Aotearoa New Zealand Initial Ceilometer Analysis

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Executive summary

Cloud cover significantly impacts the Earth's energy balance by reflecting incoming solar energy and trapping infrared radiation. Accurate representation of clouds in climate models is crucial for predicting climate change. However, biases in cloud simulations remain, particularly in high latitudes, as evidenced by the World Climate Research Programme's CMIP3 models. These biases often stem from inadequate cloud cover representation and difficulties in simulating super-cooled liquid water clouds, leading to errors in shortwave radiation estimates. This study aims to address these biases by analysing cloud data from ceilometers across Aotearoa New Zealand, focusing on the proportion of super-cooled liquid water clouds.

Data was collected from a network of 16 Vaisala CL31 ceilometers operated by MetService at various airports across Aotearoa New Zealand, covering both North and South Islands and Chatham Island. The ceilometers, primarily used for detecting cloud base height and vertical visibility, provided data from July 2021 to February 2023. The uncalibrated backscatter data was converted to NetCDF format using cl2nc software and processed with the Automatic Lidar and Ceilometer Framework (ALCF) for consistent noise removal, calibration, and cloud detection.

The default backscatter threshold for cloud detection, developed using LIDAR data from Antarctica, was found to be too low for mid-latitudes, leading to misclassification of surface aerosols and instrument artifacts as clouds. A higher threshold was selected to improve cloud detection accuracy. This adjustment significantly reduced the misclassification of low-altitude clouds while maintaining the detection of higher altitude clouds.

Rainfall, distinguishable in backscatter plots as diagonal bands, can interfere with cloud detection. The backscatter of rain can sometimes be as strong as clouds, complicating the accuracy of the automatic cloud identification mask generated by ALCF. Future analyses will incorporate rain gauge data to filter out periods of rainfall more effectively.

Hourly climatologies of cloud occurrence showed minimal variation between sites, with a slight increase in higher altitude clouds between 1100 and 1700 at most Te Ika-a-Māui / North Island sites. Most sites had a maximum cloud base height of around 2000 metres although some were higher at around 2500 metres, and some lower around 1500 metres. This could be due to weather patterns or surrounding terrain; further investigation is required. The available data was insufficient for developing monthly climatologies.

Future steps will include developing a rain mask, dividing the data based on the prevailing south westerly wind patterns and further analysing cloud heights concerning wind direction. Advanced models capable of classifying super-cooled liquid water clouds, such as G22-Davis and G22-Christchurch, will be used to refine climatologies and improve the accuracy of cloud representation in climate models.

1 Introduction

The Earth energy balance is influenced by cloud cover, affecting surface temperature by reflecting incoming solar energy and trapping infrared radiation in the atmosphere. Observation and model simulation comparisons reveal biases in cloud representation. Large biases were noticeably found over high latitudes in The World Climate Research Programme (WCRP) Coupled Model Intercomparison Project CMIP3 models (Trenberth & Fasullo, 2010). Although further research has improved cloud simulations and their properties, biases remain and can include compensating errors that hide the bias (Schuddeboom & McDonald, 2021; Kuma et al., 2023). Prior research has found that biases are contributed to by insufficient cloud cover and issues with the amount of super-cooled water clouds simulated. The latter problem arises because different types of clouds influence radiation differently. In particular, models often struggle to accurately simulate super-cooled liquid water clouds, leading to significant biases in shortwave radiation (Bodas-Salcedo et al., 2016; Kay et al., 2016; Kuma, 2020). These clouds, which form between the 0°C isotherm and the -38°C isotherm (the homogeneous freezing level), are prevalent over the Southern Hemisphere, especially over the Southern Ocean (Bodas-Salcedo et al., 2016; Kuma, 2020) and Antarctica (Listowski et al., 2019) For example, (Listowski et al., 2019) found that the fraction of super-cooled liquid-water-containing clouds (SLC) ranged from 0-35% over the Antarctic continent. These issues are significant because changes in the global Effective Climate Sensitivity (ECS) between CMIP5 and CMIP6 have been largely attributed to changes in the representation of extra-tropical Southern Hemisphere clouds (Zelinka et al., 2020).

This analysis provides a first look at cloud data from a network of ceilometers across Aotearoa New Zealand and details some of the challenges in processing the data available. The initial analysis provides a better understanding of the data to be used in preparation for following previous methods to determine levels of supercooled liquid water clouds across Aotearoa New Zealand.

2 Methods

2.1 Data

A network of Vaisala CL31 ceilometers operated by MetService at airports across Aotearoa New Zealand had data available for analysis. Nine sites were in Te Ika-a-Māui / North Island, six in Te Waipounamu / South Island and one site on Chatham Island. The 16 sites are shown in figure 1 and details in table 1.

Figure 1 Locations of Aotearoa New Zealand Metservice Ceilometers with available data.

Table 1: **Details of Aotearoa New Zealand Metservice Ceilometers with available data.**

SITE	Lon	Lat	Altitude	Viewing Angle
Kaitaia Aero (NZKTA)	173.2863	-35.0678	76 m	zenith
Whangarei Aero (NZWRA)	174.3655	-35.7669	37 m	zenith
Auckland Aero (NZAAA)	174.8072	-37.009	6 m	zenith
Hamilton Aero (NZHNA)	175.3318	-37.8609	52 m	zenith
Gisborne Aero (NZGSA)	177.9851	-38.6586	4 m	zenith
New Plymouth Aero (NZNPA)	174.1838	-39.0079	27 m	zenith
Napier Aero (NZNRA)	176.8646	-39.4703	2 m	zenith
Ohakea Aero (NZOHA)	175.372	-40.203	46 m	zenith
Nelson Aero (NZNSA)	173.2161	-41.3008	5 m	zenith
Wellington Aero (NZWNA)	174.8057	-41.3312	3 m	12°
Hokitika Aero (NZHKA)	170.9844	-42.713	39 m	zenith
Christchurch Aero (NZCHA)	172.5276	-43.4893	35 m	zenith
Chatham Island Aero (NZCIA)	-176.475	-43.8168	11 m	zenith
Queenstown Aero (NZQNA)	168.7402	-45.0176	356 m	zenith
Dunedin Aero (NZDNA)	170.1968	-45.9268	1 m	zenith
Invercargill Aero (NZNVA)	168.3178	-46.411	2 m	zenith

