

All-Sky Camera Upward-Looking Thermal Infrared Cloud Characteristics



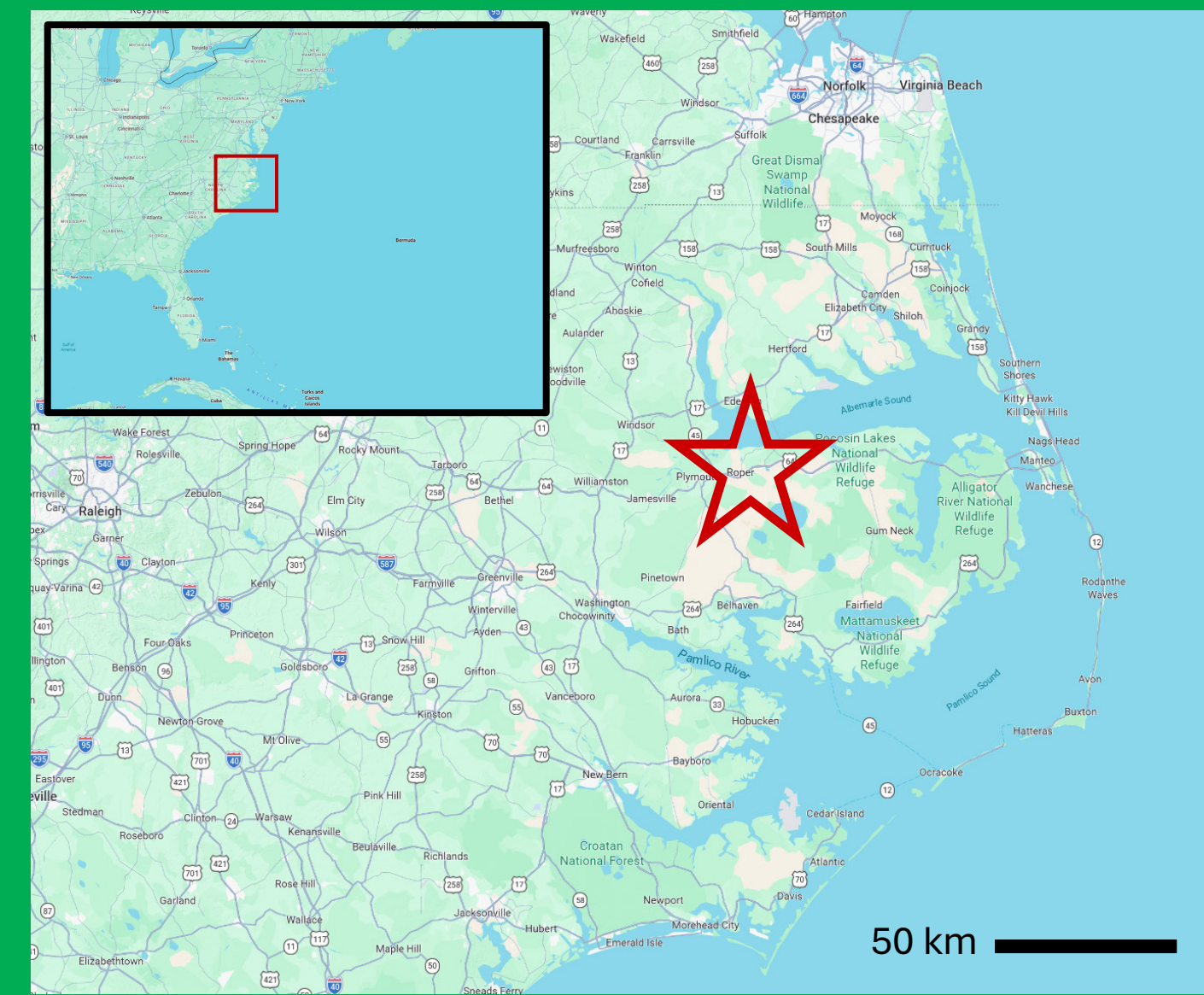
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Introduction

