DeepSky: A ground-based cloud observation system

Dimitrios Tsourounis
Physics Department (ELLAB)
University of Patras
Rio Patras, Greece
dtsourounis@upatras.gr

Dimitris Kastaniotis
Physics Department (ELLAB)
University of Patras
Rio Patras, Greece
dkastaniotis@upatras.gr

Panagiotis Tzoumanikas
Physics Department (LAPUP)
University of Patras
Rio Patras, Greece
tzumanik@ceid.upatras.gr

George Andrianakos
Computer Vision Systems
Irida Labs
Magoula Patras, Greece
andrianakos@iridalabs.com

Alexios Kotronis
Computer Vision Systems
Irida Labs
Magoula Patras, Greece
akotronis@iridalabs.com

Orestis Panagopoulos
Physics Department (LAPUP)
University of Patras
Rio Patras, Greece
orestis.panagopou@upatras.gr

Andreas Kazantzidis
Physics Department (LAPUP)
University of Patras
Rio Patras, Greece
akaza@upatras.gr

Christos Theocharatos
Computer Vision Systems
Irida Labs
Magoula Patras, Greece
htheohar@iridalabs.com

George Economou
Physics Department (ELLAB)
University of Patras
Rio Patras, Greece
economou@upatras.gr

***Abstract*—DeepSky is a collaborative project between the Physics Department of the University of Patras and Irida Labs, a computer vision company, focused on developing a ground-based cloud observation system. The DeepSky system captures sky images in different modalities, encompassing optical and thermal representations, while collecting meteorological and solar measurements, including temperature, relative humidity, and various forms of irradiance. The primary objective of the DeepSky system is to estimate a range of geophysical variables related to cloud dynamics, given their significant impact on the climate system through sunlight reflection, heat absorption, and participation in the hydrological cycle. Utilizing propagation models of radiation, computer vision techniques, and deep learning methods, the DeepSky system performs cloud type classification, estimates cloud coverage percentage, predicts irradiance values, and analyses aerosol optical depth and precipitable water vapor.**

Keywords—ground-based cloud observation, cloud classification, all-sky images, sky-patch images, deep learning

I. Introduction

Ground-based cloud observations offer valuable insights into local sky areas, providing detailed information at the bottom of clouds with high temporal and spatial resolution, all at a cost-effective price point. The DeepSky project combines cameras, meteorological and solar sensors, and advanced algorithms to accurately estimate various geophysical variables associated with clouds. This collaborative effort involves the Laboratory of Atmospheric Physics (LAPUP) and the Electronics Laboratory (ELLAB) of the University of Patras in partnership with Irida Labs, a computer vision company.

II. Data Capture

A. Image representations

The DeepSky system utilizes a visible light sensor with a fisheye lens (Mobotix Q26B-6D016 and lens B016) to capture all-sky images (ASIs), providing a comprehensive view of the entire sky dome. Additionally, the system features a dual camera (Mobotix M73) that operates in both the optical and far infrared spectrums. The dual camera combines an optical sensor, capturing visible light (390-770 nm), and a thermal-infrared sensor that detects long wave infrared radiation (LWIR, 8-14 μm). These sensors utilize wide-angle lenses, enabling the capture of sky-patch images (SPIs). The dual camera provides simultaneous an RGB image, measuring the intensity of red, green, and blue light, as well as a thermal image that displays variations in temperature by detecting the heat emitted by different objects in the sky. All cameras are positioned to capture sky images directly overhead (zenith), and the DeepSky system is located at the Physics Department of the University of Patras (38° 17' 29" N, 21° 47' 20" E).

B. Meteorological and solar measurements

The DeepSky system is equipped with a temperature and humidity sensor (SHT20) that measures temperature in degrees Celsius (ºC) and relative humidity (%RH). Also, solar irradiance and sunshine are measured using high-quality pyranometers from Kipp & Zonen (CMP11, CM121, and SD3). These pyranometers provide accurate measurements of the Diffuse Horizontal Irradiance (DHI), Global Horizontal Irradiance (GHI), and Global Tilted Irradiance (GTI).

III. Datasets

With the expertise of our faculty in atmospheric physics, the images are manually labeled with cloud category information by expert meteorologists. The images are divided into seven sky types according to the presented clouds: 1) cumulus, 2) altocumulus and cirrocumulus, 3) cirrus and cirrostratus, 4) clear sky, 5) stratocumulus, stratus, and altostratus, 6) cumulonimbus and nimbostratus, 7) mixed cloudiness, following the international cloud classification system criteria published in the World Meteorological Organization (WMO) as well as the visual similarity of cloud in practice. Table I provides a description of the generated datasets.