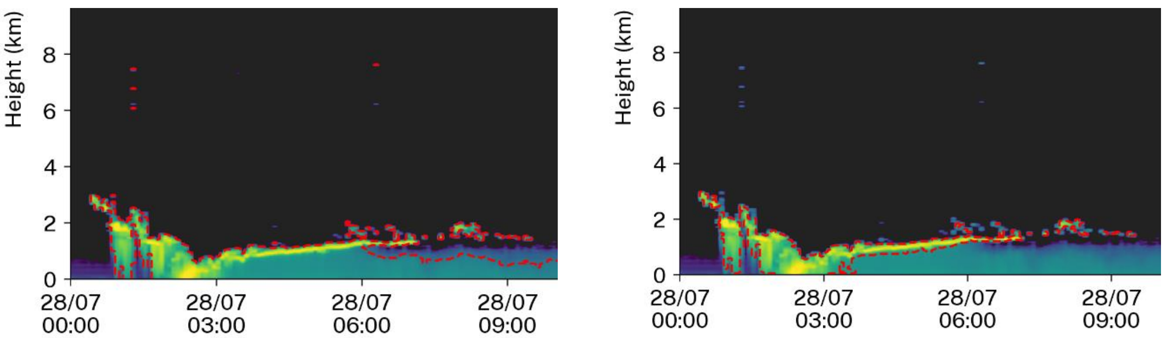
CL31 ceilometers have a maximum vertical range of 7.6 km, a measurement resolution of 10 m and a measurement interval of 2 s. and are primarily for airport operations detecting cloud base height and vertical visibility. Data was available between and July 2021 to February 2023. The uncalibrated data output files of attenuated volume backscattering coefficients were converted to NetCDF using cl2nc (Kuma, 2017/2023).

2.2 Post processing

Post processing was done using the Linux software package: Automatic Lidar and Ceilometer Framework (ALCF). ALCF provides consistent processing of the data by applying the same level of noise removal, calibration, time resampling, height resampling, cloud detection and cloud base detection to each of the instruments (Kuma et al., 2021).

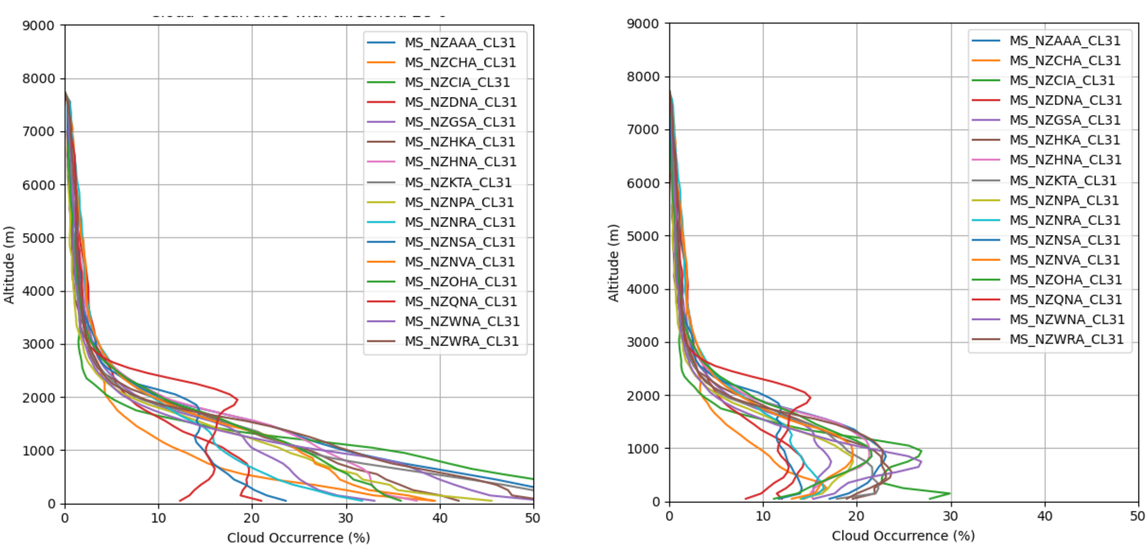
2.3 Threshold Selection

An automatic cloud detection mask using the ceilometer backscatter values is applied with in the ALCF processing. The default backscatter threshold for cloud detection of $2 \times 10^{-6} m^{-1} sr^{-1}$ was developed using LIDAR data from Antarctica. This value has been too low in previous uses of the tool in Aotearoa New Zealand (Whitehead et al., 2023) and potentially misclassifies surface aerosols and instrument artefacts in the mid-latitudes.Figure 2 shows the difference in how the threshold is applied in the backscatter plots. The cloud mask, indicated by the red line, with the default threshold encompasses much of the weaker 'haze' beneath the clouds, while the cloud mask with the stronger threshold ($6 \times 10^{-6} m^{-1} sr^{-1}$) envelopes the cloud while excluding much of the haze. This can be seen in Figure 3 with over 50% of cloud occurrence below 500m at some sites across Aotearoa New Zealand using the default threshold. A stronger threshold of $6 \times 10^{-6} m^{-1} sr^{-1}$ was selected for further analysis to reduce the low-altitude mis-classified clouds while not greatly affecting higher altitude cloud detection. Increasing the cloud mask threshold above this provided diminishing returns in classifying the clouds.



