Lidar observations of Cirrus clouds at Palau island ($7°33'$ N, $134°48'$ E): Supplementary material

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Abstract. An analysis of depolarization, optical thickness and LR, and their relationship with the thermal and dynamic histories of the air masses is presented.

1 Introduction

Clusters of 1000 trajectories were launched backward from the altitude and time of the clouds observations for 15 days, and the averaged trajectory over each cluster, together with its dispersion, was used for further analysis. Along each of the averaged backtrajectories, the minimum temperature encountered T_{min} and the time elapsed since that $t(T_{min})$ was computed, together with the derivatives of temperature dT/dt, potential temperature $d\theta/dt$ and pressure dp/dt at the time of lidar measurements, computed as averages over the previous 18 hours. Moreover, the following quantities were also computed: the time during which the air mass remained below the temperature attained at the lidar observation $t(T(t) < T_0)$; the minimum potential temperature θ_{min} and the maximum pressure p_{max} and the relative times elapsed from the lidar observation $t(\theta_{min})$ and $t(p_{min})$.

For each averaged backtrajectory, the convective fraction' - defined as the percentage of the trajectories in the cluster that had met convection - was also computed. The time elapsed since the most probable convection encounter was defined as the time from the maximum increase of the convective fraction in the cluster.

This information obtained from the analysis of the retro-trajectory was connected to three measured optical parameters: depolarization, optical thickness and LR. We present here figures of them, color coded according to the different quantities computed along the respective backtrajectory. The optical parameters have been computed as average values of the lidar cloud measurements (i.e. BR>1.15) over windows of ± 0.15 Julian days and ± 2.5 Kelvin from the starting time and potential temperature of each backtrajectory.

2 Dependence of the optical parameters from the trajectory characteristics

2.1 Effects of the difference between the temperature at observation and the backtrajectory minimum temperature

Figures 1, 2, 3 report the influence of the difference between the observation temperature and the minimum temperature along the backtrajectory, on depolarization, optical thickness and lidar ratio. These differences are often lower than 5 K, apart from some cases in the lower part of the altitude range, connected with medium-high optical thickness.

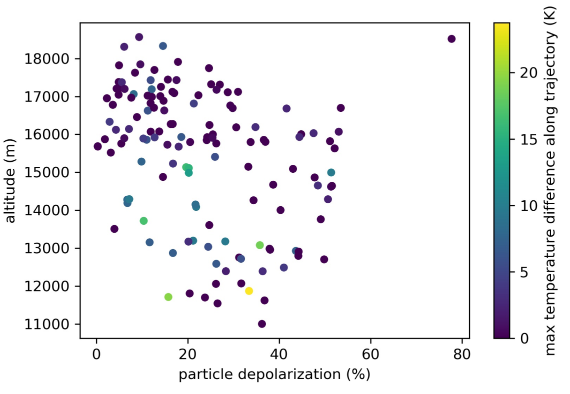

Figure 1. Particle depolarization vs altitude. The colour codes the difference between the temperature at observation and the minimum temperature along the backtrajectory.

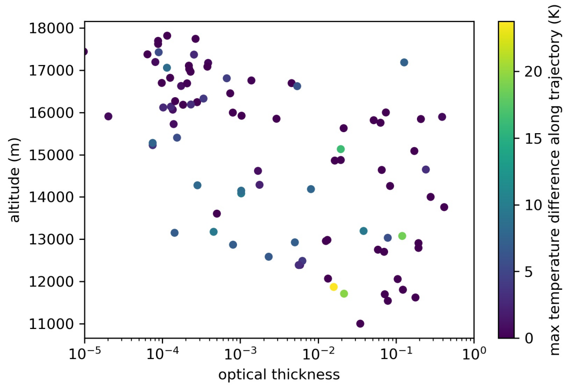

Figure 2. Optical thickness vs altitude. The colour codes the difference between the temperature at observation and the minimum temperature along the backtrajectory.

