

Cloud Types and Geometrical Properties Observed above PANGAEA Observatory in the Eastern Mediterranean [†]

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Abstract: In this work, we utilize space-based radar products from CloudSat mission and provide statistics on the properties of the clouds observed above the PANGAEA (PANhellenic GEophysical observatory of Antikythera) observatory, located in the Eastern Mediterranean. We found that the variable atmospheric conditions that prevailed above the region in 2007–2017 resulted in complex cloud structures. From the clouds observed, 39.8% were low-level clouds formed at the top of the marine boundary layer (≤ 2 km), 34.2% were mid-level clouds (between 2–7 km), and 25.9% were high-level or deep convective clouds (between 7–15 km). Thin clouds (< 1 km depth) are observed in 33% of the cases, while thick clouds (> 6 km) in 15% of the cases. The results of this study can be used from regional and climate models to evaluate their cloud predictions and investigate the performance of different cloud microphysics schemes.

Keywords: clouds; microphysical properties; remote sensing; CloudSat; PANGAEA



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1. Introduction

Earth's energy budget, climate system and weather are intensely affected by clouds. Different cloud types have different radiative effects (e.g., shortwave cooling and longwave warming effects), which plays an indispensable role in modulating the global radiative budget [1]. The main knowledge gaps and limitations in current state-of-the-art Global Climate Models (GCMs) are attributed to their inability to correctly describe the ice content in clouds, while the uncertainty is even higher for the quantification of ice and/or water content in mixed-phase clouds [2]. These limitations significantly affect the estimation of the cloud albedo in GCMs, altering the equilibrium climate sensitivity scenarios [3]. State-of-the-art methodologies use combined lidar–radar satellite observations (e.g., DARDAR-MASK product) to evaluate or constrain cloud predictions in GCMs. These products can provide mixed-phase cloud identification and estimations of the microphysical properties for ice particles [4].

The Eastern Mediterranean is a climate “hot-spot” characterized by a large variability of cloud systems, ranging from frontal and convective systems to mid-latitude cyclones [5]. Despite the significance of clouds over the Mediterranean basin, for both climate science

and regional impacts, there are only a few observational studies available for the region [6], while there are no studies utilizing the CloudSat/CALIPSO multiannual datasets.

In this work, we utilize space-based radar products from the CloudSat mission to provide statistics on the geometrical and microphysical properties of the clouds observed above the Eastern Mediterranean. We present the first quantification of the cloud abundance in the region, in respect to their altitudes, depth, and types. These findings can be used in combination with regional and climate models to investigate their capability to accurately predict the cloud properties observed.

2. Data and Methodology

2.1. Study Area

The PANGEA (i.e., the PANhellenic GEophysical observatory of Antikythera) observatory is located in the center of the Eastern Mediterranean basin, at the small island of Antikythera (35.86° N, 23.29° E, elevation: 110 m a.s.l.) in Greece. PANGEA is a remote site, far away from anthropogenic pollution sources (Figure 1). In Gkikas et al.'s work [7], the atmospheric homogeneity in the broader area around PANGEA is presented, for a radius up to 100 km away, using climatological MODIS Aqua AOD (Aerosol Optical Depth) measurements as a homogeneity tracer. Marine aerosols up to the boundary layer are considered the background conditions of the site, with clouds frequently formed on top of the boundary layer. Saharan dust elevated layers are also frequently observed with ice clouds forming occasionally at the top of the dust layers. Seasonal statistics of dust abundance above the area are provided by Marinou et al. [6], based on nine years of CALIPSO measurements. The PANGEA site is frequently affected by frontal and convective systems, mid-latitude cyclones, and occasionally by medicanes, with the relevant clouds passing above the PANGEA observatory. Apart from marine and dust aerosols, the site is affected by the long-range transport of pollution from the Mediterranean megacities, smoke from forest fires in Europe and even the US/Canada, and volcanic ash from Etna eruptions.

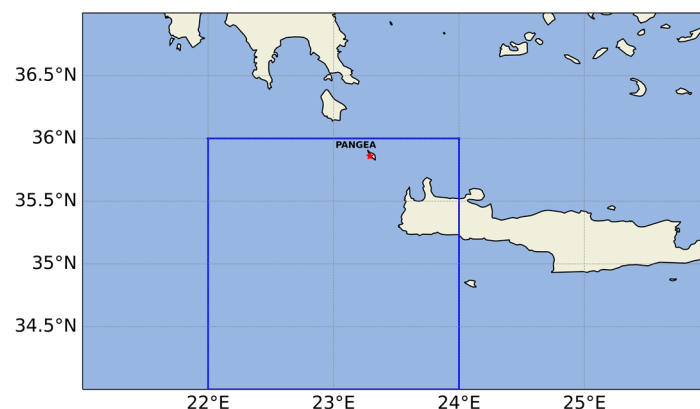


Figure 1. Location of PANGEA observatory (35.86° N, 23.29° E) in Greece.