Default: $2 \times 10^{-6} m^{-1} sr^{-1}$ $6 \times 10^{-6} m^{-1} sr^{-1}$

Figure 2 Detail of ALCF output plot showing the cloud mask in red for default and selected cloud mask thresholds.



Default: $2 \times 10^{-6} m^{-1} sr^{-1}$ $6 \times 10^{-6} m^{-1} sr^{-1}$

Figure 3 Cloud occurrence plots from ALCF output of default and selected cloud mask thresholds at locations with available data.

2.4 Rainfall

Rainfall can often be easily identified from backscatter plots, as moving diagonal bands coming from a band of stronger signal with a band of cloud above. The backscatter of rain can sometimes be as strong as clouds and can be picked up in the cloud mask (Figure 4). It is not possible to change the cloud mask threshold to remove the mis-classified rain as the cloud mask is created from the strength of the backscatter, and so other methods will need to be used to filter out the times with rainfall such as using rain gauge data from the ceilometer locations to create a rain mask.

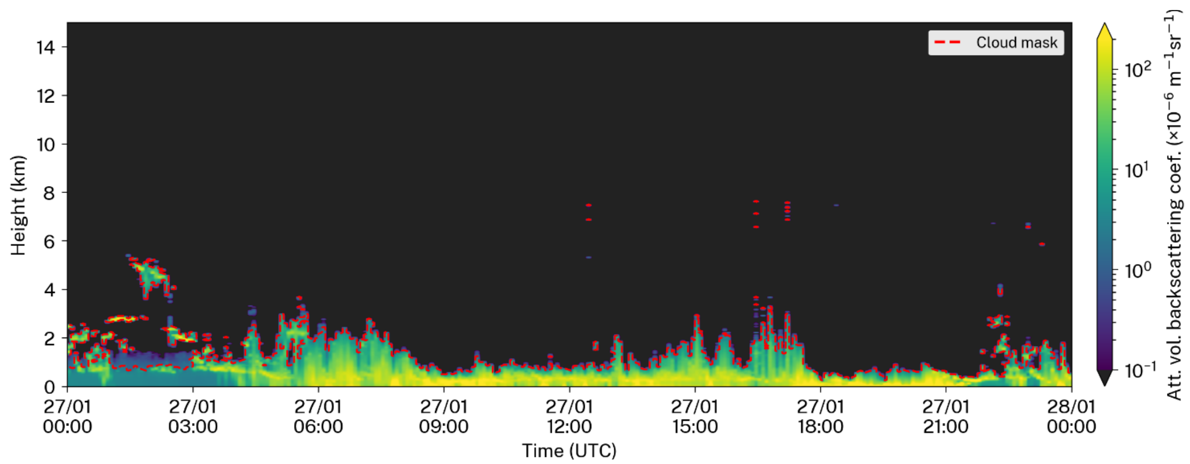


Figure 4 ALCF backscatter plot at Auckland Airport during heavy rainfall January 27th, 2023.

3 Climatologies

Hourly climatologies of cloud occurrence showed little variation between each site, with similar patterns throughout the day. Variation across different hours of higher altitude cloud occurred between 1100 and 1700 hours at all Te Ika-a-Māui / North Island sites except Wellington. Nelson, Napier, Ohakea, Queenstown had a higher maximum cloud base height around 2500 metres. The higher maximum could be due to the higher surrounding terrain, although this would not explain Ohakea, and other sites also have higher surrounding terrain so may have other influences. Wellington, Christchurch, Chatham Islands had a lower maximum cloud base height of around 1500 metres. This could be due to the wind patterns at these locations, but this could also be an influence at other sites and so further investigation is required. All other sites had a maximum cloud base height of around 2000 metres. Queenstown was the only site that had visually distinct cloud layers compared to all other sites, potentially due to the site's location in the Southern Alps. Not enough data was available for monthly cloud occurrence climatologies. Hourly climatologies of cloud height at each site are presented in Appendix A.

4 Further Analysis

Further steps should include applying a rain mask to remove the , analysing a south-westerly transect of the sites following the country's prevailing winds. Also, a further split of wind direction at each site to explore variation of cloud heights should be conducted. Climatologies should then be developed when the data has been passed through a model that can classify sections of the clouds that contain super cooled liquid water such as G22-Davis (Guyot et al., 2022) G22-Christchurch (Whitehead et al., 2023).

5 Open Data

Level 0 (raw) ceilometer data is owned by Metservice and is available with permission from Metservice. Level 1 (ALCF output) is available as a processed data product and is available at Zenodo. https://doi.org/10.5281/zenodo.12556402