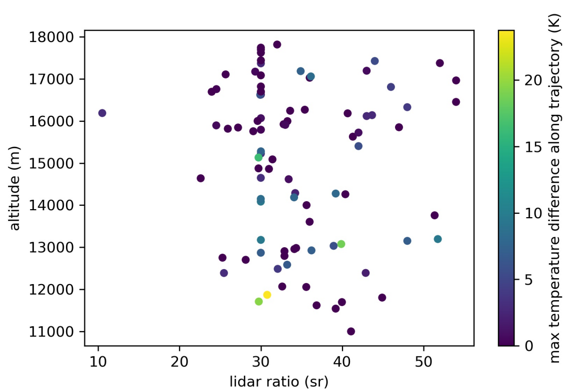

Figure 3. Lidar ratio vs altitude. The colour codes the difference between the temperature at observation and the minimum temperature along the backtrajectory.

2.2 Effects of the temperature gradient at observation

Figures 4, 5, 6 report the influence of the temperature gradient, computed as the average over 18 hrs before observations, on depolarization, optical thickness and lidar ratio. Clouds in the upper part of the altitude range are stationary or warming, while some clouds in the lower part of the altitude range, among the optically thicker, are cooling.

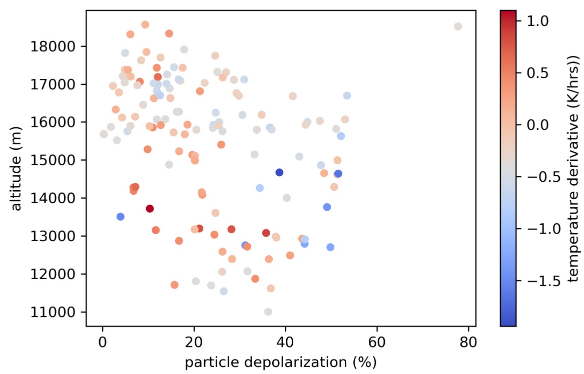

Figure 4. Particle depolarization vs altitude. The colour codes the temperature gradient at the time of the observation, computed as an average over the past 18 hrs.

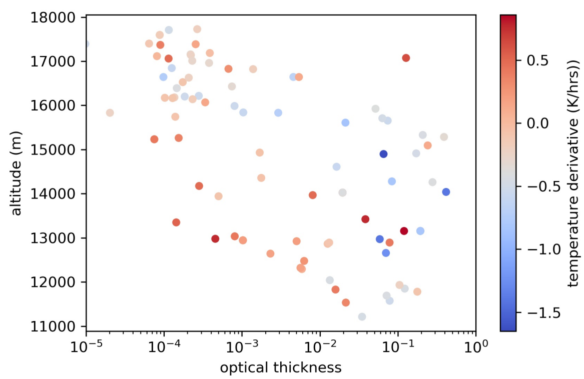

Figure 5. Optical thickness vs altitude. The colour codes the temperature gradient at the time of the observation, computed as an average over the past 18 hrs.

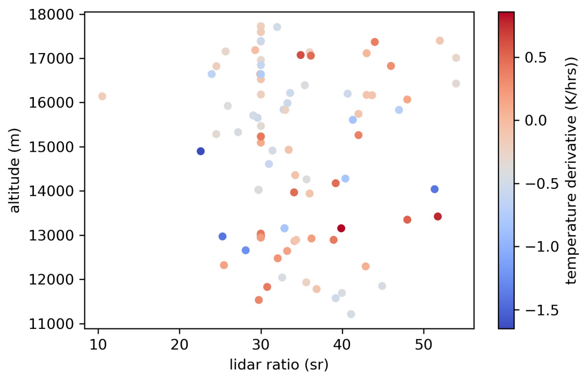

Figure 6. lidar ratio vs altitude. The colour codes the temperature gradient at the time of the observation, computed as an average over the past 18 hrs.

2.3 Effects of the potential temperature gradient at observation

Figures 7, 8, 9 report the influence of the potential temperature gradient, computed as the average over 18 hrs before observations, on depolarization, optical thickness and lidar ratio. Clouds in the upper part of the altitude range have positive gradients, negative in the lower part.