A. All-sky images (ASIs)

The DeepSky system captures an all-sky image (ASI) every 11 seconds throughout a two-year period (2021-2022) during the daytime. For diversity, the ASI dataset includes approximately one image per 30 minutes, and the rest of the images are utilized for sequence modeling methods. A Circle of Interest was used as a mask to concentrate on pertinent cloud information, and the images were standardized to a resolution of 678 × 678 pixels. In addition to the cloud

979-8-3503-4218-5/23/$31.00 ©2023 IEEE

TABLE I. CLOUD CLASSIFICATION SKY IMAGE DATASETS

	DeepSky Cloud Classification Image Datasets	**ASIs (optical)**		**SPIs (optical & thermal)**	
Classes - Cloud type	***Description***	***Years***		***Years***	
		2021 (Train)	***2022 (Test)***	***2022 (Train)***	***2023 (Test)***
1.Cumulus	Low clouds - Fluffy and puffy clouds with a distinct dome-shaped appearance	661	610	278	82
2.Altocumulus	Middle clouds - Patched clouds with mosaic-like appearance	464	521	259	87
3.Cirrus	High clouds - Thin, wispy, and fibrous clouds with a feathery or filamentous appearance	559	572	275	70
4.Clear sky	Cloudless sky or a very few cloudiness	655	601	286	426
5.Stratocumulus	Low clouds - Lumpy clouds with broken to almost overcast	431	570	223	93
6.Cumulonimbus	Vertical structure - Thick clouds with mostly overcast	568	266		
7.Mixed	More than two genera of clouds	645	185	-	-
Total		3983	3325	1321	758

category labels, the ASIs were annotated with irradiation measurements, further enriching the dataset with meteorological information for various applications.

B. *Sky-patch images (SPIs)*

Each sky-patch image (SPI) in the dataset consists of two modalities: optical and thermal representation, enabling the utilization of SPIs as two distinct datasets. Due to technical limitations related to the waterproof protection of the dual camera, we could not capture images at a standard frequency. However, the recordings span a period of one and a half years (2022 and first half of 2023). Also, mixed cloud images are difficult to find because of the restricted sky area on the SPIs and so, this class is removed from the dataset. Additionally, the stratocumulus and cumulonimbus cloud types were merged due to the limited number of images in each independent class, resulting from the inability to capture images in rainy conditions. All the images have a resolution of 480 × 640 pixels (Height × Width).

IV. RESULTS

DeepSky system integrates optical and thermal images, along with meteorological models and machine learning methods, to estimate different geophysical variables. The DeepSky system employs deep learning models to predict cloud types, using the training set for training the model and evaluating their performance on the corresponding test set [1]. The results, depicted in Figure 1, reveal that the Convolutional Neural Network (CNN) model operating on all-sky images (ASIs) exhibits a higher level of confusion between stratocumulus and cumulonimbus images due to their visually similar texture structure. Additionally, the mixed cloud category presents the greatest challenge as it is a combination of other categories. On the other hand, the performance of the CNN model on the sky-patch images (SPIs) demonstrates that the optical and thermal images complement each other in classifying cloud types. Specifically, optical images are effective in distinguishing the cumulus class, while the thermal images excel in identifying the stratocumulus-cumulonimbus category.

Other geophysical variables estimated by the DeepSky system include cloud coverage percentage (CCP), which quantifies the percentage of the sky covered by clouds. This is calculated by applying thresholds to the RGB image channels and referencing a clear sky library. Leveraging the irradiation measurements associated with the ASIs, we develop an initial CNN-based approach to estimate diffuse and global horizontal irradiances (DHI and GHI) taking as input the optical ASIs [2]. Additionally, the system estimates aerosol optical depth (AOD), which is the measure of aerosols distributed within a column of air. Shallow machine learning models, such as Random Forests, utilize information extracted from RGB images, irradiance measurements, sun's position, temperature, and relative humidity to estimate AOD [3]. Lastly, precipitable water vapor (PWV), the column water vapor amount in the atmosphere, is estimated using the sky zenith temperature from thermal images along with statistical techniques in clear sky images. Also, the Red-to-Blue Ratio (RBR) of color intensities is utilized to estimate aerosol optical properties using a radiative transfer model, such as the libRadtran.

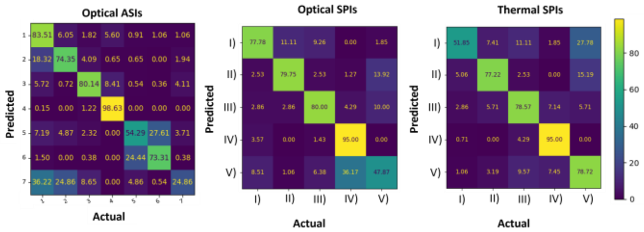

Fig. 1. Confusion matrices presenting the test set results for the optical ASIs (7 classes) dataset and the optical and thermal SPIs (5 classes) datasets.

ACKNOWLEDGMENT

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T2EDK – 00681, MIS 5067617).

REFERENCES

[1] D. Tsourounis et al., "DeepSky dataset: A new benchmark for ground-based cloud classification using all-sky images", presented at the Irish Machine Vision and Image Processing Conference 2023 (IMVIP2023), University of Galway, Ireland, Aug. 2023. doi: 10.5281/zenodo.8208505.

[2] S. A. Logothetis et al., "Benchmarking of solar irradiance nowcast performance derived from all-sky imagers", Renewable Energy, vol. 199, 2022, p. 246-261, https://doi.org/10.1016/j.renene.2022.08.127.

[3] G. Kosmopoulos et al., "Feasibility of low-cost technologies on simultaneous PM2.5 and AOD measurements at a typical East Mediterranean site", presented at the 11th International Aerosol Conference (IAC 2022), Athens, September 4 - 9, 2022.