Satellite data sets are the primary source of observations of cloud characteristics, but downward-looking passive sensors cannot see lower-level clouds obscured by higher clouds nor cloud bases. Observations of low clouds with downward-looking satellite IR are hampered by the small brightness temperature differences between the low cloud top and the underlying land surface. In contrast, upward-looking thermal IR can readily distinguish warm clouds against the cold sky. By sampling thermal IR cloud characteristics across the diurnal cycle, upward looking thermal IR observations have the potential to yield improved understanding of transitions in low cloudiness at sunrise and sunset and differences in the relative importance of different cloud processes with and without SW fluxes.

From infrared imagery we can infer cloud fraction, cloud coverage characteristics relating to the size and shapes of cloud elements, and estimate the altitude of cloud bases across the 24-hour day. Sequences of images reveal the evolution of individual cloud elements and provide information on the phase space of cloud properties across the diurnal cycle and related to air mass changes, such as the passage of fronts. Combined with other data from lidar and visible all sky cameras, the upward-looking thermal IR data on cloud outer surface temperature details at small spatial scale (10s of meters) and few minute time scale have high potential to yield new insights on cloud initiation and dissipation.



Our instruments are located at the Eastern Carolina Atmospheric Observing Site (ECAOS) in Plymouth, NC, USA. In addition to the visible and IR all-sky cameras, the site hosts a Vaisala CL61 ceilometer, three Lufft CHM 15k ceilometers, a Metek Micro Rain Radar, an OTT Parsivel laser disdrometer, a Campbell Scientific SunScout surface weather and solar radiation measurement station, and a PurpleAir Zen laser particle counter.



Visible All-Sky Camera

Our visible all-sky camera was assembled using commercial off-the-shelf parts. It features a zenith-pointing Raspberry Pi HQ camera with a 180° field of view fisheye lens controlled by a Raspberry Pi 5 single board computer. The image capture software is the open-source allsky library which is popular with the amateur astronomy community. Image are captured every 45 seconds during daytime and every 60 seconds at night.