6 Acknowledgements

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7 References

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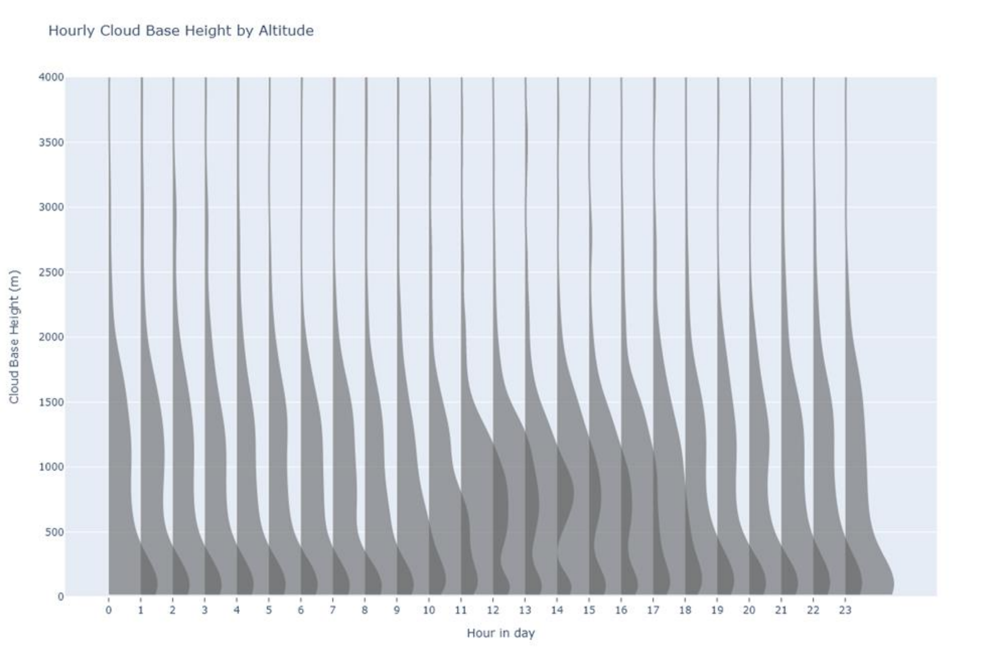
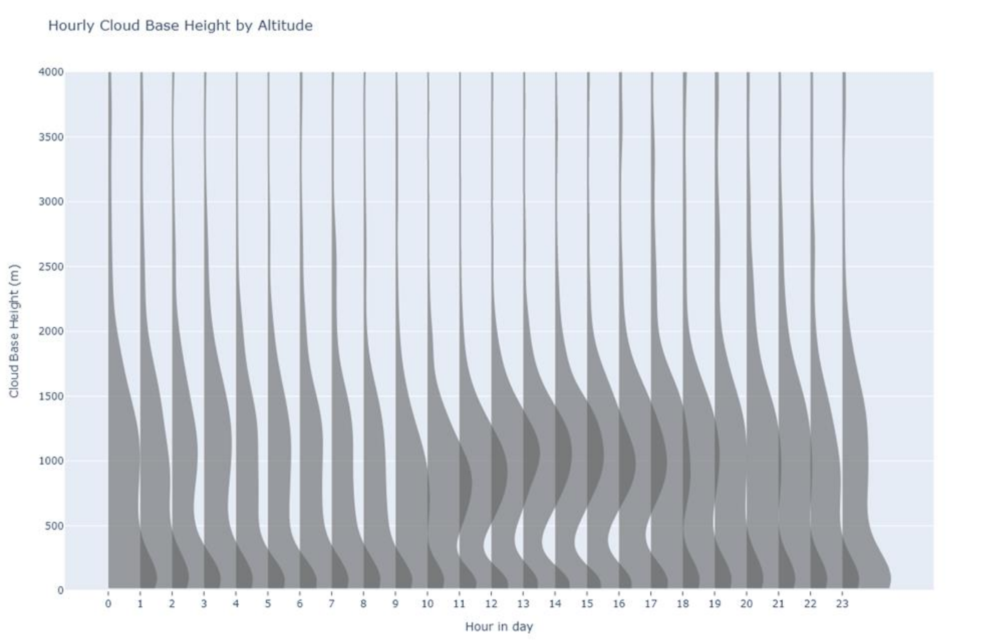
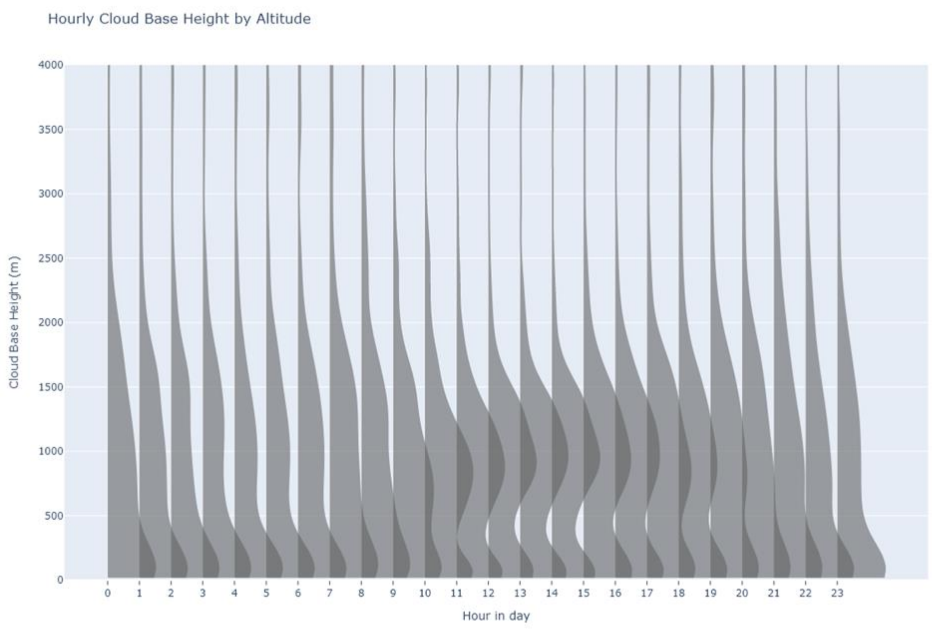
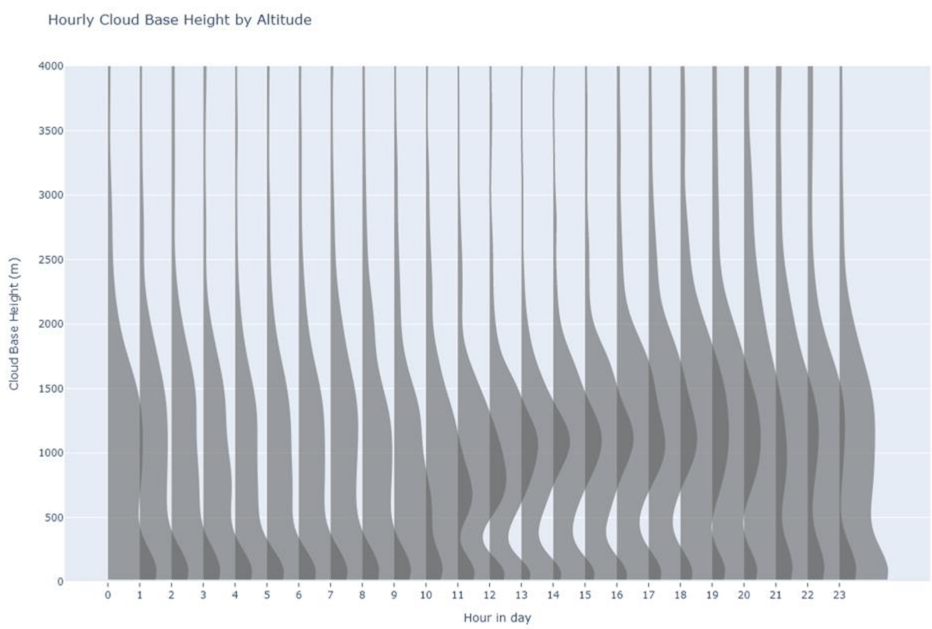
Appendix A Cloud occurrence as a function of altitude by hour