Given that few locations on Earth experience such complex aerosol and cloud structures, vertical layering, and aerosol mixtures as in the Mediterranean, conditions that can significantly influence cloud evolution, lifetimes, and precipitation processes, the PANGEA observatory is ideal for providing representative cloud statistics for the broader Mediterranean basin.

2.2. Dataset

CloudSat's cloud profiling radar (CPR) [8,9] has been operating since 2 June 2006 in the NASA A-Train constellation of satellites. It operates at 94 GHz with a sensitivity of -30 dBZ. Radar reflectivities (Z_e) are sampled every 240 m with a vertical resolution of ~ 480 m. Profile spacing is approximately 1 km along track with a volume resolution of 1.8 km along track and 1.5 km cross-track. The A-train constellation is in a Sun-synchronous

orbit with equator crossings at around 01:30 and 13:30 local time. In this study, we use the 2B-GEOPROF (R05) radar reflectivity product [10,11] and the 2B-CLDCLASS (R05) cloud type product [12], from the 2007–2017 period. We use only reflectivities associated with a “CPR_cloud_mask” value ≥ 30 , which indicates high confidence in the cloud retrievals.

The CloudSat algorithm classifies clouds into eight categories—stratus (St), stratocumulus (Sc), cumulus (Cu), nimbostratus (Ns), altocumulus (Ac), altostratus (As), deep convective clouds (deep), and high-level clouds (high)—based on the hydrometeor vertical and horizontal scales, the maximum Ze measured, indications of precipitation, and ancillary data including modeled ECMWF temperature (T) profiles and surface topography height [13]. CloudSat products at a spatial resolution of $2^\circ \times 2^\circ$ from PANGEA are used in this work. We analyze the data record collected between January 2007 and December 2017 (550 overpasses) to characterize the cloud properties over the PANGEA observatory, and the broader area.

3. Results

Figure 2 presents the cloud geometrical characteristics (Figure 2 (a) top, (b) base, (c) depth/thickness) above PANGEA. We separate the observed clouds into low-level (with cloud tops < 2 km), mid-level (with cloud tops between 2–7 km), and high-level clouds (with cloud tops > 7 km). We found a 39.8% abundance of low-level clouds, 34.2% of mid-level clouds, and 25.9% of high-level clouds in the total dataset. The majority of the cloud bases are found in altitudes below 1 km (28%).

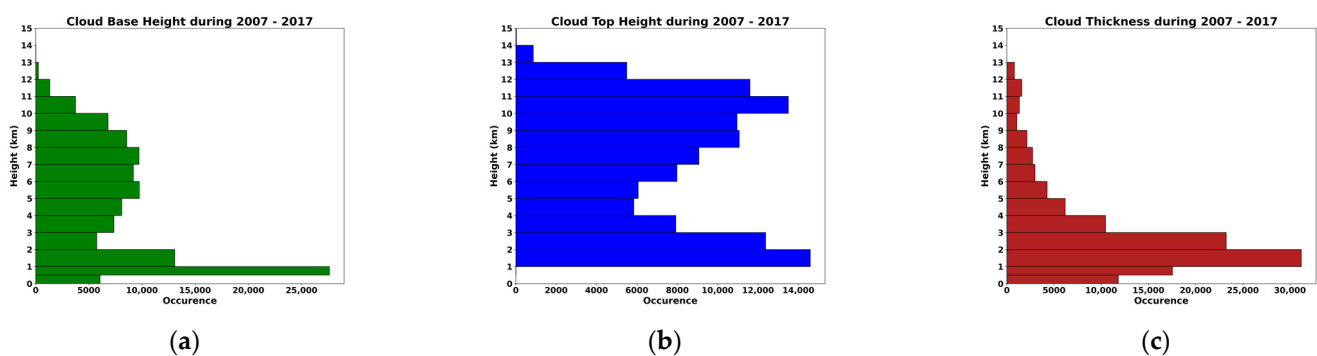


Figure 2. Clouds geometrical characteristics of (a) cloud top, (b) cloud base, (c) cloud thickness, above PANGEA observatory, based on Cloudsat 2007–2017 dataset.

Cloud thickness varied significantly, from less than 1 km up to 9 km. A total of 33% of the clouds observed were thin clouds (with depth < 1 km), and 15% were thick clouds (with depth > 6 km).

In the study of Marinou et al. [6] over the Finokalia station in Crete, they reported occurrences of mid-level clouds in 38% of the cases, high-level or convective clouds in 58% of the cases, and low-level clouds in 2% of the cases. We found that PANGEA has significantly more marine low-level clouds in relation to the Finokalia site, which is attributed to the fact that PANGEA is located on a very small island of low elevation, and is representative of the marine environment in the broader region.