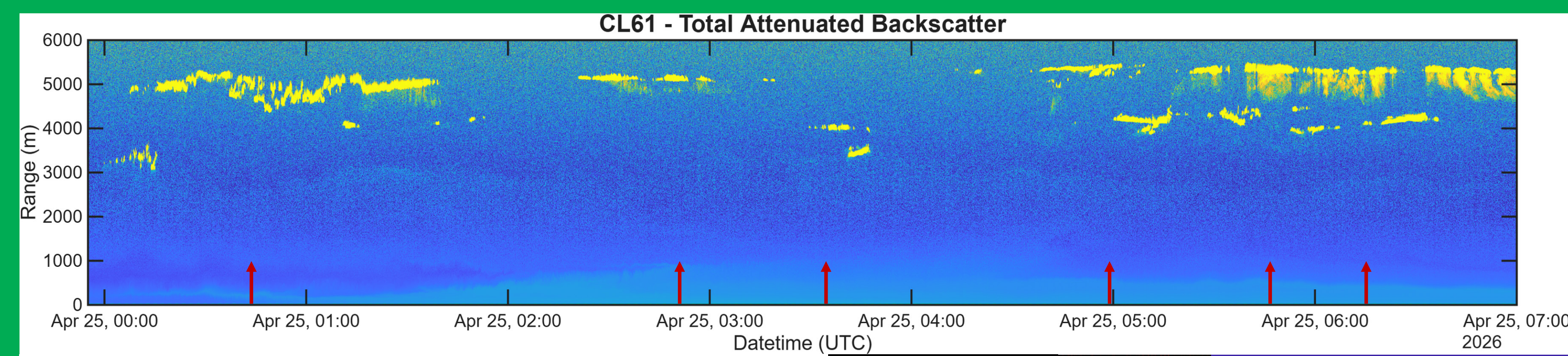
Thermal IR Camera

Our thermal IR all-sky camera is constructed using commercial off-the-shelf parts. It features a FLIR Boson 640 longwave infrared camera with a 50° field of view mounted to a FLIR PTU-5 pan-tilt mount. The camera is controlled using a Raspberry Pi 5 running Python code that makes use of open-source repositories for control of both the camera (flirpy) and the pan-tilt mount (FLIR-PTU-Python). The IR all-sky camera images the entire sky by pointing the camera in multiple directions and stitching the images together into a hemispheric image. The scan strategy is tuned for a "rapid update" scan pattern which forgoes low elevation angles and uses 7 images to capture the sky from zenith down to 35° elevation off the horizon.

Thermal IR Camera Scan Schematic

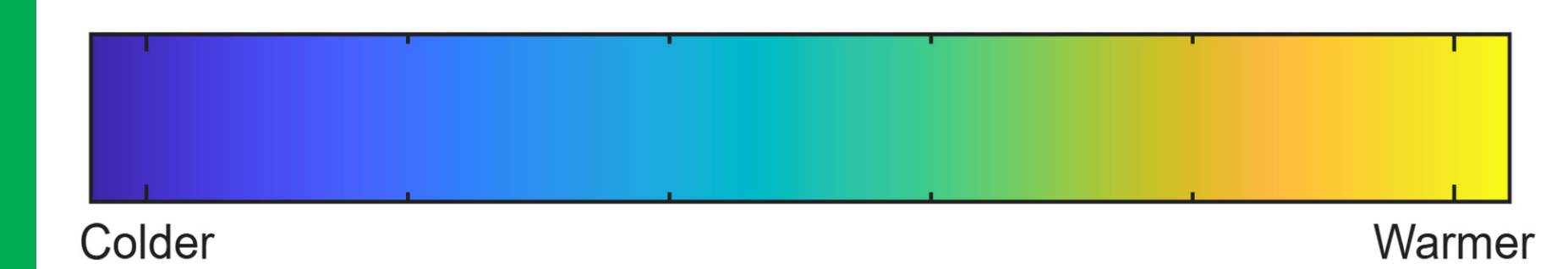
Camera coverage boundaries as projected on a hemisphere. The quasi-rectangular boundaries represent the edges of each captured sub-image. The circles represent the center of each captured image. The black lines denote the spherical Voroni boundaries between each image center. Image data for a given image that lies outside its local Voroni polygon are discarded. This volume coverage pattern is executed every thirty seconds. All sub-images are captured within 16 seconds with roughly 2-3 seconds between successive images.