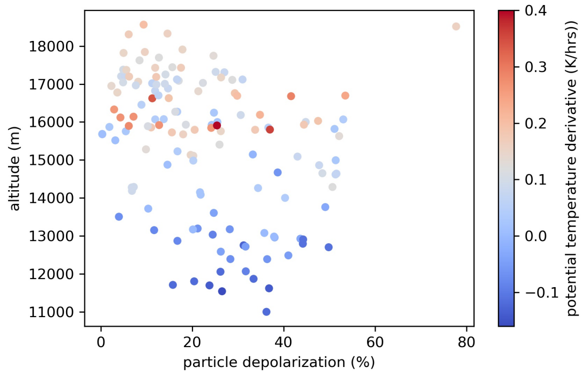

Figure 7. Particle depolarization vs altitude. The colour codes the potential temperature gradient at the time of the observation, computed as an average over the past 18 hrs.

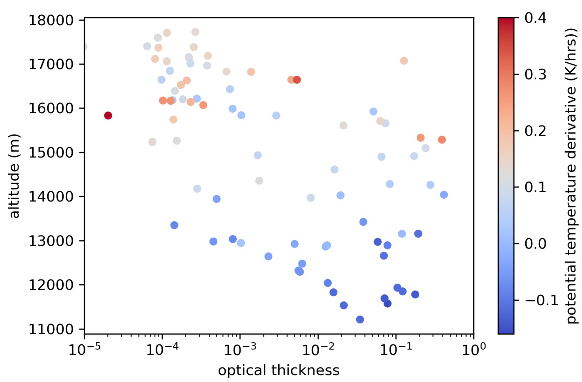

Figure 8. Optical Thickness vs altitude. The colour codes the potential temperature gradient at the time of the observation, computed as an average over the past 18 hrs.

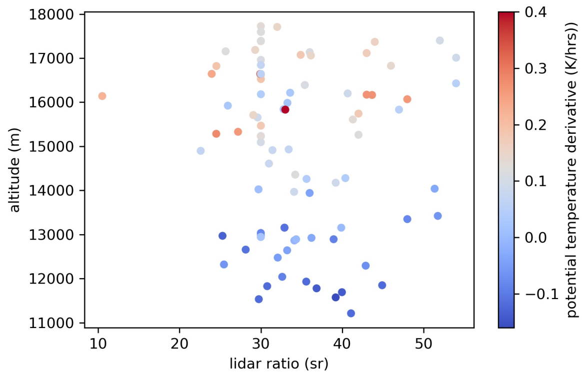

Figure 9. Lidar ratio vs altitude. The colour codes the potential temperature gradient at the time of the observation, computed as an average over the past 18 hrs.

2.4 Effects of the pressure gradient at observation

Figures 10, 11, 12 report the influence of the pressure gradient, computed as the average over 18 hrs before observations, on depolarization, optical thickness and lidar ratio. Clouds in the upper part of the altitude range have positive gradients, negative in the lower part.

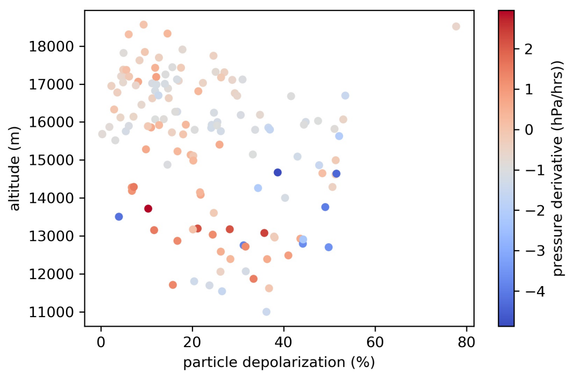

Figure 10. Particle depolarization vs altitude. The colour codes the pressure gradient at the time of the observation, computed as an average over the previous 18 hrs.

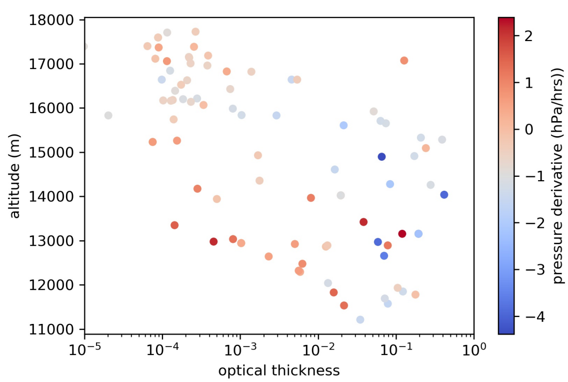

Figure 11. Optical thickness vs altitude. The colour codes the pressure gradient at the time of the observation, computed as an average over the previous 18 hrs.