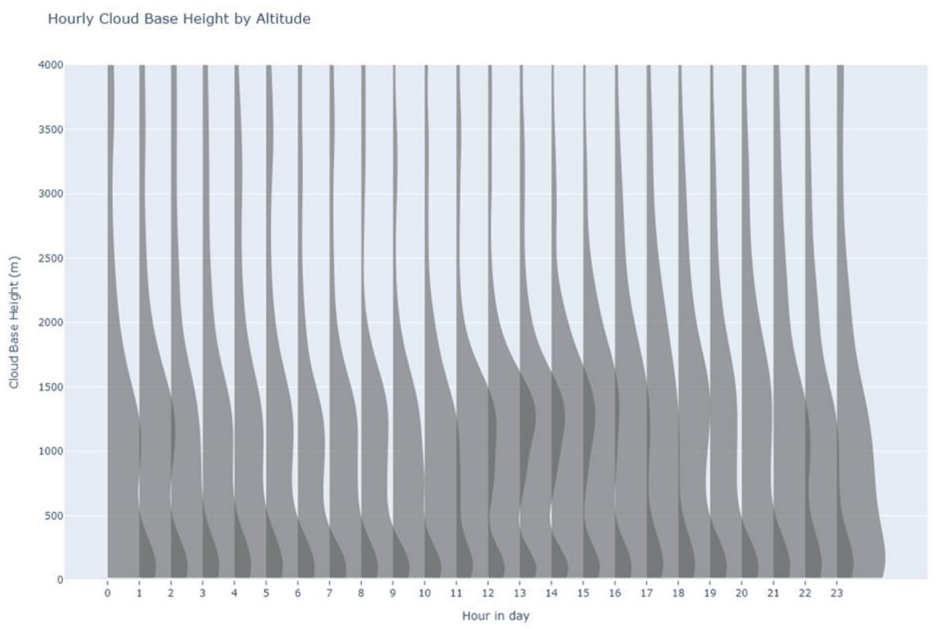
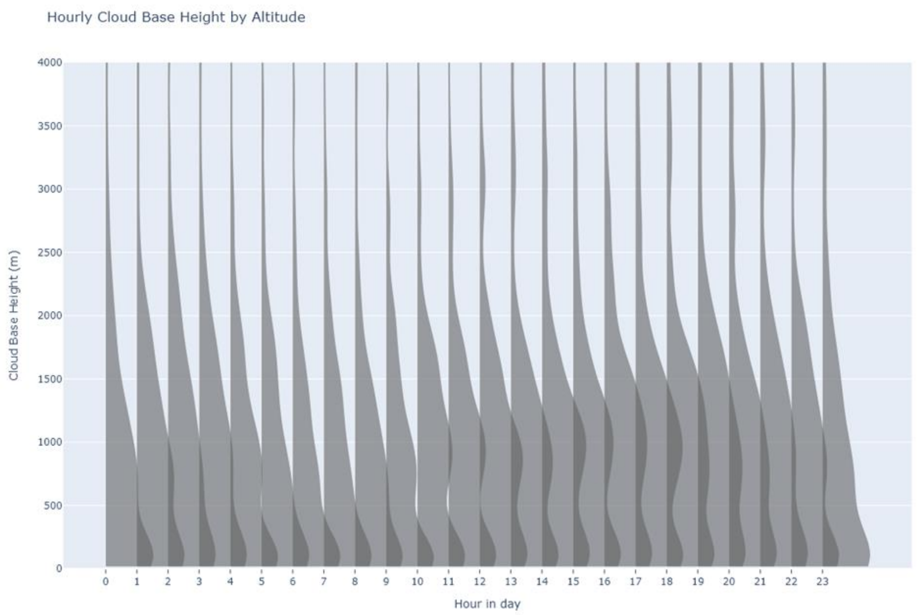
SITE	
Kaitaia Aero (NZKTA)	
Whangarei Aero (NZWRA)	

Auckland Aero (NZAAA)