Cloud Fraction Variations

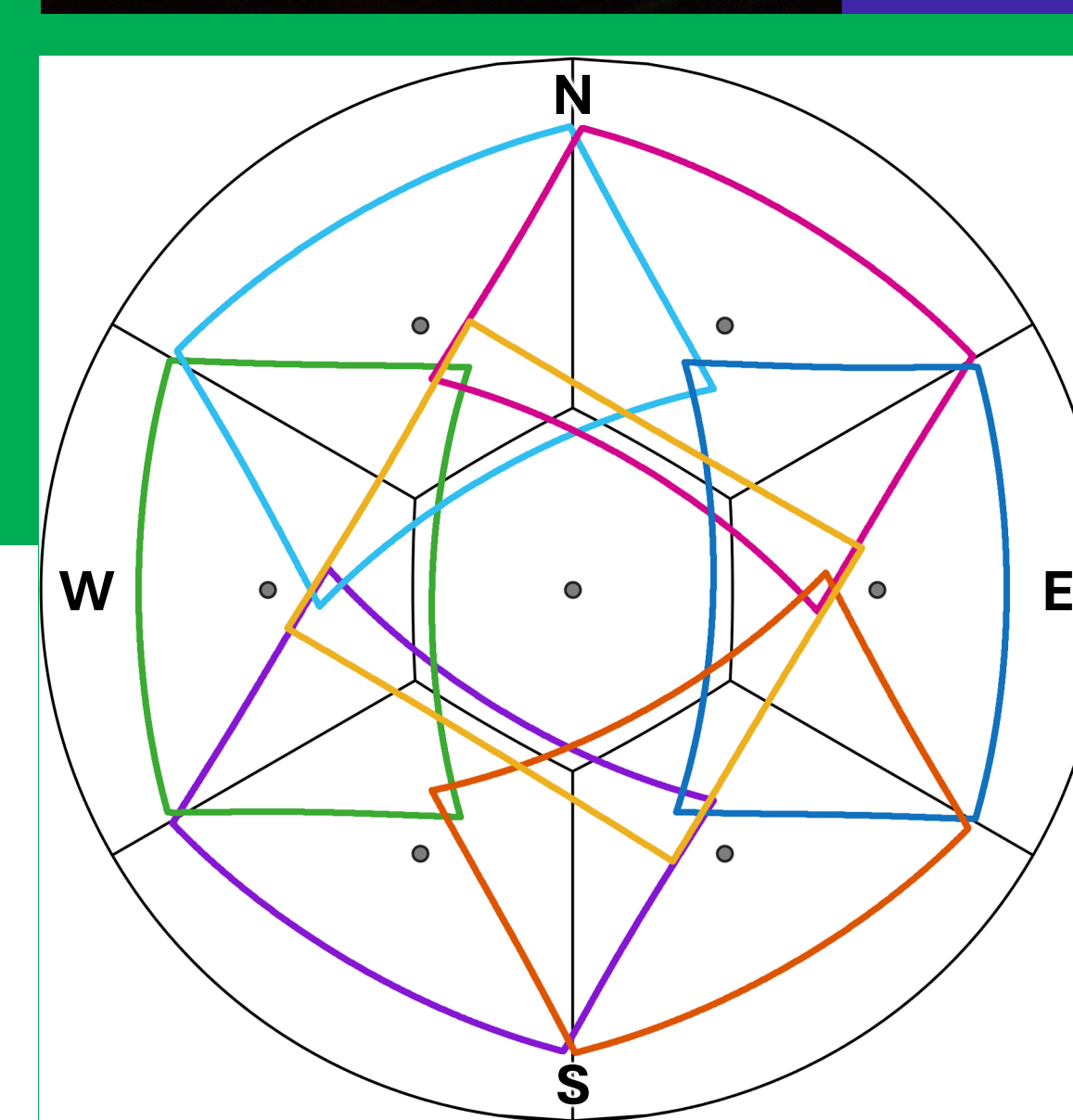