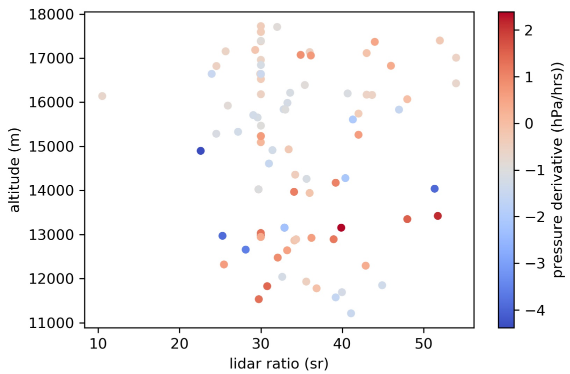

Figure 12. Lidar ratio vs altitude. The colour codes the pressure gradient at the time of the observation, computed as an average over the previous 18 hrs.

2.5 Effects of the time elapsed from the backtrajectory minimum temperature occurrence

Figures 13, 14, 15 report the influence of the time elapsed from the backtrajectory minimum temperature occurrence, on depolarization, optical thickness and lidar ratio. This time rarely exceeds few tens of hours, except on rare cases in the lower part of the altitude range, for some of the optically thicker clouds.

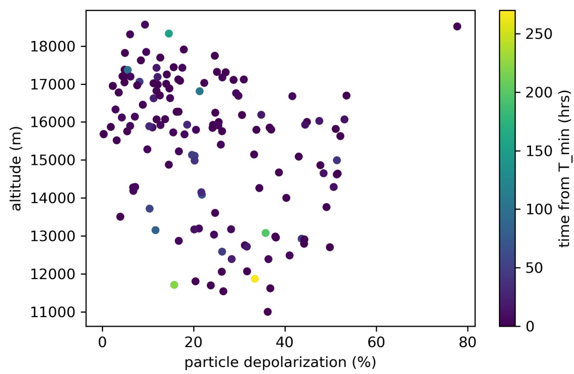

Figure 13. Depolarization vs altitude. The colour codes the time elapsed from the minimum temperature occurrence along the backtrajectory.

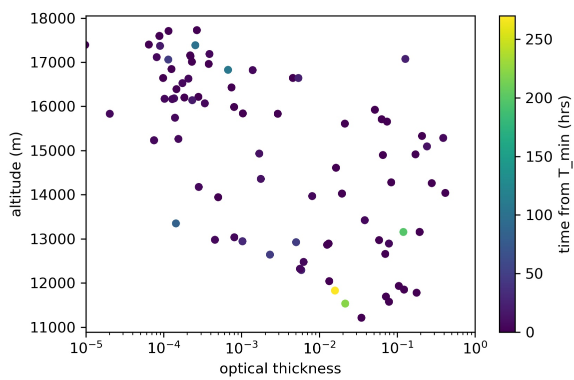

Figure 14. Optical thickness vs altitude. The colour codes the time elapsed from the minimum temperature occurrence along the backtrajectory.

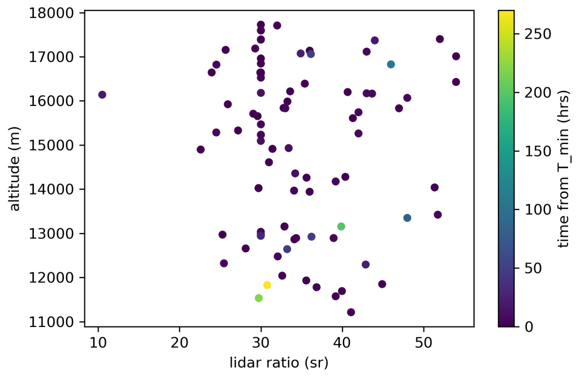

Figure 15. Lidar ratio vs altitude. The colour codes the time elapsed from the minimum temperature occurrence along the backtrajectory.

2.6 Effects of the time spent with temperatures lower than that at observation

Figures 16, 17, 18 report the influence of the time spent with temperature below the one at the observation, on depolarization, optical thickness and lidar ratio. This time rarely exceeds few tens of hours, except on rare cases distributed in the upper and lower parts of the altitude range; no particular influence on the optical parameters is discernible.

