Cloud observations over Limassol, Cyprus using CLOUDNET facilities

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Abstract

This study utilizes the results of the Cyprus Cloud Aerosol and Radiation Experiment (CyCARE) campaign that took place in Limassol, Cyprus, during the period October 2016 - March 2018. The Cloudnet target classification scheme was followed for the retrieval of cloud geometrical and microphysical properties and a climatological statistical analysis was applied for the investigation of cloud seasonal variability and characteristics. Of the total number of available vertical profiles, 35% were found to contain hydrometeors. The hydrometeor statistical analysis revealed that ice phase was the most frequent (83%), followed by mixed phase (44%) and liquid phase (30%). Precipitation occurred in 32% of the cases. The seasonal analysis showed that clouds over Limassol were more frequent during the winter season (58%) followed by spring (24%) and autumn (18%), while in summer clouds were absent (<1%). The most frequent cloud types were mixed phase clouds (44%) and pure ice clouds (29%). Clouds' seasonal geometrical characteristics (cloud base, top and thickness) were also investigated for each cloud type (ice, mixed, liquid). Since June 2024, a new permanent ground-based remote sensing station (Cyprus Aerosol Remote sensing Observatory - CARO) has been established in Limassol and the continuous observations will be used in future aerosol-cloud interaction relevant studies.

Data and Methodology

Dataset: LACROS Cloudnet station

Period: 19th October 2016 - 25th March 2018

Location: Limassol, Cyprus

Fig. 1. The location of the LACROS station (left) and the instruments installed (right).

Methodology

The Cloudnet target classification algorithm (Illingworth et al., 2007) synergistically combines all data from the various remote-sensing instruments (lidar, radar and microwave radiometer) and by combining them with model forecast data provides a classification of the various targets in the atmosphere, distinguishing between aerosols, liquid, ice, mixed phase targets etc.
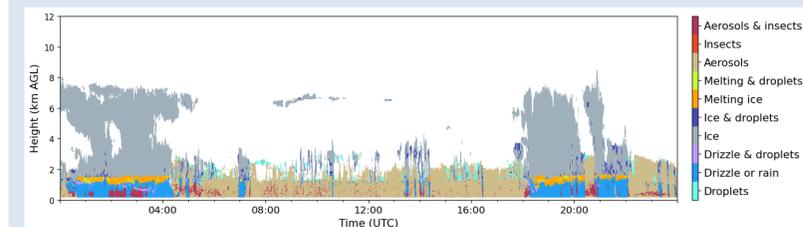

Fig. 2. Target classification over Limassol at 10/1/2017 according to the Cloudnet algorithm (30 sec intervals with vertical resolution of 30 m).
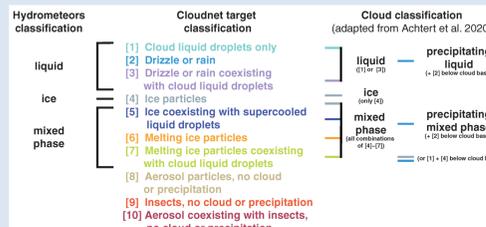

Fig. 3. Cloudnet target classification types, the hydrometeors classification and the cloud classification methodology. From Pîrloagă et al., 2022.

For the cloud classification (Achtert et al., 2020, Fig. 3) at least five consecutive height bins containing hydrometeors in a vertical profile are required for defining a cloud. Multiple clouds can exist in a single profile if they are separated by at least five height bins. A cloud is defined as liquid if its profile contains only height bins with classification values 1 and 3. For an ice cloud all height bins must be of value 4 only and for a mixed phase cloud it can contain any possible combination of values 4 to 8. If below the cloud base of liquid or mixed phase clouds exist values of 2, then the clouds are defined as precipitable. So, five cloud types were defined: liquid, precipitating liquid, ice, mixed phase and precipitating mixed phase.

References

Achtert P et al. (2020) Properties of Arctic liquid and mixed-phase clouds from shipborne Cloudnet observations during ACSE 2014. ATMOS CHEM PHYS 20(23), 14983-15002. https://doi.org/10.5194/acp-20-14983-2020
Illingworth AJ et al. (2007) Cloudnet: Continuous evaluation of cloud profiles in seven operational models using ground-based observations. B AM METEOROL SOC 88(6), 883–898. https://doi.org/10.1175/BAMS-88-6-883
Pîrloagă R et al. (2022) Ground-Based Measurements of Cloud Properties at the Bucharest–Măgurele Cloudnet Station: First Results. Atmosphere. 13(9): 1445. https://doi.org/10.3390/atmos13091445

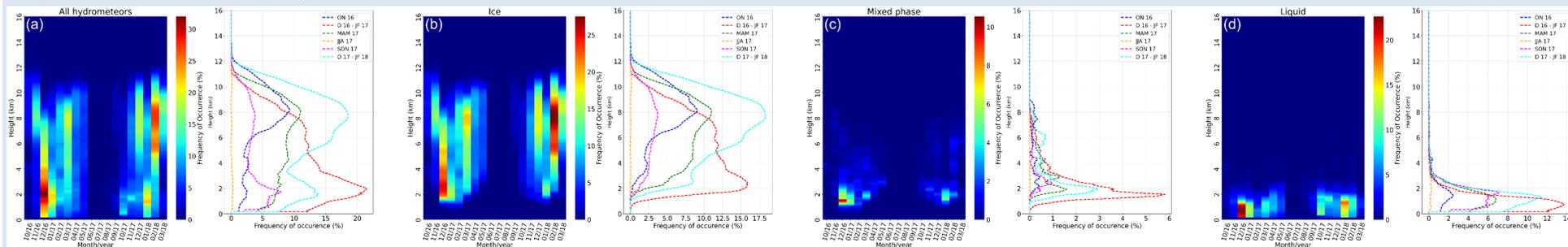## Hydrometeor classification and statistics