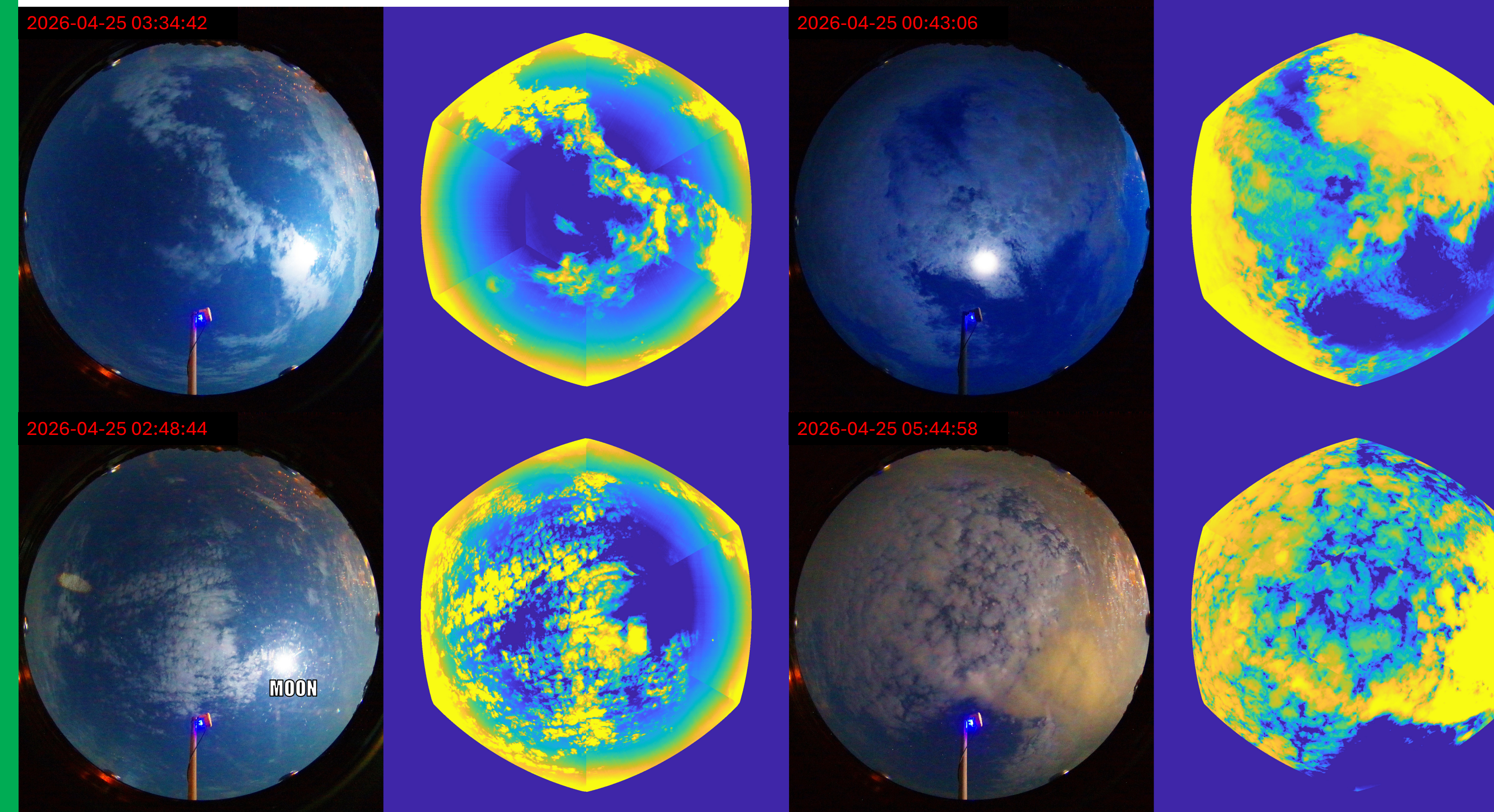