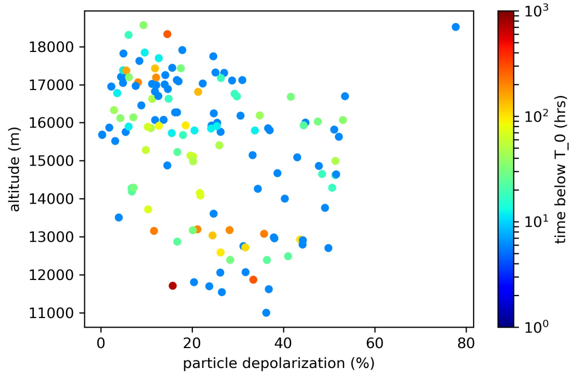

Figure 16. Depolarization vs altitude. The colour codes the time spent with temperature below the one at the observation.

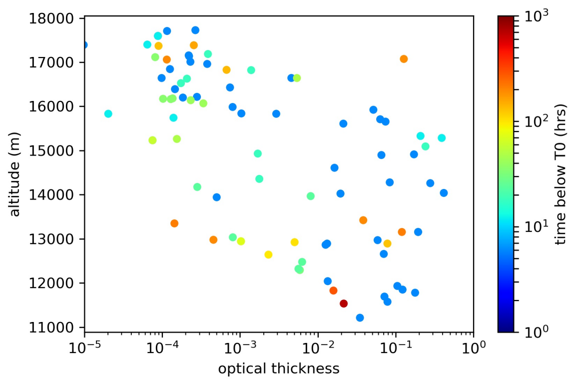

Figure 17. Optical thickness vs altitude. The colour codes the time spent with temperature below the one at the observation.

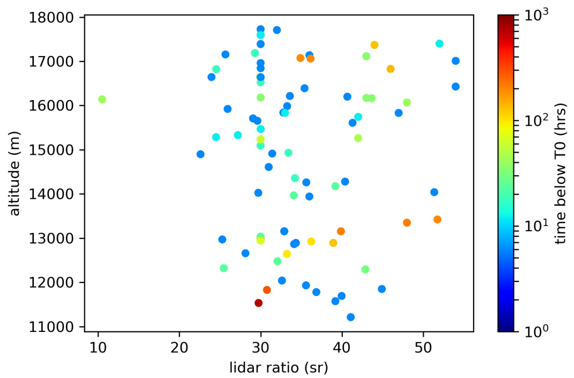

Figure 18. Lidar ratio vs altitude. The colour codes the time spent with temperature below the one at the observation.

2.7 Effects of the difference between the potential temperature at observation and the backtrajectory minimum potential temperature

Figures 19 20 21 report the influence of the difference between the potential temperature at observation and the backtrajectory minimum potential temperature, on depolarization, optical thickness and lidar ratio. Such difference rarely exceeds few K below 16 km, becoming more significative, up to 40 K, in the upper part of the altitude range. No particular influence on the optical parameters is discernible.

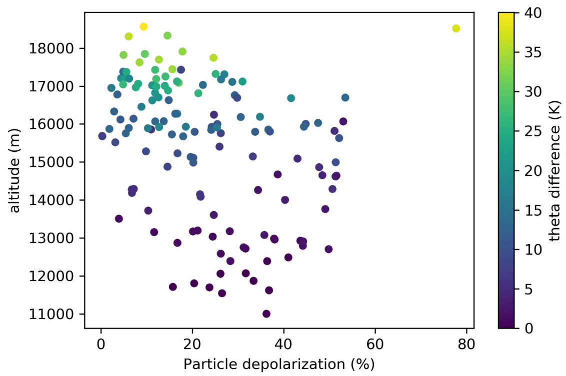

Figure 19. particle depolarization vs altitude. The colour codes the difference between the potential temperature at observation and the backtrajectory minimum potential temperature.