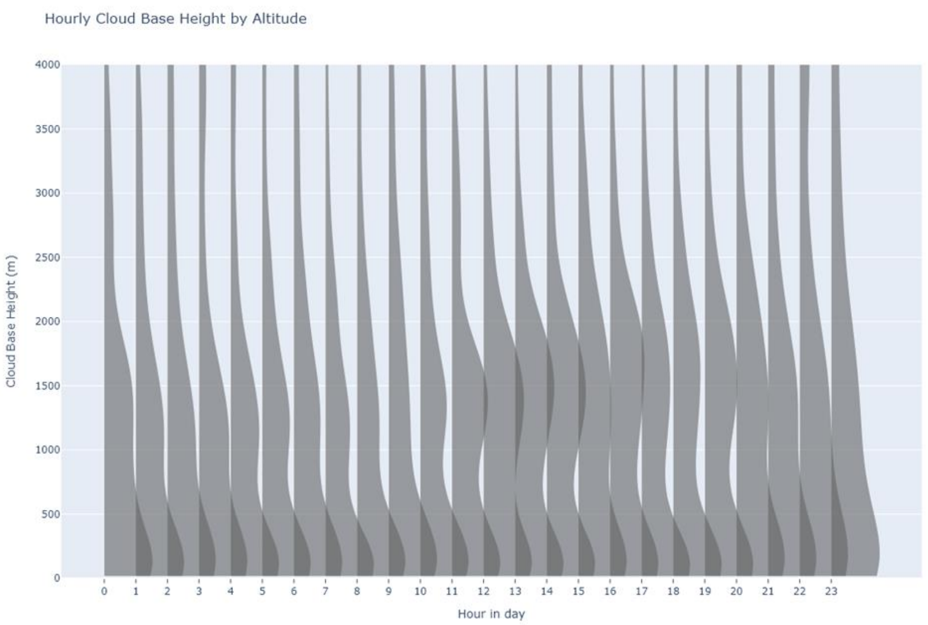


Hamilton Aero (NZHNA)

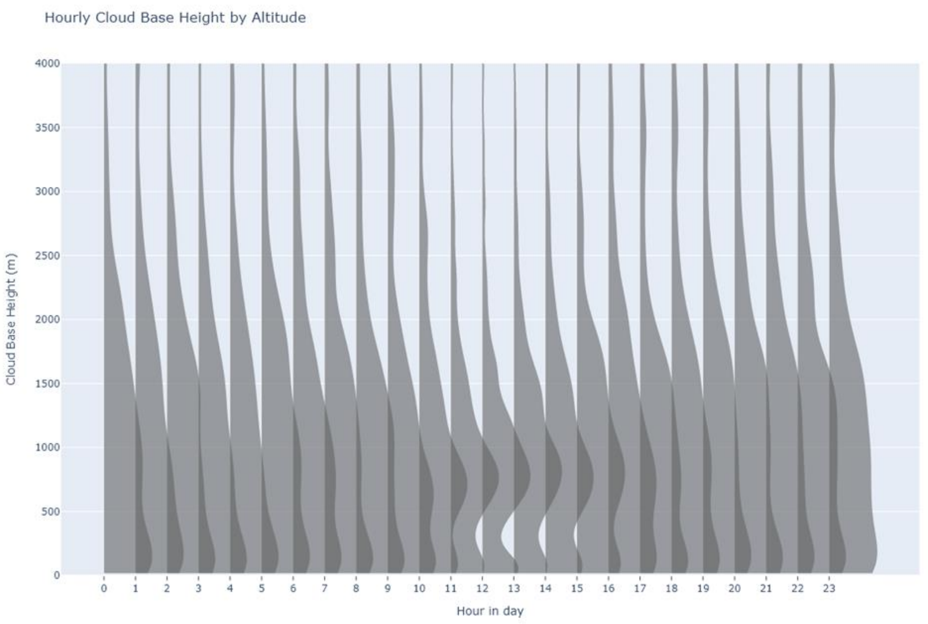


Gisborne Aero (NZGSA)	
New Plymouth Aero (NZNPA)	

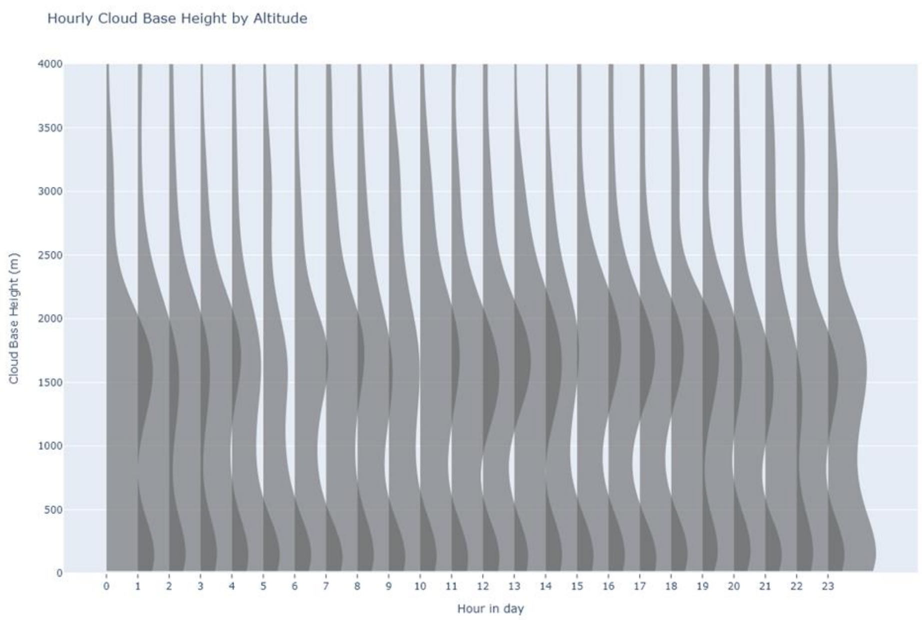
Napier Aero (NZNRA)