Top rows show vertically pointing CL61 lidar ceilometer time-height profiles of backscatter from the surface to 6 km altitude for time periods spanning each set of paired visible and IR all-sky images.

The colorscale for each sequence of IR all-sky images corresponds to a fixed temperature range. The temperature range is different between sequences since the dynamic range of IR brightness temperatures varies throughout the day and using too large a range lowers the visible contrast within an image and affects the quality of the visualization. The color scale varies from blue through green to yellow. Blue represents the colder end of the scale and yellow the warmer.



The data projection of the visible and IR images are not currently matched. The fisheye lens used for the visible camera shows objects at a low elevation (i.e. toward the horizon) more towards the center of the image than in the IR imagery. For the IR imagery the radial distance from the image center is proportional to the sine of the elevation angle. The top of the all-sky images is north and the bottom is south. East is to the left and west is to the right.



A gallery of nighttime images on 25 April 2026 captured between 00 and 07 UTC (20 to 03 local time). Sunset occurred at 00:18 UTC (20:18 local time). The bright spot in the visible imagery is the moon. There is an antenna in the southern portion of the image. The paired visible and thermal IR images show a variety of cloud fractions. CL61 ceilometer data (top of column) show the cloud base heights vary between 3.3 km and 5.3 km. These examples highlight the utility of the thermal infrared imagery for detecting clouds at night versus visible-light imagery. The thermal IR imagery also supports the differentiation of clouds with different base heights more easily than in visible imagery.

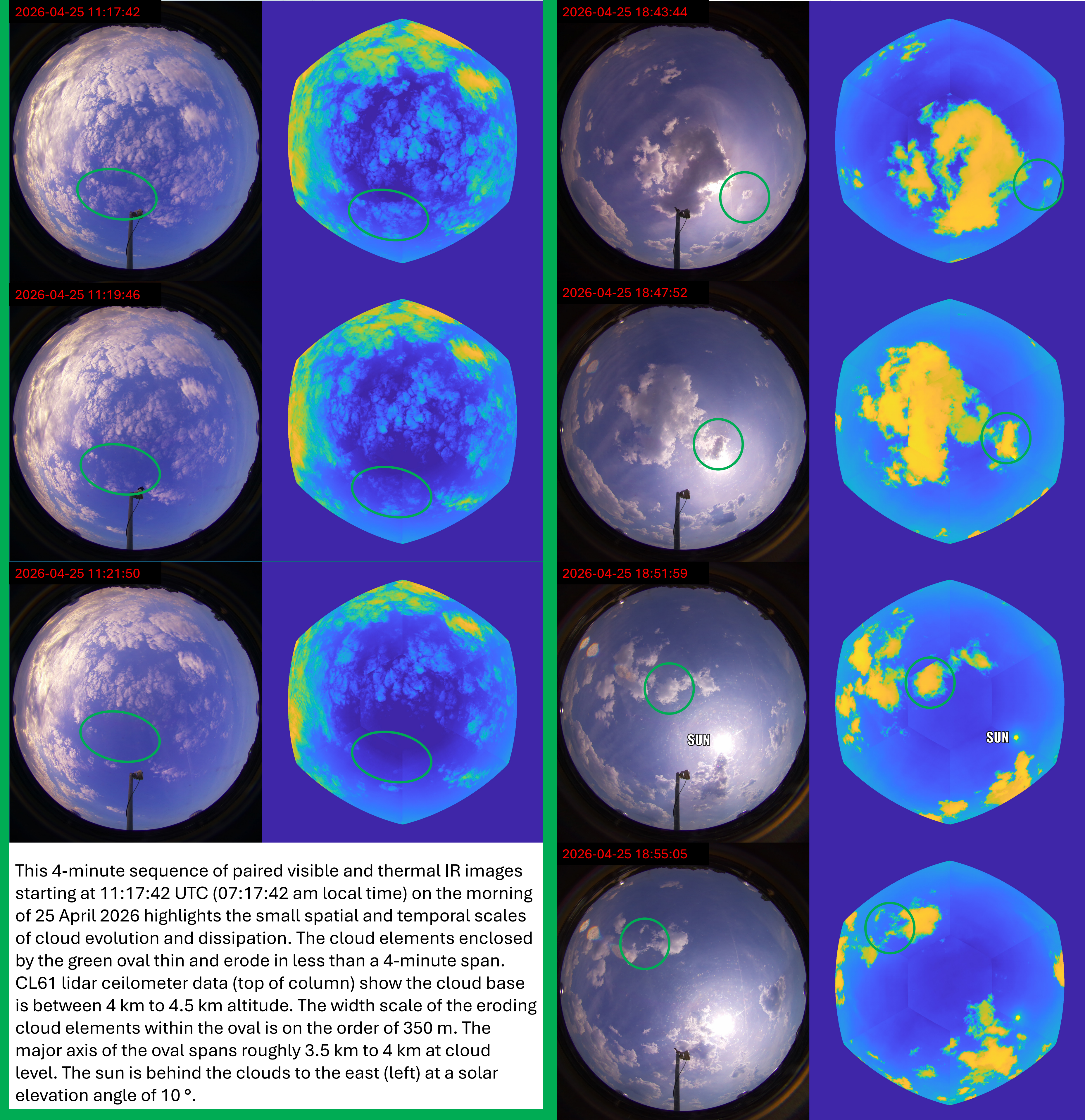
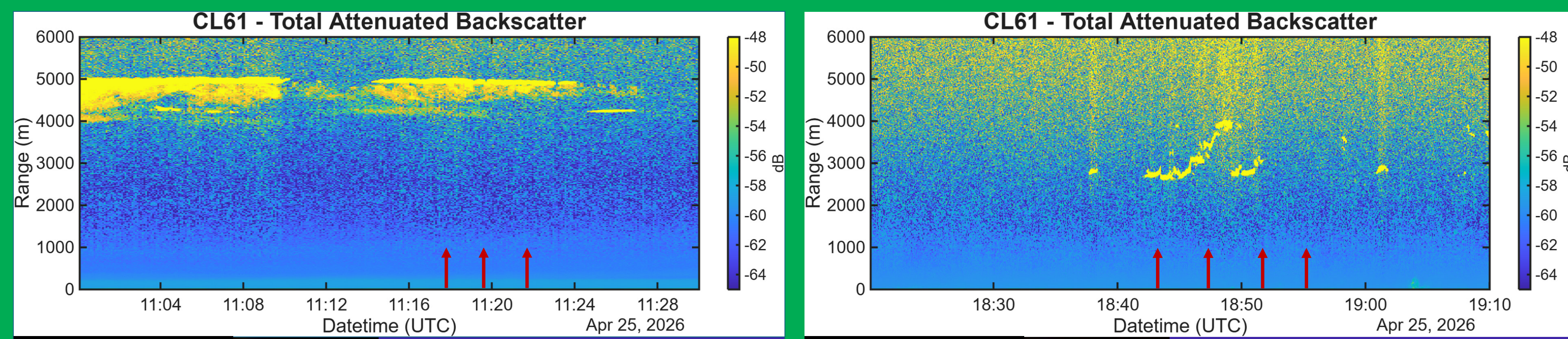
Acknowledgements