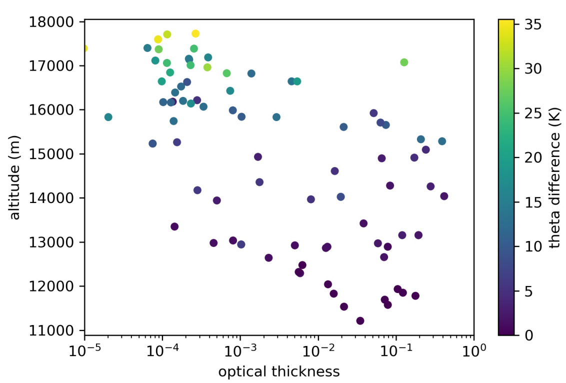

Figure 20. Optical thickness vs altitude. The colour codes the difference between the potential temperature at observation and the backtrajectory minimum potential temperature.

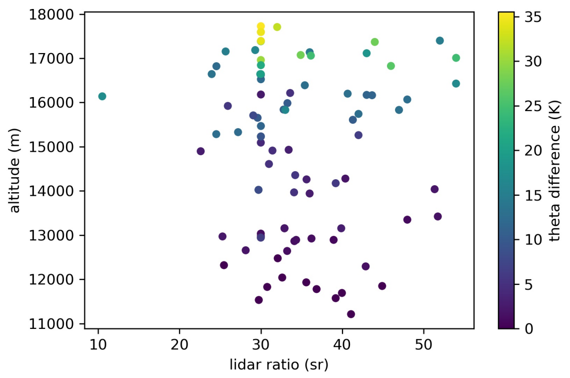

Figure 21. Lidar ratio vs altitude. The colour codes the difference between the potential temperature at observation and the backtrajectory minimum potential temperature.

2.8 Effects of the time elapsed from the backtrajectory minimum potential temperature occurrence

Figures 22, 23, 24 report the influence of the time from the minimum potential temperature on the backtrajectory. There is a clear and steady increase of such time with increasing altitude, going from few tens of hours in the lower part of the altitude range, to some hundreds hours in the upper part. An increase of such time with decreasing optical thickness seems discernible.

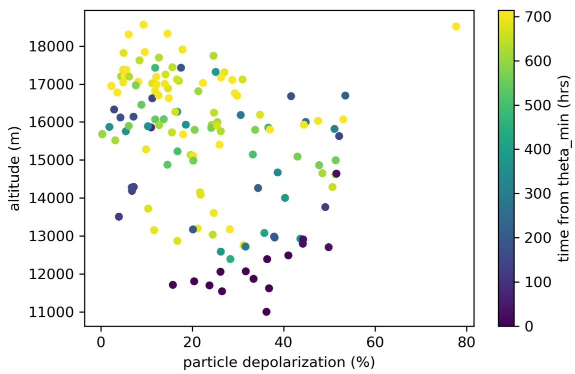

Figure 22. Deoplarization vs altitude. The colour codes the time elapsed from the minimum potential temperature on the backtrajectory.

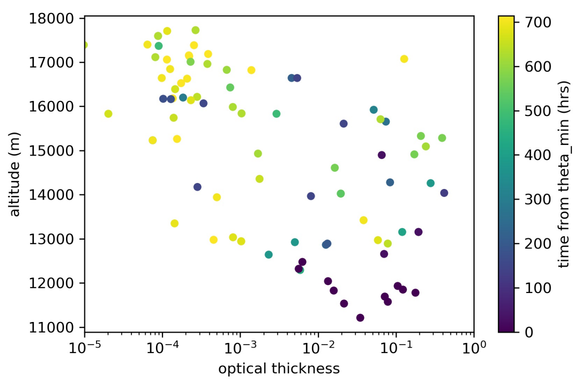

Figure 23. Optical thickness vs altitude. The colour codes the time elapsed from the minimum potential temperature on the backtrajectory.

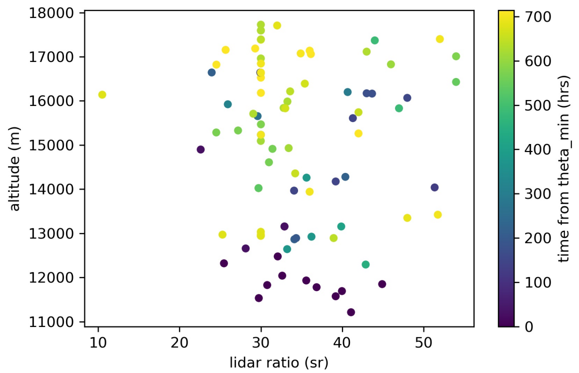

Figure 24. Lidar ratio vs altitude. The colour codes the time elapsed from the minimum potential temperature on the backtrajectory.

