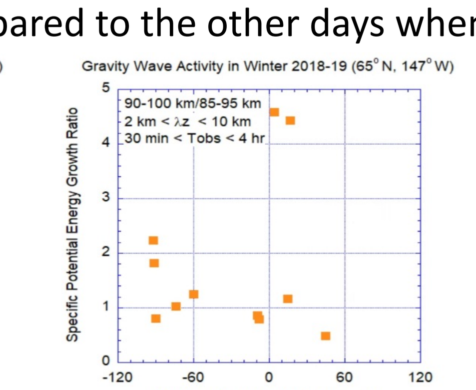

Figure 14

Figure 13 shows the growth ratio between 40-50 km (GR3) and 45-55 km and figure 14 shows the growth ratio between 85-95 km and 90-100 km (GR4). The mean GR3 and GR4 are 1.54 and 1.76 respectively with standard deviations of 0.5 and 1.44, respectively.

CONCLUSION :

1) Vortex displacement is observed during the SSW periods in 2018-19 and 2020-21 winters. However, the polar vortex remains intact in the quiet winters of 2019-20 and 2021-22. 2) The stratopause disappears during the peak of SSW and reappears again around 80 km before returning to its normal position at the end of SSW. 3) The gravity wave activity is lower in the SSW winters compared to the ones when there is no SSW. 4) Even though there is not much difference in the mean buoyancy periods in different winters, the period is more during the SSW (First week of January in 2019 and 2021) compared to other days of the same winter. This indicates to a more unstable background atmosphere during SSWs. 5) The rms density fluctuates more in the non-SSW winters compared to the SSW winters.