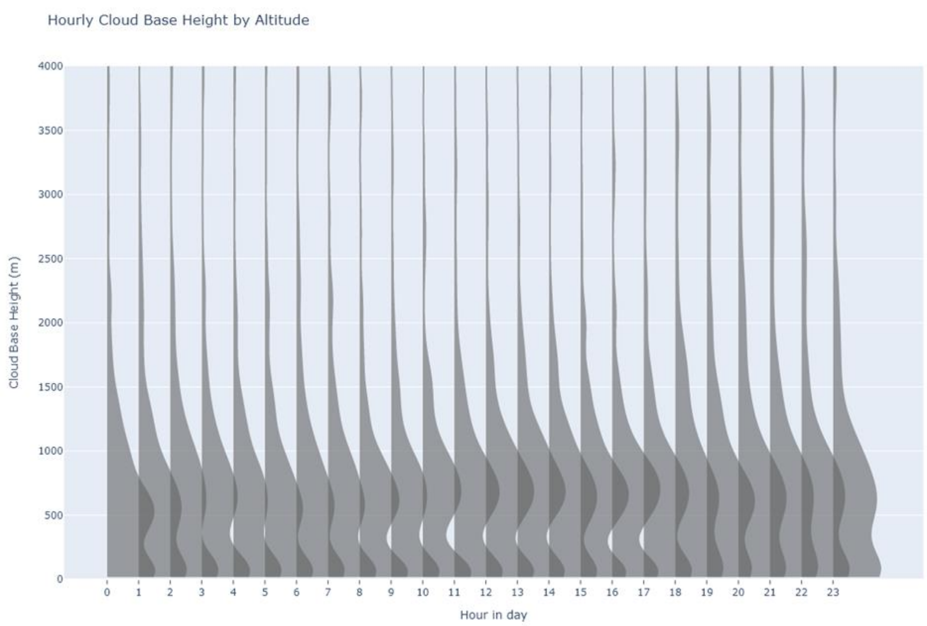
Ohakea Aero (NZOHA)

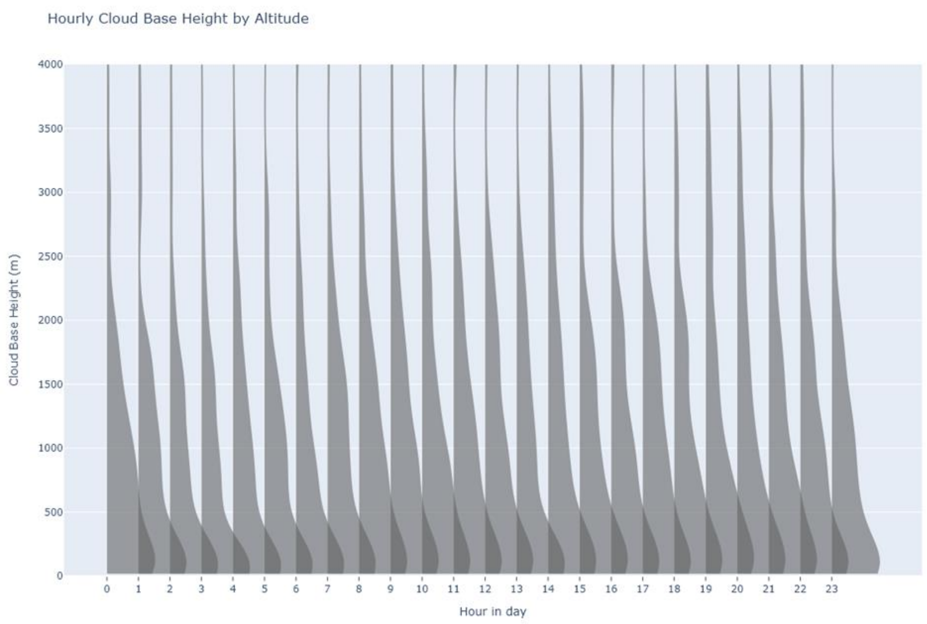
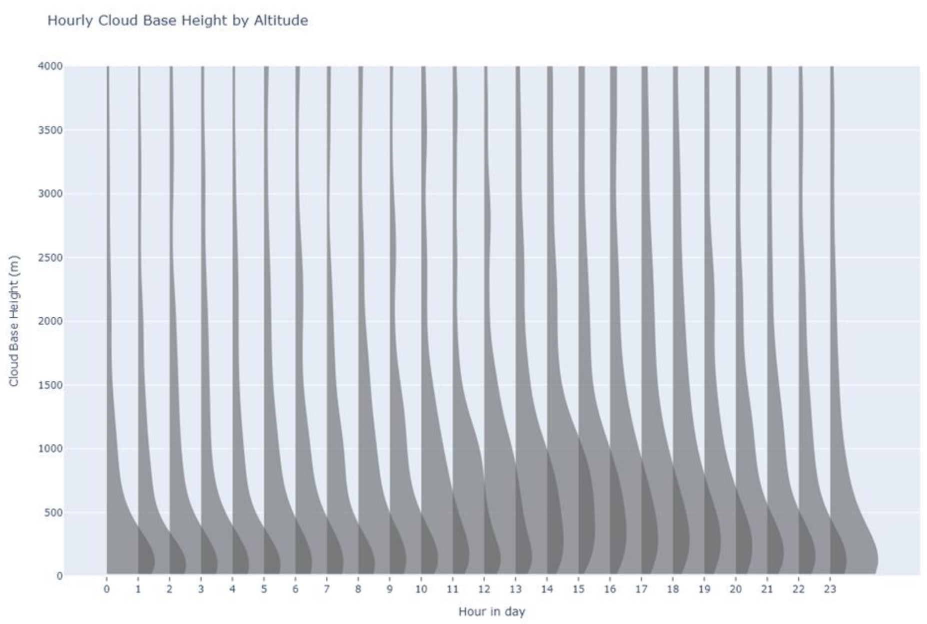