2.9 Effects of the minimum potential temperature along the backtrajectory

Figures 25, 26, 27 report the influence of the minimum potential temperature encountered along the backtrajectory. No particular feature is discernible.

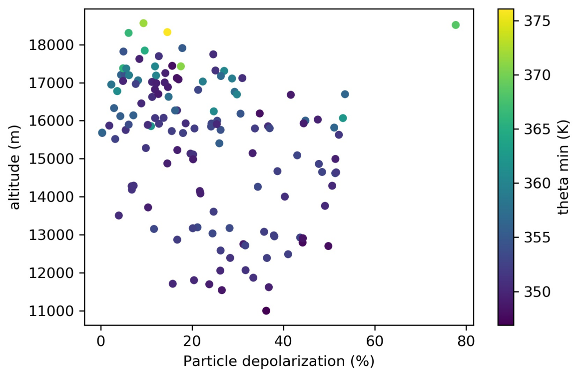

Figure 25. Particle depolarization vs altitude. The colour codes the backtrajectory minimum potential temperature.

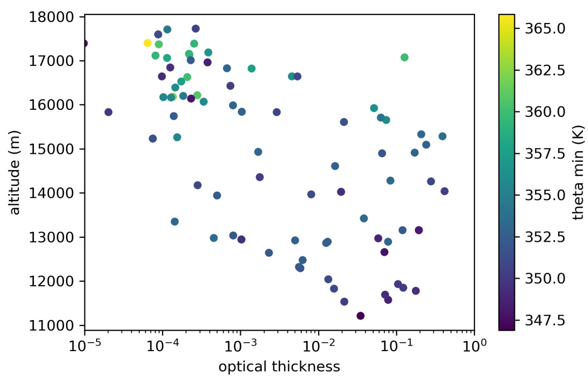

Figure 26. Optical thickness vs altitude. The colour codes the backtrajectory minimum potential temperature.

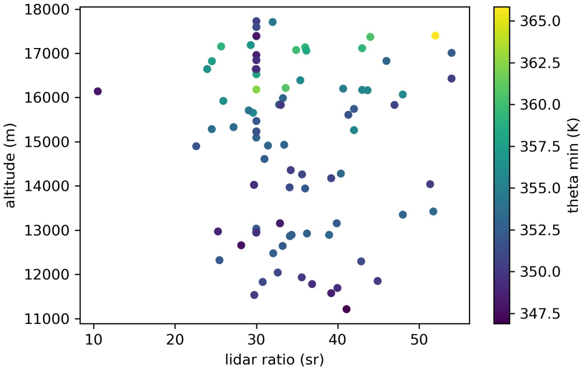

Figure 27. Lidar ratio vs altitude. The colour codes the backtrajectory minimum potential temperature.

2.10 Effects of the convective influence

Figures 28, 29, 30 report the influence of the convective influence. This spans from 20 to 60% on few cases, and is somewhat larger for the upper clouds.

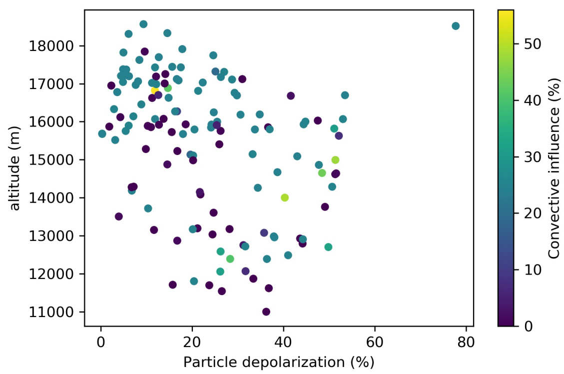

Figure 28. Particle depolarization vs altitude. The colour codes the convective influence.