The statistics of the Cloud Sat’s cloud type per height level are presented in Figure 3. We see the Sc dominance in heights < 3 km. Low As and Ac occurrences are observed at every altitude. Their highest occurrences are found between 2 and 9 km, although they are also present at altitudes of less than 2 km. Similar findings are presented by [14]. High clouds are observed between 5 and 14 km. Cu are present below 7 km. Deep convective clouds and Ns are observed across all heights. It should be noted that high-level clouds, as determined by CloudSat, are not only exclusively composed of ice, but may also consist of mixed-phase observations [15].

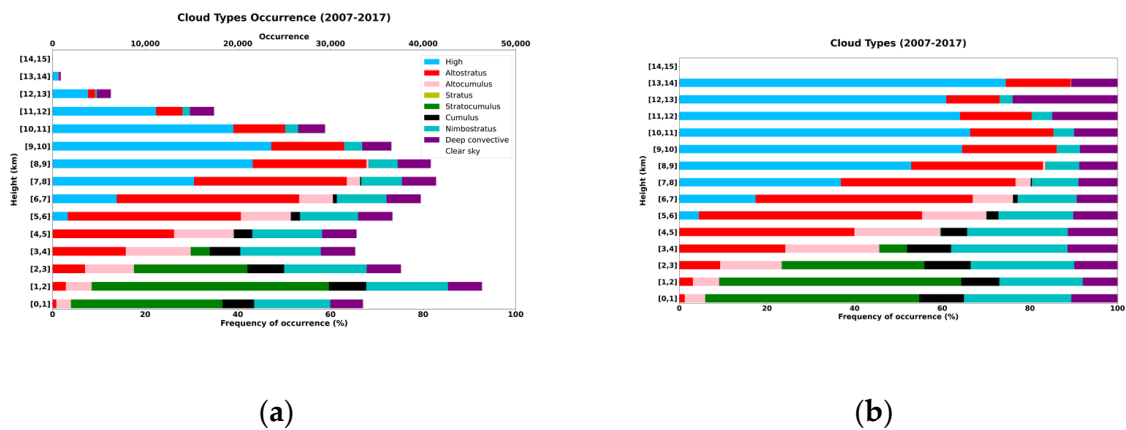


Figure 3. Cloud types (a) occurrence and (b) statistics per height above PANGEA observatory, based on Cloudsat 2007–2017 dataset.

A percentage of cloudiness per height is presented in Figure 4. The highest cloudiness percentage (83%) is observed between 1 and 2 km and the clearest sky is observed at the upper levels between 10 and 15 km, as expected.

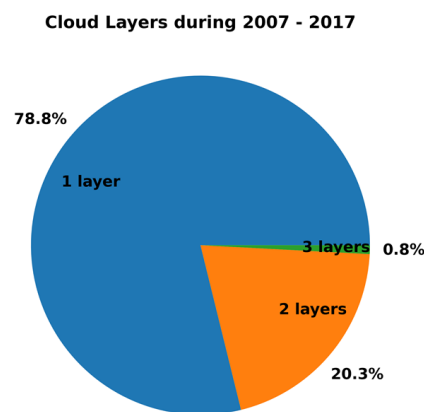


Figure 4. Percentages of the cloud layers observed above PANGEA observatory, based on Cloudsat 2007–2017 dataset.

Figure 4 presents the statistics of cloud layers observed above the PANGEA site. Single-layer clouds are observed in 71% of the cases. Double-layer clouds are observed in 15% of the cases, while more layers are observed in the rest of the cases.

4. Conclusions and Future Work

In this work, we use 11 years of space-based radar products from the CloudSat mission to provide statistics on the cloud geometrical properties and types observed above the PANGEA observatory in the Eastern Mediterranean. The predominance of low clouds is evident in the region, with the majority of the clouds measuring less than 2 km in depth (57% of the cases). The findings of this work provide, for the first time, a decadal-based vertical distribution of the cloud types and geometrical properties above PANGEA observatory, which is a representative marine station of the Eastern Mediterranean.

In the next steps, we will use the full CloudSat dataset to study the seasonal cycle and the vertical variations of the observed cloud types and the precipitation patterns over the PANGEA observatory, and we will extend our analysis to the Mediterranean basin.

The outputs of this study can be compared with cloud predictions from regional/global models in order to investigate the performance of the models to predict the clouds observed in the Mediterranean. Additionally, cloud vertical distributions and types from

Cloudsat can be combined with collocated aerosol properties derived from CALIPSO towards studying the aerosol–cloud interactions in the Mediterranean [16] and investigating the performance of microphysics parameterizations in numerical weather prediction and regional/climate models.

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