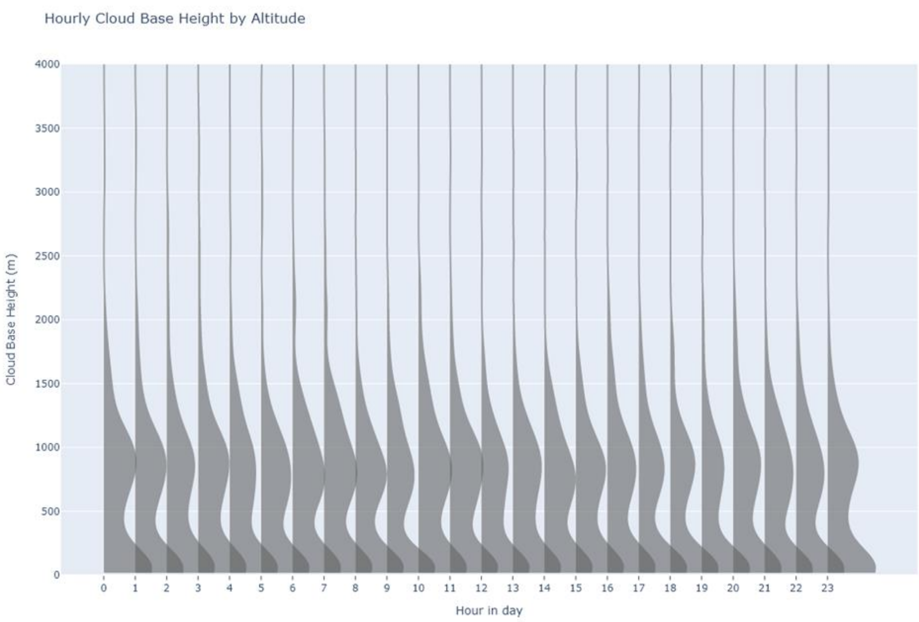
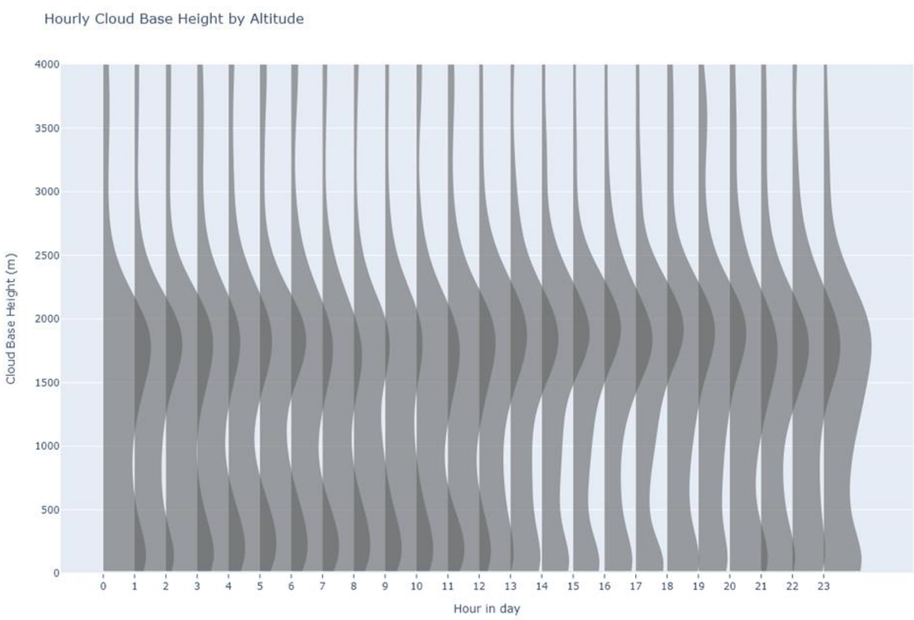
Nelson Aero
(NZNSA)

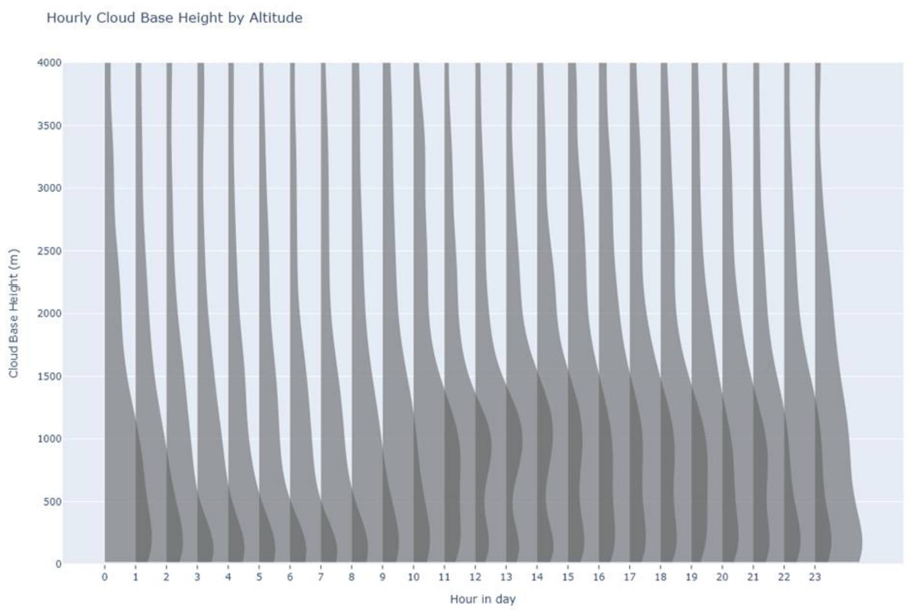


Wellington
Aero
(NZWNA)



Hokitika Aero (NZHKA)	
Christchurch Aero (NZCHA)	

Chatham Island Aero (NZCIA)	
Queenstown Aero (NZQNA)	

Dunedin Aero (NZDNA)	
Invercargill Aero (NZNVA)