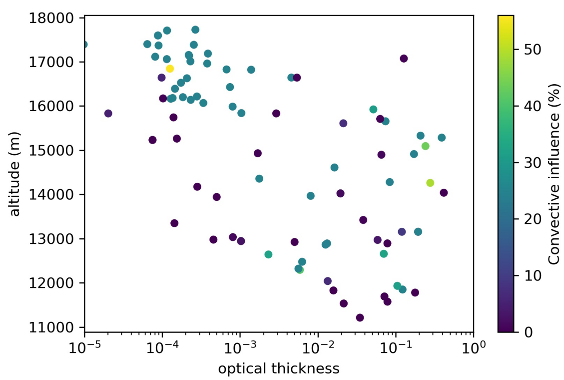

Figure 29. Optical thickness vs altitude. The colour codes the convective influence.

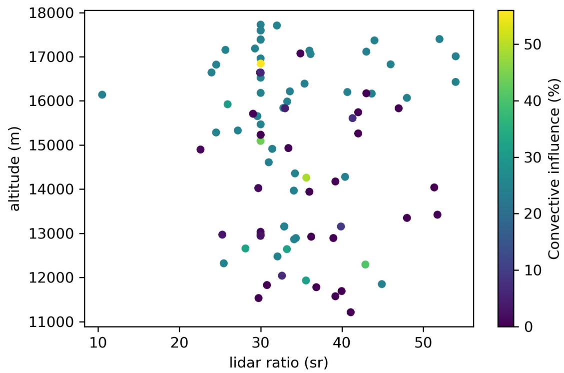

Figure 30. Lidar ratio vs altitude. The colour codes the convective influence.

2.11 Effects of the time elapsed from the convective influence

Figures 31, 32, 33 report the influence of the time elapsed from convective influence, which is generally below 200 hours except on few cases, scattered through the whole altitude range that can reach several hundreds of hours. No particular influence is discernible on the optical parameters.

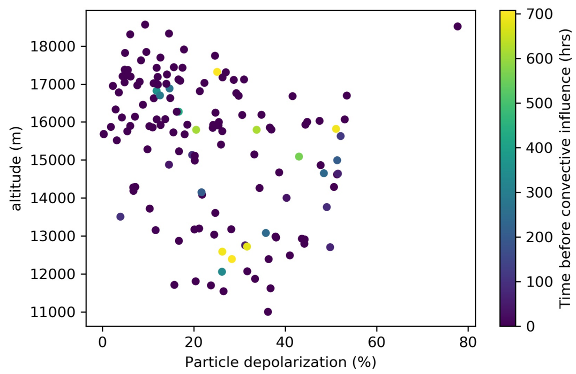

Figure 31. Particle depolarization vs altitude. The colour codes the time elapsed from convective influence.

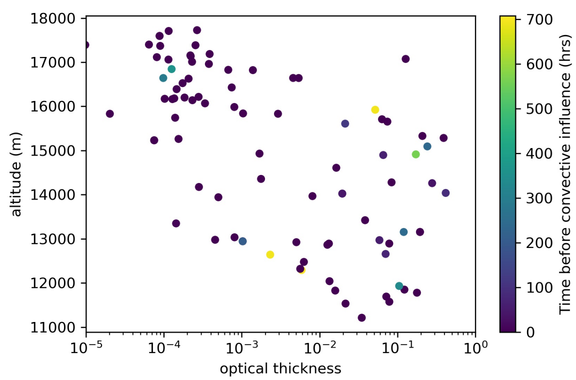

Figure 32. Optical thickness vs altitude. The colour codes the time elapsed from convective influence.

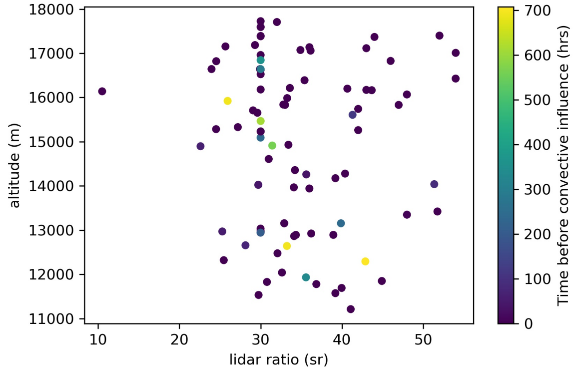

Figure 33. Lidar ratio vs altitude. The colour codes the time elapsed from convective influence.