Fig. 4. Monthly (left) and seasonal (right) normalised frequency of occurrence for (a) all, (b) ice, (c) mixed phase, and (d) liquid hydrometeors.
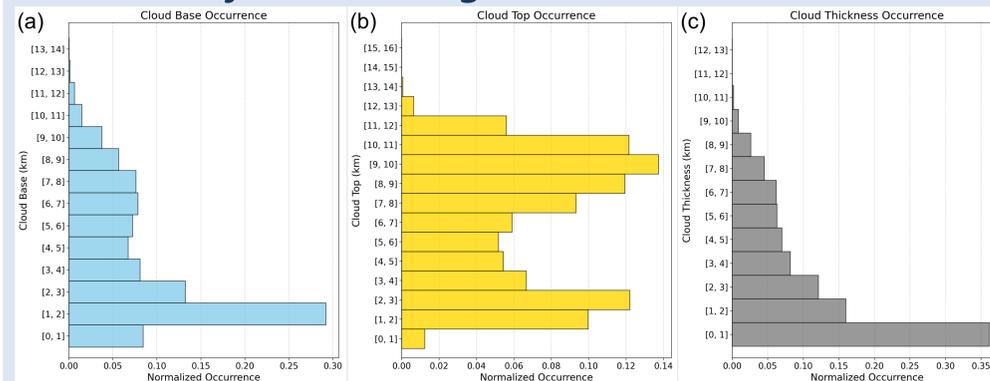
Cloud classification and geometrical characteristics

Fig. 5 and Table 1. Height normalized occurrence of cloud (a) base, (b) top and (c) thickness.

Height (km)	C base (%)	C top (%)	C thickness (%)
[0, 1]	8,4	1,2	36,1
[1, 2]	29,2	10,0	16,0
[2, 3]	13,2	12,2	12,1
[3, 4]	8,1	6,7	8,2
[4, 5]	6,7	5,4	7,0
[5, 6]	7,2	5,2	6,3
[6, 7]	7,8	5,9	6,2
[7, 8]	7,6	9,3	4,5
[8, 9]	5,6	11,9	2,6
[9, 10]	3,7	13,7	0,9
[10, 11]	1,5	12,2	0,2
[11, 12]	0,6	5,6	0,1
[12, 13]	0,1	0,6	0,1

Season	Geom Char	Ice	Mixed-phase	Mixed-phase precipitable	Liquid	Liquid precipitable
Winter	C base	5,5	3,4	1,5	1,4	1,2
	C top	8,8	7,5	5,0	1,8	1,5
	C thickness	2,4	2,5	3,2	0,2	0,2
Spring	C base	6,5	5,4	2,1	0,9	1,1
	C top	9,2	8,9	8,0	1,7	1,7
	C thickness	1,9	2,1	4,8	0,3	0,3
Summer	C base	9,7	9,2	3,4	1,3	2,3
	C top	10,2	9,7	3,8	1,6	3,2
	C thickness	0,4	0,4	0,5	0,2	0,4
Autumn	C base	7,1	6,4	2,4	1,5	1,4
	C top	9,2	8,7	5,0	1,9	2,0
	C thickness	1,7	1,6	1,4	0,2	0,3

Fig. 6 and Table 2. Box-and-whiskers plots of the seasonal distributions of cloud base height, cloud top height and cloud thickness of (a) ice, (b) mixed phase, (c) mixed phase precipitable, (d) liquid, and (e) liquid precipitable clouds. The numbers in the parentheses are the total number of profiles for the type of cloud and for each season. The seasonal median values (in km) of cloud base height, cloud top height and cloud thickness for each cloud type are shown in the table.

Conclusions

❖ **Most hydrometeors** were recorded during **winter**, while hydrometeors are completely **absent during summer**. Ice hydrometeors formed mostly in the **higher troposphere** and between **2-4 km altitude**. **Mixed phase** hydrometeors were detected **around 2 km** altitude, while **liquid hydrometeors** were observed **below 2 km** altitude.

❖ **A cloud base height** frequency **maximum** (29%) was found in **1-2 km altitude** and a second maximum (23%) in 5-8 km altitude. **Cloud top height** frequency shows a **maximum (47%)** between **7-11 km** altitude and a second maximum (22%) between 1-3 km altitude. **Cloud thickness** was **less than 2 km for 52%** of clouds and 32% of clouds have a thickness from 3 to 8 km.

❖ The **seasonal analysis** showed that **cloud base** was detected **at lower altitudes during winter** compared to summer. Ice clouds display the **highest cloud top** detected **reaching up to 10 km**. **Mixed phase precipitable** clouds show the **largest vertical extend** reaching up to 4.8 km in thickness. **Liquid clouds were quite shallower** compared to mixed phase and ice clouds.