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Visit this link or click the QR code to view movies of the paired visible and IR data from this poster.

<https://go.ncsu.edu/miller-egu2026>

Cloud Evolution Over Small Spatial and Temporal Scales



This 4-minute sequence of paired visible and thermal IR images starting at 11:17:42 UTC (07:17:42 am local time) on the morning of 25 April 2026 highlights the small spatial and temporal scales of cloud evolution and dissipation. The cloud elements enclosed by the green oval thin and erode in less than a 4-minute span. CL61 lidar ceilometer data (top of column) show the cloud base is between 4 km to 4.5 km altitude. The width scale of the eroding cloud elements within the oval is on the order of 350 m. The major axis of the oval spans roughly 3.5 km to 4 km at cloud level. The sun is behind the clouds to the east (left) at a solar elevation angle of 10°.

This 11-minute sequence of paired visible and thermal IR images starting at 18:43:44 UTC on 25 April highlights the formation growth and erosion of a cumuliform cloud. CL61 lidar ceilometer data (top of column) shows the cloud bases range from 2.8 km to 4 km altitude. The width scale of the circled cloud element is on the order of 1400 m at its largest. The cloud forms, grows, and erodes in a 12-minute span. Growth of some cloud elements coincide with erosion of neighboring cloud elements. Note the sun at a solar elevation angle of 57°.

Future Work

- Estimation of clear-sky brightness temperature to facilitate cloud segmentation
- Image processing retrieval of cloud area, altitude, and textural properties of cloud base temperature
- Objective identification of virga
- Analysis of cloud edge temperature variations
- Cloud tracking for assessment of evolving cloud properties
- Projection matching the visible and thermal IR imagery

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